Starliner

Final Design Review

Team Name: Starliner
Country: Poland

Content

1. Changelog
-we added 3 motors- 2 for deploying wheels and one for moisture sensor deployment and parachute cutting
-we will use “yagi” antenna with 9 instead of 12 elements (more compact and reliable during testing)
-we deleted camera from the mission- CanSat because of its small size was taking unreadable pictures from the ground level and taking too much space in CanSat
-we won’t be using “J-type” antenna anymore- it doesn’t meet our requirements
-we redesigned the wheel extension mechanism
-we added new sensor (APDS-9960-DFRobot SEN0187) which measures distance from an obstacle and RGB colours
-bi-quad is our main antenna and will be mounted on tripod with tracking system
-yagi is our backup antenna- it has worse range test results

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. Everyone is responsible for their part of CanSat, where each of the 5-person group have part in each element, so that in case of illness or temporary indisposition of one of us, the project won’t stop.
Mr. Michał Żurawski is our supervisor. He is a physics teacher at our school. Mr. Żurawski also assist in management of the budget for our project and he motivates the team members to work.
Tasks of individual group members:
Kacper Grobelny - team captain; he has big experience in programming. Kacper creates the main CanSat program, the antenna receiving and control program, as well as the program which is drawing graphs and he connects the sensors to the main system. He also manages our team github.
Mikołaj Koralewski – he is responsible for the communication between Cansat and the station on the ground and the construction of the receiving antenna. He is CanSat prototype constructor. Mikołaj deals with soldering and troubleshooting electronic stuff. He also applied solar panel to our rover.
Mikołaj Krzyżostaniak – he deals with 3D printing, he is also responsible for translations and visual aspect of our reports. Mikołaj is our team coordinator and he is responsible for transport matters. Providing necessary resources is also his task.

Piotr Skoracki – he deals with the frame, cover design and construction in Solid Edge. He designs the wheel retraction mechanism and parachute detaching. Piotr is also responsible for the website, social media management and visual documentation of our progress.
Dawid Betka - deals with the construction of the parachute and electrical design. He is responsible for constructing and testing our moisture sensor. Interpreting GPS coordinates is within the scope of his duties.

2.2 Mission objectives

The general assumption of our mission is the search of water and favorable conditions for life on foreign planets or moons. We want to focus on finding single places on the planet where it will be possible to set up a base or a colony in the future. The device is created to be dropped into an area where, based on remote sensing from the orbit, there is a probability of water presence. The probe will measure the presence of water in the soil. If the battery in the CanSat is discharged, the device will go into sleep mode until it charges the battery from the solar panel.
An important element for us is also our wheel extension system, thanks to which we are able to maintain the standard CanSat size and increase its off-road capabilities. Thanks to the mobility of our CanSat, we can conduct research in many different places on the planet with one rover.

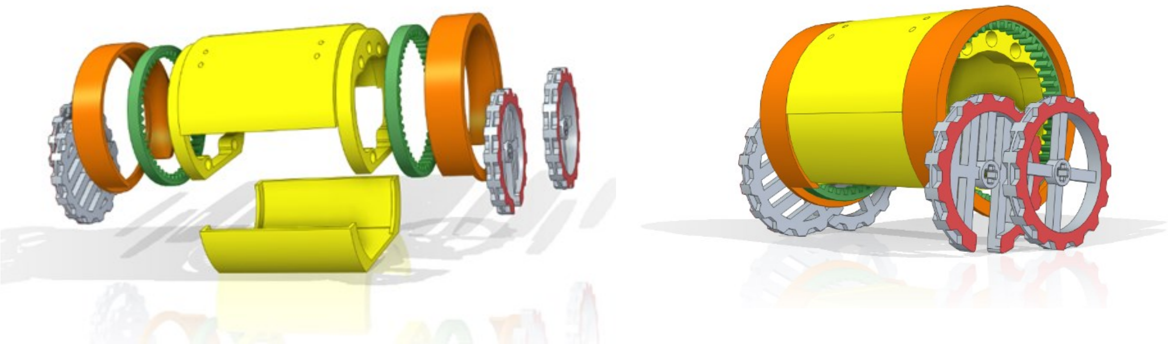
3. CanSat description

3.1 Mission overview

We are going to build a rover that will fit the cylinder size of 115x66mm. It will be launched from a rocket to a height of about 3 km. After it is released from the container, it will fall at a speed 8-10m/s. It will measure inside and outside temperature, pressure, air humidity, acceleration, orientation, and magnetic field as it descends. The height at which the rover is located will be measured on the basis of pressure changes. All data will be sent to the ground and analyzed by the program which will be creating graphs in real time. Based on GPS coordinates and altitude, the antenna will direct itself to the falling CanSat. After landing, the probe will detach its parachute and will unfold its wheels. The probe is equipped with an algorithm that will try to follow to the lowest point, because there is the highest probability of finding water there. This is where it will measure the soil moisture. If surface will be flat it takes 5 measurment of soil moisture in one place every 3 minutes and will calculate the average. During travelling with average speed of 2,5m/min (measured on flat, hard surface) CanSat also measures temperature, pressure, air humidity, location, acceleration, orientation, and magnetic field. The travel and measurement process will be repeated many times.

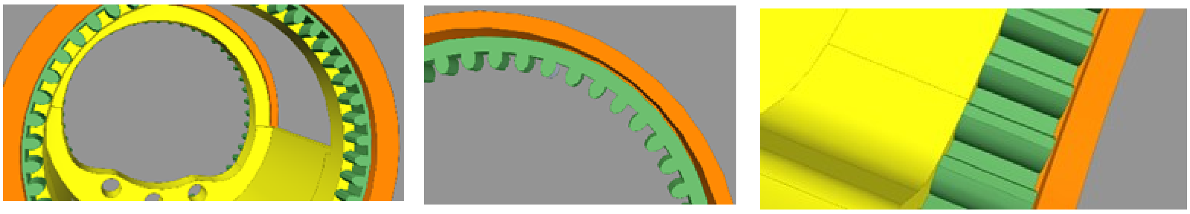
3.2 Mechanical/structural design

3.2.1 3D design project



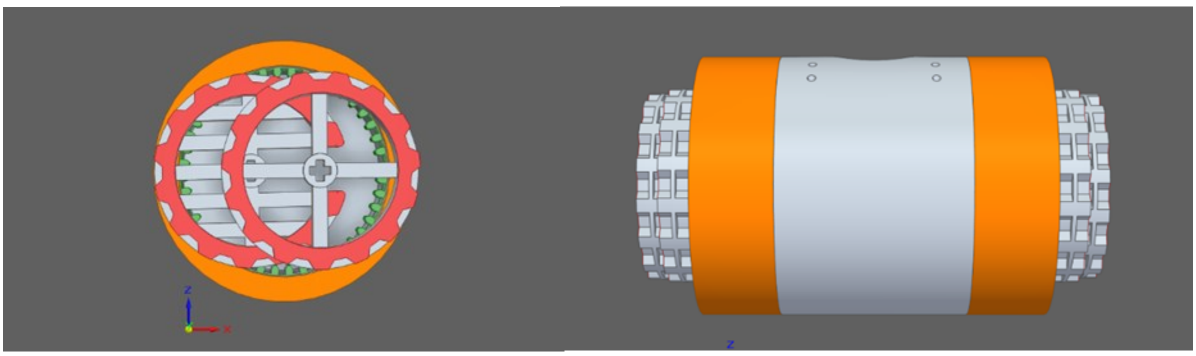
Picture 1:Every single part of CanSat and assemble

CanSat cover was designed in Solid Edge 2020 to print it on a 3D printer. The box consists of a middle segment and two gears with internal toothing, fixed by a cover. The middle segment consists of two parts for easy access to the components inside. All folded elements have clearances (0.4- 0.8 mm) so we can easily put them together and the gears rotate without any problems.



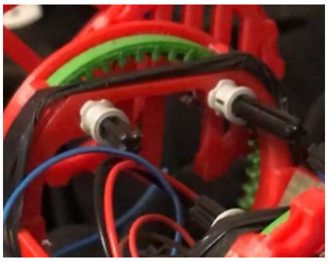
Picture 2: Loose fitting

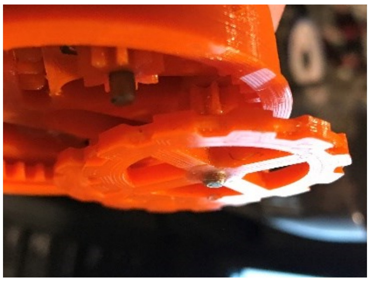
The CanSat, both in flight and on the ground, will move horizontally, which will make it more stable while driving. The battery will be placed at the bottom of the box to move the weight as close to the ground as possible. At the beginning we wanted to use tracks, but we came to the conclusion that it is too complicated and heavy mechanism, so we gave it up in favour of the wheels. The wheels have been designed so that their diameter is as large as possible. This diameter is 46mm. One of the wheels has a cut-out so that the wheels could be folded while in the container. The CanSat will be equipped with a wheel extension system.



Picture 3: CanSat state in the rocket container

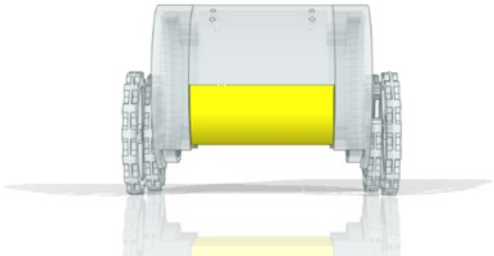
For mounting wheels to our first CanSat prototype we used Lego axles, to which we adjusted the through holes in the design, then we replaced the Lego axles used before by our own designed ones (also printed). Now we're using metal screws. It's more stable and more accurate.

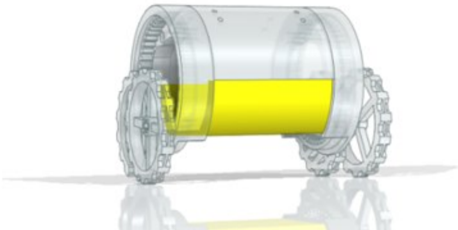




Picture 4: Comparison of the axles

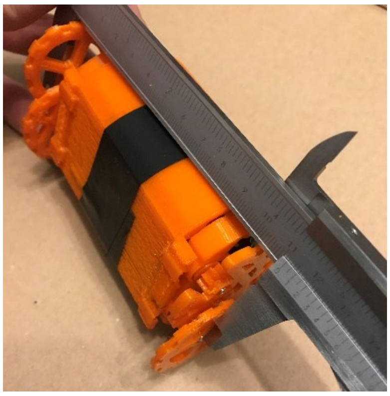
Looking from the side, you can see that the CanSat is cut from the bottom, which allows it to overcome more uneven terrain. The ground clearance of the rover is 10mm.





Picture 5: Cut bottom

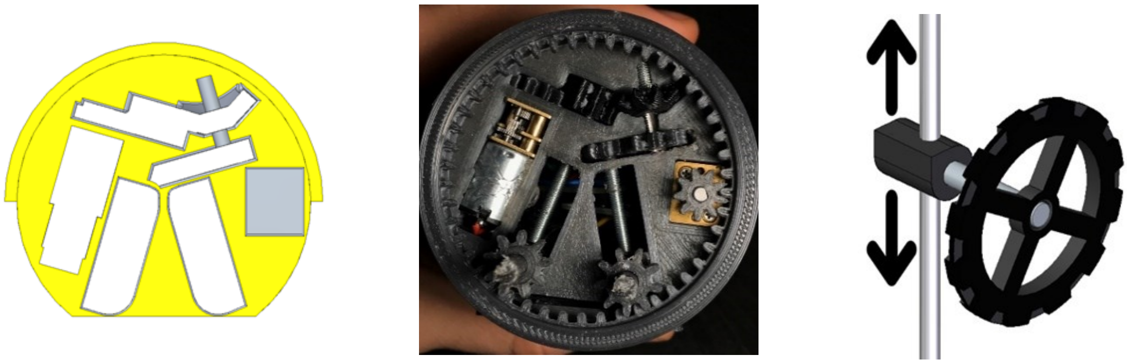
In the upper part of the main segment there are 4 holes for attaching the parachute. The overall dimensions of the CanSat are designed with a margin of 3mm to the maximum possible.



