1. Introduction

The team Lënster Space FallCan consists of the 2GIG (engineering) class of the Lënster International School under the supervision of Dr. Zimer Marc.
The team intends to accomplish in addition of the primary mission a secondary mission which comprises advanced telemetry.
The advanced telemetry was chosen for its scientific value in:

1. Determining the composition of the atmosphere
2. Determining the trajectory of the CanSat

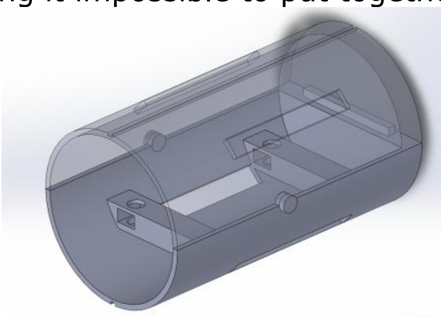
2. Project description

2.1 Mission overview

Our goal is to accomplish the primary mission with the highest degree of precision. To this end, the TMP117 and the BME680 are used.
The secondary mission on the other hand consists of two parts.
The first part consists of advanced telemetry relating to the position of the CanSat in space. This is achieved by the 3-axis accelerometer/magnetometer using the FXOS8700 and by a 3-axis gyroscope using the FXAS21002. Additionally, the position is retrieved from the TEL0132 GSSN module.
The second part consists of advanced telemetry relating to environmental sensing. The SCD41 sensor is used for CO_2 measurement in the atmosphere.

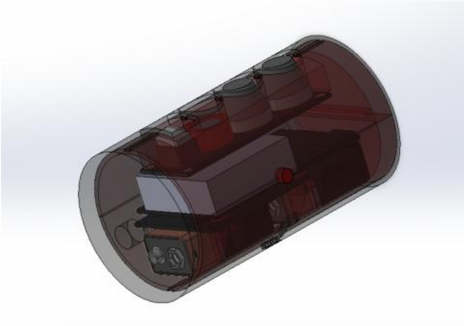
2.2 Mechanical design

The mechanical design was closely linked with the electronics design, as the integration of parts and their requirements dictated the evolution of the CanSat.
The first version was straightforward, with wide air gaps to let an air flow to the sensors. It should also be noted that the model did not respect any tolerances, making it impossible to put together.



Assembly of V1

In the second version, electronics components were modeled, the tolerances issues were fixed, and the environmental sensors were moved outside. Only two small airgaps were left open, one for the intake of a small airflow, the other for the connection of the USB cable to the Feather M0 Express and as inlet for the wind flow.



Assembly of V2

Finally, the third and last version has been repainted to show our support to Ukraine. Minor changes have been made to the placements of supports and screws have been added on the bottom of the can. The sensor holes have been deleted. Two handles to attach the parachute and a hole for the antenna also have been added in the positive radial direction.

Case of V3

V3 on Launch Day

2.3 Electronic design

The electronics consists of 2 independent parts. The first part consists of multiple custom pcbs, while the second only was only considered as backup. As we will see below, we were forced in the end to make use of this backup.

The central concepts of the electronics design are as follow:

- Compacity: The goal was to reduce the weight and volume by creating our own printed circuit boards.
- Reliability: By integrating all the components on 3 board and the use of a backup battery, the risk of a failure of the system is mitigated.
- Precision: By using high precision sensors, we reduce the chance of false measurements and guarantee the quality of our results.

- TMP117

The TMP117 is Texas Instruments most precise digital temperature sensor. With a ±0.1 °C precision from −20 °C to 50 °C and a resolution of 0.0078 °C, it is effectively one of the most precise sensors on the market and is thus to be used over the BME680. Additionally, it has a very low consumption of 3.5-µA at an 1Hz conversion cycle (Same in our implementation). The interface of the sensor is assured over I^2C.

- BME680

We were surprised by the choice of including a BMP280 in the provided CanSat kit as it is listed as obsolete by Bosch. We thus decided to take one of the more versatile BME68x series sensor, as it also included Volatile organic compounds, humidity, and temperature (which we will not use) sensing capabilities in addition to the BMP280's pressure sensing capabilities. The BME680 was chosen over the more recent BME688 which incorporated AI due to the simplicity of implementation. (The BME688 requiring training and acquisition on a ~100-euro development board) The interface is assured over SPI.

- SCD41

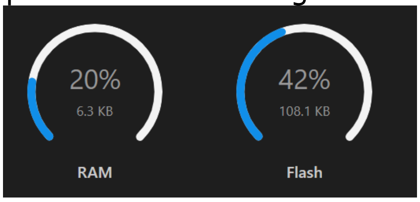
The SCD41 is a device that is capable of sensing Carbon dioxide up to 40ppm with a precision of 5%. The interface is assured by I2C

- LiPo 3.7V, 1300mAh Battery (Adafruit)

Finally, the central piece and the hearth of our concept:

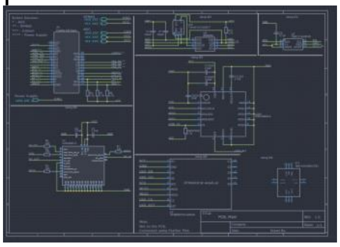
- Feather M0 Express

Sent in the CanSat kit, this Adafruit board revealed to be an excellent choice. First, it has an incredibly high ram and memory with 32KB RAM and 256KB Flash Storage. After inspecting the capacity required to run our program, we found out using the PlatformIO Inspection Tool that not even half of the capabilities were being used:



Additionally, the 2 MB SPI flash memory chip is an incredible advantage over the conventional SD-card reader. This also makes it possible to make the design much more compact. We ran calculations (using a script) and found out that at the rate of 22 values per second (same as per loop as we run at 1Hz), we can effectively store data for ~97000 seconds, which amounts to ~27h. Additionally the data can be retrieved via USB.

We then designed and manufactured custom pcb's, but had to renounce after failing to correctly solder the SMD parts and used the backup version instead. You may note that the temperature sensor worked.
The backup version consists of the same sensors, just as off-the-shelf parts.

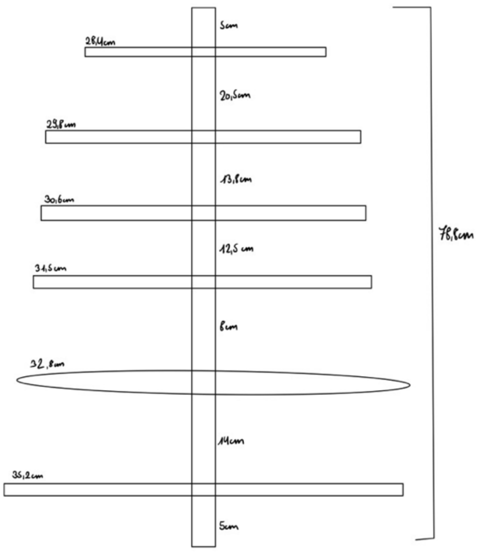



2.4 Ground station design

The ground station consists of a laptop, a Yagi antenna, and a mobile power supply. The ground station has 3 objectives:

- Receive and store the signal
- Keep the CanSat 3.7V battery charged (only a precaution measure, battery life is assumed to hold over 20h as mentioned before)

The signal is first received by a Yagi antenna. The signal is then led to a Arduino connected to the laptop. The laptop (Ubuntu machine) runs a script to save the received Informations. The laptop is also equipped with all the software to reprogram the CanSat for the right frequency if it had to be changed for some reason during the launch campaign.



