CanSat 2021
Critical Design Review (CDR)
OSATeam, Poland

VIII Prywatne Akademickie Liceum Ogólnokształcące w Krakowie

1. CHANGELOG

- LORA gateway will be built from CanSat circuit, because it is less expensive and easier to program
- Logo has been changed
- To fit battery inside we decided to use 6 probes instead of 8
- We resigned of using LSM9DS1

2. INTRODUCTION

2.1. Team presentation

OSA (in Polish "Opadający Satelita Atmosferyczny" is loosely translated into "Falling Atmospheric Satellite") is a project of 4 students from one class out from one of Cracow's high schools, who decided that, apart from school, they wanted to take on a serious project. Together, they decided to take part in the CanSat competition.

2.2. Team organisation and roles

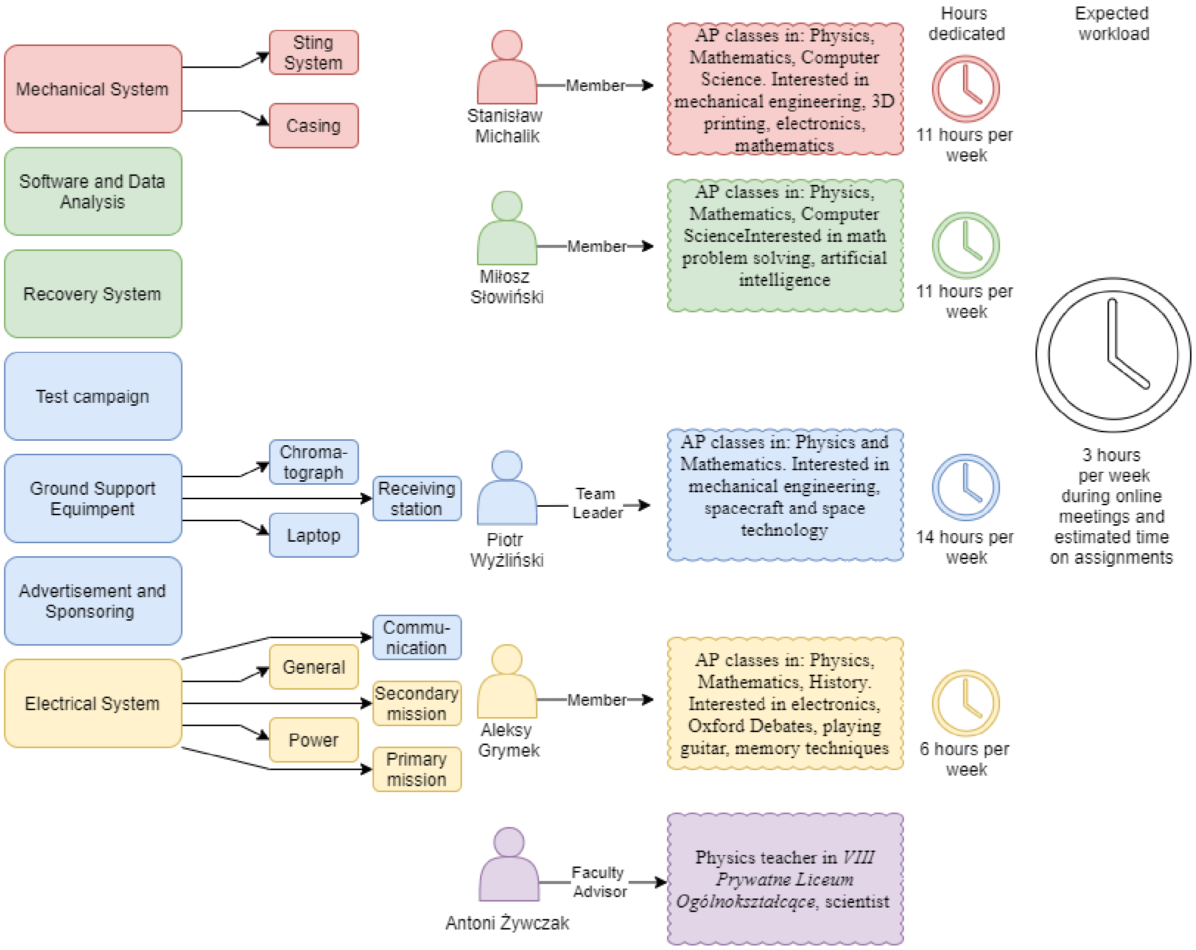


figure 1. Team organisation, hours dedicated, expected workload

2.3. Mission objectives

CanSat's primary mission is to measure the pressure and the temperature of the atmosphere during its descent and to send those measurements to a radio ground station every second. These data will be simultaneously saved in the local CanSat's memory so that it can be analyzed after the satellite lands.