Picture 6: CanSat size

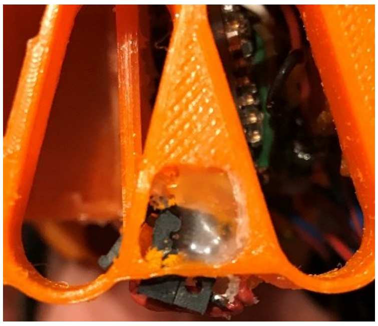
After assembling the frame of the prototypes and applying corrections, we got a weight of 100g. We replaced the full walls, on the both sides of the CanSat with wheel retraction mechanism. All these changes allowed us to save 8mm inside the Can.

The wheel retraction mechanism is based on five gears, transferring the rotations from the motor to two screws, and two blocks with wheels attached to them. There is a nut in each block. We had to apply bevel gear to our CanSat because of different screw deviation. Each gear has 9 teeth so the gear ratio is the same everywhere. The screws by its rotation lower the blocks with nuts and get the CanSat on its feet. Then the gears on the wheel axles are driven by an internal gear. Before deployment and during the descent the wheel are retracted but when the rover is on the ground the wheel extension starts.



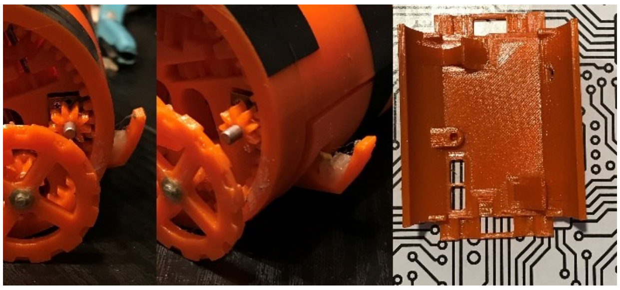
Picture 7: Wheel extension system

To stop the wheel extension we used the limit switches, detecting the fully extended position. Then the limit switches cut off the power supply and the motor will stop



Picture 8: Limit switch

We designed and applied to our CanSat the system to recover the overturning Can. When the rover will be overtuning, this system will help to keep it vertical. The supports on both sides slide out equal with the wheel extension. They are connected by steel cable. https://bit.ly/3dRw0nv



Picture 9: Side support

At the beginning we tried to use the gears printed on the resin printer but the products were too small and brittle. We had to change our concept and stay with the old printing method.

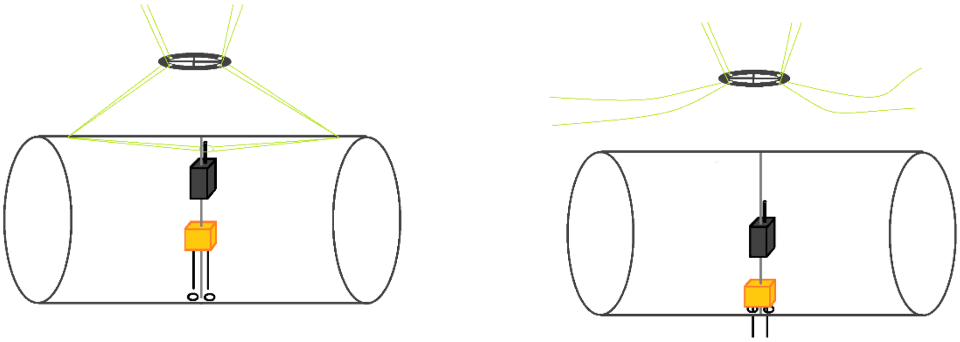
Picture 10: Resin gears

Videos describing CanSat working:

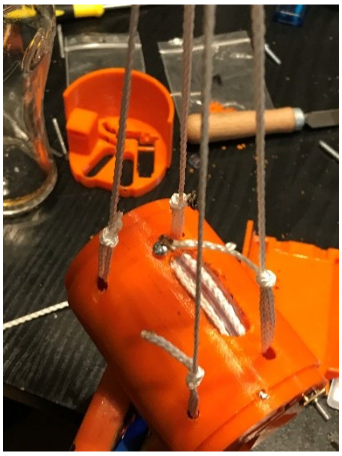
https://bit.ly/2N4FyjQ https://bit.ly/3bD0tTu
https://bit.ly/3dRnDZ7 https://bit.ly/3q09XNS

If we are looking for the water it means that there is a lack of it, so the risk of flooding with water is low. We have kept dust access to a minimum, but due to the complexity of our CanSat's mechanical systems, we are unable to provide IP6X protection.

We created the mechanism detaching the parachute. After providing the information about landing, the parachute will be separated from the CanSat by expending the pin on the soil moisture . From the inside to the outside of the CanSat, the parachute strings are going into flexible tubes (to isolate it’s from the components inside the CanSat). Then the rover will start the mission. https://bit.ly/3aY6Hyg



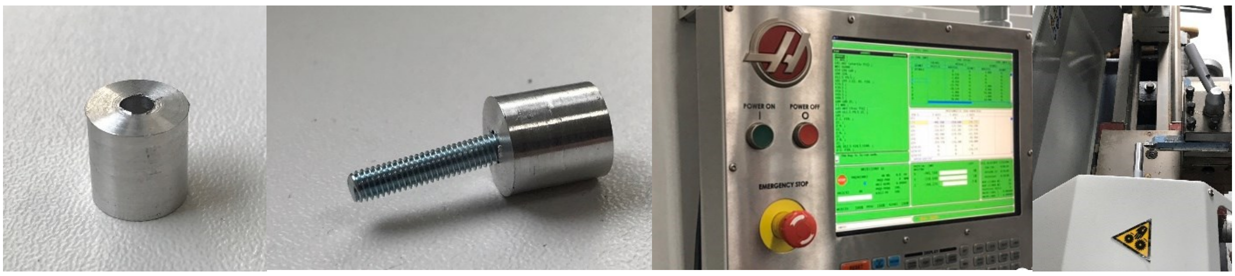
Picture 11:Parachute cutting system before and after landing



We also printed a test can for the parachute test. It is simply a weight with the same shape and weight as the finished CanSat. We tested it on the tower in Siekowo. The CanSat cover and frame will be printed on a 3D printer. The materials we will use are mainly PET-G and ASA as well as PLA. We will decide on the exact printing parameters such as filling or the type of material for a given part after strength tests.

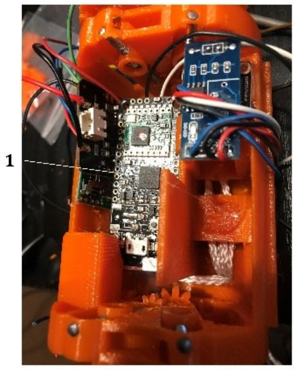
Picture 12:Dummy-mass for parachute tests

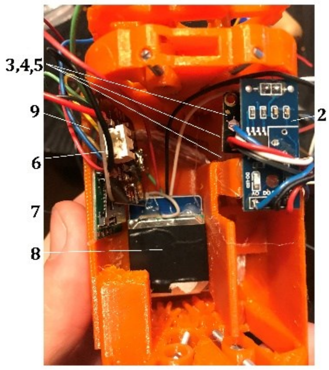
In the meantime we were trying to refine our construction. One of these changes was the attempt to replace our printing blocks (to wheel retraction) with block made on a CNC-machine and on a lathe. Aluminium blocks could be more durable. After applying it to our CanSat, the blocks were too inaccurate. Any slight deviation prevents fluid movement. We didn’t have access to CNC-lathe with an accuracy of 0,1mm or more. Our 3d printer has an accuracy of 0,4mm so we decided to stay with our previous idea.

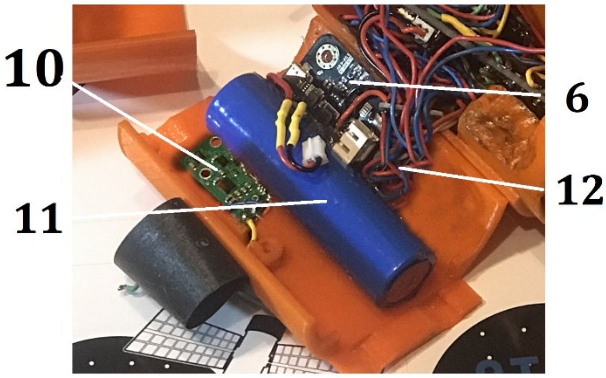


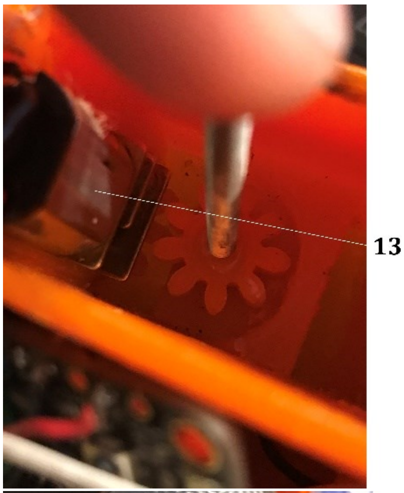
Picture 13: Blocks created with CNC-machine and Lathe

