Starliner

Final Design Review

Team Name: Starliner
Country: Poland

Table of Content

1. Changelog

-added chapter 4.5 Energy budget tests
-added chapter 8. Summary
-we changed the adapter for SD card on Pololu sdc01a.
-to the previous transfer to the ground station (temperature, pressure, GPS coordinates) we have added another one (gyroscope, accelerometer and current time).
-the construction of the parachute will be changed - it will be slightly larger and it will have a hole in the middle.
-during the competition we choose our new logo. (Visible on the title page)
-a few improvements in CanSat construction have been done
-we changed the material and 3D printer.
- thanks to the improvements in the program, we can read the remaining voltage on batteries on an ongoing basis. A hole in the housing has been added to allow you to charge the batteries without removing them.
- we've compressed the form in which data is sent to earth. Now instead of 131 characters only 64 are sent. The program at the station with the antenna converts them to data in readable form.
- we decided that we would send all collected data to the ground - in the event that CanSat was not found or completely destroyed.
- a station with a follower antenna was built and modified
- change in the construction of parachutes - enlarged hole for better stability and added a disc to prevent tangled lines.
- a ground station was built to compare air and ground data
- overload and collision resistance tests were carried out - cover change.
- functional tests and correctness of sensor reading were carried out.
- Yagi antenna tests
- construction and testing of a backup "J" type antenna
- reducing the weight of the Yagi antenna
- PMS7003 is used in the ground station- such as in CanSat
-we also send to the ground information about which sensors work

2. Introduction

2.1 Team organisation and roles

The team's work was divided proportionally among all team members. Each element of the project will have its lead member, who will be responsible for their part of CanSat, where each of the 6-person group will have part in each element, so that in case of illness or temporary indisposition of one of the people the project will not .Mr Michał Żurawski is our supervisor. He is a physics teacher at our school.
Tasks of individual group members:
Kacper Grobelny - team captain; deals with programming the controller and connecting sensors to the main system.
Mikołaj Koralewski- antenna construction, soldering CanSat system and ground station system, stepper motors, communication module.
Mikołaj Krzyżostaniak- 3D printing, translations of the reports and taking care of our Facebook page.
Piotr Skoracki - deals with the

frame,cover design and construction and is responsible for the project’s website.
Dawid Betka - deals with the construction of the parachute and is responsible for reading GPS coordinates. He is also responsible for reading and interpretation data from accelerometer and gyroscope, commissioning and modification of the follower antenna system
Michał Jędrzejak - deals with powering the system and the selection of appropriate batteries

2.2 Mission objectives

The objective of the project is to examine the vertical distribution of suspended particles PM 2.5 and PM 10. In the case of research missions to foreign planets, it will allow to obtain information about atmospheric dust and possible subsequent research missions using optical tools. From the point of view of the Earth's mission, we want to investigate how high suspended particles are raised by vertical air movement and at what height the dustiness decreases to acceptable values. The range of drones is too small and optical tools (lidars) are out of our reach. Air dustiness changes seasonally, however, even in summer (field work), standards for suspended particles are often exceeded. We want to see at what heights (hypothetically) peoples should live to limit the impact on human life. Would placing an object in Poland modeled on the Burj Khalifa from Dubai solve the problem for its residents and whether living in high-rise buildings allows people to breathe clean air without mechanical filtering.
In order for the project to be considered completed, we want the sensors to be placed in the system to correctly read all the information needed for our tests. Then we will process them and take conclusions.

3. CanSat description

3.1 Mission overview

Our mission is to build a CanSat with a cylindrical shape measuring 115mm x 66mm which will be released from the rocket to examine the following values: temperature, pressure, humidity, acceleration, vertical distribution of the dust, location and the position of the CanSat plane relative to the ground. All measurements will be saved on the microSD card and sent to the ground station.

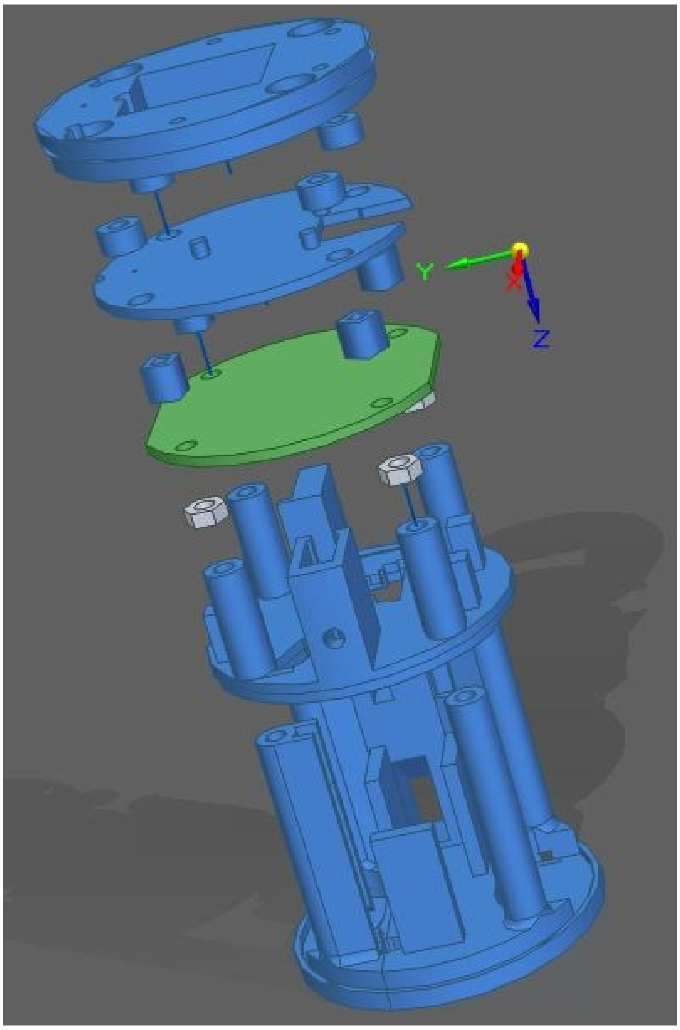
Ultimately, CanSat will be dropped on a parachute at a speed of ~10 m/s.

The signal will be picked up by a Yagi antenna with a follower system. It is to make the whole system more reliable and eliminate the human error factor.

A research station will be located on the ground to collect comparative data for us. An "J" type antenna will be attached to the ground station if the system does not work with the Yagi antenna.

3.2 Mechanical/structural design

3.2.1 3D design project



Scheme 1: 3D design

CanSat cover was designed in Solid Edge 2020 to print it on a 3D printer. The box consists of two bases, an outside cover, four columns and place for contact plate. One of the bases is permanently attached to four columns, while the other will be attached with four screws through the holes in the columns. In order that the heads do not protrude outside the cover, in bases there are holes in which these heads will be hidden.

The bottom base will contain a dust sensor protected by three 25 mm high walls with four batteries (each with a capacity of 800mAh and weight of 20g). They will be placed in special holes and attached with appropriately shaped metal plates. Two channels are discharged from the dust sensor: one for the inlet, the other for the air outlet. Holes are cut out in the cover to fit the outlet and inlet air channels. Wires coming out of the sensor and battery will be led to the board through a channel mounted on one of the columns, then through the floor and then directly to the board. An outside temperature sensor will be placed in the hole inside the base, which will also be led to the plate.

The first level is also permanently attached to the columns. It has rectangular columns with holes for placing the main board and a place for the swith and regulator. A hole will be made in the cover to the switch, through which will be placed to turn on and off whole wystem. (If the screw is in, everything will be off.)

A higher level will be placed the plate, which task is to connect all wires. It will be attached with bolts passing through the holes in the columns, which are coaxial to the holes in the plate. The other sensors will be soldered directly on the board.

On the last level there will be a platform with the space for the motherboard.

The cover will be applied from above, it will rest on the lower base and will be locked by the upper base. It will be locked against rotation by a tongue in it and a groove in the rack.

A GPS module will be placed in the hole in the top base. 6 holes will also be made through which the parachute lines

will pass.
Protection against water: Because we are not able to predict weather conditions during the satellite drop, we must consider the possibility of precipitation. There is no problem when it comes to sealing the housing itself and the temperature sensor as well as the GPS antenna.
It was debatable to limit the amount of water sucked in by the air quality module intake. The best solution seems to be to use a protective mesh with small mesh sizes (perhaps against insects) that would limit the sensor damage.
Material and production:
The can is printed from red PLA with a 40% filling called "tri-hexagonal". The cover is printed from red PET-G, because it tolerates impacts much better, so the housing does not crack.
The seal used to protect against water will be printed from a specialized rubber filament, unfortunately currently only available in yellow.
Everything is printed on FDM printers - main Ender 3 Pro and supporting Ender 5 Pro. In both cases we use a 0.4mm nozzle.

3.2.2 CanSat building

The first printed can with batteries, necessary electronics and parachute weighs 347g. We planned to reduce the weight to 340g by reducing the filling. We reduce the loss of strength with help of additional supports (they are still lighter than high fill). Currently whole working CanSat which is ready to deploy from rocket weights 335g. This is our final CanSat which we will use at final rocket launch.

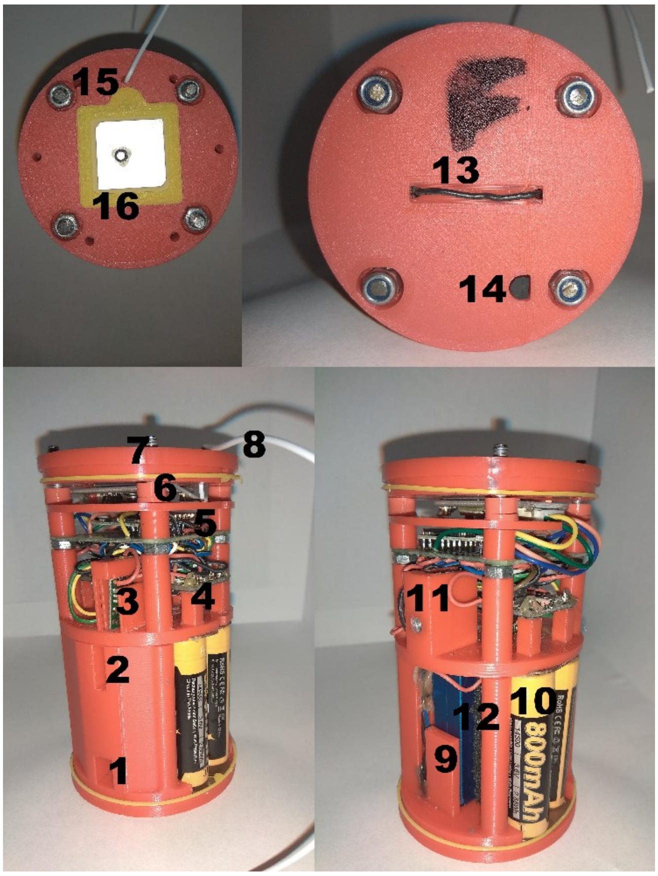


Photo 1: Final CanSat construction

1.Air inlet to the dust sensor.
2.Air outlet to the dust sensor.
3.Step-up module for the dust sensor (3.3V→5V).
4.Main control board (Adafruit Fearther M0 with LoRa radio).
5.Contact plate with sensors (BME280, AltiMU-10 v5) and microSD card adapter.
6.Upper base with GPS module.
7.Fastening screws.
8.Transmitting antenna.
9.PMS7003- air pollution sensor
10.4 batteries.
11.Main switch.
12.Foam for easier battery installation.
13.Battery parallel connection (wire is pastes and isolated).
14.Outside temperatre sensor (D18B20).
15.Antenna output.
16.Water preventing gasket .