The antenna:
Through research on the Internet, we calculated our distances for a wavelength of 430 MHz. We decided to build the antenna out of aluminum and pvc. Unfortunately, the aluminium cannot be soldered, so we had to make the driven element out of copper. We then attached the cross bars to the middle section with two screws each. We soldered the alligator cable to the driven element and fastened it with cable ties. We have attached an F connector to the other side. We can connect this to the laptop using an adapter.

2.5 Software design

The programming was completed using sound software engineering practices. This includes the use of methods to keep the code flexible and clear and the use of Object-oriented programming. The program was written on the popular Visual Studio Code IDE using PlatformIO (https://platformio.org/), as it offers many advantages over the basic Arduino IDE.

All the data is written in the “DataPL” object, which is instantiated by a defined data structure called “Payload”. It should also be noted that important variables like frequency can be changed fairly quickly as they are regrouped at the beginning of the program.

The program is divided in 2 main parts, the first being the initialization phase. This is where the sensors perform the necessary calibrations in order to perform at maximum efficiency. In the second phase, the MCU runs continuously a loop, where the sensors perform the tasks and data is being send.

```
void loop() {
  count++;
  DataPL.id = count;
  DataPL.time = millis();
  digitalWrite(BME_CS, LOW);
  bmeStartRead();
  tmpRead();
  scdRead();
  bmeEndRead();
  digitalWrite(BME_CS, HIGH);
  icmRead();
  fxoRead();
  fxaRead();
  gpsRead();
  saveWrite();
  delay(1000);
  if(count%500==0){
    saveOutput();
  }
  digitalWrite(RFM69_CS, LOW);
  rfmSend();
  digitalWrite(RFM69_CS, HIGH);
  resetPayload();

}
```

2.6 Recovery system

We decided to make a cross parachute. For the parachute we first calculated the required area with the help of the file "Parachute Design". Then we calculated the required dimensions and sewed the parachute afterwards. When we tested the parachute, we noticed that it descended too fast, so we calculated a new parachute that had triangles sewn on in addition to the usual pattern of the cross parachute.

Final Calculations:

	Minimum	Maximum
Masse m	0,30 kg	0,34 kg
Zeit t	90 s	125 s
Geschwindigkeit v	8 m/s	11 m/s

$$m \cdot g - \frac{1}{2} C_D \cdot \rho \cdot A \cdot v^2 = 0$$

$$\Leftrightarrow m \cdot g = \frac{1}{2} \cdot C_D \cdot \rho \cdot A \cdot v^2$$

$$\Leftrightarrow 2 \cdot m \cdot g = C_D \cdot \rho \cdot A \cdot v^2$$

$$\Leftrightarrow A = \frac{2 \cdot m \cdot g}{C_D \cdot \rho \cdot v^2}$$

Dichte der Luft : $1{,}225 \frac{kg}{m^3}$

Ortsfaktor : $9{,}81 \frac{m}{s^2}$

Drag coefficient Cross : 0,8

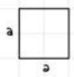
$$A_{min} \text{ bei } 0{,}34\,kg = \frac{2 \cdot 0{,}34\,kg \cdot 9{,}81 \frac{m}{s^2}}{0{,}8 \cdot 1{,}225 \frac{kg}{m^3} \cdot (11 \frac{m}{s})^2} \qquad A_{max} \text{ bei } 0{,}34\,kg : \frac{2 \cdot 0{,}34\,kg \cdot 9{,}81 \frac{m}{s^2}}{0{,}8 \cdot 1{,}225 \frac{kg}{m^3} \cdot (8 \frac{m}{s})^2}$$

$$\underline{\underline{A_{min} \approx 0{,}0563\ m^2}} \qquad \underline{\underline{A_{max} \approx 0{,}1064\ m^2}}$$

maximale Fläche eines Quadrates:

$$A_\square = \frac{0{,}1064\ m^2}{6}$$

$$\underline{\underline{A_\square = 0{,}0177\ m^2}}$$



$$A_\square = a^2$$

$$\Leftrightarrow a = \sqrt{A_\square}$$

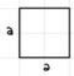
$$= \sqrt{0{,}0177\ m^2}$$

$$\underline{\underline{a = 0{,}1330\ m}}$$

minimale Fläche eines Quadrates:

$$A_\square = \frac{0{,}0563\ m^2}{6}$$

$$\underline{\underline{A_\square = 0{,}0094\ m^2}}$$



$$A_\square = a^2$$

$$\Leftrightarrow a = \sqrt{A_\square}$$

$$= \sqrt{0{,}0094\ m^2}$$

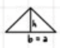
$$\underline{\underline{a = 0{,}0970\ m}}$$

maximale Fläche eines Dreieck:

$$A_\triangle = \frac{A_\square}{4}$$

$$= \frac{0{,}1064\ m^2}{4}$$

$$\underline{A_\triangle = 0{,}0266\ m^2}$$



$$A_\triangle = \frac{a \cdot h}{2}$$

$$\Leftrightarrow 2 A_\triangle = a \cdot h$$

$$\Leftrightarrow h = \frac{2 \cdot A_\triangle}{a}$$

$$= \frac{2 \cdot 0{,}0266\ m^2}{0{,}1330\ m}$$

$$\underline{\underline{h = 0{,}4000\ m}}$$

minimale Fläche eines Dreieck:

$$A_\triangle = \frac{A_\square}{4}$$

$$= \frac{0{,}0563\ m^2}{4}$$

$$\underline{\underline{A_\triangle = 0{,}0141\ m^2}}$$

$$A_\triangle = \frac{a \cdot h}{2}$$

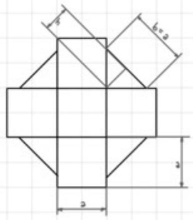
$$\Leftrightarrow 2 A_\triangle = a \cdot h$$

$$\Leftrightarrow h = \frac{2 \cdot A_\triangle}{a}$$

$$= \frac{2 \cdot 0{,}0141\ m^2}{0{,}0970\ m}$$

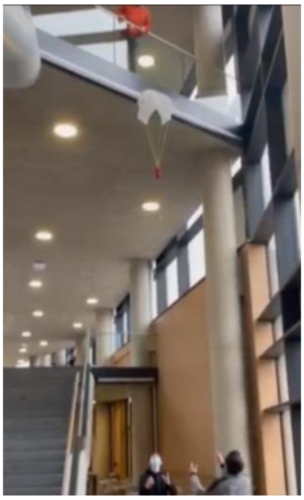
$$\underline{\underline{h = 0{,}2907\ m}}$$

Skizze:



2.7 Testing

Parachute test and velocity:
The case was tested several times by letting it fall down by 10 - 15 m. That way we tested our parachute and the robustness of the case itself. We found that the first parachute was too small and the CanSat came down too fast but with our last parachute the CanSat felt with a velocity speed of almost 10 m/s.