The data from the primary mission will be used to calculate the height from which the CanSat will have been dropped and to calculate live altitude, and hence the speed and the time of the descent. Based on these calculations, there will be adjusted times when the next atmosphere samples are going to be collected (The first sample will be taken when the descent begins. We plan to decide if it will be detected by an accelerometer or by a different device)

The satellite will also provide the GPS location, necessary to locate CanSat after landing. Additional data related to the measurement process itself will be collected at the time of sampling, that is recording initial pressure in tanks, final pressure, filling time of tanks and diagnostic data of the filling mechanism. After analysis, this data will be used to control the filling process. At least 6 atmospheric sample containers are expected to be filled and delivered to ground, and process related data recorded.

The second mission was inspired by information from a recent Venus study, which detected phosphine that could indicate that there was life on this planet. OSATeam wants to test the Earth's atmosphere sampling system so that later a similar solution could be applied to a real mission.

The purpose of our second mission is to show that it is possible to collect samples without building satellites equipped with expensive and heavy research equipment, instead, samples can be effectively collected to be analyzed in an external specialized laboratory. Instead of investing in satellites with multiple sensors, you can invest in building many cheap satellites that collect valuable material for later analysis. The mission aims to demonstrate that this is realistic and that samples can be collected and safely delivered this way.

To ensure the success of the mission, the following goals must be met:

- Recovery system: the parachute must open and ensure a safe CanSat landing
- Electronic system and mechanical structure must work: after flight conditions (rocket acceleration),during descent (changes in pressure, temperature, humidity) and survive landing (impact)
- Sampling system: it must be hermetic, keep the tanks ariditile until sampling, it must not be damaged,
- Communication system: must ensure at least one-way communication (satellite -> ground station) during the flight and after landing,
- Software: must correctly implement the assumed algorithm, save all delivered data and send it by radio.
- Power supply system: must be safe, the energy reserve must be sufficient for the assumed number of working hours.

Optionally, samples collected during the tests will be tested for their composition in external laboratories. The analysis of the Earth's atmosphere could, for example, show that air pollutants (carbon dioxide, methane, ozone, freons, microplastics) can be detected in the air not only at the Earth's surface, and that the amount of pollutants varies depending on air humidity, altitude.

3. CanSat Description

3.1. Mission overview

The OSACan is designed to be launched and dropped from a rocket or drone from an altitude of 500-2500 meters. After equalizing the forces, CanSat should drop at a speed of about 6 meters per second. The most important task of CanSat is to collect atmospheric samples into sealed containers while falling, using a sampling and filling mechanism at various heights. The samples are meant to be safely delivered to Earth, which requires proper protection of the probes against damage or leakage.

CanSat will descend on a parachute that will expand spontaneously as soon as it is dropped out of a rocket or a drone.

The satellite will be equipped with sensors to measure the parameters of the atmosphere outside the satellite (pressure, temperature and air humidity) and the parameters of the collected samples (pressure in the tank). The on-board computer will be responsible for the acquisition of data from sensors, their recording on the SD card and control of the radio communication system. It will also be responsible for starting and checking the air filling system for containers.

The radio communication system is designed to send these data at least once a second using a radio transmitter to the ground station, both during descent and after landing.
The GNSS module connected to the on-board computer will provide information about the current CanSat position based on the reception of GPS, Galileo or Glonass signals. The signal will be transmitted for at least 5 hours to make it easier to find CanSat after landing.
The *Mechanical Subsystem* (sampling and probe filling) is a key element of the second mission. A special sting system has been designed to fulfil the purpose of filling. An atmosphere sample at a certain altitude will be sucked from the outside of the CanSat by a gas pump. The gas, compressed to about 0.5 atm, will be forced into the vacuum tube by means of a needle piercing the sealed stopper. Several test tubes will be arranged around the CanSat circumference so that samples at atmospheres of different heights can be collected. In order to fill the next tube, a rotating system (the so-called carousel) was designed, driven by a stepper motor. The vertical position of the needle will be servo-controlled. The moment the tube is full will be identified by the pressure sensor. The mechanical subsystem is controlled by the **Microcontroller Subsystem** based on CanSat Kit pcba and additional pcba shield. All are powered by battery and **Power Supply System.** The microcontroller subsystem sends data to **Ground Receiving Station** using the LoRa radio module. Block diagram (figure 2.) presents the proposed architecture of the whole system.