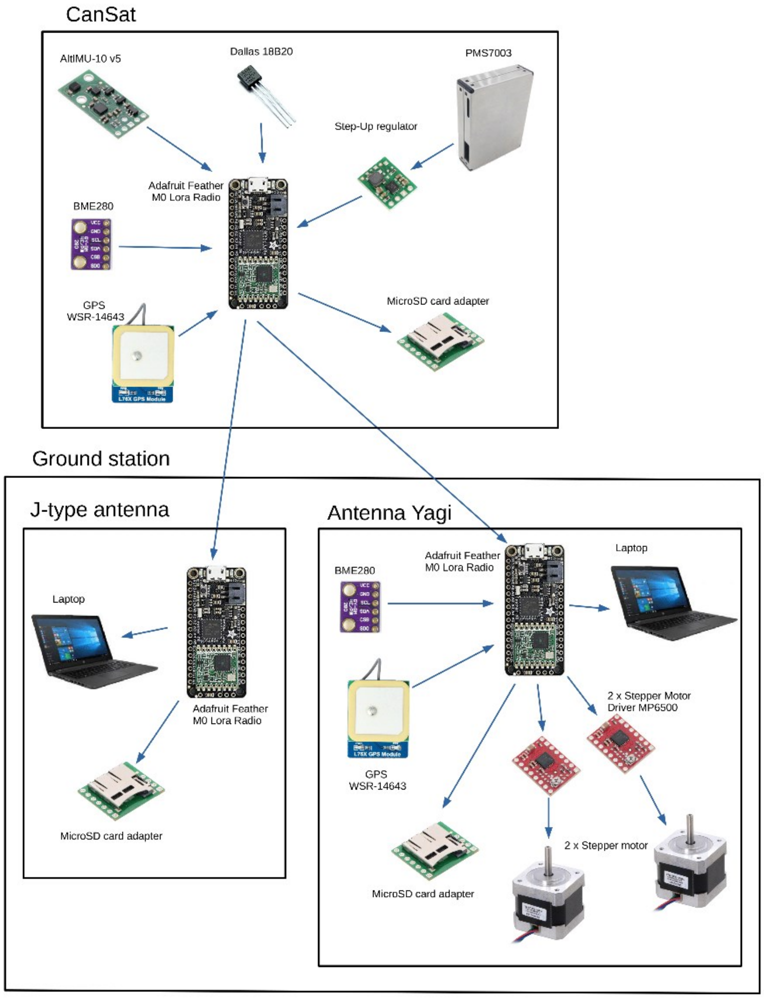
Photo 2: Our methods for waterproofing

1.Insect net (the surface tension of the water on the tiny net prevents small amounts of water from getting in. Even if water will be able to go trough only air dust sensor will start measuring the wrong values).
2.Yellow, round gaskets sealing the cover.
3.Rubber plug for the main switch hole.
4.Rubber plug for the micro USB slot.
We have ordered stickers with our logo which we will stick to the bottom of CanSat for identification after landing.

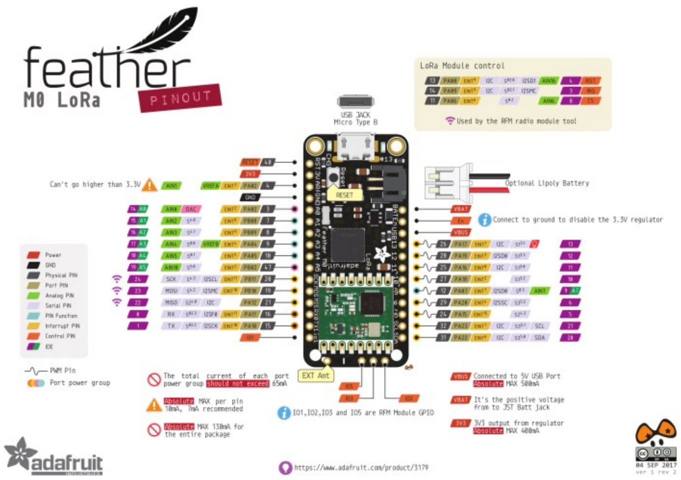
3.3 Electrical design

3.3.1 General architecture

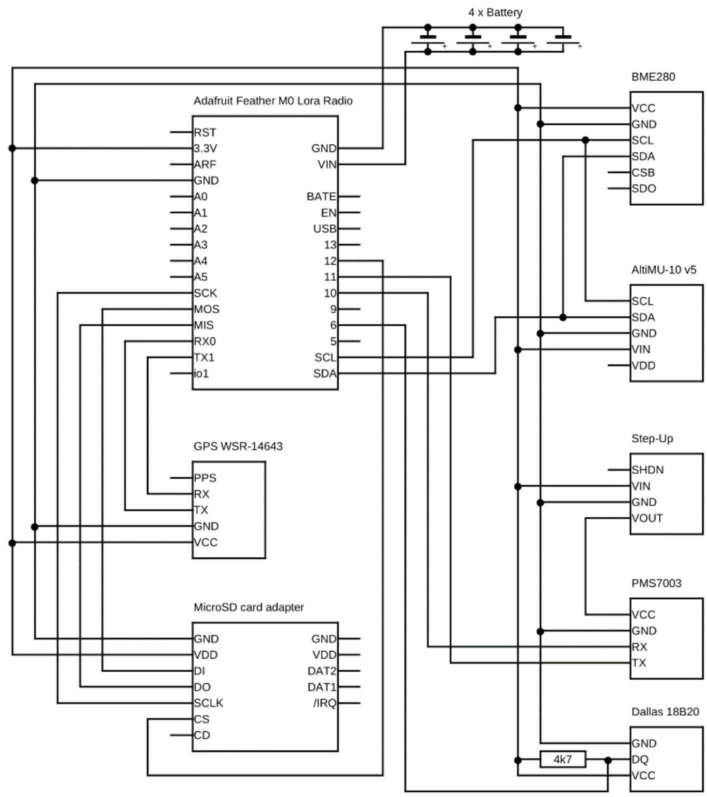
The modules presented in this report are connected on the "Adafruit Feather M0 433mhz RFM96 LoRa radio". The final model will be built on this. The built-in LoRa radio module communicates with the Adafruit Feather M0 via the SPI bus.
Characteristics:
Input: 3,3V
Radio frequency: 433Mhz
Mass: 6g
Size:51x23x8[mm]
Pins:20 GPIO, 8PWM, 10 inputs and 1 analog output.



Scheme 2: Overall mission plan



Scheme 3: Our main control module



Scheme 4: Detailed electronics connection

3.3.2 Primary mission devices

BME280- digital sensor connected to the Adafruit Feather M0 via the I2C bus, able to measure:
1) temperature:
-measuring range: from -40°C to 85 °C
-accuracy ± 1°C
2) humidity:
-measuring range from 10% to 80% RH
-accuracy ± 3 % RH
3) atmospheric pressure
-measuring range from 300-1100hPa
-accuracy ± 1 hPa
Dallas 18B20- to outside temperature measurment. Connected with 4,7kΩ resistor. It connects to the Adafruit Feather M0 with the 1-Wire bus.
-measuring range from -55°C to 125°C
-accuracy ±0,5°C in -10°C to 85°C range
MicroSD Card Adapter with microSD card. It communicates with the Adafruit Feather M0 via the SPI bus.

3.3.3 Secondary mission devices

AltiMU-10v5- all-in-one accelerometer and gyroscope (LSM6DS33), magnetometer (LIS3MDL) and barometer(LPS25H). It is connected to the Adafruit Feather M0 via the I2C bus.
PMS7003 for air dust pollution measurment. The data is sent over the serial bus with a hardware UART device.
GPS WSR14643- to determine CanSat's position and landing place.
In PMS7003 and GPS module the data is sent over the serial bus with a hardware UART device.

Summary for chapter “3.3.2 Primary mission devices” and “3.3.3 Secondary mission devices”:
We compared BME280, AltiMu-10v5 and D18B20 to a digital weather station for home use (certified) and it turned out that the most accurate temperature shows D18B20 and BME280, and the AltiMu-10v5 has a large deviation. Also, the atmospheric pressure according to the BME 280 sensor is closer to the actual (practically the same) than in the AltiMU-10v5-we compared to an analog weather barometer.
We decided to use BME280 as sensor designed to weather stuff and the AltiMU-10v5 will serve as a gyroscope, accelerometer and magnetometer.

3.3.4 Power supply

Due to the weight and dimensions imposed by the designed CanSat capsule, we used batteries: 4 pcs. Li-lion 14500 3.7V, 800mAh, parallel connection, weighing 20g piece which gives (according to our calculations) theoretically 5.8h battery life.
The ground station is powered by a 2200mAh, 3.7V, 8.14Wh Li-Po battery, which is charged from a 5W power and 12V solar battery by the SkarkFun MPPT 12885 solar charger. This charger was chosen because it has the ability to charge the battery with a current up to 2A and has convenient connectors for us to connect the battery, solar panel and control board.

Device name	Average electricity consumption [mA]	Supply Voltage [V]	Effi-ciency	Battery power consumed [W]
Adafruit Feather M0	180mA	3.3V	0.5	0.594~0.6 W
GPSL76x Multi	11mA	3.3V	0.5	0.36W
Humidity Sensor BME 280	0.0036mA	3.3V	0.5	0.0036W
Dust sensor Adapter PMS5003	100mA	5V	0.8	0.5W
Dallas 18B20	1.5mA	3.3V	0.5	0.05W

Table 2: Ground station electricity consumption

Device name	Current electricity consumption [mA]	Supply voltage [V]	Effi-ciency	Battery power consumed [W]
Adafruit Feather M0 RFM 96 LoRa radio	180mA	3,3V	0,5	0,6W
GPS module	11mA	3,3V	0,5	0,36W
Humidity Sensor BME 280	0.0036mA	3,3V	0,5	0,0036W
AltiMU10v5	6mA	3,3V	0,5	0,03W
Dust sensor Adapter PMS7003	100mA	5V	0,8	0,5W
Temperature sensor	1,5mA	3,3V	0,5	0.05W

Table 1: CanSat maximum electrical power consumption.

3.3.5 Communication system

We use the 433 MHz open frequency which we will change when we get the exact bandwidth on which we are supposed to work. We use 2 devices transmitting data from the CanSat and a receiving module on the ground that receives signals, both modules operate at the same frequency.
The transmitters used for communication are "Adafruit Feather M0 433mhz RFM96 LoRa radio" with the appropriate antennas mounted, the communication works unilaterally, that means we send the signal from the CanSat and receive it to the receiver, but the receiver does not send the response to the transmitter.
To get the most effective and most human error-free information transfer, we've built a system that directs the antenna directly to the falling CanSat. In case the system will broke, we have reserve omnidirectional J-type omnidirectional antenna.
The tracking system calculates horizontal location by GPS location and altitude from pressure changes. For this reason, we had to place a GPS sensor and a pressure sensor to be able to use the current data, otherwise the antenna incorrectly indicated the height. Now everything is already built and tested.
We conducted tests of signal reception from the Yagi and J-type antennas. At a distance of 1km, the RRSI antenna indicated by the antennas was 10 better in favor of the Yagi antenna.