Battery-test:
The longevity of the battery was first calculated and then tested in our school lab.
Our longevity test showed that in continuous use the 3.7V battery lived for 20h.

Antenna-test:
We tested our antenna outside. We drove with the Yagi- antenna to a distance of 1 km from the CanSat and the data was received clearly. Therefore, we concluded that our Yagi-Antenna is working properly, and we would be able to receive data while descending from 1km above.

3. Requirements

Number	Requirement	Checked
#	Explanation of the requirements	
	Mass/weight	
1	All CanSat components may not exceed the size of a standard can (115mm in length and 66mm in diameter). An exception can be made for radio and GPS antennas, which can be mounted outdoors. The payload area of the rocket usually has 4.5cm of additional space per CanSat available, in the axial direction of the CanSat (i.e. height), which must allow for the placement of external elements, including: parachute, equipment of fixing of the parachute and possible antennas.	X
2	The CanSat, including the parachute, must have a mass of at least 340 g to 350g. If it is lighter, it must be loaded with weights to achieve a mass of 340 g	/
	Material restricitons	
3	The use of projectiles, fireworks or other explosive materials, as well as easily flammable and hazardous materials are not permitted.	X
	Power supply	
4	The CanSat must have an independent power supply (e.g. battery, accumulators, solar panels, etc.). The power supply must be easily accessible in case it has to be replaced/recharged. The battery capacity must be sized so that the CanSat can be operated for at least 4 hours continuously.	X
5	The satellite must have an easily accessible main switch.	X
	Recovery system	
6	The CanSat must have a recovery system, such as a parachute, which can be reused after launch. It is recommended to use coloured or bright material, which will facilitate the recovery of the CanSat after landing.	X
7	The attachment of the recovery system (and the recovery system itself) must be solidly constructed and able to withstand the high loads.	X
8	A descent rate around 10-12 m/s is highly recommended for recovery reasons. In any case, the CanSat's descent speed must not be lower than 5 m/s or higher than 12 m/s for safety reasons.	X
	Statics and dynamics	
10	The CanSat must be able to withstand an acceleration of up to 20g.	X
11	The duration of the flight is limited to 120 seconds.	X
	Cost	
12	The total budget of the final CanSat model should not exceed 500€, including the cost of the CanSat kit provided during the mentors workshop. Ground stations and any related non-flying item will not be considered in the budget.	X
13	In the case of sponsorship, all sponsored items should be specified in the budget with the actual corresponding costs on the market.	X
	Mission requirements	
14	The CanSat must at least measure temperature and air pressure, as described in the primary mission	X
15	The assigned frequency must be respected by all teams during the launch campaign. The range of allowed frequencies changes depending on the country where the event is hosted and will be communicated in due time. It is recommended that teams pay attention to the design of the CanSat so that the radio frequency can be easily modified if necessary	X
16	During the CanSat descent, the data must be transmitted both to the ground station and to the onboard SSD card	X
17	To avoid surprises with the battery being empty or any other malfunction, a green LED must indicate if the CanSat is up and running. The green LED must be visible outside the CanSat case	/

4. Overall progress
4.1 Human resources

Social Medias:

Khan Hanna – Social Media Manager, Social media enthusiast
- Managing of various accounts on social medias

Tim Reuland – Social Media Manager
- Manager of the team website
- Managing of various accounts on social medias

Engineering:

Alexander Clemen - Radio Frequency Engineer
- Calculations concerning RF
- Performing data recovery
- Construction of YAGI antenna

Pedroso Ramos Noah – Lead Mechanical Engineer
- Develop high density CanSat concepts
- Refine models
- Perform weight optimisation

Dos Santos Pinho – Mechanical Engineer
- Perform weight optimisation

Schaeffer Gina – Lead Parachute Engineer
- Calculate optimal parachute parameters
- Build the parachute

Oliveira Pintado Diogo – Parachute Engineer
- Test the parachute

Schroeder Olivier – Electronics & Software Engineer
- Selection of electronics components
- Develop schematics
- Design and manufacturing of printed circuit boards
- Programming of the electronics

4.2 Planning

Task	January				Febuary				March	
	3-Jan	10-Jan	17-Jan	24-Jan	31-Jan	7-Feb	14-Feb	21-Feb	28-Feb	7-Mar
Design Report Submission										
PCB Design		Part1						Part 2		
CAD-model optimisation										
PCB Fabrication										
Parachute Fabrication										
Antenna Fabrication										
Antenna Test										
Assembly										

Task	March			April				May		
	14-Mar	21-Mar	28-Mar	4-Apr	11-Apr	18-Apr	25-Apr	2-May	9-May	16-May
Design Report Submission			Feedback			Launch				
PCB Design										
CAD-model optimisation										
PCB Fabrication										
Parachute Fabrication	1st Version				2nd Version					
Antenna Fabrication										
Antenna Test										
Assembly										

Planned	In Progress	Delayed		Submission
Expected	Done			

4.3 Budget

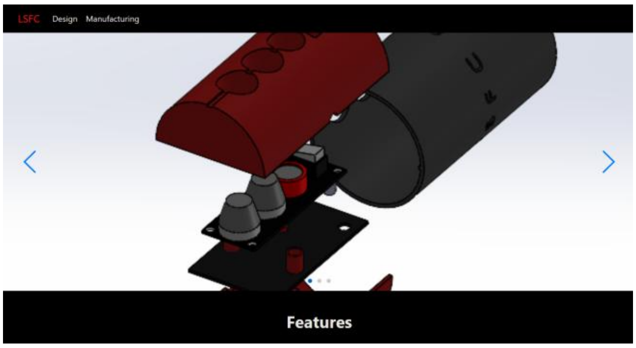
Mass By Component		Price
Battery 3.7V	23	8.8
SEK-SCD41-Sensor		53.42
Feather M0 Express		18.15
Stacking Headers		1.14
Precision NXP 9-DOF		13.6
Adafruit BME680		17.24
Adafruit TMP117		10.47
Adafruit ICM-20649		20.97
Modules GPS		16.29
Jumpers		5
Components	150	
Case	120	

Mass Used	Mass left	CanSat Total Price
293	62	165.08

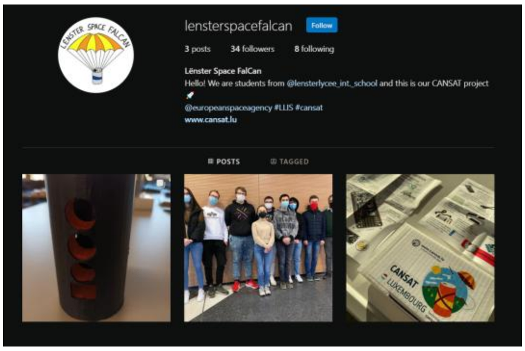
4.4 Outreach

Our project is publicly visible on following pages:

Website: lsfc.space



Instagram: https://www.instagram.com/lensterspacefalcan/

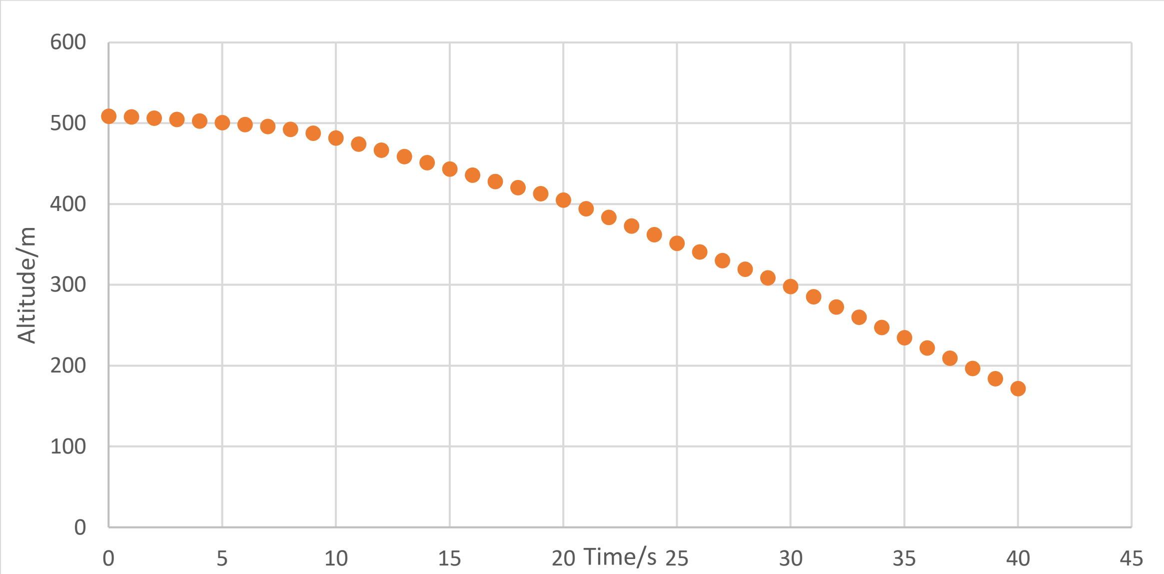


Twitter: https://twitter.com/LensterSFC

5. Scientific results

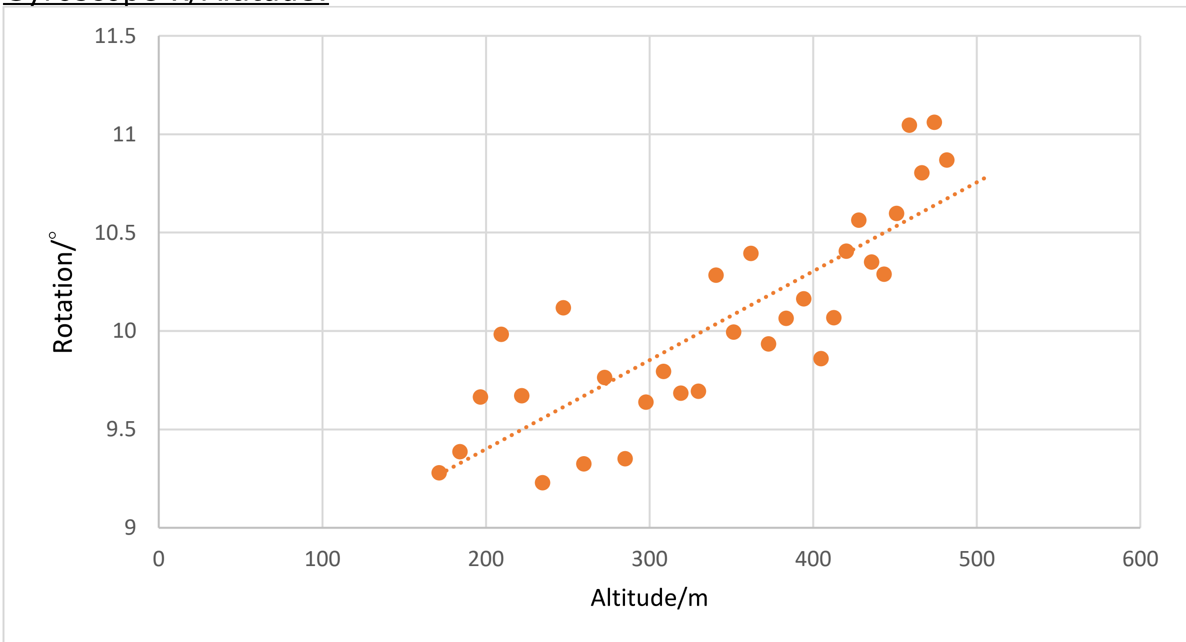
In this section, we evaluate the collected data by plotting a set of diagrams. First, we start with the altitude over time. This allows us to visualize the descent of the CanSat, as we decided to discard the ascend. You may also note that the data stops after 40 seconds.

Altitude/Time:



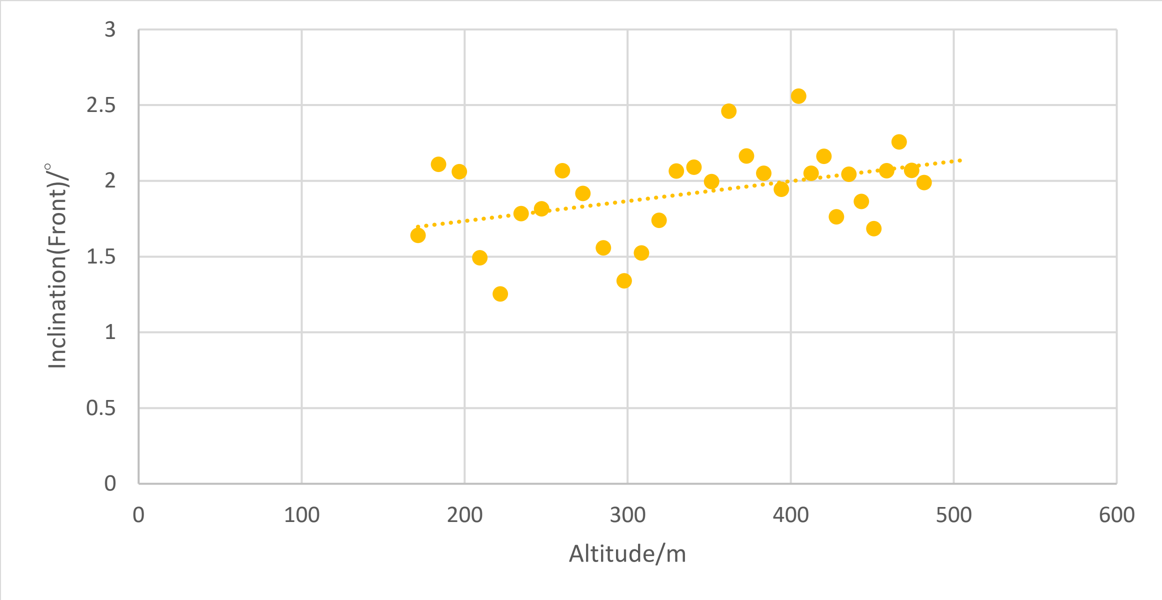
As expected, the CanSat has an average descent speed of 10.19 $\frac{m}{s}$ and we can infer from the curve that it took approximately ~50 seconds to fall back to earth.