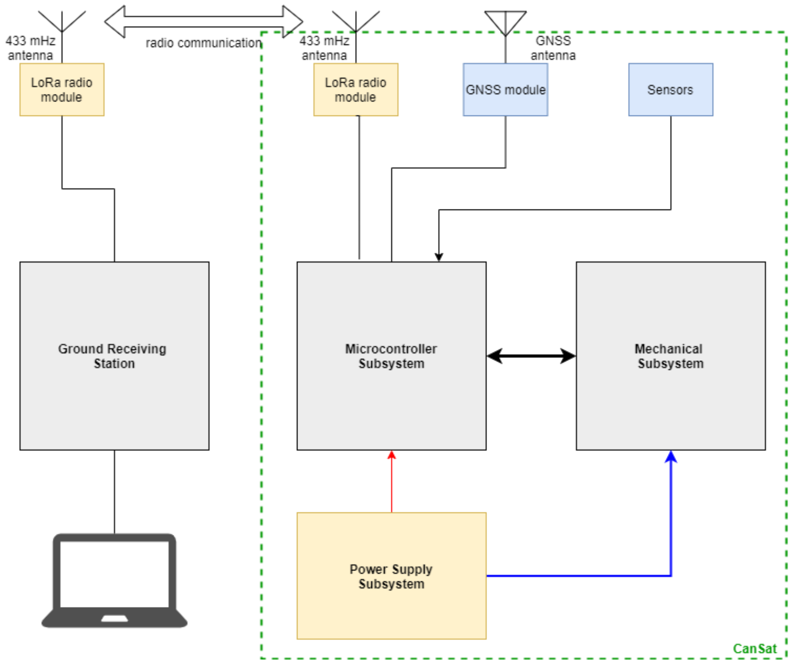


figure 2. electrical system diagram

3.2. Mechanical/structural design

Mechanical was designed in fusion 360. Full project is available to watch with this link : https://a360.co/3m6YfiX

Figure 3. presents the Sting System. A pump will be used to collect air samples. Its inlet will lead to the outside of the CanSat and its outlet will lead to the needle. The needle will be driven into the test tubes by a servo with a special arm. To fill another tube, the servo will be rotated by a stepper motor.

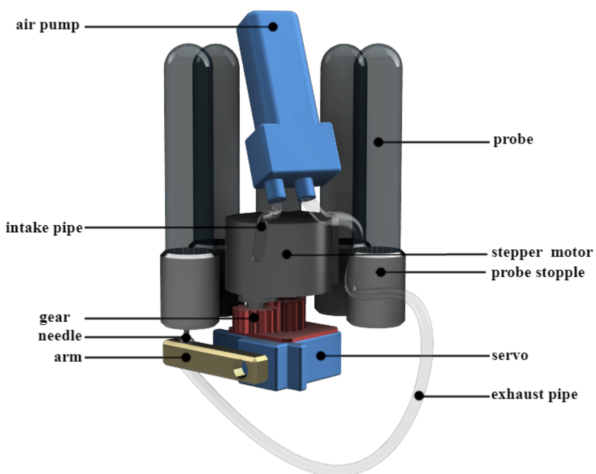


figure 3. structural design scheme

3.2.1. Carousel

The carousel (figure 4.) is designed to turn the servo. It uses a stepper motor and a gear. The motor does not have a centered shaft, therefore a gear consisting of two gears will be printed on a 3D printer.

28BYJ-48 stepper motor (figure 5.): It was chosen due to the fact that it is the smallest stepper motor on the market with low voltage supply in a reasonable price range in the shape of a cylinder.

Parameters: Supply voltage: 5 VDC, Current consumption per coil: 100 mA, Number of phases: 4, Gear: 64: 1, Number of steps per full revolution: 64, Rotation angle per step: 5.625 °, Torque: 0.3 kg * cm (0.03 Nm), Frequency: 100Hz, Resistance: 50? ± 7%, Weight: 35g, Price: 1.94 €

The motor is pressed onto the body, also holding the test tubes around it (figure 6.).

Servo gear is printed with base of case as one part. Servo gear is mounted on the round body (figure 9.), so it will not fall apart.