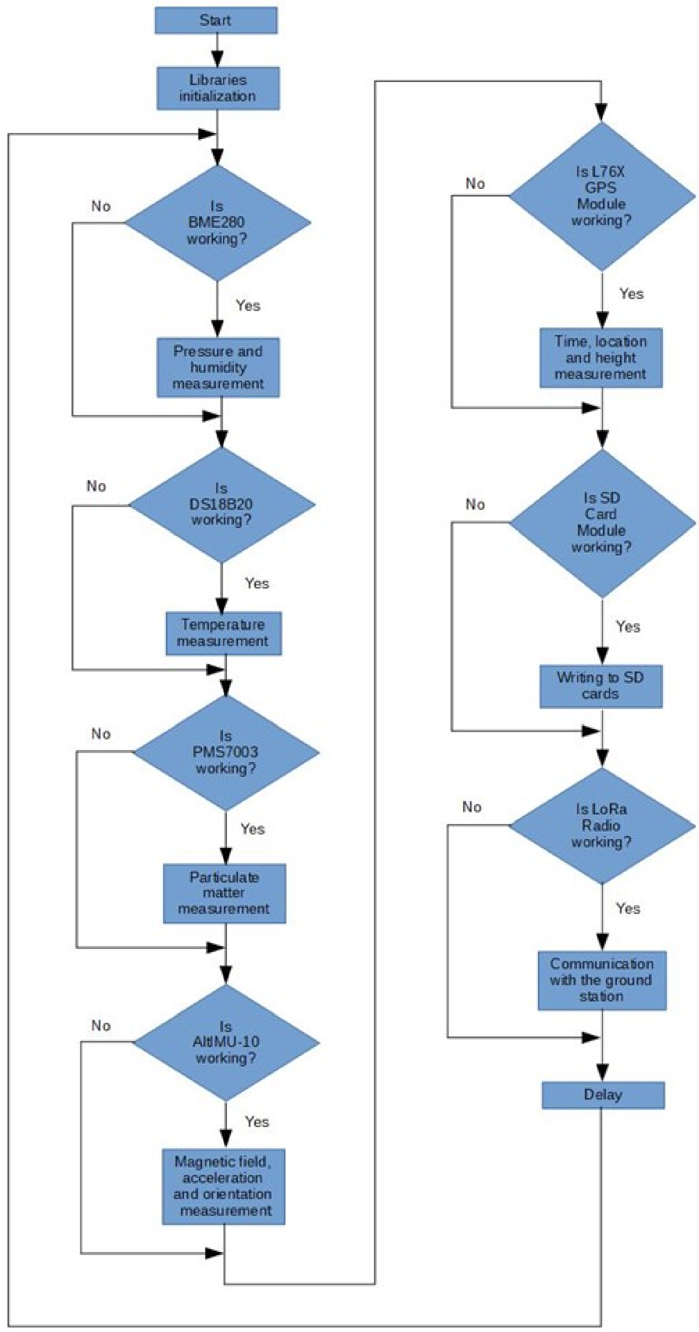
Photo 3: Yagi antenna with tracking system

Description:
1.A tripod from a home telescope adapted for our purposes.
2.Yagi antenna.
3.Box with control board and GPS module and BME sensor.
4.Vertical and horizontal gearing
5.2 stepper motors (hidden behind gearing).

3.4 Software design

Our program on GitHub:
https://bit.ly/2VrZCie
The program has been written in such a way that in the event of a failure of one of the sensors, the program will not hang. In the program we used the following libraries: Adafruit unified sensor, Adafruit gps library, Adafruit BME280 Library, SD Library, RadioHead Library, OneWire. Added following libraries: lis3mdlarduino-master, lps-arduino-master, lsm6-arduino-master.
Using the transmitter, we will send temperature, pressure and GPS coordinates. Now we added measurements of the accelerometer, magnetometer and gyroscope. All measurements will be saved to the microSD card.
Data from the sensors will be collected every 1s. The estimated flight time is about 5 minutes, (about 300 measurments).The program was written in C ++ in the Arduino IDE.
We were able to fix it. We had to edit the libraries so that the program would not hang in the event that it does not receive a response from the sensors (a cable will be disconnected or the sensor will stop working). The program waits a certain amount of time for a response from a given sensor. If it does not receive it, it bypasses the sensor. This required only changing the libraries

from AltIMU-10 and BME280, because disconnecting other sensors does not cause the program freezing. Now we are also sending data about which sensors are working and whether the microSD card is working properly. We plan to optimize the program. In the event of a critical error when programming improvements, we have ready CanSat with a fully functional program running. Additional program improvements are tested on earlier prototypes. If we are sure that the improvements are correct, we will upload them to the final CanSat.
During testing, we encountered a problem with the program hanging when one of the wires was broken. Test results are shown in the table on the next page.
We were already very close to abandoning the idea of illustrating the tilt of CanSat because it was problematic, it took too much time and we decided that this was not an essential element of our mission. The day before the date of sending the FDR, we found a way to do visualization using a magnetometer.
Due to the fact that the magnetometer has 3 axes (x, y, z) in which it measures, it is possible to examine the magnetic field in 3 directions. Based on the measured magnetic field strength, we examine deviation from the direction of the earth's magnetic field lines, so we know vertical and horizontal tilt of our CanSat.



Scheme 5: Overall program structure

Table 3: Effects of system faults

Sensor	Broken wire	Result
BME280	VCC or GND	complete hang of the program
	SCL or SDA	does not hang the program, weird values are read, after reconnecting everything returns to normal
SD Card	CS, SCK or MOSI	does not hang the program, does not save, returns to normal after reconnection
	SD card, VCC or GND	does not hang the program, does not save, after reconnecting does not return to normal and does not save
GPS	RX	does not hang the program, no visible effects
	TX, VCC or GND	does not hang the program, the same values are read all the time, after reconnecting everything returns to normal
PMS7003	TX, VCC or GND	does not hang the program, weird values are read, after reconnecting everything returns to normal
	RX	does not hang the program,no visible effects
AltiMU-10 v5	SCL, SDA, VCC or GND	permanent hang of the program
Dallas 18B20	GND, pin10, resistor	does not hang the program,no values read, after connecting is working correctly
	VCC	does not hang the program, incorrect values read, connected is working correctly

3.5 Recovery system

During the recovering the most important thing are geographical locations of CanSat. Our current equipment is GPS WSR 14643 module with antenna. GPS gives different coordinates according to the record NMEA. The record was successfully converted into more readable form. The module gives geographical coordinates, altitude, number of satellites in range, speed, and correctness of reading. In addition to geographical coordinates, measurements are burdened with an error due to the accuracy of the antenna and the number of satellites nearby. The minimum number of satellites should be at least four.

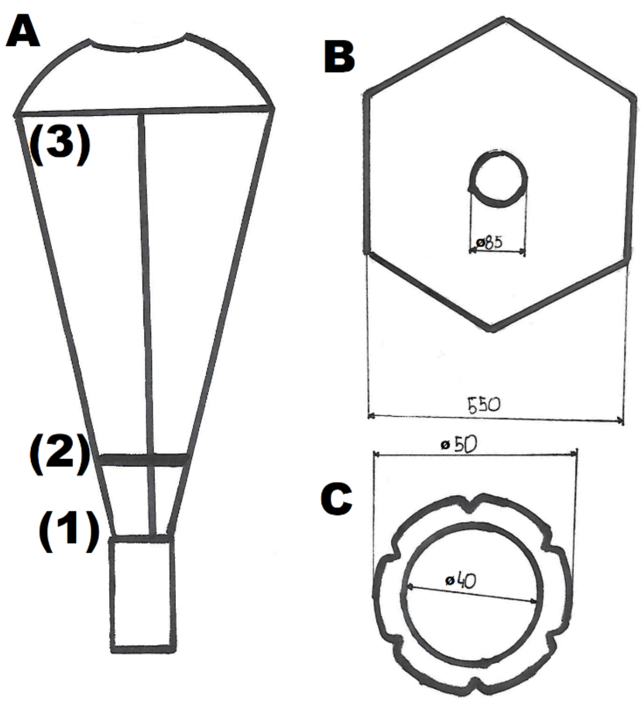
To recovery system we can also include falling inhibitory system. For this purpose we apply the parachute. After our calculations, in which we considered the maximum CanSat weight (350grams), the falling speed, which is on average 10 m/s, air density, resistance coefficient equal to 0.5. The pattern itself looks like this:

$$S = \frac{2Q}{cVg}$$

When:
s-parachute surface
Q-weight
c-drag coefficient
v-falling speed
q- air density

After an in-depth analysis and proper calculation, the satellite at constant drag and stable flight, the flight time is ideally at the assumption of a maximum altitude of three kilometers, (it will be five minutes) it needs to include additional drag and a larger distance when the satellite will endure, the time can be up to seven minutes.

In first prototype we used a parachute in the shape of a hexagon without a hole at the top, so it could not catch air properly and it had not fully unfold. The hole will have about 8,5cm diameter. The whole parachute has 55cm maximum diameter.

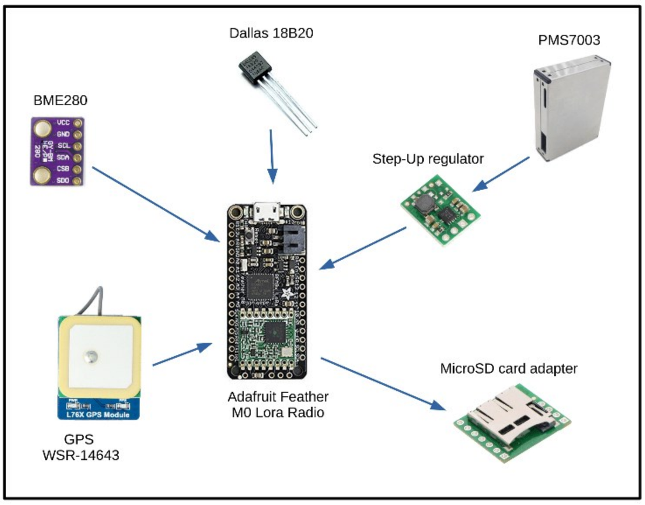


Scheme 6: Parachute scheme

This is the scheme of our parachute. In draught A there is a general view from the side, draught B shows the shape of the parachute canopy from above and draught C shows the disc which prevent tangling of the lines.
The distance between point 1 (attachment of cables to CanSat) and point 2 (disc) is 150mm. From point 2 to point 3 (canopy parachute) the distance is 200mm.

3.6 Ground support equipment

To collect the data we need, at the ground we will use:
- “Yagi” antenna cooperating with "Adafruit Feather M0 433mhz RFM96 LoRa radio" together with the follower system
-a laptop for live monitoring of collected data. It also be used for reading location of our CanSat landing.
- ground testing station containing the same sensors as in CanSat to compare the results
-"J" type antenna which will be a spare antenna in case the following system refuses to follow. It will collect data all the time and save to a microSD card. It is an omnidirectional antenna so it does not require our service.
Antenna:
We were using makeshift transmitting antenna made of ¼-wavelength wire, (17,5cm).
We are using the main receiving "Yagi" antenna, because by making many analyzes regarding the collection of the signal sent from the transmitter, we came to the conclusion that this antenna will suit best, it can be easily modified and adapted to our needs, it offers a relatively wide reception angle of signal, and receiving a weak signal over long distances, using a signal amplifier built into the receiving system.
Adafruit Feather M0 433mhz RFM96 LoRa radio is a system programmed to receive and proceess data from CanSat and to send data to the computer. This system consists of the Adafruit Feather M0 board and a built-in transmitter-receiver module (transceiver) that allows us to contact the device transmitting over long distances (stick program suction and translation). It will also control the operation of the follower system and data transmission to the computer.



Scheme 7: Research station plan

Ground station assembly:
https://bit.ly/2vwBDDM

In the ground station, we were placed a research station containing PMS7003, BME280, Dallas 18B20, GPS module and SD card adapter. This give us the opportunity to compare dust, pressure, humidity and temperature measurements from CanSat and measurements on the ground at the same time. Adafruit Feather M0 433mhz RFM96 LoRa radio will also be a computer in the ground station. All measurements are saved to the SD card. The program is the same as in CanSat, without the part responsible for AlitMu-10 and the radio transmitter

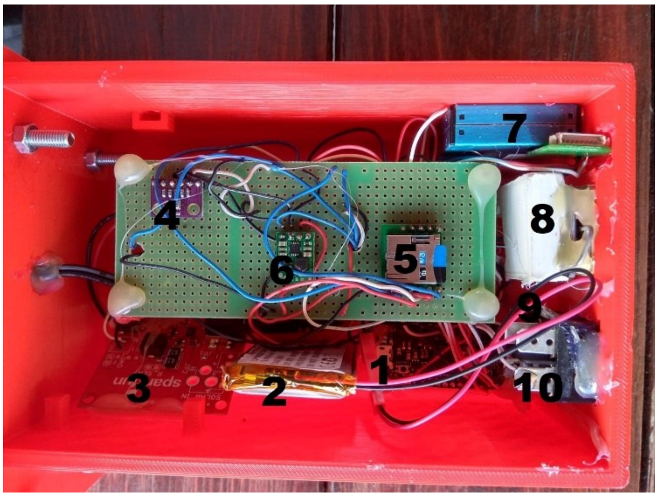


Photo 4: Interior of the research station

1)Main control board Adafruit
2)Battery
3)Solar charger
4)BME280 sensor
5)microSD adapter with microSD card
6)Step-up module for PMS7003
7)Dust sensor PMS7003
8)GPS module
9)Temperature sensor D18B20
10)Main switch
We have built a ground station on a 2-meter folding mast, powered by a solar panel. The position and angle of the panel is adjustable 0-90 degrees vertically and 360 degrees horizontally.