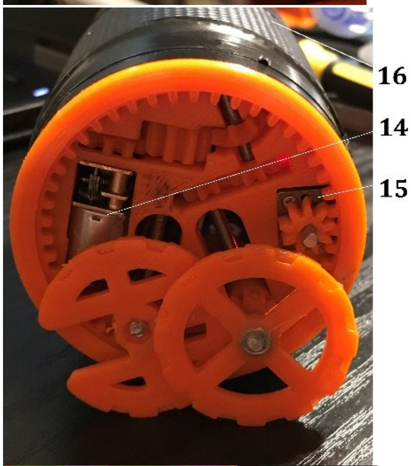
3.3.2 CanSat building

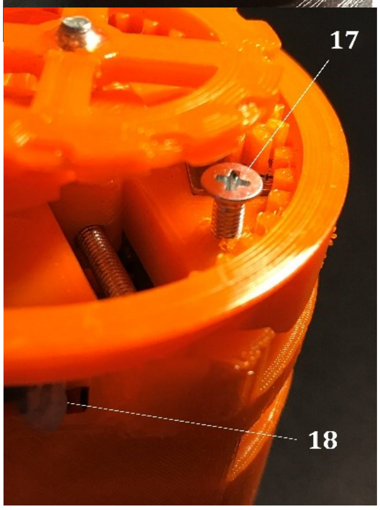










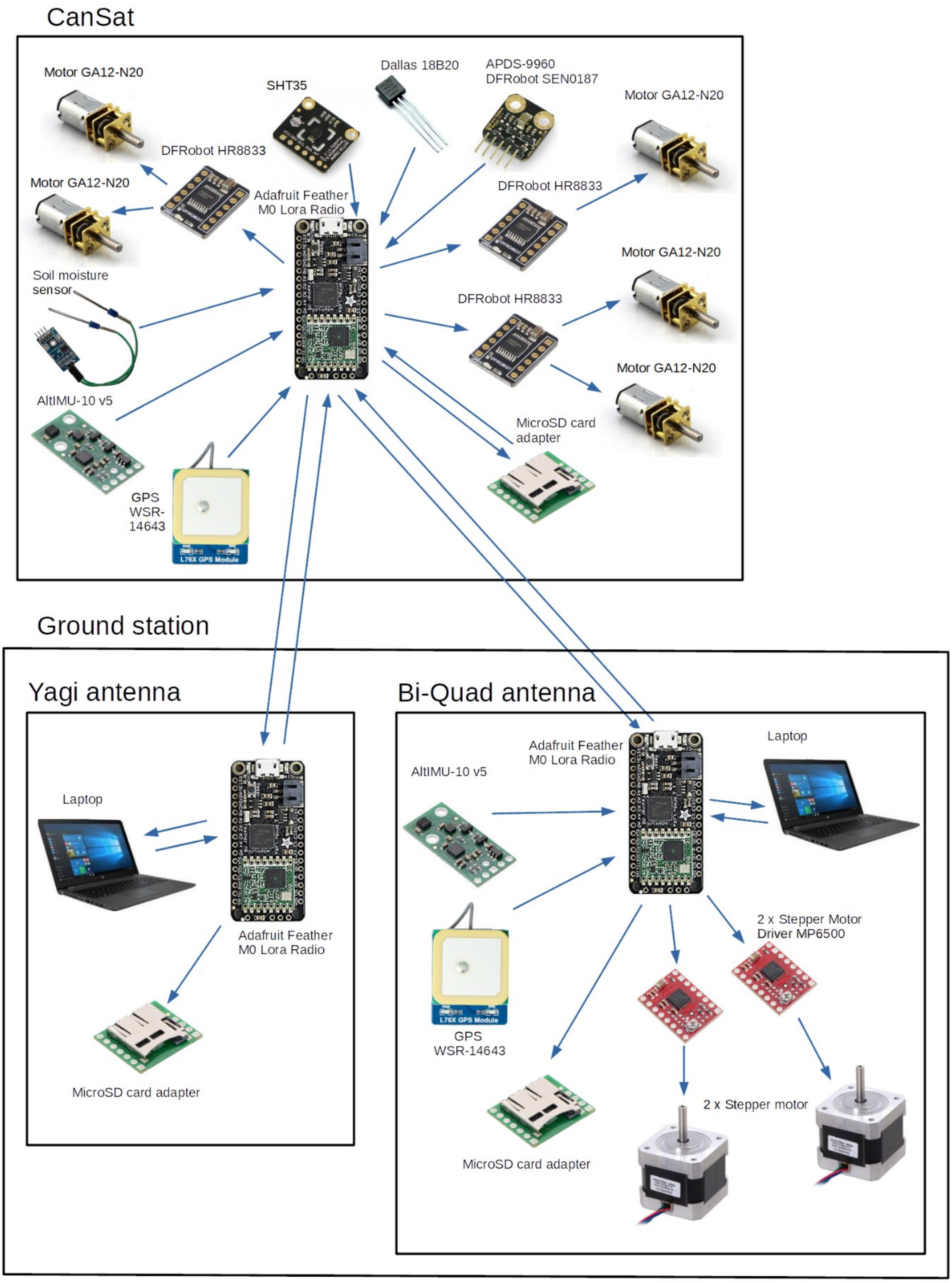


1. „Adafruit Feather M0 433 Radio MHz RFM96 LoRa”
2.Soil moisture sensor module
3,4,5.Controller „DFRobot HR8833”
6.Solar Power Manager Micro SKU DFR0579
7.MicroSD card reader module- Pololu 2597
8.Module “GPS L76X - Waveshare 16332”
9.Gesture and color sensor “RGB I2C - APDS-9960 - DFRobot SEN0187”
10.AltIMU-10 v5 - gyroscope, accelerometer, compass and altimeter I2C 3-5V - Pololu 2739
11.Battery Li-ion 18650 2500mAh
12.Temperature sensor DS18B20
13.Motors moving the moisture sensor 13-Mini GA12-N20 - 50RPM - 9mm- 3-6V
14.Motors extracting the wheels.
15.Motors driving the CanSat. 13-Mini GA12-N20 - 50RPM - 9mm- 3-6V
16.Waterproof Folding Solar Panel 0.3W 2V
17. Main switch (if screw is in that means CanSat is turned off)
18. Limit switch for wheels deployment

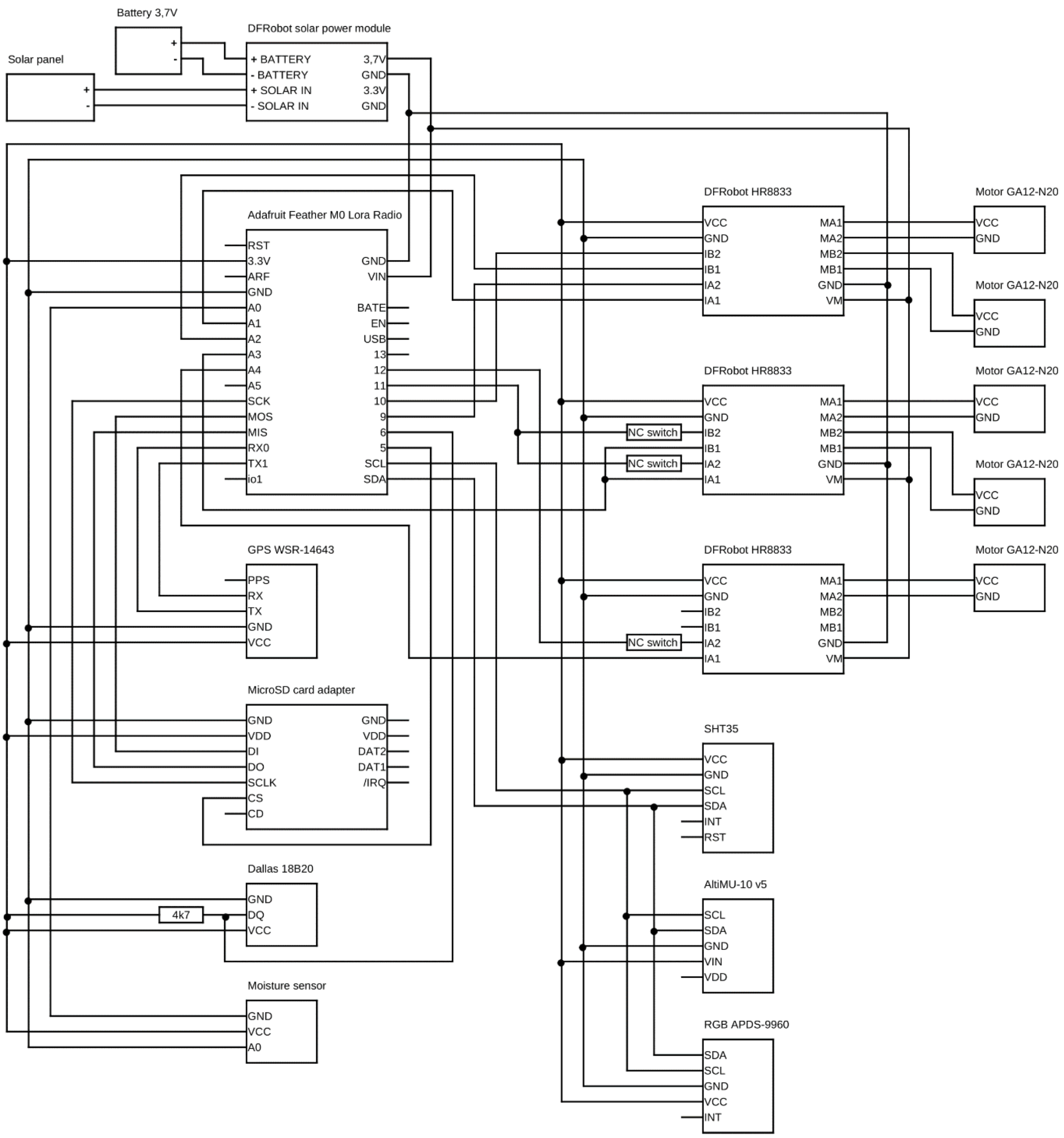
3.3 Electrical design

3.3.1 General architecture

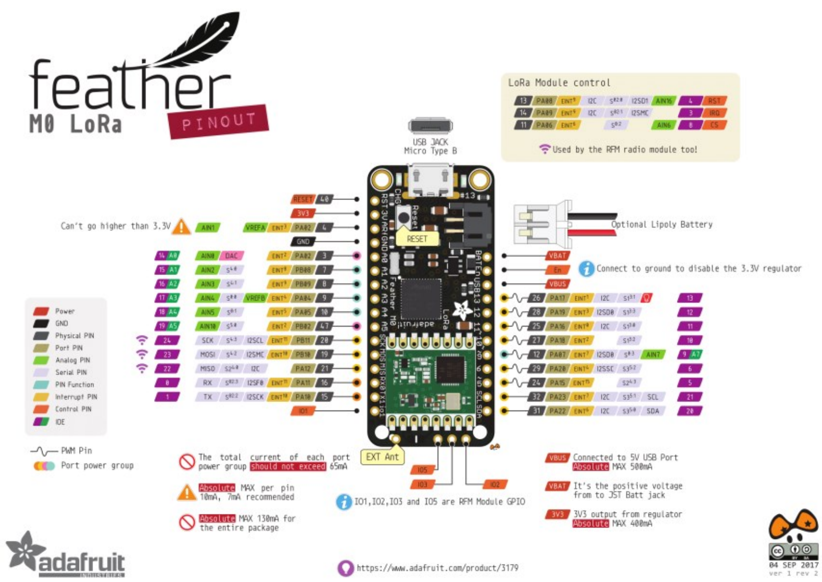
The modules presented in this report are connected on the "Adafruit Feather M0 433mhz RFM96 LoRa radio". The built-in LoRa radio module communicates with the Adafruit Feather M0 via the SPI bus. Characteristics: -input: 3,3V -radio frequency: 433Mhz -mass: 6g -size:51x23x8[mm] -pins:20 GPIO, 8PWM, 10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



Picture 14: Overall mission plan



Picture 15: Detailed electronics connections



Picture 16: Our main control board

3.3.2 Primary mission devices

Dallas 18B20- to outside temperature measurement. 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
AltiMU-10v5- with barometer LPS25H module connected to the Adafruit Feather M0 via I2C bus
-measuring range from 26kPa do 126kPa
-accuracy ±0,02kPa
Lora Radio 433MHz – built-in main control board it communicates with the Adafruit Feather M0 via SPI bus.

3.3.3 Secondary mission devices

SHT35- digital sensor connected to Adafruit Feather M0 via the I2C bus able to measure:
1)Temperature:
-measuring range: from -40°C to 125°C
-accuracy ± 0,2℃
2)Humidity:
-measuring range from 0% to 100% RH
-accuracy ± 1,5% RH
AltiMU-10v5-all-in-one accelerometer and gyroscope (LSM6DS33), magnetometer (LIS3MDL). It is connected to the Adafruit Feather M0 via the I2C bus.
Measuring ranges (configurable):
Accelerometer: ±2, ±4, ±8, ±16 [G]
Gyroscope: ±125, ±245, ±500, ±1000, ±2000°/s
Magnetometer: ±4, ±8, ±12, ±16 gauss
L76X Multi-GNSS GPS / BDS / QZSS - Waveshare 16332-gps module that allows us to check the position of our CanSat, communication with Adafruit Feather M0 via UART
-update rate 1 Hz (default) to 10 Hz (maximum)
-baud rate 4800 to 115200 bps (default 9600 bps)
-working temperature From -40℃ to 85℃
APDS-9960 DFRobot SEN0187 - digital sensor connected to Adafruit Feather M0 via the I2C bus able to measure: colors from the RGB color palette, as well as brightness of the light and distance from the obstacle.
3x DFRobot HR8833 - a two-channel driver for DC motors controlled by PWM signal -maximum current per channel 1.5 A
-working temperature from -20°C to 85°C
5x GA12-N20 motors
-DC brush motors with mounted gear connected to DFRobot HR883 controllers
-voltages from 1V to 6V

-torque 3Nm
-50RPM
<u>Ground moisture sensor:</u>
The entire sensor consists of our self-build sensor and the driver used from the original sensor. The electrodes are made of stainless steel rod with a diameter of 1mm with pointed ends. The advantage of this solution is reliability, ease of inserting the sensor into the ground and durability.
-working temperature 0°C to 45°C
-measuring range from 0% to 100%
MicroSD Card Adapter: It communicates with the Adafruit Feather M0 via SPI bus and is saving all collected data.

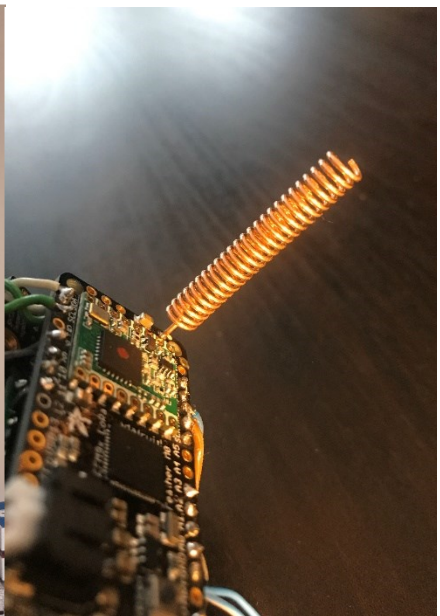
3.3.4 Power supply

In our CanSat we used a Li-ion 18650 3.7V 2.5 Ah battery. The estimated battery life, in which we took into account the operating time of the sensors and motors on full power is 7 hours under ideal conditions. All motors can be used for 8 hours without load. Our CanSat is equipped with a solar panel which, when in stand-by mode will charge the batteries to 100% within 15 hours. The panel itself in full sun gives a voltage of 1.7 V. Compared to the previous calculations, the battery wears more because there are several more elements, but after installing the solar panel our Cansat can move and collect data longer.