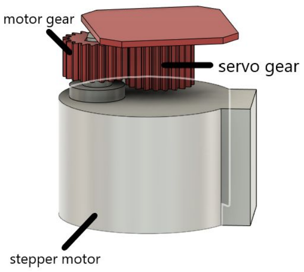


figure 4. carousel scheme

figure 5. stepper motor photo

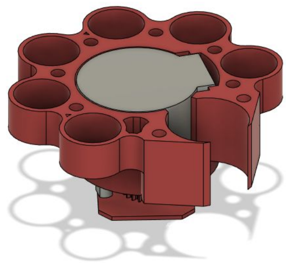


figure 6. stepper motor attachment to the casing

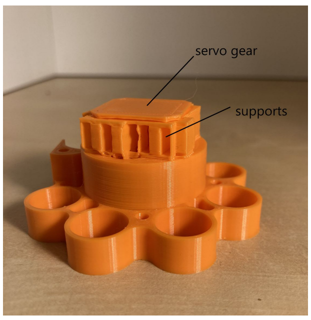


figure 7. - base with supports

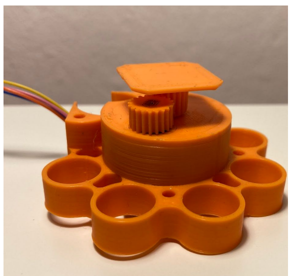


figure 8. - base

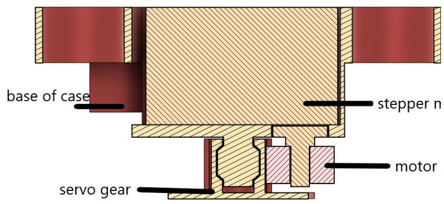


figure 9. - carusele intersection

3.2.1.1. **Tests:**

We tested many different gears designs, ways of locking them in place and printing tolerances to print in place (figure 10.) . Final result put into the main project works well and servo gear is strongly connected with the base part while easily spinning.

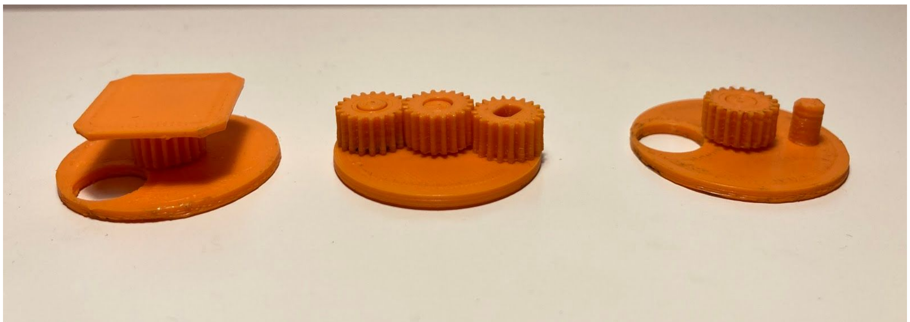


Figure10. - gears tests

3.2.2. *Servomechanism*

The servomechanism (*figure 11.*) is designed to stick the needle into the next test tubes. The main part is a micro servo that moves the arm along with the needle, which is connected to the pump by a rubber tube. The micro servo will be glued to servo gear (*figure 12.*).

Servo Hitec HS-55 - micro (figure 13.): it was chosen for its low supply voltage, high quality and reliability, extreme accuracy, metal gears and very small dimensions.

Parameters: Supply voltage: 4.8 V to 6.0 V, Range of motion: 0° to 180°, Dimensions: 23 x 12 x 24 mm, Cable length: 160 mm, Weight: 8 g, Parameters for 4.8 V - power consumption: 5.5 mA - idle state, 150 mA - movement without load, Torque: 1.1 kg * cm (0.108 Nm), Speed: 0.17 sec / 60 °, Price: 12.91 €

Servomechanism wasn't tested yet, and needs to be put in motion.

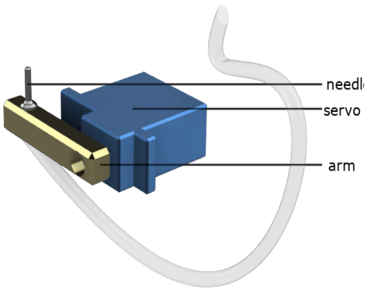


figure 11. servo scheme

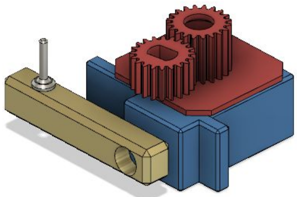


figure 12.. servo attachment to the gearing

figure 13. servo photo

3.2.3. *Pumping System*

3.2.3.1. **Description:**

The pumping (figure 15.) system is designed to collect an air sample at a specific height. One inlet gas is withdrawn and the outlet is blown into the tube through the needle.