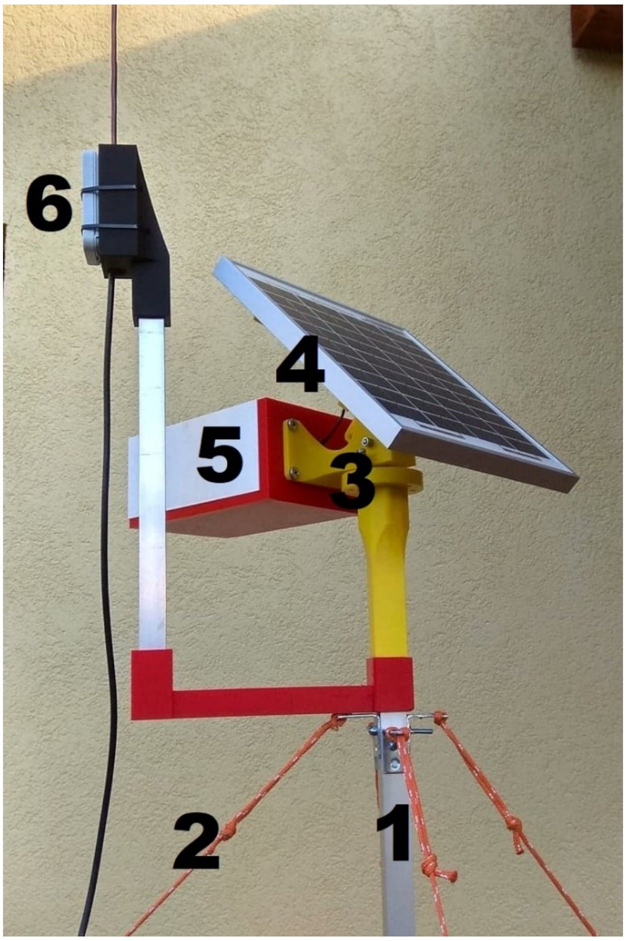


Photo 5: Ground research station and J-type antenna

1)Mast
2)Stabilizing ropes
3)Panel position adjustment
4)Solar panel
5)Case with sensors
6)J-type antenna.
It was built because we want to constantly monitor the level of pollution in our city and create vertical profiles of air pollution depending on the weather. As we know during windy days smog is blown out but we want to check if it is spreading sideways or is blown up. Our city of Gostyń does not have a natural air corridor, such as a wide riverbed, it is also located in a basin. In the center there is an old type of building heated mainly with solid fuels as coal, on the outskirts there are modern, energy-saving houses.

More information about ground station electricity power shown in chapter "3.3.4 Power supply".
We also built and tested a system that will move the antenna so that it is directed exactly at our falling CanSat. The rotation angle and elevation angle of the antenna is determined using CanSat GPS coordinates and ground station. For calculations we assumed that the Earth is a perfect sphere. The distance (in meters) between points for every 1 degree of latitude and longitude is calculated. Then the difference between the CanSat coordinates and the ground station is calculated and converted into length units (meters). The distance in a straight line is calculated from Pythagorean theory, and the angle of rotation and elevation are calculated using trigonometric functions. The distance determined on the basis of the algorithm differs by only about 307m at a distance of 100 km. The tracking program is ready. We already connected whole system and tested multiple times. We spent a lot of time calibrating the entire system to work just as well regardless of whether CanSat is 10m or 10km. away. Everything is working fine. We anticipate another tests.

4. Test campaign

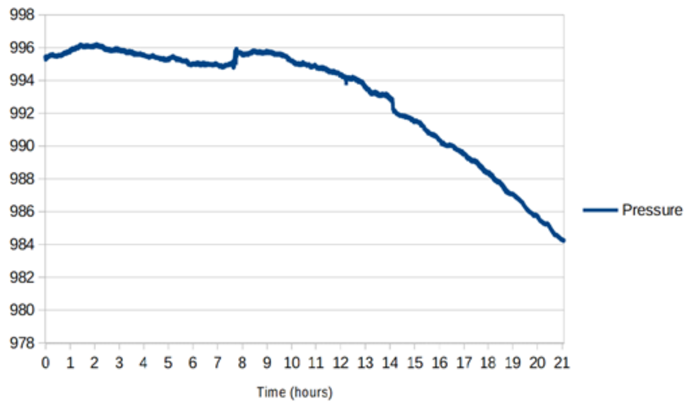
4.1 Primary mission tests

We tested our CanSat by dropping it from the observation tower in Sieków. In this way, we examined the strength of the cover and sensors and cable connections by dropping CanSat without a parachute. On the observation tower we also checked the correctness of the parachute and its attachment to the cover. In this way we will obtain large overloads comparable to those prevailing in the rocket.
We tested our sensors by connecting them and recieving data, which we compared to the other, more accurate sensors. The deviations were within the measuring error.
Durability and reliability: We dropped our CanSat from a height of about 8m (tower in Sieków) to check the strength of the entire structure and sensors inside. Thanks to this, we were able to achieve an overload comparable to those during the launch of the rocket, equal to 17G. All sensors survived and served their purpose. During the impact, the housing cracked, on which we later attached a sticker with our sponsors. We hanged the material of the cover to Pet-G wich is more flexible than PLA and survive the impact.

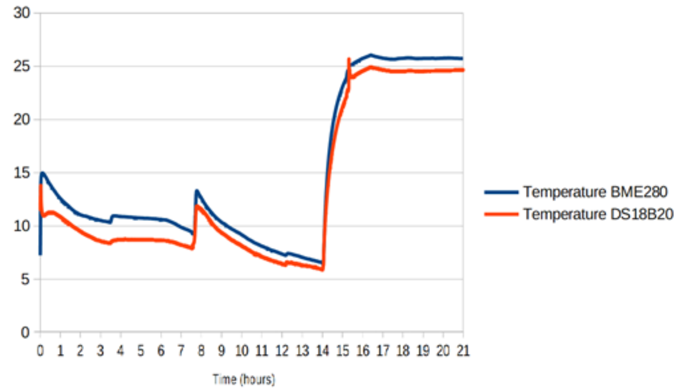
Photo 6: Broken cover after drop and sticker

In addition to advertising for our donors, the sticker significantly strengthened the whole structure, so we could carry out several more drops. We noticed a serious problem - the main switch interrupts electrical circuit and the whole system is reseted. We already fixed it. The only way to break power circuit is to destroy whole switch with cover.

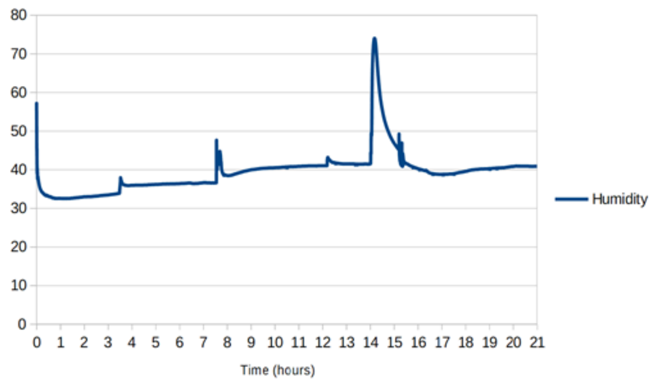
During the tests of working time we collected data from some sensors:



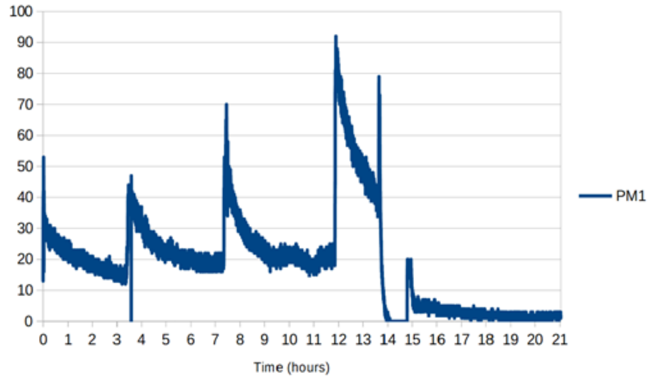
Graph 1: Pressure



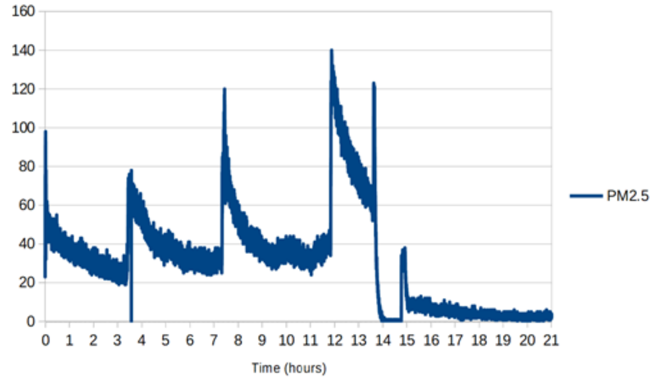
Graph 2: Temperature. DS18B20 is outside temperature sensor, BME280 is inside temperature sensor. Higher temperature inside CanSat result from heat emitted by electronics.