Device name	Current electricity consumption [mA]	Supply voltage [V]	Efficiency	Battery power consumed [W]
Adafruit Feather M0 RFM 96 LoRa Radio	180	3,3	0,5	0,6
GPS module	11	3,3	0,5	0,36
AltiMu10v5	6	3,3	0,5	0,02
Temperature sensor Dallas 18B20	1,5	3,3	0,5	0,005
Five engines	120 x5	3,7	0,7	0,6 x5
Three engine control unit	1,5 x3	3,3	0,5	0,5 x3
SHT35	1	3,3	0,5	0,003
MicroSD card adapter	8,5	3,3	0,5	0,028
Soil moisture sensor	20	3,3	0,5	0,066
APDS-9960 DFRobot SEN0187	0,25	3,3	0,5	0,0008

3.3.5 Communication system

We are using the open frequency 433 MHz with bandwidth of 125kHz. The final frequency will be set when we get the frequency assignment. After many tests, a bi-quad antenna will be used for the ground station, which has become our main antenna and will be mounted on the tracking system. Thanks to its long-distance communication capabilities, it will be used for two-way communication. The spare antenna in our set will be a "yagi" antenna which will be used only to collect data on the SD card and will be connected to the computer. We use a 9-element yagi antenna because it gives us a gain of 13.9 dBi and is less directional than the 12-element antenna. Two-way communication is provided by the main control board "Adafruit Feather M0 433 Radio MHz RFM96 LoRa" which output power we set to 19dBm. Two-way communication allows us to control the CanSat after landing on the ground and control functions such as wheel extension, CanSat movement, sensor extension. During the flight, the communication parameters are: SF=128 chips/symbol, CR=4/5, BW=125kHz, and after landing, the CanSat goes into rover mode, where the ground station with the probe changes the parameters to SF=4096 chips/symbol, CR=4/8, BW=125 kHz so that information will be sent longer but the transmission will be more reliable. Effects of these changes have been confirmed during tests. A 34.6 cm half-wave antenna was installed in the CanSat, coiled in the form of a spring, which we wrapped with insulating tape to avoid a short circuit inside the CanSat. After conducting tests between the antenna made of a wire and a spring-loaded one, the test results convinced us to choose the spring-loaded one.

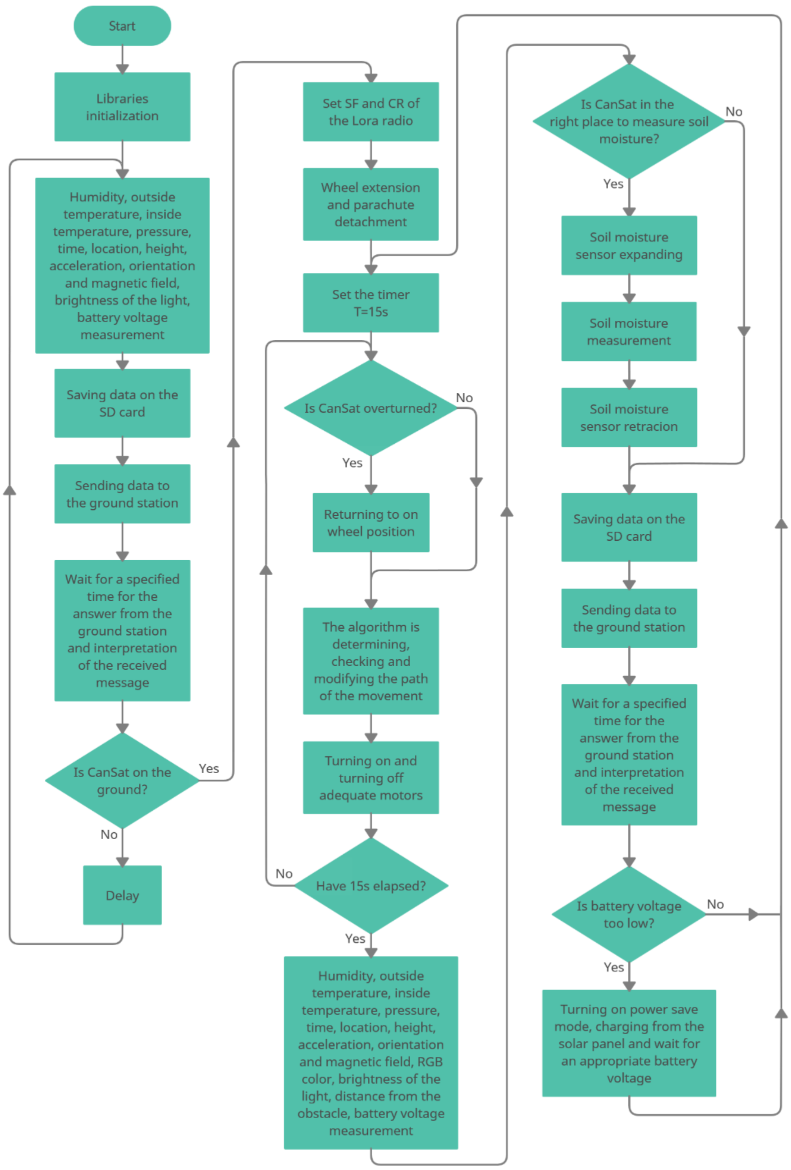



Picture 17: Antennas comaprison and our spring-shaped antenna

3.4 Software design

Link to the program: https://bit.ly/3idioD9

The program was written in C++ in the Arduino IDE. We used the following libraries: wire, DFRobot_SHTx, LSM6, LPS, SPI, SD, OneWire, RH_RF95, Adafruit_GPS, math. The program has been written in such a way that it does not hang in the event of damage to any of the sensors or the cable connecting the sensor and the on-board computer. The program works in three modes: in flight, after falling to the ground, and in sleep mode. CanSat saves the current mode on the SD card so in the event of an unwanted reset of the motherboard, e.g. after landing, it does not switch to flight mode. During the flight, CanSat will measure outside temperature, pressure, air humidity, magnetic field strength, accelerometer and gyro data, temperature inside CanSat, and GPS location and time. Data will be collected every 1s, the estimated flight time is about 4 minutes (about 240 measurements). All data will be saved on the SD card, then compressed with an algorithm created by us and sent to the ground via radio communication. CanSat also sends a checksum in the message, which makes it possible to determine if the data arriving at the ground station are correct. In the first mode, an algorithm is active that checks whether the CanSat has already fallen to the ground. After landing, the program switches to the second mode. The SF (Spreading Factor) and CR (Coding Rate) parameters are changed so that sending and recieving data is less unreliable. The program turns on the motors responsible for the extension of the wheels and the parachute release. Using data from the accelerometer, magnetometer and pressure measurements, the algorithm calculates the best route for the vehicle on an ongoing basis. The algorithm searches for depressions in the terrain where it is most likely to find water. After reaching the right place, the soil moisture sensor is pulled out and measurements are made. They are sent to the ground and saved on the SD card. The CanSat then drives out of the basin and looks for other basins. The second algorithm, which uses measurements from the accelerometer, checks the position of the rover (whether the rover has tipped over). In the event of a rollover, the program sends information to the appropriate motors to put the CanSat on its wheels. CanSat measures outdoor temperature, pressure, air humidity, magnetic field strength, accelerometer and gyro data, temperature inside CanSat, and GPS location and time. Data is collected every 15 seconds, saved on an SD card, and then compressed and sent to the ground station. CanSat is sending also checksum. The battery voltage is checked and if the voltage level is too low (3,3V), the CanSat will go into energy-saving mode and waits for the battery to be charged via the solar panel. In the first and second modes, the ground station sends information about which sensors are working and which have failed, and what the CanSat is doing at the moment. In case of damage to any of the sensors, CanSat will try to restart the damaged sensor every 5 minutes. A restart is not possible during the flight as it takes more than 1 second and it would not be possible to collect all the data during the descent. We have two-way communication. It allows you to react in the event of unforeseen problems or errors. The rover is fully autonomous, no interference from the ground station is required, but it is possible to control all processes from the Earth. CanSat has the ability to open files on an SD card and read data that was previously saved there. In the event that any signal does not reach the ground, we can send a message to CanSat to resend the data that did not reach the ground before.



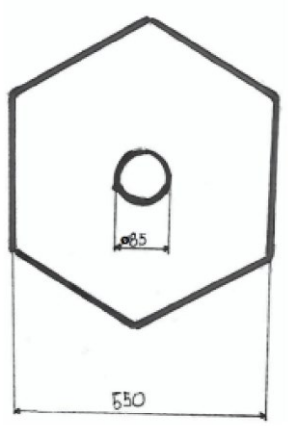
Picture 18: Overall program structure

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 if we want precise location. 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 (350 grams), the falling speed, which is on average 10 m/s, air density, resistance co-efficient equal to 0.5. The formula itself looks like this:

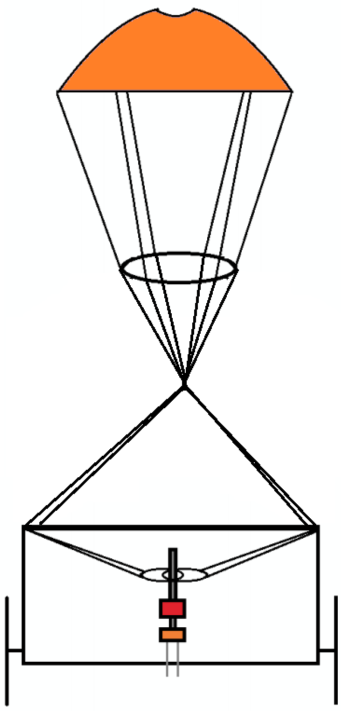
$S=\frac{2Q}{cvg}$

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.

The speed of falling down at tests was 8,2 m/s and the difference between speed calculated and speed measured was because CanSat was lighter than weight we took to calculations. The parachute is attached in one point to a lines which are going out from the CanSat. Inside our satellite is one short plexi tube used to avoid hooking the lines and detach them smoothly. They will detach when CanSat land on the ground and parachute flies somewhere. At tests parachute never falls onto satellite, always wind threw it away and any line didn’t tangle in the wheels. Detaching mechanism hides pin which makes



Picture 19:Parachute and parachute scheme

it impossible to detach the parachute during flight. When CanSat move from landing area, lines went out from the satellite and parachute stay in the landing zone if wind doesn't make it move.

3.6 Ground support equipment

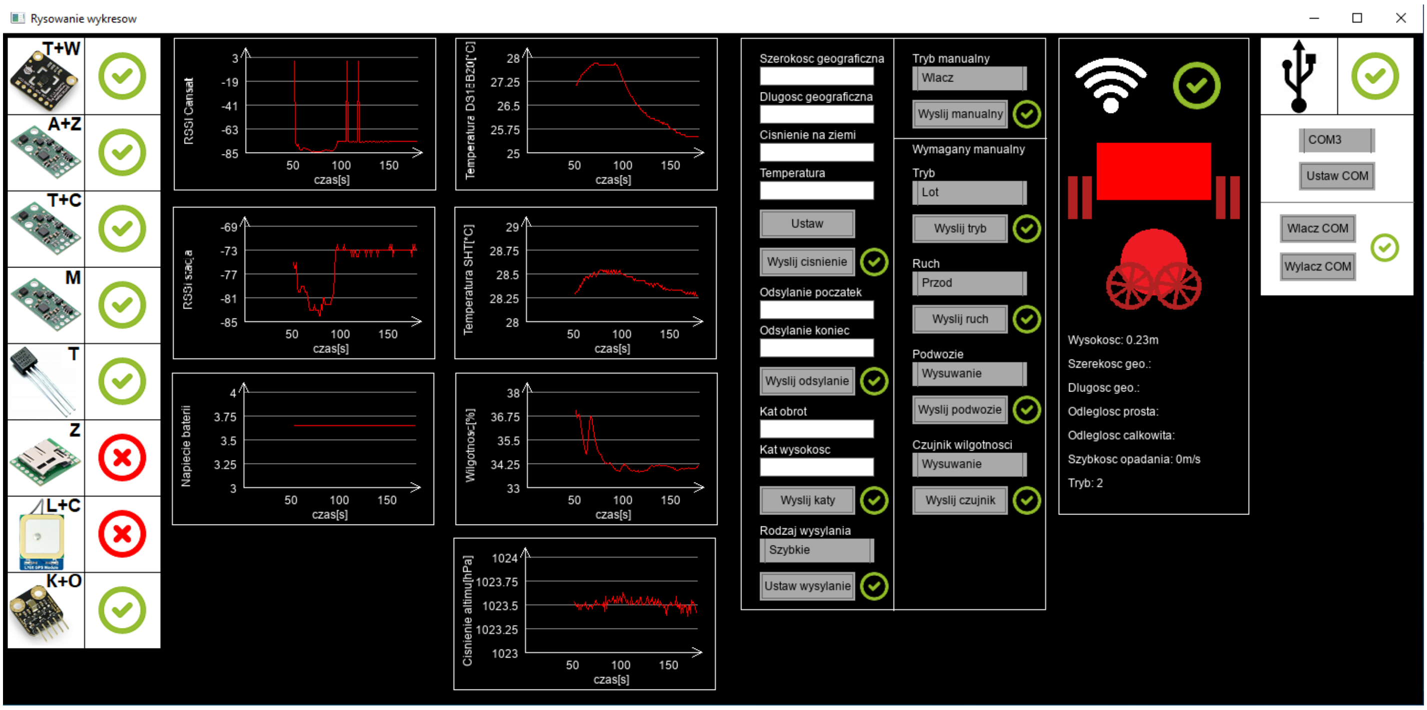
In the ground station, we will use a bi-quad and "yagi" antenna. We built more than 2 meter tripod on which the bi-quad antenna will be mounted. We done this to maximize the probability of collecting a signal after landing the probe. The "Bi-Quad" antenna is rotated by stepper motors.