Gyroscope-x/Altitude:



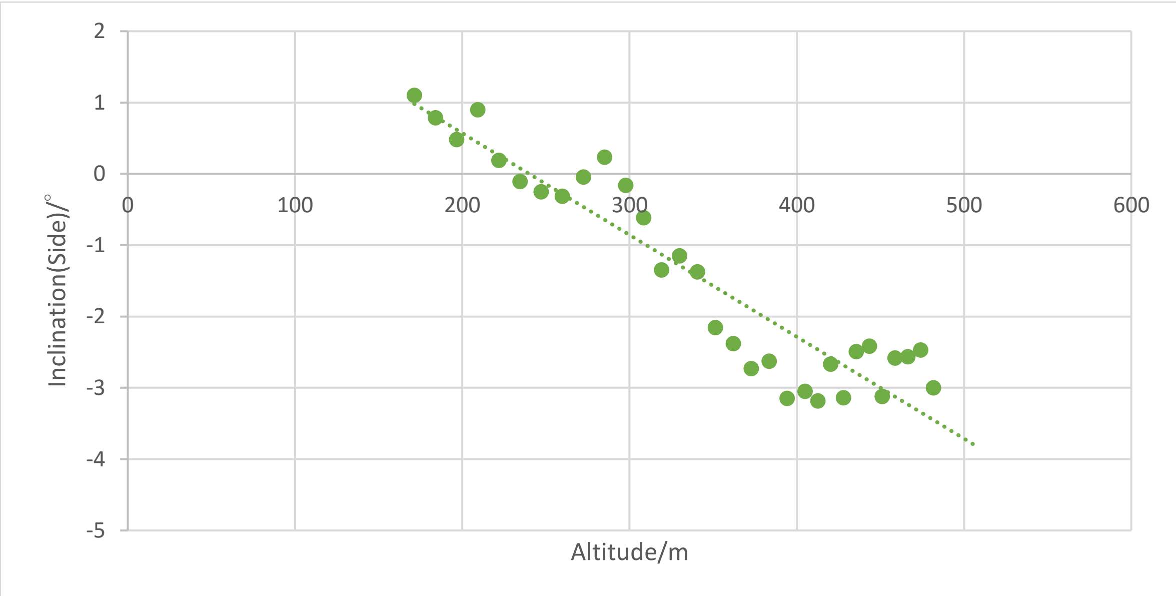
We find a linear relationship between the altitude and the rotation of the CanSat, which may indicate higher winds are applied at higher altitudes. This relationship is confirmed by [1].

<u>Gyroscope-y/Altitude:</u>



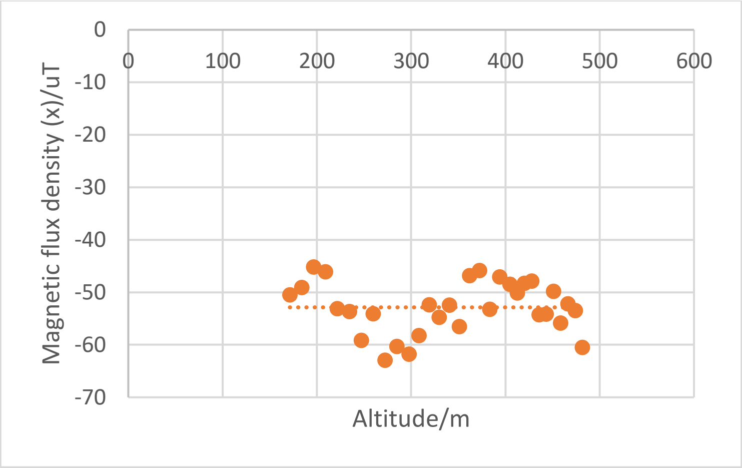
In the y-plane, the values stay constant as the asymmetric fixation of the parachute assures it remains in a stable position.

<u>Gyroscope-z/Altitude:</u>

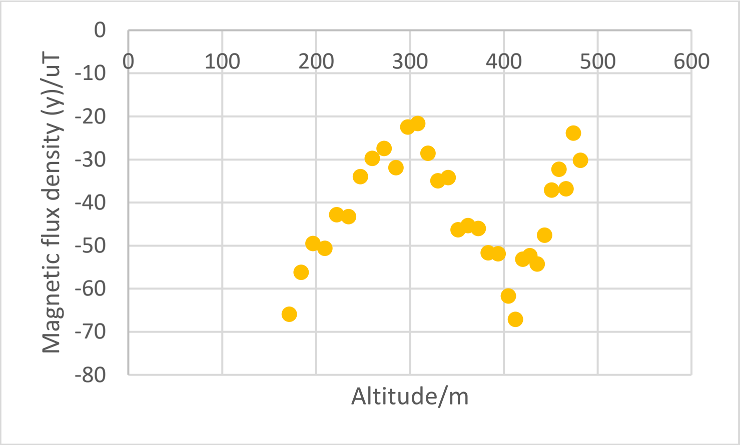


The same applies to the z-plane, where it may be noted that the inclination shifts sides, possibly as the CanSat rotated.

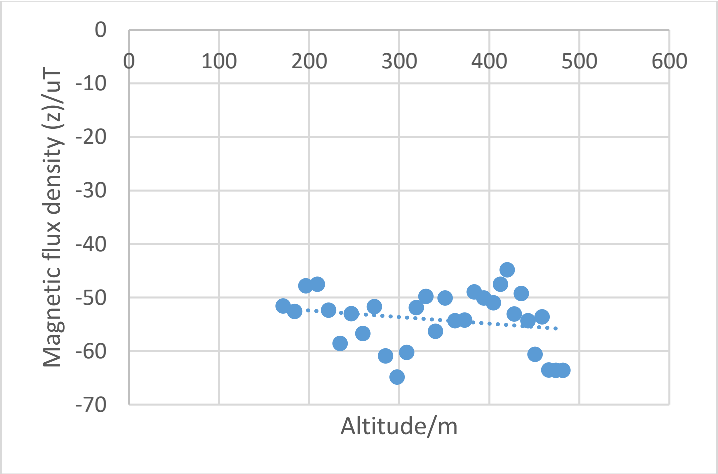
Magnetometer-x/Altitude:



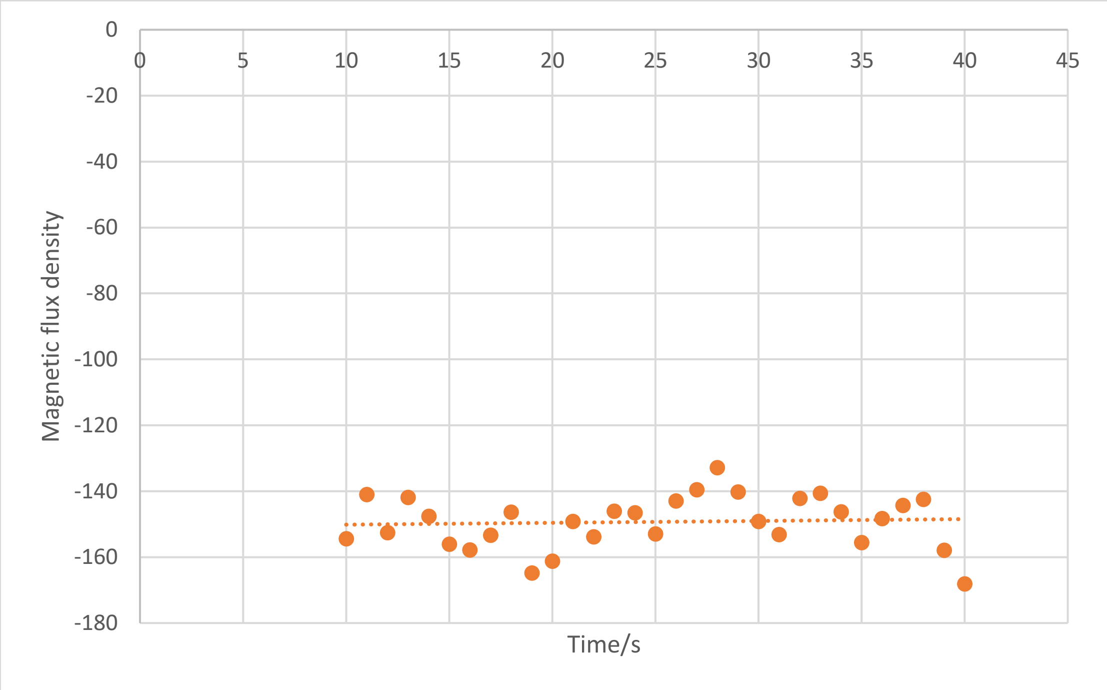
Magnetometer-y/Altitude:



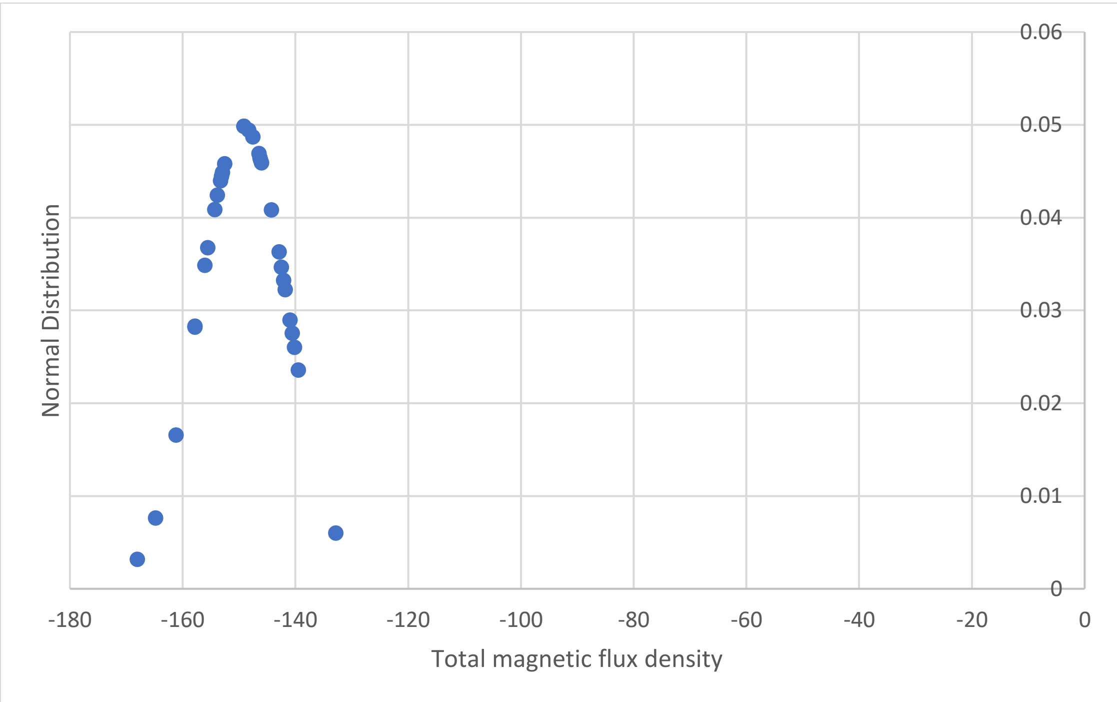
Magnetometer-z/Altitude:



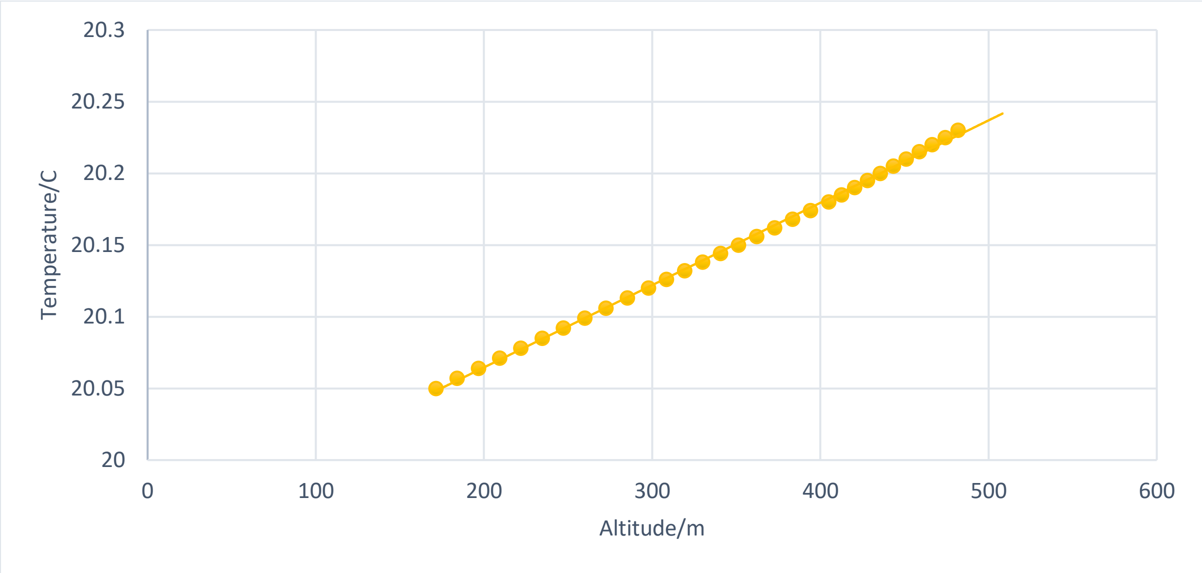
Total magnetic flux density/Time:



Total magnetic flux density – Normal Distribution:

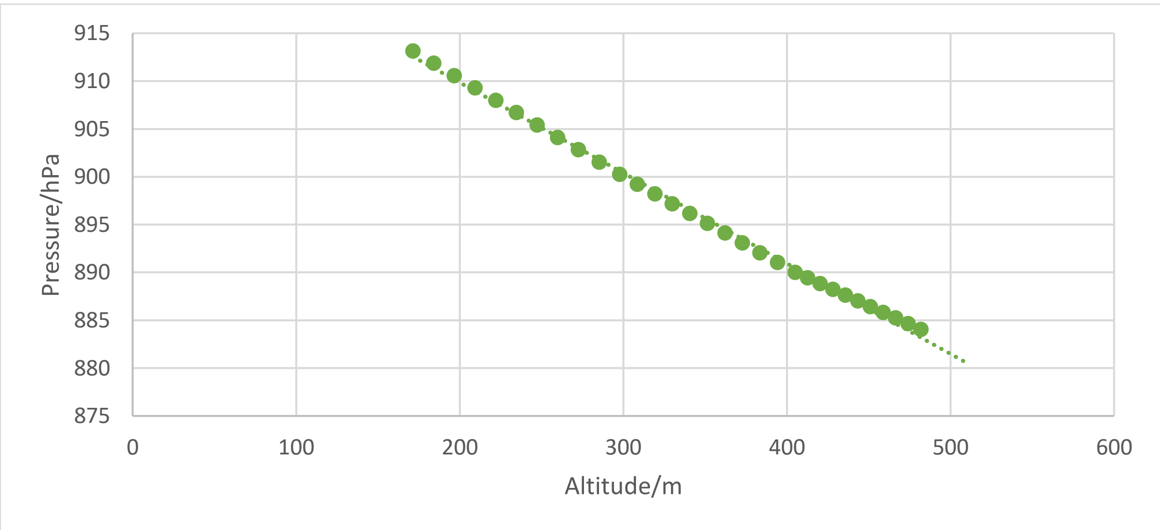


Temperature/Time:



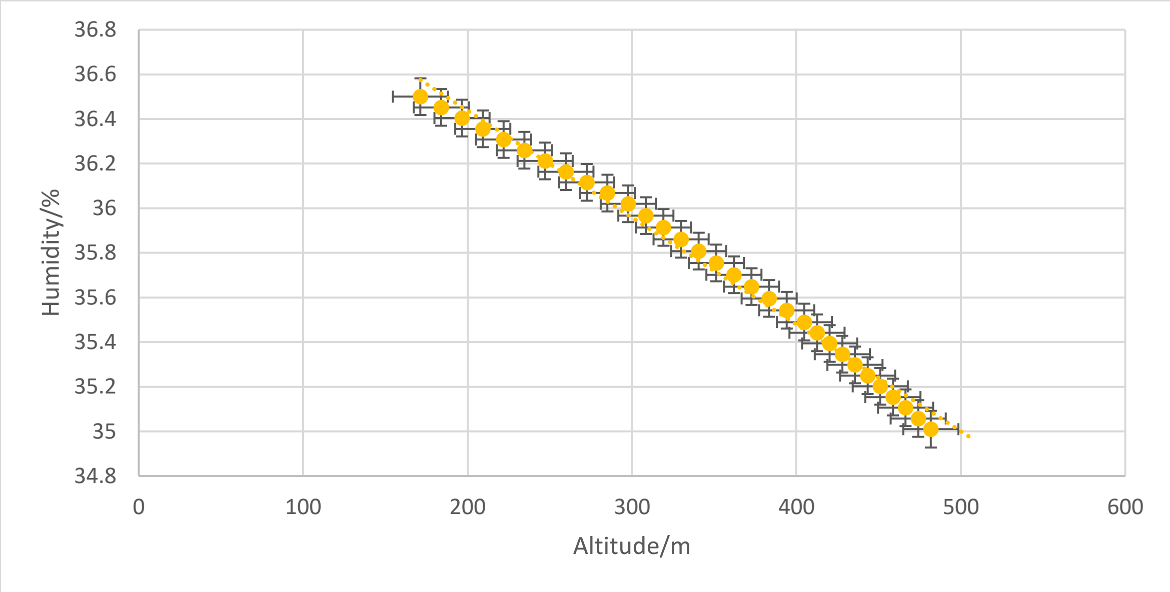
In this diagram, we can see how the temperature increases proportional to the altitude. However, we find that in literature the inverse has been documented and conclude the following:
The temperature we measured that day may have been influenced by winds or another local metrological phenomenon. Otherwise, it might be that an error occurred when measuring the temperature. This could be related to a bad sensor placement or an inability of the air to circulate inside the CanSat.

Pressure/Altitude:



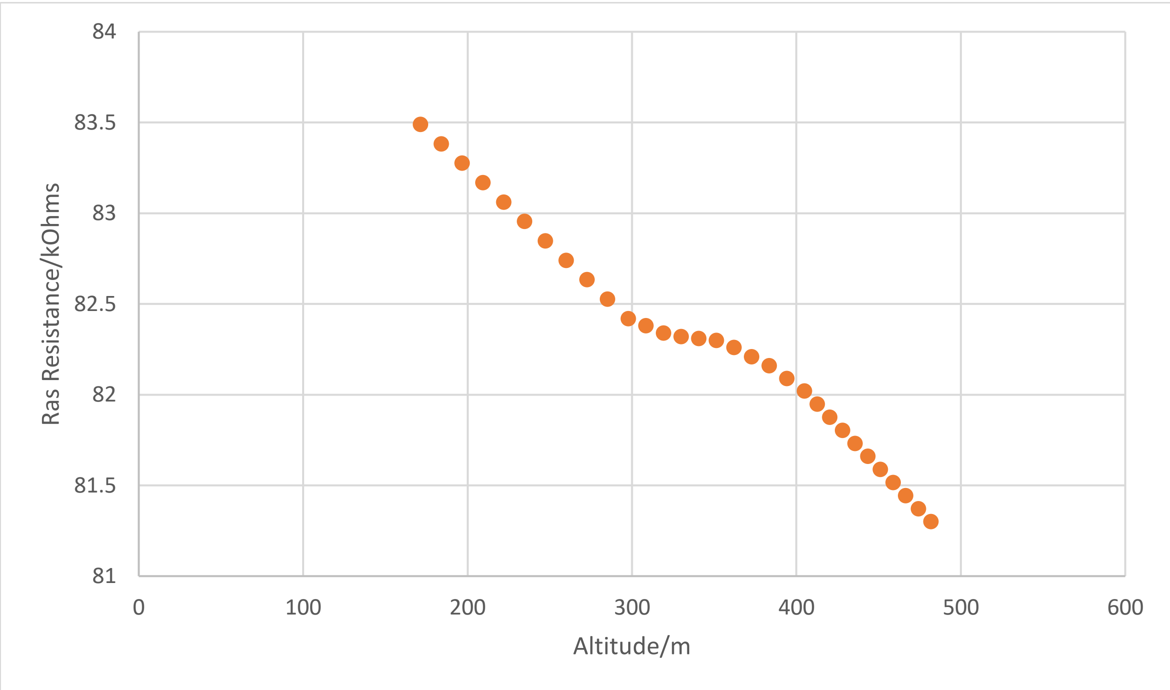
The relationship between pressure and altitude is linear.