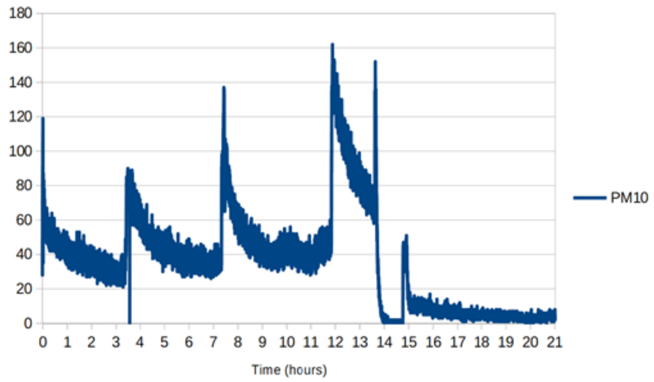
Graph 3: Humidity



Graph 4: Air pollution PM1,0



Graph 5:Air pollution PM2,5

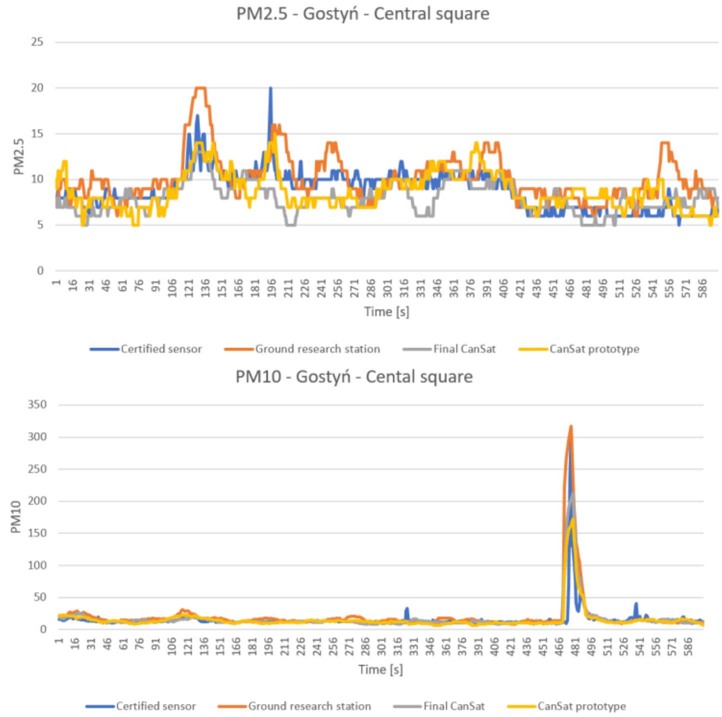


Graph 6: Air pollution PM10

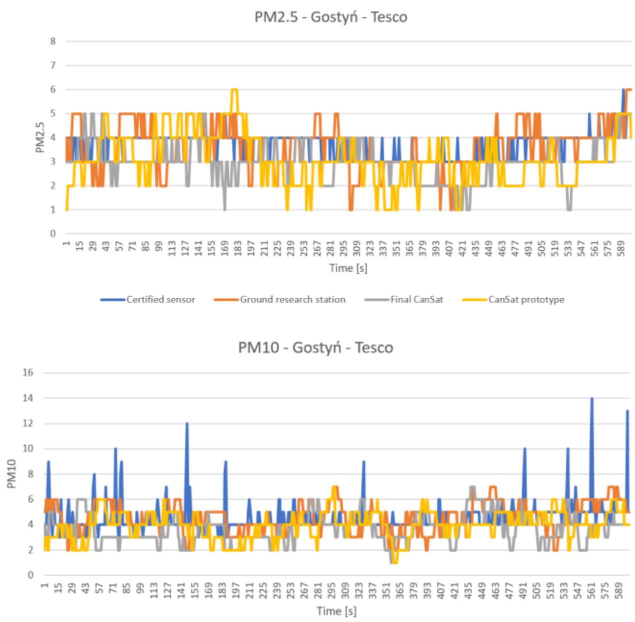
The graphs may look a bit strange but this is due to CanSat's permanent relocation. (school, car, home, garden)

4.2 Secondary mission tests

We conducted the tests by turning the gyroscope in all axes, it shows in the Cartesian system the appropriate values. A minor error is occured due to the inaccuracy of the device.
We tested both the PMS7003 and PMS5003 sensors - the data was practically the same, so we decided that PMS7003 will be located in CanSat (smaller and lighter)and in the ground station.
Then we placed working CanSats next to other dust sensors in our area. Deviations in the measurements are insignificant, apart from one moment - we suspect that water has got into the PMS sensor, which interferes with the correct measurements.
We were able to borrow a professional certified PM2.5 and PM10 dust sensor. We compared them to 2 prototypes, the CanSat final, our research station and a certified sensor. We collected data in various places - on the suburbs of the city, in the city center, in a place where someone was lighting a stove, generating smoke from a chimney, in a modern industrial zone. There are diagrams with those comparison.

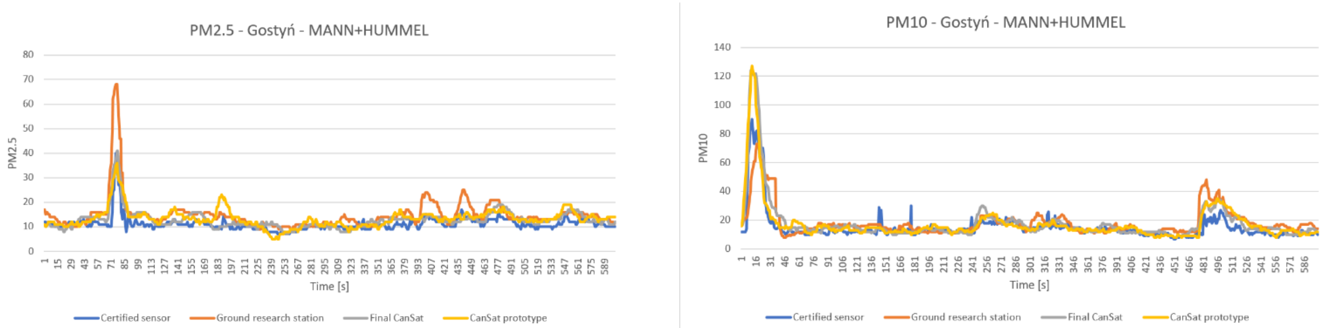


Graph 1: Air pollution in city centre

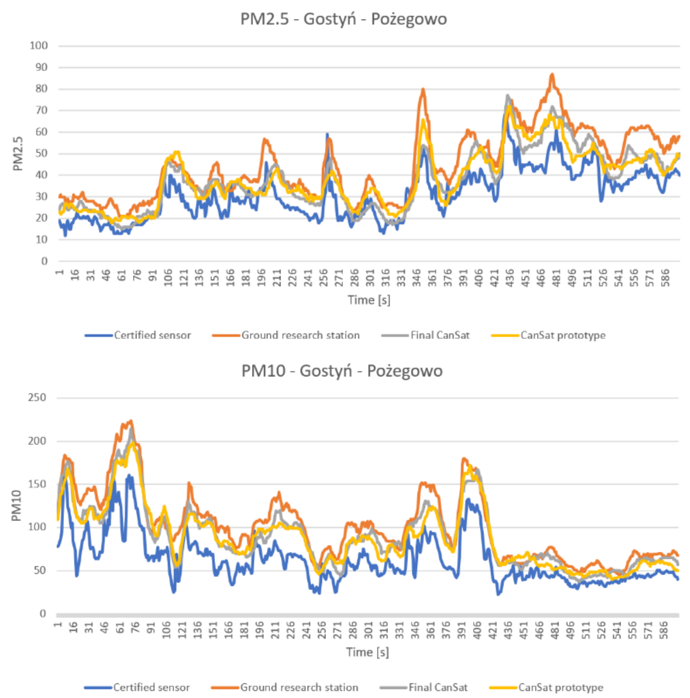


Graph 8: Air pollution at the suburbs

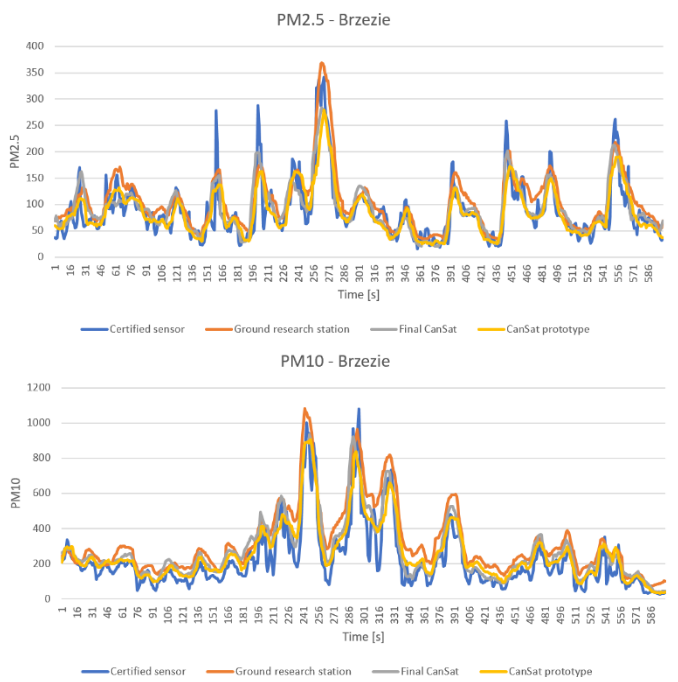
Photo 7: Certified air pollution sensor which we used



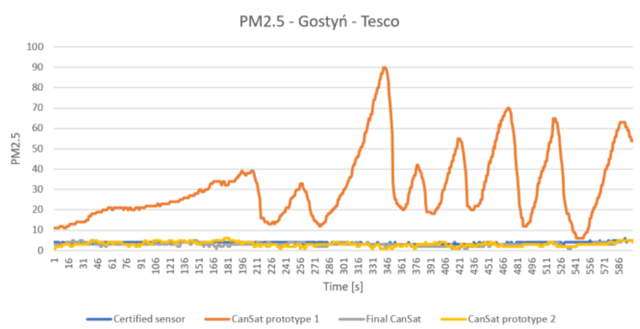
Graph 9: Air pollution in modern industrial zone



Graph 2: Air pollution in a housing estate heated mainly by solid fuel



Graph 11: Air pollution near the house with a very smoking chimney



Graph 12:Visible significant deviations on one of the sensors

The graphs show that in most cases all the sensors show the same value with a few fluctuations. However, the averages of 10 minutes are almost identical, which means that amateur pms 7003 sensors work well in applications for measuring air quality.
During tests, we used 3 CanSat prototypes, it turned out that the oldest version of PMS (the one that was subjected to repeated strength tests) was damaged and showed values that were significantly different from the rest. (labeled CanSat prototype 1)

4.3 Test of recovery system

The tests we were planning to do in two stages: the first stage involved checking the GPS module in the field, namely we will see GPS coordinates in several places and their compatibility with Internet map coordinates. In the second stage, we were planning to attach the parachute to a satellite model weighing 300-350 grams and make calculations and observation.

When compared to the coordinates of online maps, it turns out that GPS gives exact coordinates despite the small number of satellites. The final conclusion is that the GPS made an error in the form of showing speed despite stillness, a height slightly different from the basic one by about 3 meters, it means that the module is not the most accurate, but it is sufficient for our purposes. Currently, we managed to drop the test model together with the parachute from the tower in Sieków from a height of 15m (we could not go higher because the wind was too strong). Our parachute did not have a hole in the middle, which was why it caught the air weakly and did not fully unfold. That was thing we needed to fix. You can find the video of our tests on our Youtube channel. The exact drop time is given in the description of each video. The final parachute test took place during a drone drop with CanSat model with the same dimensions and weight from a height of 100m. The falling time was 10,2s, so it falls with speed of 9,8m/s. During the drop we used only 15% of the potential altitude from the drone's flight. We are still waiting for the wind to stop.

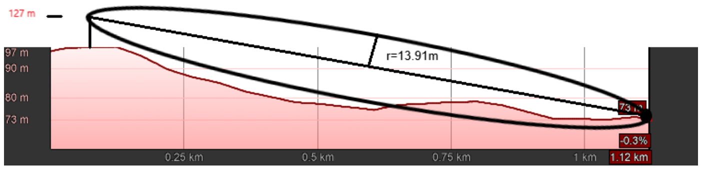
4.4 Communication system range test

The first tests were carried out using quarter-wave antennas made of ordinary copper wire. We managed to send a signal over a distance of 1.4 km. After building the receiving antenna, we conducted further tests. We managed to achieve a horizontal range of 6.4 km with a large supply of signal strength.