Picture 20: Our tracking system on tripod with stepper motors

Our tracking system consists of: 1-tripod; 2-bi-quad antenna, 3-boc with necessary electronics; 4-vertical and horizontal gearing; 5-stepper motors; 6-counterweight (temporary, target holder at the time of printing)

The antenna rotation direction is calculated using an algorithm created by us. The rotation angle and elevation angle of the antenna is determined using CanSat GPS coordinates and ground station GPS coordinates. 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.

Link to the program to receiving data: https://bit.ly/39yw87O
The program was written in C++ in the Arduino IDE. We used the libraries: RH_RF95, Wire, SPI, Adafruit_GPS, LIS3MDL, LSM6, LPS, math. The program has been written in such a way that it does not hang in the event of damage to any of the sensors or the cable connecting the sensor and the main control board. The program receives compressed data from CanSata using a Bi-Quad or “yagi” antenna. The program decodes the location and pressure from CanSat and measures the ground station location and ground pressure which is necessary to determine direction of rotation of the antenna. The data received from CanSat and measured on the ground are sent to a computer. Then the main board receives information from the serial port how many steps to turn the stepper motors. Adafruit also recieves messages from the computer that will be sent to CanSat via radio communication. After CanSat has landed, the SF (Spreading Factor) and CR (Coding Rate) parameters will be changed to make receiving and sending data more reliable.
We have also a program that draws real-time graphs for us from CanSat data.



Picture 21: Screen from program creating graphs

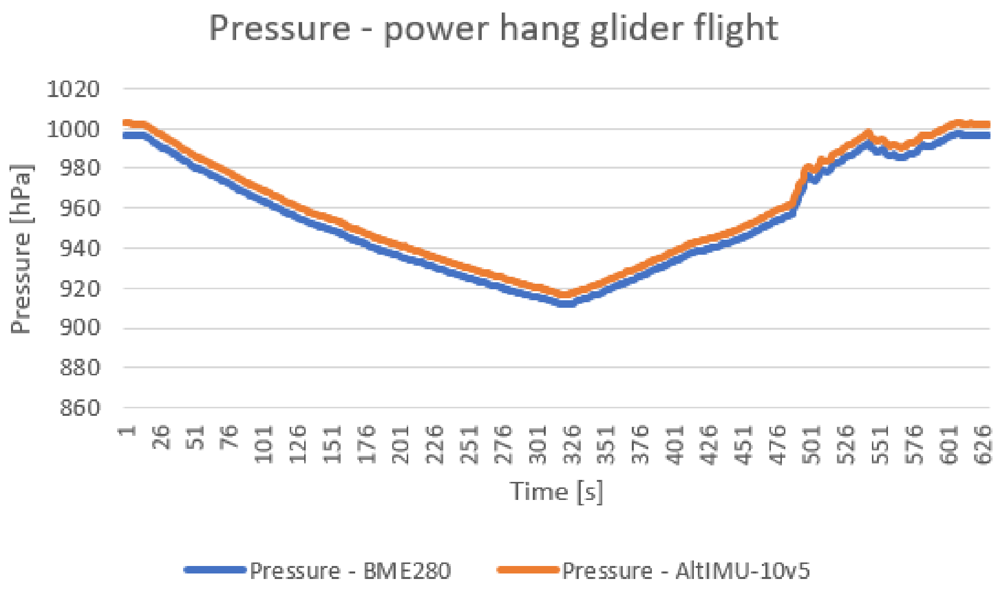
Link to the program creating graphs: https://bit.ly/3nJNRyf
The program was written in C++ in the Code::Blocks environment. We used libraries: SDL2/SDL, SDL2/SDL_image, SDL2/SDL_mixer, SDL2/SDL_ttf, iostream, time, cstdlib, sstream, cmath, windows, tchar, stdio, future. It is a multi-threaded application. The program reads compressed data from the serial port to which the Adafruit Feather M0 Lora is connected with a Bi-Quad or "yagi" antenna. Then the program

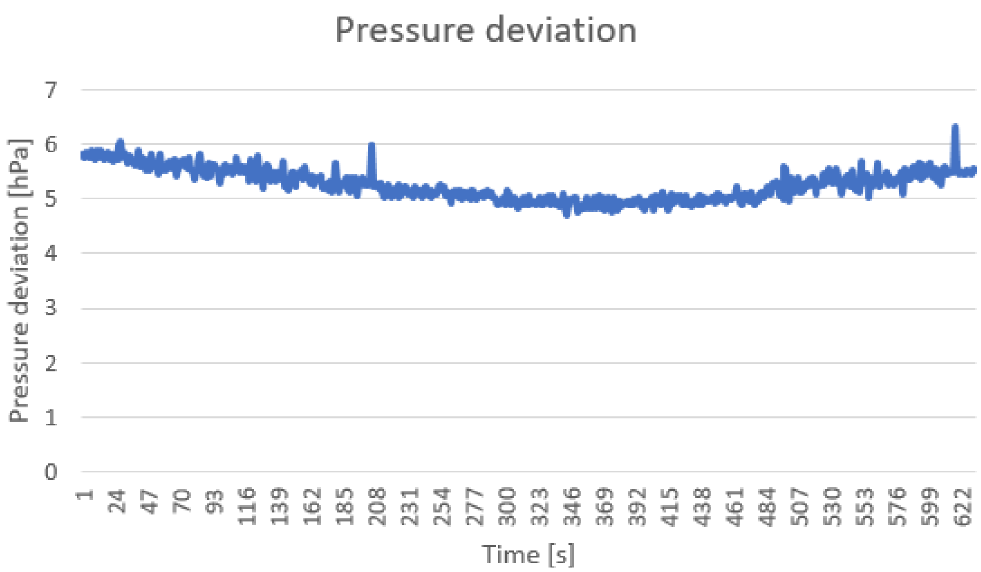
checks the correctness of the received data by calculating the checksum. If the data is correct, the data is then decoded, saved in the computer's RAM memory and displayed as graphs and text on the screen. In addition, the program displays which sensor in CanSat is working and which has been damaged, and the height of the probe above the ground, location, CanSat distance from the Ground Station, falling speed and CanSat battery voltage. The program displays what CanSat is doing at the moment and in what mode it is working. After collecting the appropriate amount of data, they are saved on the computer disk in a text file. Based on the pressure and location measured by CanSat and the location of the ground station, pressure on the ground, data from the magnetometer and accelerometer, the program calculates the distance from the CanSat and the direction in which the antenna must be oriented. The program sends information to the serial port by how many steps to turn the stepper motors that control the antenna position. The program allows you to send a message to the serial port that will be sent to CanSat via radio communication. It allows you to react in the event of unforeseen problems or errors. The rover is fully autonomous, no interference from the ground station is required, but it is possible to control all processes from the Earth.

4. Test campaign

4.1 Primary mission tests

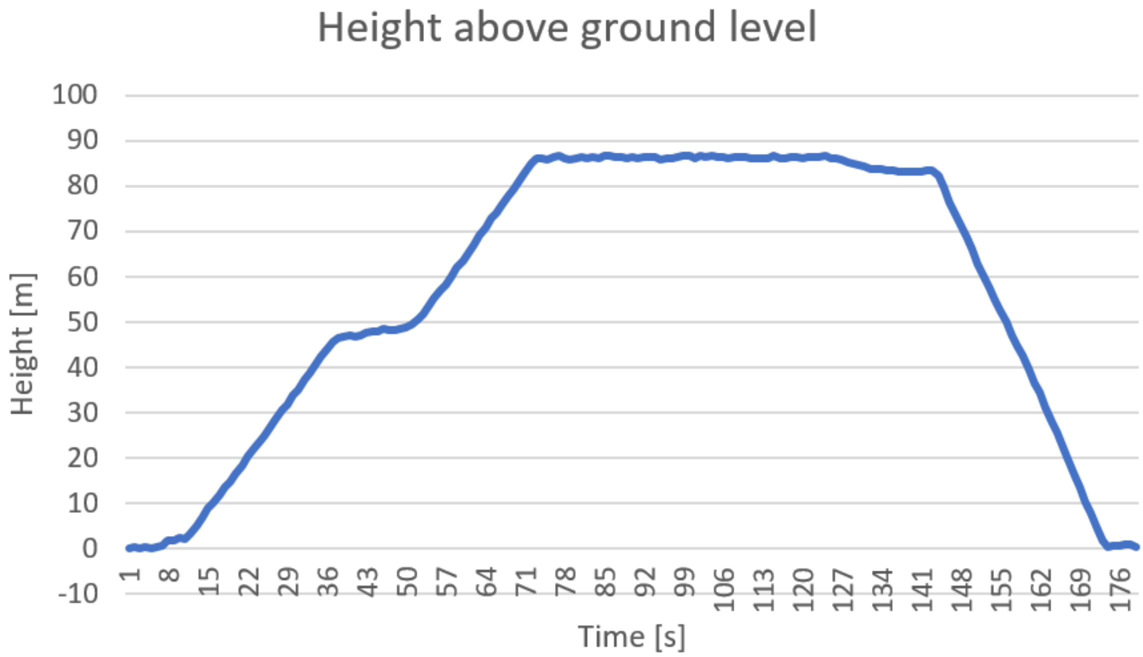
Comparison of sensor indications with more precise sensors:
Temperature sensor test (Dallas 18B20) Accuracy +/- 0.2°C
The Dallas 18B20 readings were compared to another more accurate sensor (accuracy +/-0.1°C). Measurements were made at different locations and at different temperatures. The deviations amounted to a maximum of 0.3°C.
Pressure Sensor Tests (AltIMU-10v5)
Accuracy +/-0.2hPa