Humidiy/Altitude:



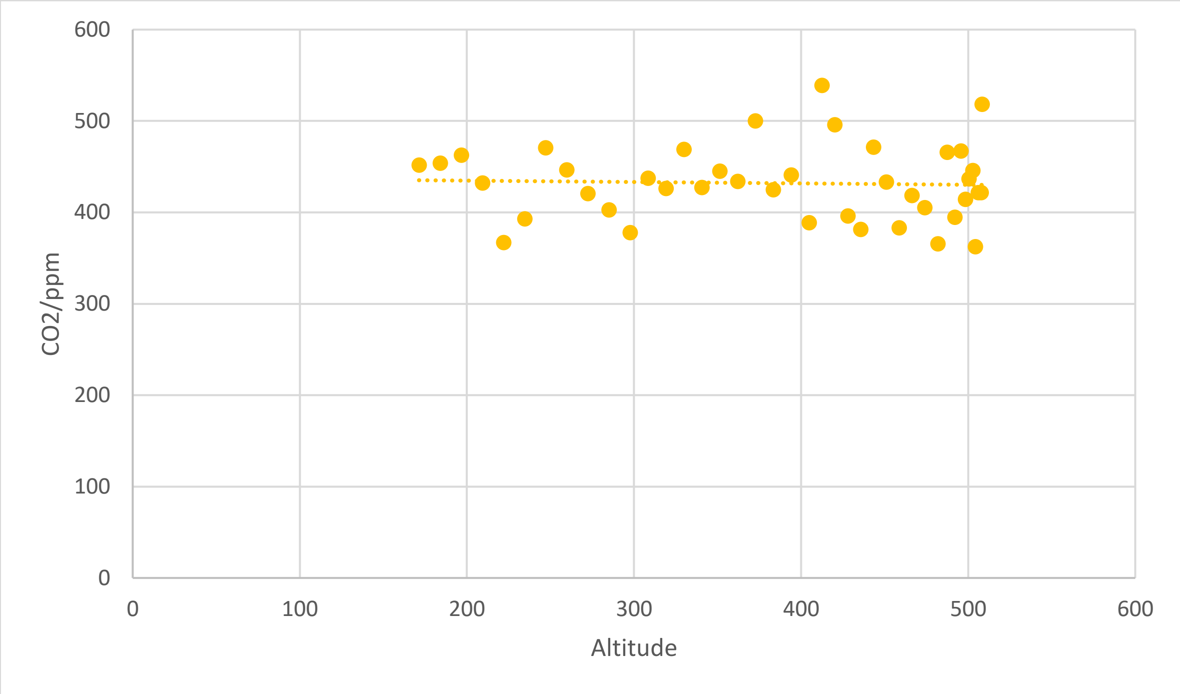
The relationship between humidity and altitude is linear.

Gas Resistance / Altitude



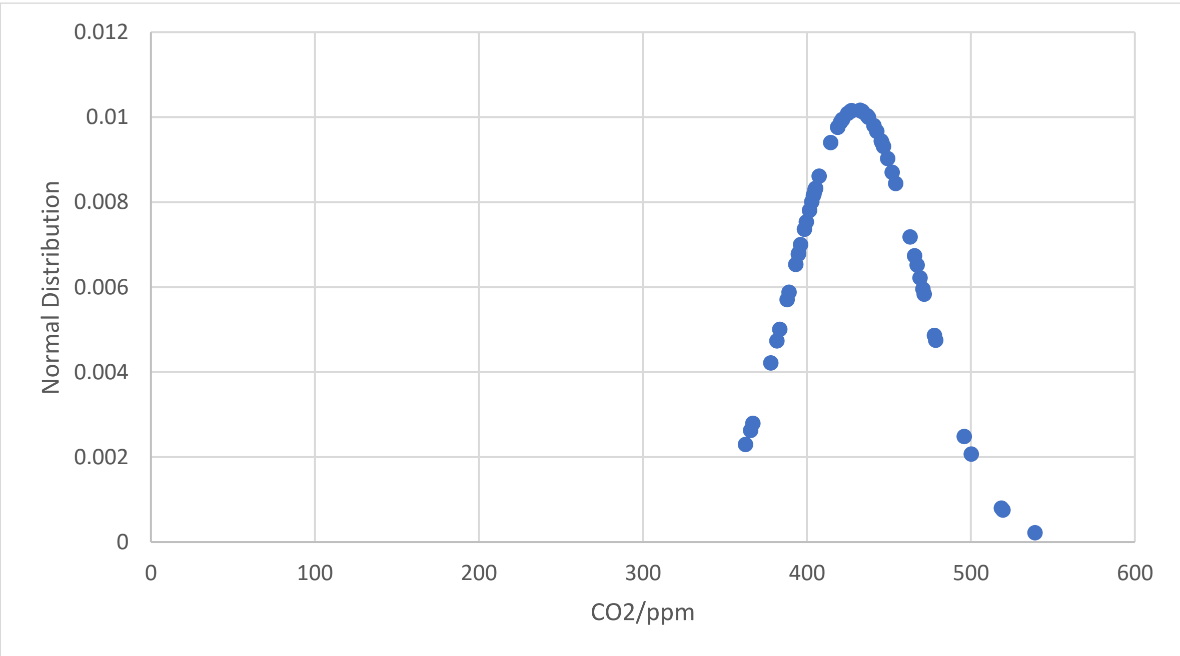
The relationship between the gas resistance and the altitude is linear, with a phase around 300m where it gets constant. The decrease in gas resistance signals an increase in volatile organic compounds in the air.

CO2/Altitude:



In this diagram, we can see how the CO_2 concentration stays constant over the measured altitude. We may note that the sensor used has a precision of 40ppm.

CO2 – Normal Distribution:



We can clearly see that the mean of the normal distribution is 430.1ppm.

6. Discussion

The project is interesting as it unlocks funding for sensors and equipment one might not see otherwise. The results found seem coherent.

For some unknown reasons, almost all the sensors failed in one moment. Our hypothesis is that a short circuit was caused by a wire inside the can, which reinforces the initial idea of using only PCB to connect the components. Additionally, GSSN module did not find any satellites and the accelerometer data disappeared, which is weird as it is taken from the same sensor as the magnetometer, which worked just fine.

Failing to manufacture the PCB's was never critical, as steps had been taken to mitigate any crisis with a backup. However, considering this was the first time doing so, we learned many concepts in electronics and PCB design and believe that the next itineration will be the right one.

Furthermore, the geometry choice of the PCB was bad as a lot of the volume was lost for the PCB antenna.

Finally, if we were to try this project again, we would use a ComSat module, so our CanSat could communicate with an actual satellite.

7. Conclusion

In conclusion, although the manner of collecting data wasn't perfect, we still can consider our objectives complete. The primary mission was a complete success, while the secondary mission had a few issues. The data we collected is insightful and mostly consisted with literature.

The temperature, volatile organic compound's concentration and wind force increase, while pressure and humidity decrease with increasing altitude.

The Carbon dioxide concentration stays constant at the measured altitudes.

References

[1]https://www.theweatherprediction.com/habyhints3/749/#:~:text=Surface%20objects%20such%20as%20trees,wind%20speed%20increases%20with%20height, by JEFF HABY, Last read 05/05/2022