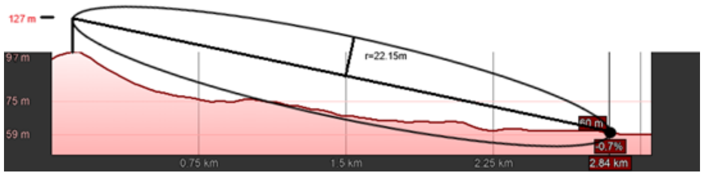
Photo 8: Our antenna Yagi during tests

Photo 9: Our teammate turning antenna in every possible direction

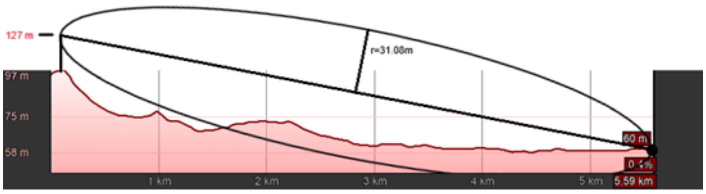
After this test we were turning antenna in random directions and we were checking the signal strength. We came to the conclusion that no matter how we turn the antenna, it will receive the signal anyway.
The Fresnel zone in radiocommunication is the area of propagation of the radio signal energy along the line connecting the transmitter and receiver. Objects such as hills, trees, buildings, etc. located in Fresnel zones have a large impact on wave propagation. In our case, we wanted to reduce the impact of the obstacles, so we went to an area with a large difference in elevation to map the conditions during the satellite flight as much as possible, when we have the entire Fresnel space at our disposal.
Below we present calculated Fresnel zones and landform during our measurements (in sequence 1150m, 3000m and 5550m):



Scheme 8: Fresnel zone for 1100m



Scheme 9: Fresnel zone for 3000m



Scheme 8: Fresnel zone for 5550m

In our next test we mounted our CanSat at the top of the tower, moved away 1150, 3000 and 5550 meters and examined the quality of the received signal both when the antenna was directed at the tower and when we tilted it vertically and horizontally. We have prepared graphics on how the signal quality changes depending on the distance (0 means lossless signal, -127 means complete signal break,). The graphics shows what results we received.