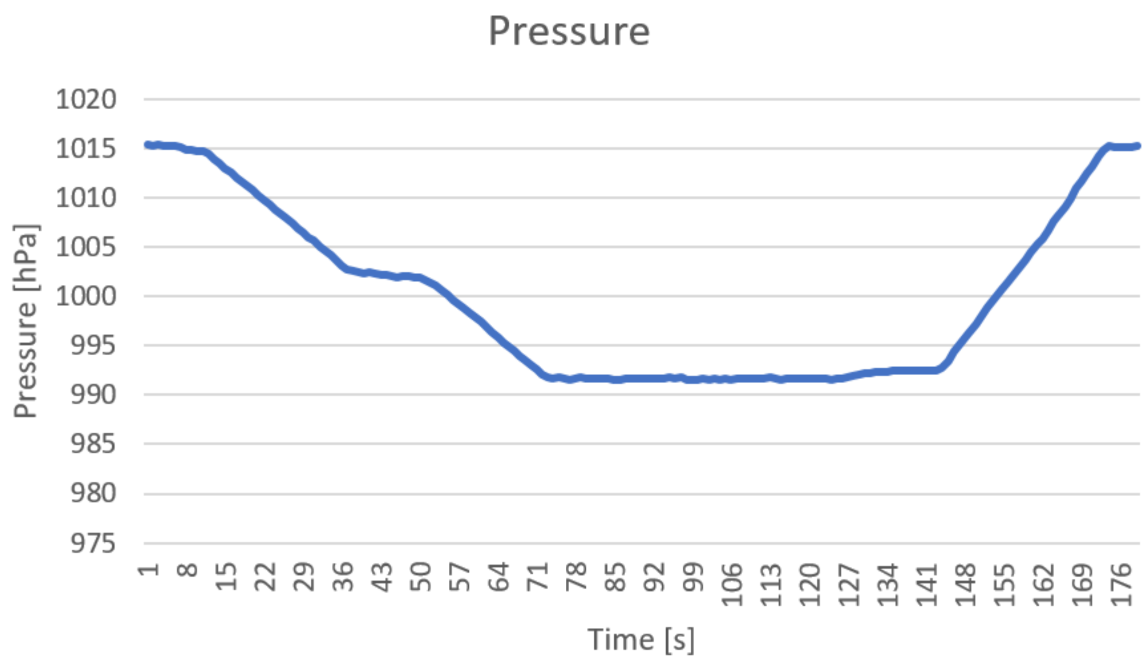


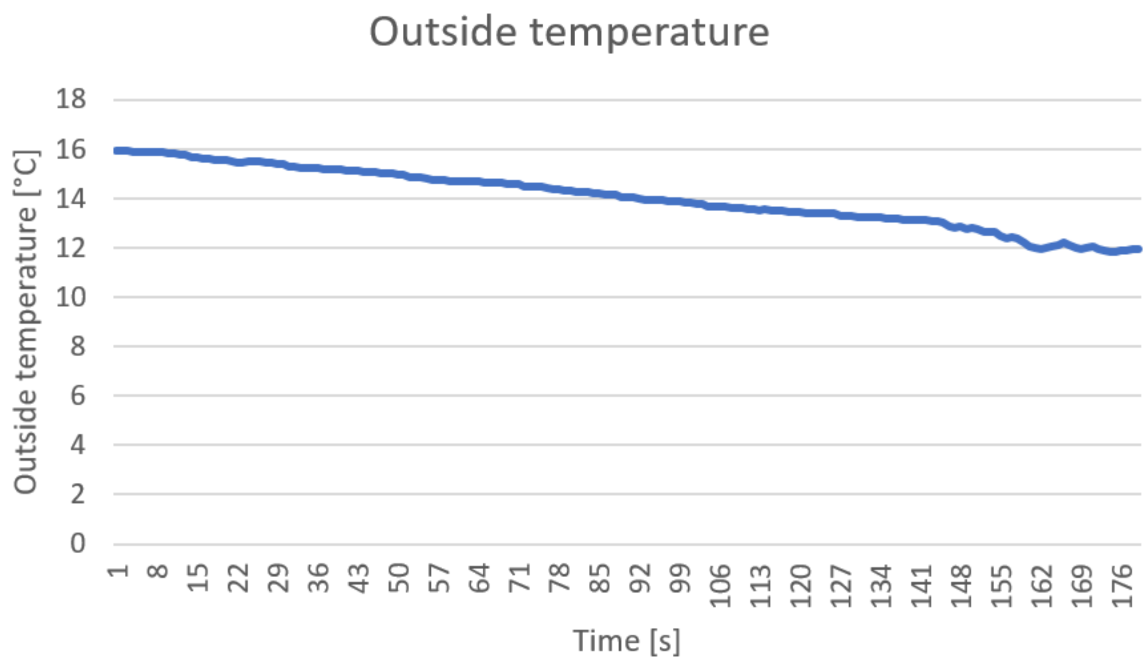


Graph 1: Sensor comparison results

The indications of the AltIMU-10v5 have been compared to another more accurate sensor (accuracy +/-0.1 hPa). The values from AltIMU-10v5 were less than 6 hPa higher. To find out which sensor is showing the correct values, we compared them to a home weather station. The results of the measurements indicated that the accurate sensor shows the correct pressure, and the AltIMU-10v5 adds less than 6 hPa to the result. We decided to check whether this deviation is always the same. We went to the tower in Sieków and the deviation on the ground and at the top of the tower (30 m above the ground) was always less than 6 hPa. We decided to investigate this deviation for higher altitudes above the ground (for lower pressure). We decided to attach sensors to a powered hang glider that will fly high above the ground. The accurate sensor was not able to write data (only real-time reading was possible). We used the BME280 sensor for comparison. It has a lower accuracy of +/-1 hPa, but it is a sensor that can be connected to the motherboard (Adafruit Feather M0) and save the collected data on an SD card. BME280 had identical indications compared to the more accurate sensor (the deviation was about 0.3 hPa). We connected the AltIMU-10v5, BME280 and the SD card module and then mounted everything on the glider housing. The glider rose to a height of over 700m. Observations show that the deviation of AltIMU-10v5, BME280 decreases slightly with height. For about 1000 hPa the deviation was about 5.7 hPa, for 910 hPa the deviation was about 5 hPa.
We also tested the primary mission sensors (temperature and pressure) by dropping it in CanSat with a drone from almost 90 meters above the ground. Falling speed was too low on the graph because this prototype was lighter than final version.





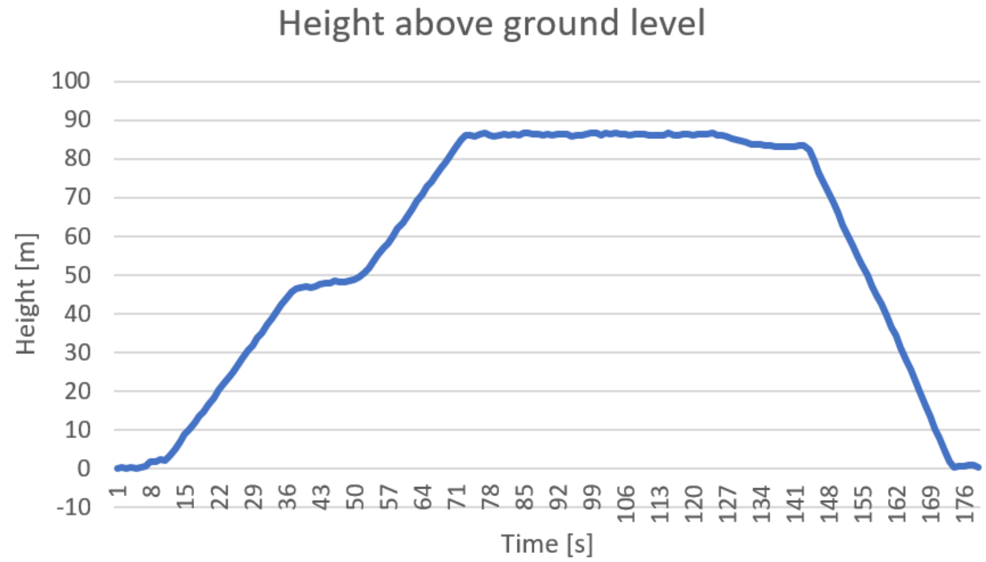


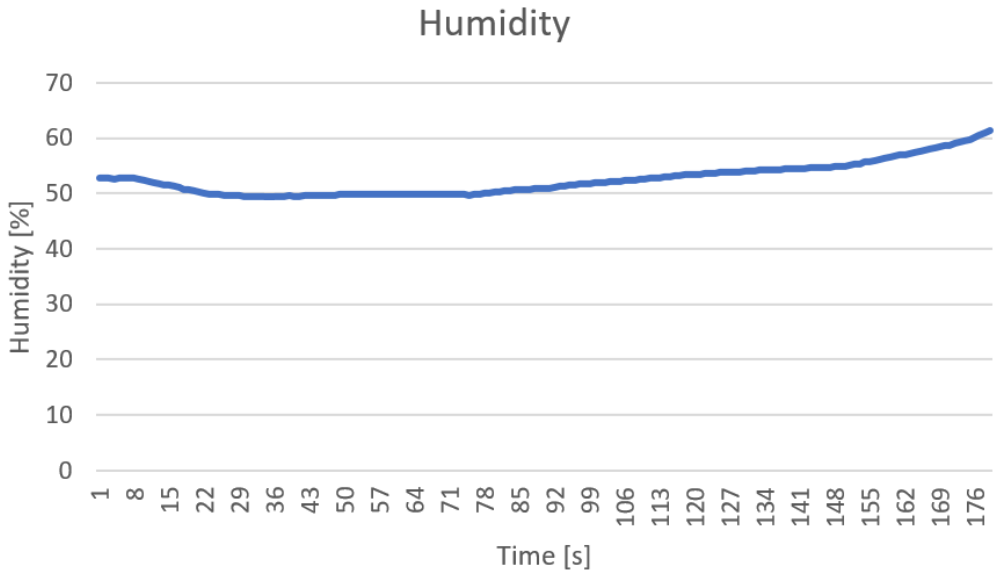
Graph 2: Primary devices test results

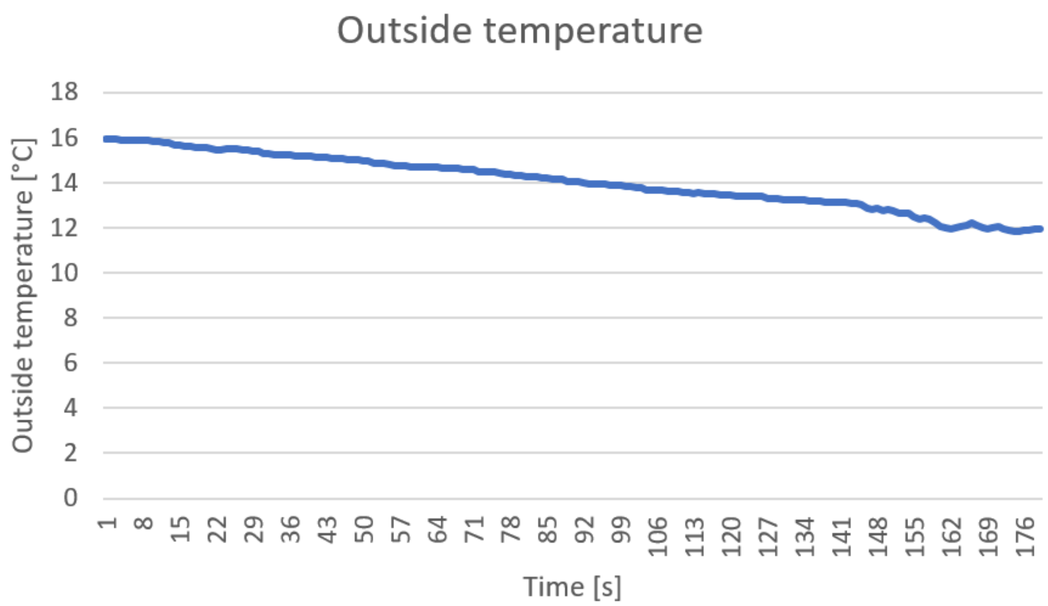
Test results meets out expectations, the pressure decreased with the height. The temperature, on the other hand, decreased with time. This was due to the fact that the CanSat before the discharge was in the car, in which the temperature was higher than the ambient temperature, so the sensor was hot and showed overvalued values.

4.2 Secondary mission tests

We also conducted CanSat tests by dropping it from the drone from almost 90 meters above the ground. The objectives of the test were to test the correct operation of the sensors and the algorithm detecting the flight and the moment of landing on the ground. After falling to the ground, CanSat was supposed to change the SF and CR parameters of radio communication, unhook the parachute and extend the landing gear, then drive a bit and take soil moisture measurements. A secondary mission objective was to test an algorithm that computes the angles at which the antenna should be positioned to follow CanSat. The tests were performed twice. On the first day of testing, we found a bug in the graph drawing program. We also noticed that 2 pieces were contained within the CanSat. We made all the necessary corrections and on the second day of testing, the mission went flawlessly. Falling speed was too low on the graph because this prototype was lighter than final version.
Secondary mission sensor data:







Graph 3: Secondary devices test results

Soil moisture sensor working: https://bit.ly/2PcUixX
After landing on the ground, the rover ran a bit and measured the ground moisture 5 times in one place. Based on these data, we calculated the average and standard deviation of the measurements. Earth humidity was 67.81 ± 0.47 [%]
Our secondary mission is to test for the presence of water on the planet where our Cansat will be. We are using our self-made soil moisture sensor and the controller included with the original sensor kit. We decided to build our own sensor because it takes up less space and is more durable (we used durable stainless steel wires with a diameter of 1mm, sharpened at the ends). As it turned out, our sensor turned out to be more accurate because the original sensor had a bigger error. The sensor extends to a constant depth. The sensor has been tested under various conditions as illustrated below. Moreover, the original sensor was tarnished and this could affect the results after some time. The technological limitation of our sensor is the small weight of the entire CanSat, which may cause problems with penetrating the sensor into hard and dry soil. After unfolding, our sensor can return to its original position by springing, the official sensor cannot bend and there is a risk of mechanical damage. We tested the influence of water acidity on the measurement results; soil with added water with acidity in the range (0-6)pH and (8-14)pH. The results differed slightly from water in the chemically inert range. All values expressed in [%]

	Dry soil		Moderate soil moisture		High soil moisture		Water	
	original	self-made	original	self-made	original	self-made	original	self-made
Dirt	0,33±0,3	0,01±0,01	28,55±0,45	30,16±0,08	69,89±0,21	71,80±0,23	99,89±0,11	100-0,07
Clay	Brak Pomiaru*	0,01±0,01	Brak pomiaru*	16,54±0,37	88,61±0,23	80,42±0,28		
Sand	0,45±0,3	0,01±0,01	10,77±0,25	8,00±0,1	93,34±0,36	94,60±0,20		

*the measurement did not take place because the dry clay is very hard and we skipped the measurement to avoid sensor damage.