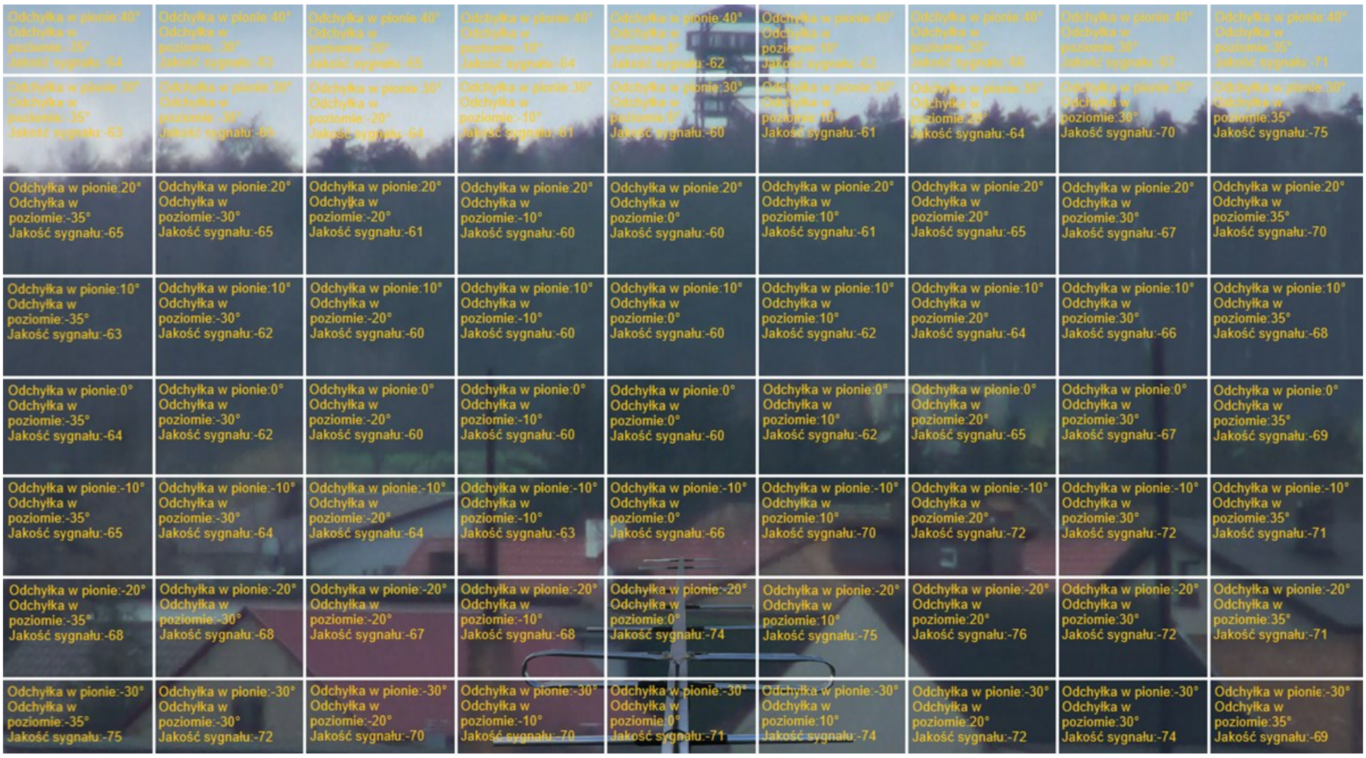


Photo 10: Signal strenght at 1150m

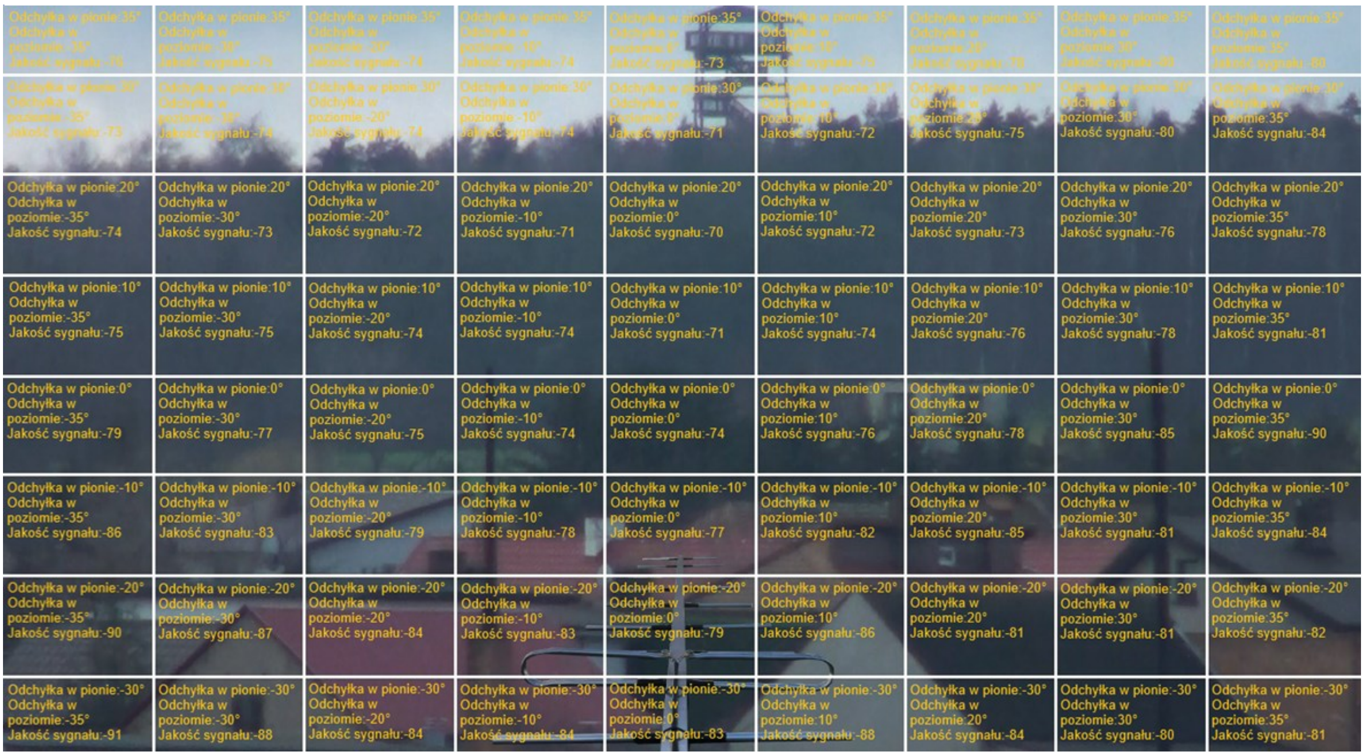


Photo 11: Signal strenght at 3000m

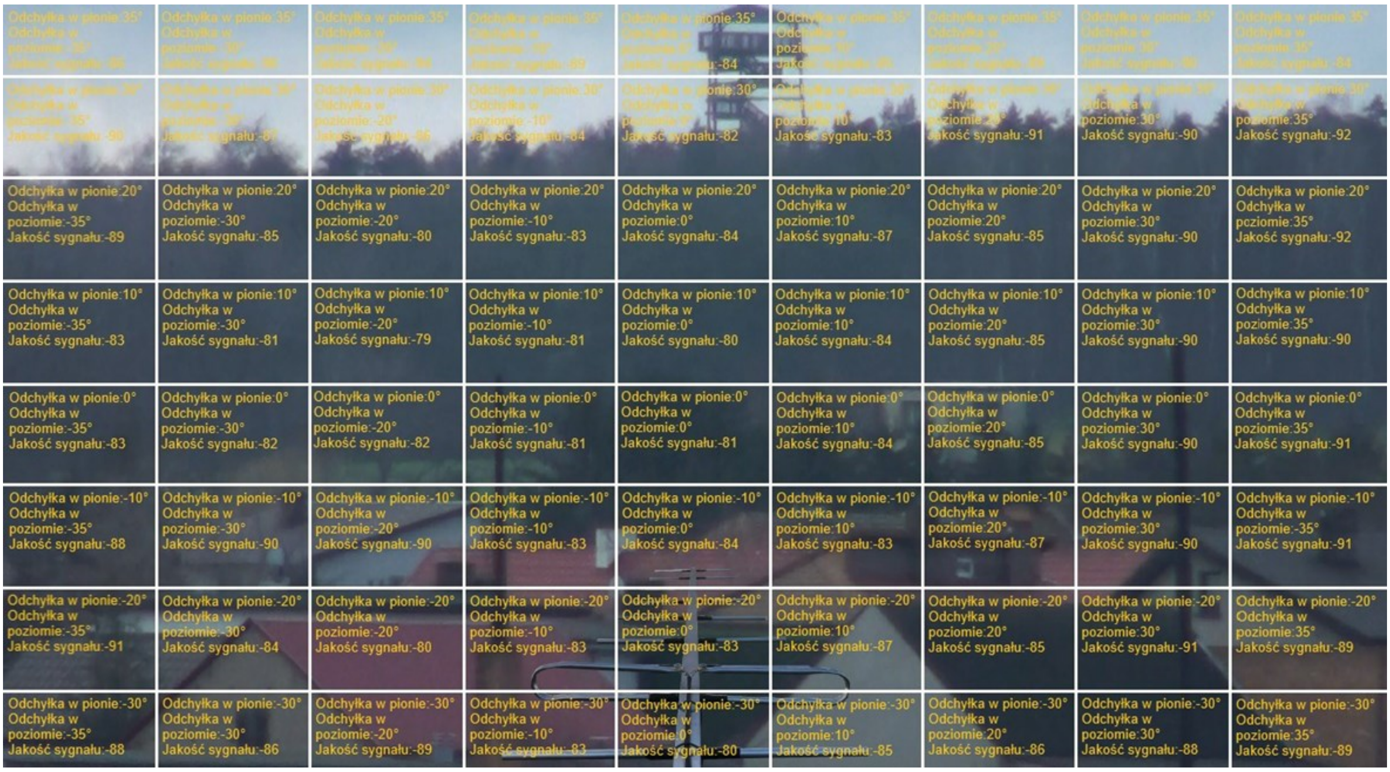


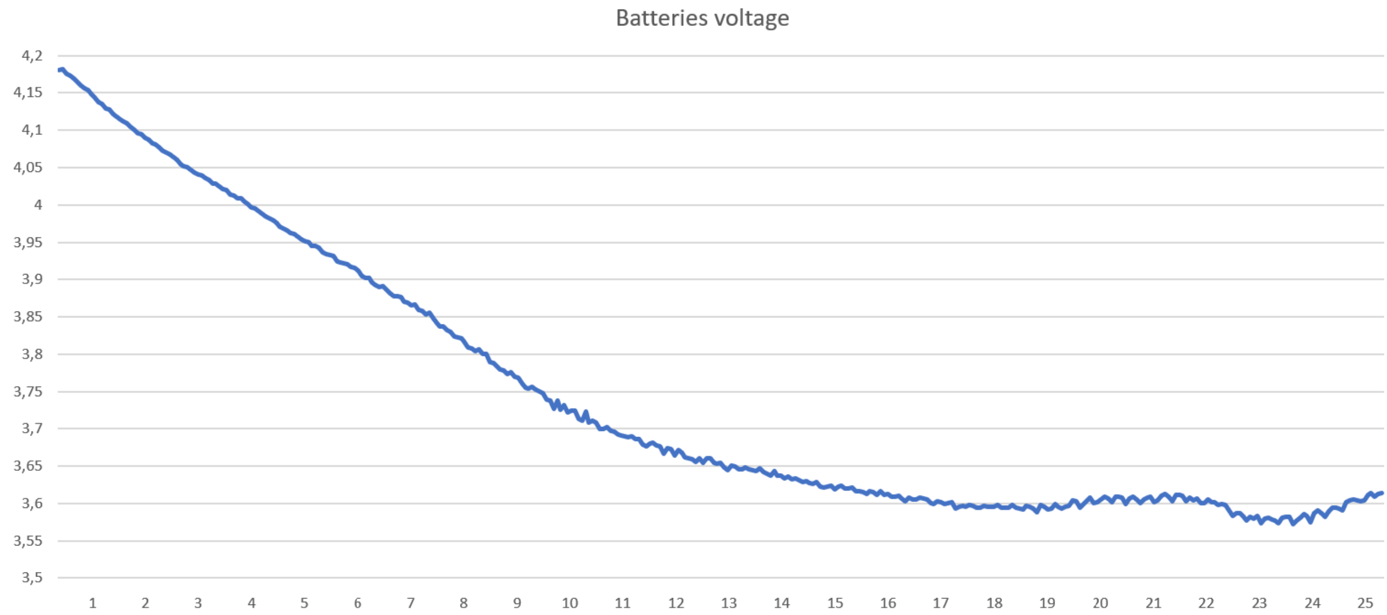
Photo 8: Signal strenght at 5550m

<u>Note: “Odchyłka w pionie” means vertical antenna deflection, “Odchyłka w poziomie” means horizontal antenna deflection, “Jakość sygnału” means quality of the signal.</u>

4.5 Energy budget tests

Working time: We launched our CanSat with fully charged batteries. It performed all measurements at various temperatures. The power supply was disconnected (probably out of voltage) after 21 hours. After checking the data on the SD card, it turned out that it performed faultless work for just over 20 hours. After this time, the measurements were duplicated, sometimes it looked as if it hang and saved the same values all the time, it did not work properly anymore. We thought that we made a mistake in the calculations because we assumed that he would work for about 6 hours, but it turned out that the producer’s website gives the maximum current absorbed by the sensor. In fact, this current is consumed in a very short period of time (only for ~250ms per second) which resulted in almost 4 times longer work time. We have not reduced the battery capacity because it is not a problem that could disrupt the mission.
Thanks to the improvements in the program, we can monitor live the voltage of the battery so we know how much time is left to drain it. Here is a chart from one of our tests:

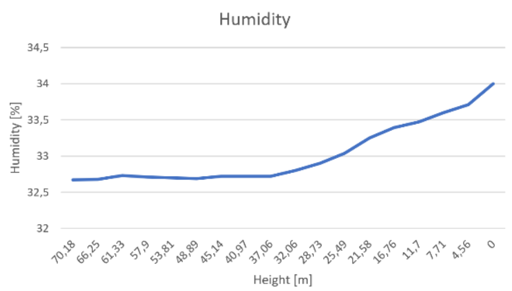
As we can read from the graph at the next page, during one of the CanSat tests it worked without interruption for 25 hours, but after about 19-20 hours the voltage was too low for the system to work properly, so we see errors in measurements - the voltage should not increase.



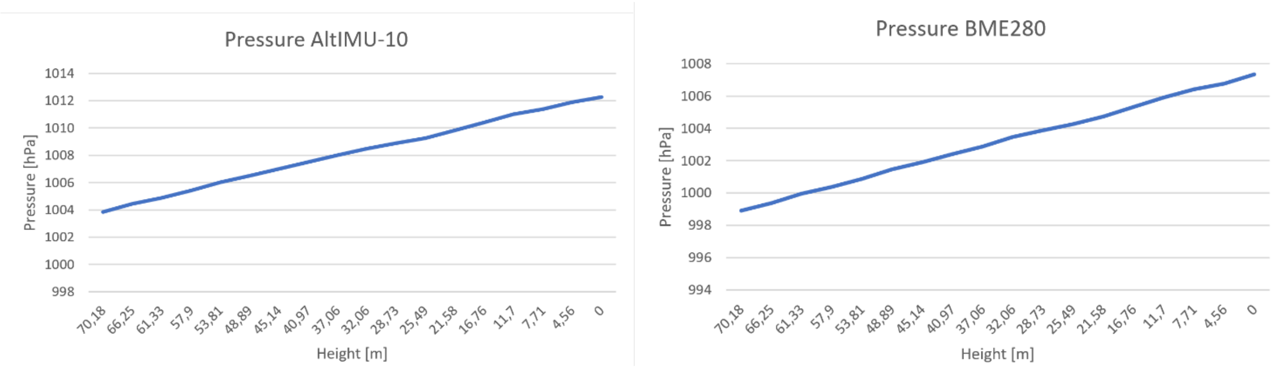
Graph 3:Battery voltage depending on the working time

4.6 Collected Data

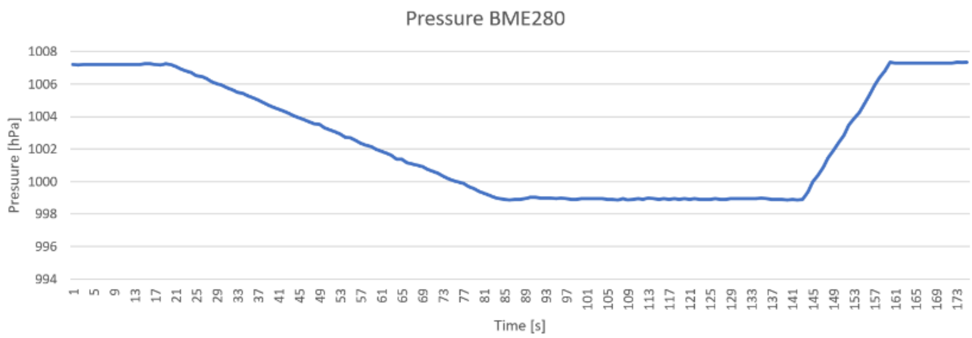
During the drone drop, we collected data to check if all sensors are working. We specially used a larger parachute to extend the descent time. In this case the falling speed was 4.2 m/s. In the final version of CanSat we will use a parachute tested earlier in Sieków whose falling speed was 9.8m/s.



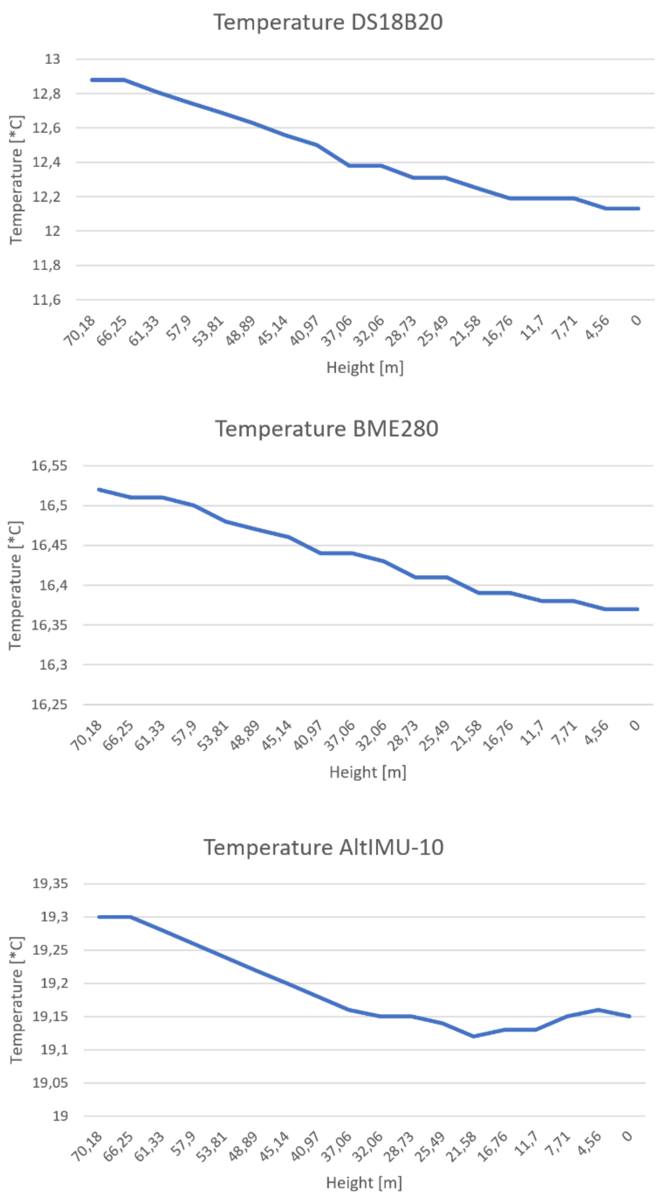
Graph 14: Air humidity



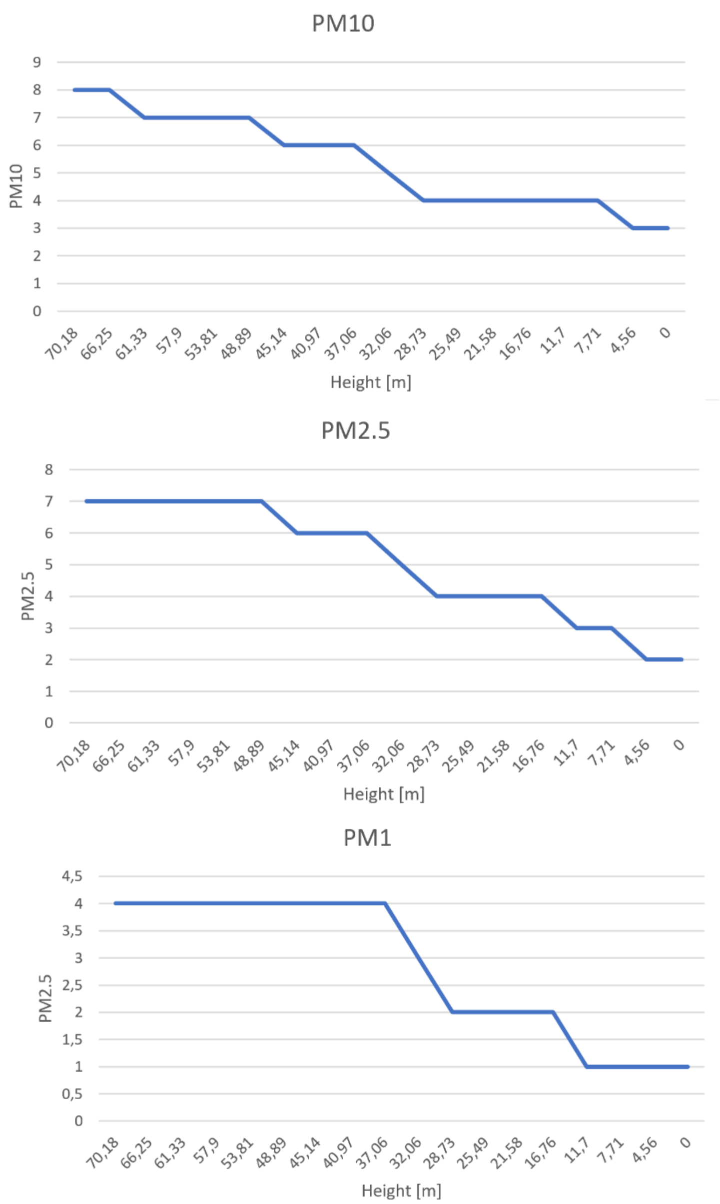
Graph 15: Pressure measured by AltIMU-10 and BME280. Values are different, but always the difference is 6hPa.



Graph 16:Difference in pressure at time - you can see the moment the drone ascends and CanSat falls



Graph 17:Comparison of outside (DS18B20) and inside (BME280 and AltiMU-10) temperatures



Graph 18: Measured values of air pollution with PM1, PM2.5 and PM10 dust

<u>We noticed, that the vertical pollution profile is invert (in comparison to the literature data) during the windy weather.</u>

Why didn't we take more test drops? The weather was unfavorable all the time. On the day we did the above tests, we used the drone to the limit and exhaustion of its battery packs.

Photo 9: Drone with attached CanSat during takeoff

5. Project planning

5.1 Time schedule

Done:

Date	Activity
30.09-06.12.2019	Layout of CanSat construction
07.10-06.12.2019	Sensor connection
07-18.10.2019	Design power system
07.10-22.11.2019	Design 3D frame
10.10.2019-01.03.2020	Marketing activities
12.11-10.12.2019	Finding sponsors
25-29.11.2019	3D printing
02-06.12.2019	Implement power system
02-06.12.2019	Soldering entire system
04-06.12.2019	Assembly first prototype
07.12.2019	Tests of first prototype
09-16.12.2019	Analysis of collected data
10.12.2019-08.01.2019	Writing a running program and program upgrades
10-20.12.2019	Drawing conclusions
16.12.2019-08.01.2019	Fixing program to not hang (libraries)
23.12.2019- 04.01.2019	Ground station plans
27.12.2019-08.01.2020	Creating CDR
02-07.01.2020	Parachute fixing
02-07.01.2020	Main switch fixes
02-07.01.2020	Improvements in the CanSat construction
1-6.02.2020	Ground station construction
6-10.02.2020	3D printing of second prototype
21.02.2020	Logo competition summary
11-13.02.2020	Second prototype assembly
24-25.02.2020	Working time tests
19.02.2020	Test drops
21-27.02.2020	Development of water protection
23-26.02.2020	Creating the final CanSat
26-28.02.2020	CanSat manual writing
21.02-1.03.2020	Creating FDR

Table 4: Things done

To do:

2-14.03.2020	Ending gyroscope visualisation (using magnetometer)
3-22.03.2020	Collecting data
3-14.03.2020	Thanks to the sponsors
26-29.03.2020	Taking part in CanSat finals

Table 5:Things to do

5.2 Task list

Done:

- Layout of CanSat construction
-Some marketing activities (local newspaper, local radio and scools)
-Finding sponsors
-Writing a running program
-Sensor connection
-Design and implementation of the power system
-Printing all elements on a 3D printer
-Soldering the entire system
-Assembly first working prototype
-Tests of first working prototype (measurment, falling with and without parachute, long-time battery test)
-Analysis of collected data
-Drawing conclusions and plans for necessary corrections
-Exact ground station plans
-Parachute fixing
-Main switch fixes
-Some improvements in the CanSat construction
-Fixing program to not hang when one of the wires is broken
-Ground station
-More marketing activities
-Tests and test drops
-Program improvements
-Create manual of CanSat switching On/Off
-Development and implement of water protection

To do:

-Thanks to sponsors and supporters
-More tests and data collects to be sure
-Taking part in CanSat finals

5.3 Resource estimation

5.3.1 Budget

Element	Cost (PLN)
Adafruit Feather M0 with RFM96 LoRa Radio	200
GPS	65
PMS sensor	100
AltiMU-10v5 (gyroscope)	90
Dallas 18b20 sensor	5
Bme 280 sensor	50
PMS adapter	10
4x battery	112
mechanics	50
Filament	20
Parachute	70
MicroSD Card Adapter	3
MicroSD Card	37
Together	812

Table 6: CanSat budget

5.3.2 External support

People who supported us and provided appropriate equipment and advice:
-Justyna Błaszczyk-checking the correctness of translations
-Tomasz Koralewski-help with the communication module
-Tomasz Betka-help in modifying the tracking system
-Krzysztof Borowczyk-suggestions for parachute and communication, help in removing CanSat from the tree.
-Radek Koralewski- CanSat elevation service with a drone

SPONSORS:

Powiat Gostyński

Zespół Szkół Zawodowych w Gostyniu im. Powstańców Wielkopolskich

ZSZ Gostyń
Stowarzyszenie Absolwentów i Sympatyków

Lucyna Przybył
BIURO RACHUNKOWE

mondi

ArdaghGroup

4Lan.eu

MEBLE
JAROCIN GOSTYŃ

FMW

KORAL Sklep RTV
Tomasz Koralewski

6. Outreach programme

During the searching for sponsors and donors, we disseminated information about our activities among local entrepreneurs. According to the schedule, we will organize workshops for primary school students, this will be our participation in the promotion of the school. We are planning to have our own stand in the upcoming science picnic. 2 months ago we had a meeting with the starosta gostyński, thanks to whom we received a large amount of funding. On our facebook we recorded more than 400 original users. In local newspapers ("Życie Gostynia", "Fakty Powiatowe") were also published some articles about us and audition in local radio "ELKA Leszno". Two people from our team took part in the Climate Conference in Krobia, presenting our project and what does our school do to improve environmental protection. In our school there are screens presenting current events from school life. The photos from our test are also there.

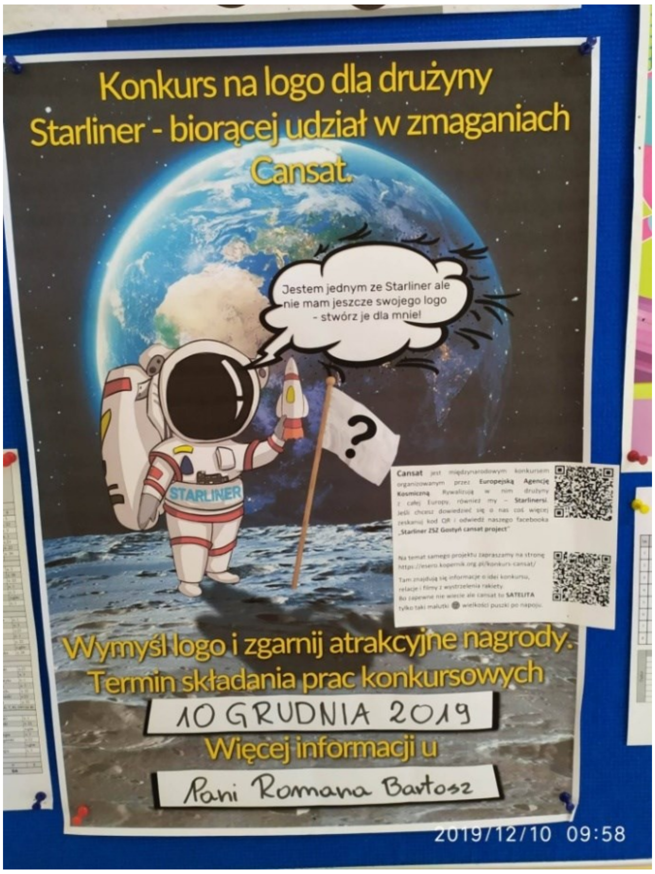


Photo 14: Poster informing about the competition

In local elementary schools, we ran a competition to design our logo. There were also QR codes referring to our Facebook page on the posters announcing the competition. We chose 2 works, one as our main logo (visible on the title page) and the other which will serve as the background on Facebook.

On January 23, 2020, we presented the CanSat project at two local primary schools and rewarded the winners. One of the awards was a Starliner t-shirt, just like all the members have.

Photo 15:Presentation at schools and awarding prizes

If we qualify for the final 10 teams, the editors of gostyńska.pl have assured us that they will interview us and write an article about our entire preparation an progression to the competition.

We are also going to take part in the "Museum Night" which actually will take place after the finals (May 16), but we want to further promote the school and our own names.

We decided that one of the forms of thanks to sponsors would be commemorative emblems of our logo printed on a 3D printer with the help of decorative filaments.

Photo 10:Emblems with our logo

Our website:
https://bit.ly/2Tms4iF
Our facebook:
https://bit.ly/32ye5L9
Our school website:
https://zsz-gostyn.com.pl
Our school facebook:
https://bit.ly/2Tj5GqI
Our Youtube channel, where you can find videos recorded during our tests:
https://bit.ly/2wKGuS7
Articles about us:
https://bit.ly/32xi5ez
https://bit.ly/2Pw8boq
https://bit.ly/393Gefu

7. CanSat characteristics

CHARACTERISTICS	FIGURE
Height of the CanSat	114,2mm
Diameter of the CanSat	63,8mm
Mass of the CanSat	335g
Estimated descent rate	9,8m/s
Radio transmitter model and frequency band	Adafruit Feather M0 RFM96 Lora with radio module 433Mhz
Working time on battery	20h of stable work
Cost of the CanSat	812PLN

Table 7: CanSat characteristics

8. Summary

Thanks to the CanSat project, we have learned many things that will be helpful in the future.

Kacper Grobelny trained his skills in programming and data analysis. Now he is able to put things in programs that we didn't even know existed before. Dawid Betka mastered the control of stepper motors and trained in the aerodynamics department during the construction of the parachute. Mikołaj Koralewski became our specialist in antennas and all things related to communication. Michał Jędrzejak learned how to create electrical systems. Piotr Skoracki worked with programs for creating 3D structure, thanks to which he is able to use the full potential of CAD / CAM programs. Mikołaj Krzyżostaniak improved his English skills and found a new hobby - 3D printing.
Everyone also learned how to work in a team and link their actions over time with other team members.
Our biggest problems for some time were the organization of work, and the time running out. We think we've prepared ourselves as well as possible. We tried to protect against everything that may not go with the plan during the rocket launch. Here are some examples of the problems we anticipated and their solutions:
- Non-working main antenna with a follower system - additional "J" antenna at the research station.
- CanSat damage during the drop from the drone on the first day - 2 CanSat pieces and the third which was our first prototype serving as the "donor" of spare parts.
- Rainy day or fall into a puddle – gaskets and other water protection in

our CanSat
- Weather or other factors preventing the drone or rocket from taking off - we have the data collected so far and the ones we will collect while waiting for the jury's verdict, so we will have something to take conclusions from.
To safely transport CanSat to the finals, we've created a special suitcase. When the FDR report is sent, it is printed.
Assembly film: https://bit.ly/2I3FuLs

9. Statement

We declare that we are fully ready for tests at the military training ground. We have 2 fully operational CanSats, 2 antennas, one of them with an innovative tracking system and a ground station for collecting measurements. Everything is working and has been tested.

10. Register

Schemes:

Photos:

Tables:

Graphs:

All links:
CanSat program: https://bit.ly/2VrZCie
Ground research station assembly: https://bit.ly/2vwBDDM
Tracking antenna program: https://bit.ly/38eRCDO
CanSat suitcase: https://bit.ly/2I3FuLs
Our website: https://bit.ly/2Tms4iF
Our facebook: https://bit.ly/32ye5L9
Our school website: https://zsz-gostyn.com.pl
Our school facebook: https://bit.ly/2Tj5GqI
Our YouTube channel: https://bit.ly/2wKGuS7
Articles about us:
https://bit.ly/32xi5ez
https://bit.ly/2Pw8boq
https://bit.ly/393Gefu
https://bit.ly/2Tg9c6p
https://bit.ly/39jZ2Hy