4.3 Test of recovery system

Picture 22: Lifting our CanSat during test

We tested our parachute in two places. First place was observation tower in Siekowo. We dropped our dummy-mass from a height of 30m, but we don’t collect data during this parachute test because there was a lot of trees so it was difficult to drop it correctly. We decided that will drop it from drone. We dropped it away from buildings on wet fields. We dropped our dummy-mass from different heights. We tested it using 350g weight in both tests. When wind was weak, the weight with parachute reach 9,5m/s velocity. We calculated it using height of drone and time of falling. It is faster than test with official CanSat, because CanSat is lighter than our dummy-mass. We used weight accepted in the calculations for this test to see differences between calculations and reality.
The parachute mount has been tested for resistance to sudden jerks and gusts of wind. Its lines are very durable and can withstand strong momentary jerks. Its descent speed is within 8,2m/s of the final CanSat but everything will depend on the weather. We will read the position of our satellite using GPS coordinates. The GPS module has a very small deviation (tests show that it is about 2-3m), so we will be able to find our CanSat without any problems.

4.4 Communication range system test

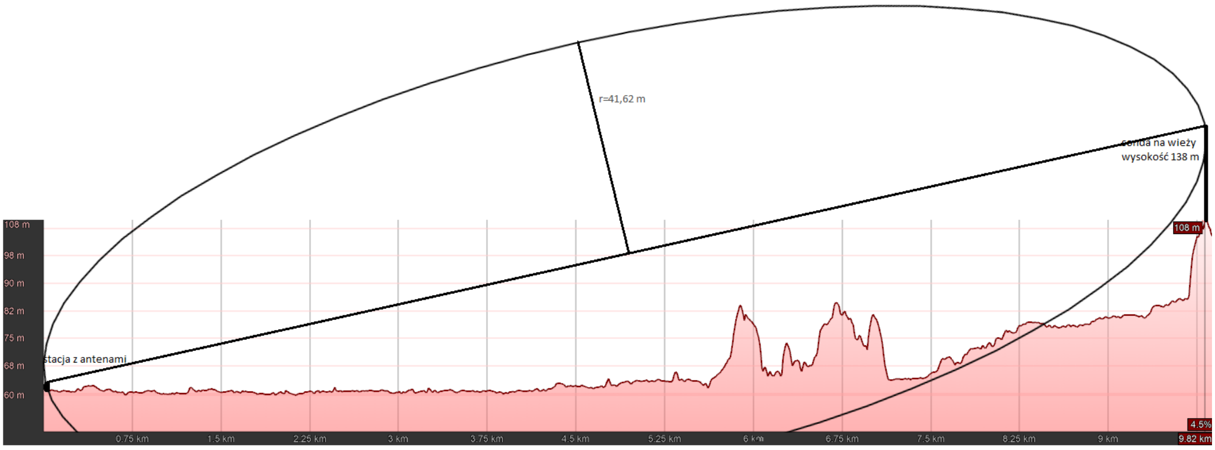
We conducted tests using three antennas (9-element, 12-element yagi and bi-quad) with two different antennas mounted in CanSat. They were half-wave antennas, one was in the form of straight wire and the other was coiled into a spring. The test results are shown in the tables below for the different distances.

Distance: 2km					
9-element "yagi"		12-element "yagi"		bi-quad	
straight wire	spring	straight wire	spring	straight wire	spring
one-way communication at the ground level, RSSI -92	two-way communication at the ground level, RSSI -91	one-way communication at the ground level, RSSI -87	two-way communication at the ground level, RSSI -90	one-way communication at the ground level, RSSI -90	two-way communication at the ground level, RSSI -90

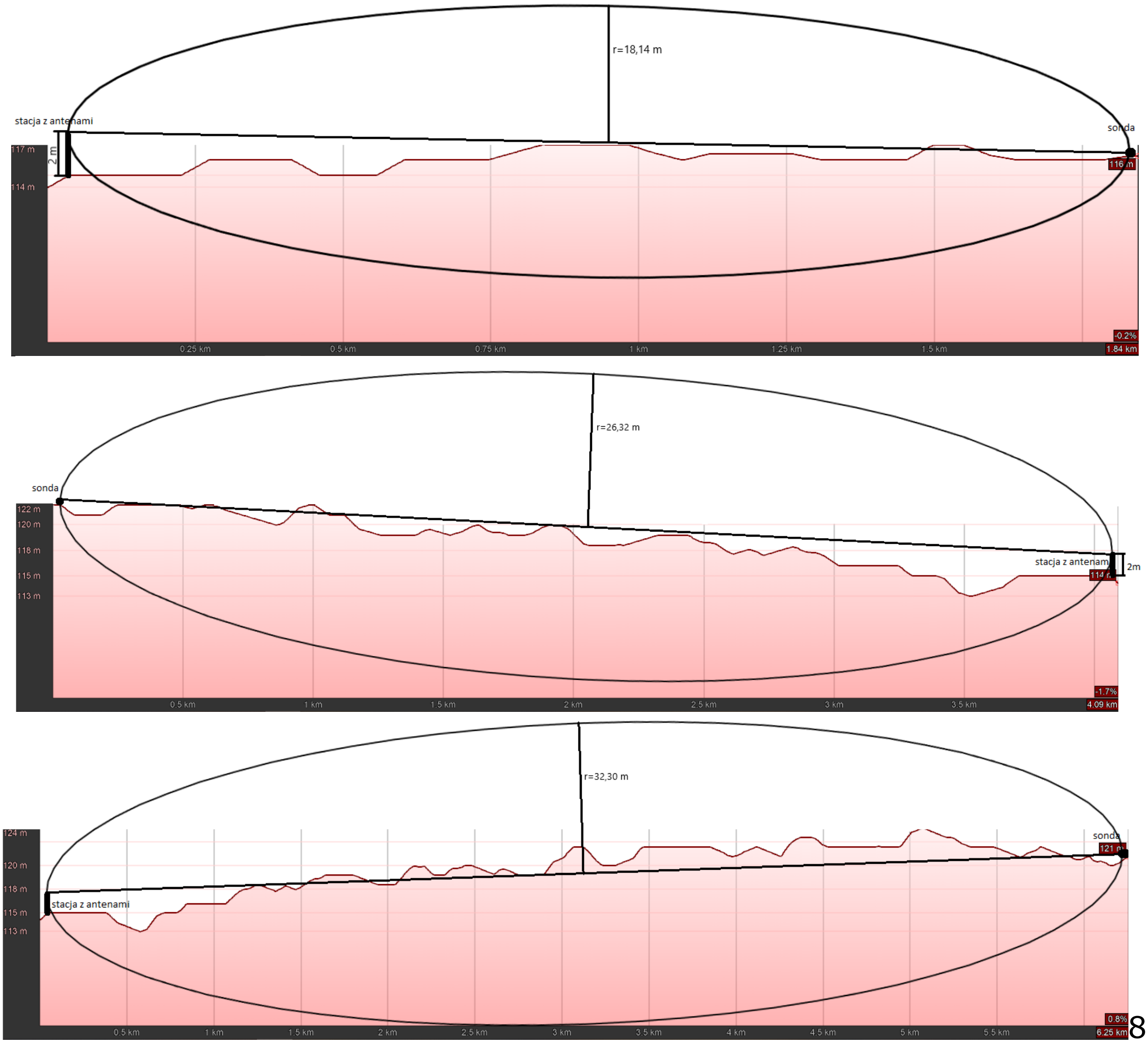
Distance: 4,2km					
9-element "yagi"		12-element "yagi"		bi-quad	
straight wire	spring	straight wire	spring	straight wire	spring
one-way single signals at the ground level, RSSI -92	two-way communication at one meter above ground, RSSI -93, single two-way signals at the ground level	one-way communication at one meter above ground, RSSI -90, single one-way signals at the ground level	two-way communication at one meter above ground, RSSI -93, single two-way signals at the ground level	one-way communication at one meter above ground, RSSI -93, single one-way signals at the ground level	two-way communication at the ground level, RSSI -94

Distance: 6,3km					
9-element "yagi"		12-element "yagi"		bi-quad	
straight wire	spring	straight wire	spring	straight wire	spring
one-way single signals at the one meter obove ground, RSSI -95, no signal at the ground	one-way communication at the one meter above ground RSSI -93, no signal at the ground level	no signal	one-way communication at the one meter above ground RSSI -93, no signal at the ground level	single one-way signals at the one meter above ground, RSSI -95, no signal at the ground	one-way communication at the one meter abowe ground, RSSI -93, no signal at the ground level

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 the big flat area.
maximum range test (10km):



Picture 24:Fresnel zone for 10km test (tower in Siekowo)

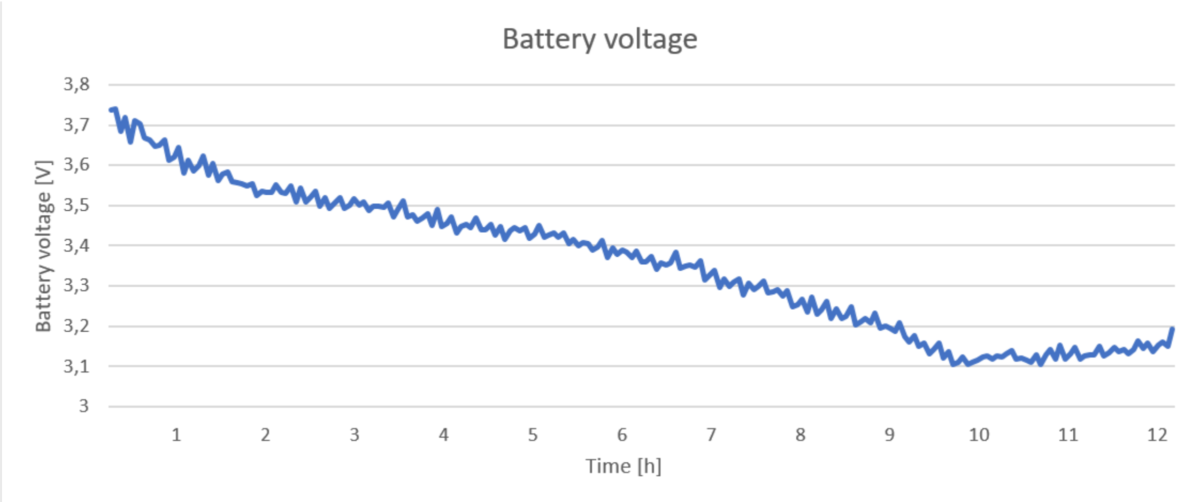


Picture 23: Fresnel zones for 1.9km; 4.2km; and 6.25km

4.5 Energy budget test

	Rover mode	Sleep mode	Air descend mode
Sensors	Supply voltage 3,3V The current consumption depends on the sensor, it is constant for each sensor	Not in use	Supply voltage 3,3V The current consumption depends on the sensor, it is constant for each sensor
Drive motors	Supply voltage 3,3V current depends by motor load	Not in use	Not in use
Wheels expand motors	Supply voltage 3,3V , current consumption 85 mA used ony for about one minute, starting rover mode.	Not in use	Not in use
Sensor expand motor	Supply voltage 3,3V, current depends by motor load, rarely used	Not in use	Not in use
Solar panel	Its role in this mode is negligible, because it will not be able to charge the battery faster than it discharges during the working mode	Its role in this mode is the most important, it charges our CanSat to the appropriate voltage so that it can work again	Its role in this mode is negligible, because the can from the tray will fly out charged

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 8 hours. After checking the data on the SD card, it turned out that it performed faultless work for just over 7 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. The current is consumed in a very short period of time, only for max ~300ms during one second. We have not reduced the battery capacity because it is not a problem that could disrupt the mission, we already installed solar panel which charge our battery. 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.



Graph 4: CanSat battery voltage drop over time

4.6 Software malfunction test

We noticed during building our CanSat, that our program is hanging when some wires were damaged or disconnected

Sensor	Broken wire	Result
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
AltiMU-10 v5	SCL, SDA, VCC or GND	permanent hang of the program
Dallas 18B20	GND, pin5, 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

SHT35	VCC	complete hang of the program
	GND	does not hang the program,no values read, after connecting is working correctly
	SCL or SDA	hang of the program, after connecting is working correctly
Moisture sensor	VCC, GND, A0	does not hang the program,no values read, after connecting is working correctly
APDS-9960 DFRobot SEN0187	SCL, SDA, VCC or GND	permanent hang of the program

After that, we edited the libraries in such a way that if any of the wires or sensors were damaged, the program would not crash.

5. Project planning

5.1 Time schedule

Done:

10.09.2020-27.09.2020	Choosing the elements
31.09.2020-09.10.2020	Design CanSat project in Solid Edge
05.10.2020-10.10.2020	Create connection schemes
10.10.2020-13.10.2020	Print first elements
14.10.2020	Meeting with a specialist of motion system
22.09.2020-15.11.2020	Graphing program
28.09.2020-16.12.2020	Write a running program
31.09.2020-16.12.2020	Layout of CanSat construction
01.10.2020-08.11.2020	Find sponsors
10.10.2020-16.12.2020	Design and implementation of the power system in CanSat
26.10.2020-29.10.2020	Build of antennas
04.11.2020-13.01.2021	Create CDR
05.11.2020-12.11.2020	Range tests of antennas
09.11.2020-25.11.2020	Selfmade ground moisture sensor
25.11.2020-10.01.2021	Test our ground moisture sensor
01.12.2020-16.12.2020	Wheel deploying system
18.12.2020-20.12.2020	Parachute tests
10.01.2021-27.01.2021	Create ground station
01.01.2021-01.03.2021	Some marketing activities
08.01.2021-23.01.2021	Returning to on wheel position of CanSat
13.01.2021-22.02.2021	CanSat drop tests
08.01.2021-23.01.2021	Moisture sensor deploying system
08.01.2021-23.01.2021	Parachute cutting system
16.01.2021-31.01.2021	Optimizing distribution of elements mass
15.02.2021-26.02.2021	More tests of reliability

28.12.2020-24.01.2021	CanSat processes control from the ground station
17.01.2021-31.01.2021	Antenna tracking system
15.12.2020-24.01.2021	Driving algorithm
25.01.2021-21.02.2021	Driving algorithm tests
14.02.2021-20.02.2021	More tests of reliability
16.01.2021-23.01.2021	Course and permission to fly the drone
14.02.2021-28.02.2021	Create FDR

To do:

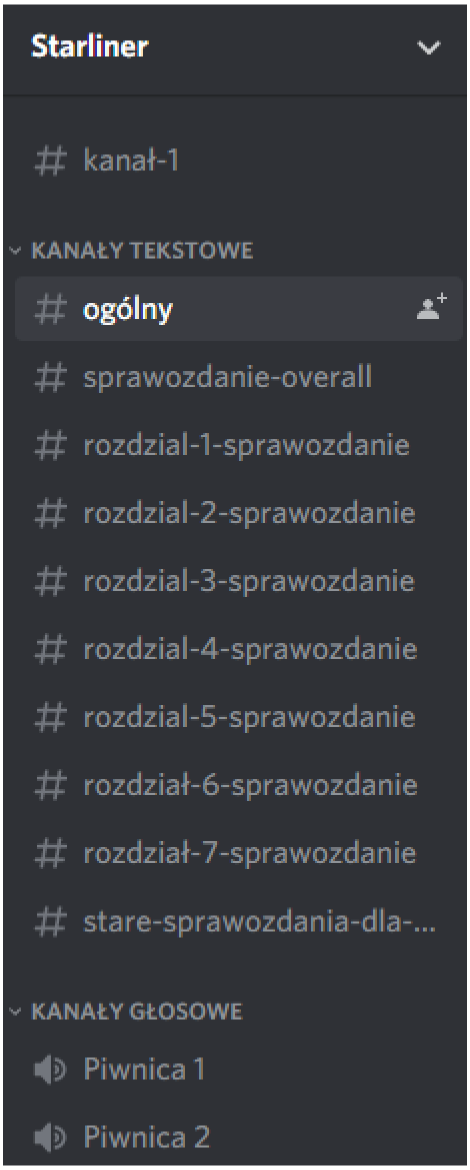
01.03.2021-03.03.2021	Installing a stable counterweight
02.03.2021-04.03.2021	Better gyroscope mounting (tracking antenna system)

5.2 Task list

Done	**In Progress**	**To do**
Choosing the elements	Some marketing activities	Better gyroscope mounting (tracking antenna system)
Design CanSat project in Solid Edge	Creating tutorials for young successors	
Create connection schemes	Installing a stable counterweight	
Print first elements		
Meeting with a specialist of motion system		
Graphing program		
Write a running program		
Layout of CanSat construction		
Find sponsors		
Design and implementation of the power system in CanSat		
Build of antennas		
Create CDR		
Range tests of antennas		
Selfmade ground moisture sensor		
Test our ground moisture sensor		
Wheel deploying system		
Parachute tests		
Create ground station		
Returning to on wheel position of CanSat		
Moisture sensor deploying system		
Parachute cut system		
CanSat processes control from the ground station		
Driving algorithm		
CanSat drop tests		

Optimizing distribution of elements mass		
More tests of reliability		
Antenna tracking system		
Driving algorithm tests		
Course and permission to fly the drone		
Create FDR		

Organizing time and coordinating activities was a big challenge for us. That's why we decided to use Trello. We started writing down the first records and plans on 5 December 2020.
In order to reduce the risk related to the pandemic and to be able to use every free moment, we have also set up a server on the Discord platform, thanks to which we communicate and create reports together.



Picture 25:One section from our Trello and our Discord organisation

5.3 Resource estimation

5.3.1 Budget

Element	Cost (PLN)
Adafruit Feather M0 with RFM96 LoRa Radio	200
GPS	70
AltiMU-10v5	90
Dallas 18b20 sensor	5
MicroSD Card Adapter	13
MicroSD Card	40
Parachute	70
Filament	20
Battery	30
SHT35	75
5X motor	93
3x DFRobot HR8833	66
Soil moisture sensor	15
APDS-9960-DFRobot SEN0187	66
Total	**853**

5.3.2 External support

Immediately after the information about the qualification of our team to the next stage of the competition, we prepared an estimation of the planned expenses. Thanks to this, our sponsors were sure that the money they would spend on support would be properly used. The funds are controlled by the School Association of ZSZ Supporters and Graduates in Gostyń. Our planned expenses are presented in the table:

No.	Equipment name	Amount	Unit price (PLN)	Value
1	Adafruit	6	200	1200
2	Motors	4	25	100
3	Motor drivers	4	25	100
4	GPS module	4	80	320
5	MicroSD module	6	20	120
6	Dallas 18B20	8	8	64
7	SHT35	3	80	240
8	Extension cord	1	100	100
9	Charger and batteries	3	100	300
10	Filament	1	250	250
11	Materials for antennas	1	100	100
12	Shipping costs	4	20	80
13	Altimu-10v5	4	100	400
14	Mechanical parts for CanSat	1	200	200
15	Solar panels+converter	4	50	200
16	Mechanical parts for ground station	1	500	500
17	Unexpected expenses	1	500	500
18	DJI Mavic Air 2	1	4930	4930
	Total			**9704**

The funds for the drone (Mavic Air 2) were provided by Gostyń governor, Robert Marcinkowski. From the sponsorship of local entrepreneurs, we managed to obtain an additional 4,800PLN, which almost covers our initially estimated cost.

We also used the help in checking the correctness of the translations by Justyna Błaszczyk, an English teacher from our school.

6. Outreach programme

During the search of sponsors and donors, we disseminated information about our activities among our schoolmates. On our facebook we got over 160 followers and one of our post got more than 2100 viewers. In our school there are TVs presenting announcements and current events from our school life. The GIF promoting our Facebook was also presented there.

Picture 26: Post reach

Picture 27: Photos showing our gif

Two interviews were conducted with us, one for the local radio ELKA Leszno, the other for the Gostyń24 portal.
Due to the pandemic and difficulties in meeting local youth, we decided to create guides related to what we do. Each person will create a tutorial of what they did in the project. Thanks to this, young successors people will be able to avoid our mistakes and they will know what to pay attention to.
Two of our team members, (Piotr Skoracki and Kacper Grobelny), received a scholarship from the Marshal of the Wielkopolska Province. It was

possible thanks to their participation and successes in many competitions, including participation in the Finals of last year's CanSat competition.
We have also prepared educational materials for educational lessons on developing your passions and interests based on our participation in the Cansat competition. We handed it over to all primary schools in Gostyń district and two schools outside of the district. We have feedback on its use in SP in Piaski, SP in Krobia, SP No.3 in Gostyń, SP in Siemowo, SP in Sikorzyn, SP in Gola, SP in Kunowo. In total, over 200 students in grades 4-8 of primary schools participated in the extended promotion.
As part of counteracting the effects of the pandemic, in order to stimulate students to learn, information about participation in the competition as an example of the implementation of the dream "Reach the stars and develop your passions" appeared on the schools' websites or Facebook:
SP in Piaski, SP in Szelejewo, SP in Bodzewo, SP in Borek, SP in Zimnowoda, SP in Pogorzela, SP in Krobia, SP in Stara Krobia, SP in Pudliszki, SP in Poniec, SP in Pępowo, SP No.1, SP 2, SP No.3, SP No.5 in Gostyń, SP in Siemowo, SP in Sikorzyn, SP in Daleszyn, SP in Gola, SP in Kunowo, SP in Dolsk, SP in Lubin. In this way, we reached over 3,000 primary school students in the Gostyń County and two from outside, not counting their parents and families.

Promotion movie: https://bit.ly/3aXB8EH
Sample article (more will be soon): https://bit.ly/3r73Kkt
Our website: https://starlinergostyn.wixsite.com/2021
Our facebook: https://bit.ly/2TlAMhM
Our Instagram: https://www.instagram.com/starliner_gostyn/
Our school website: https://zsz-gostyn.com.pl
Our school facebook: https://bit.ly/32cwHP1
Our Youtube channel, where you will be able to see our future videos of our work: https://bit.ly/37G8Sp9
Films with working parts of CanSat:
CanSat suport: https://bit.ly/3dRw0nv
Rover and wheel retraction working: https://bit.ly/2XIVdY3
Wheel extension: https://bit.ly/3dRnDZ7
Wheel extension. moving forward and backward: https://bit.ly/3bD0tTu
Wheel hiding: https://bit.ly/3q09XNS
Soil moisture sensor working: https://bit.ly/2PcUixX
Interview for Radio ELKA: https://bit.ly/35G4CE2
Interview for the Gostyń24 portal: https://bit.ly/39y8mZu
Information about scholarship: https://bit.ly/2N4bG7b

7. CanSat characteristics

Characteristics	Figure
Height of the CanSat	112mm
Diameter of the CanSat	63mm
Mass of the CanSat	320g
Estimated descent rate	8,2m/s
Radio transmitter model and frequency band	Adafruit Feather M0 RFM96 Lora with radio module 433Mhz
Working time on battery	7h with motors on full power, 22h without motors
Driving speed (rover mode)	2,5m/min (flat,hard surface)
Radio bandwidth	125kHz
Output power	19dBi
Cost of the CanSat	853PLN

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. 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 "yagi" antenna.
-CanSat damage during the drop from the drone on the first day – second fully operational CanSat
To safely transport CanSat to the finals, we've created a special suitcase.

9. Statement

We declare that we are fully ready for tests at the Błędowska Desert. We have 2 fully operational CanSats, 2 antennas, one of them with an innovative tracking system. Everything is working well and has been tested.

10. Register