3.2.3.2. **Tests:**

We tested 5 different air pumps, all different sizes and power. To test the max. pressure we used target probes (figure 14) and analogue air pressure sensor. We built a special system (figure 15) built of pipes moulded tee, needle and seals. Electronics are Arduino Due, SSCDANV030PASA3 HONEYWELL air pressure sensor and power supply built of bench supply and special circuit (figure 16).

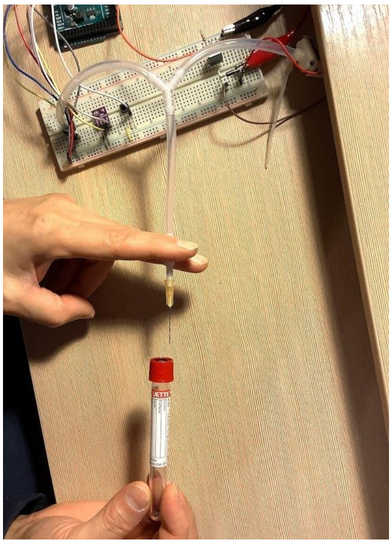


figure 14. - testing filling probes

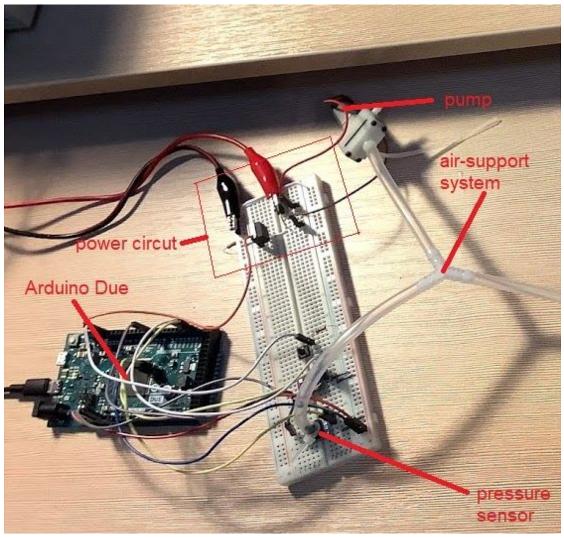


figure15. - pumps testing system

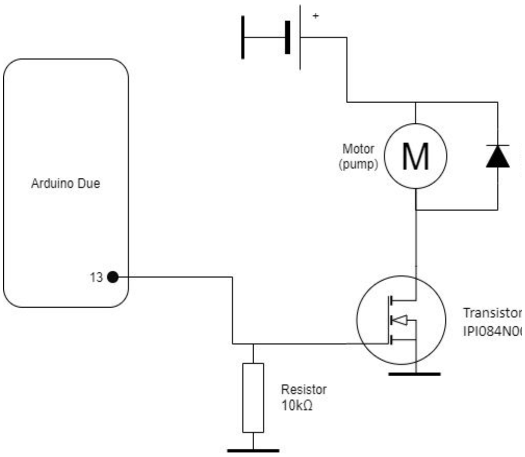


figure 16. - power circuit

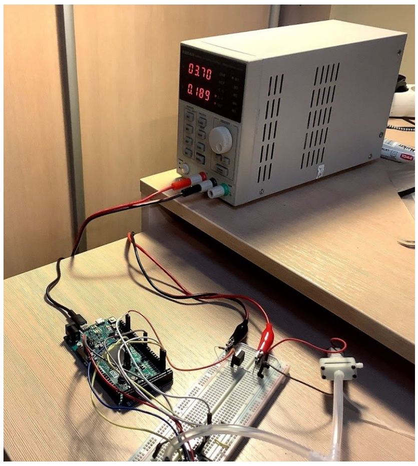


figure 17. - bench supply

3.2.3.3. **Chosen pump:**

The test showed that the best model is a 3,0V motor AJK-B03V1405C (figure 19.): The pump has a pressure of approx. 1,65 atmosphere and fills a 500 ml container (bottle) with air in 150 seconds. The maximum current in the motor circuit was 220mA. The pump will be attached to the body as shown in *figure 20* (beveled as it fits diagonally), and the air supplied and exhausted is as shown in *figure 13*. We used a needle 0,6 mm.

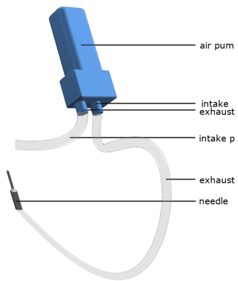


figure 18. air pump scheme

figure 19. air pump photo

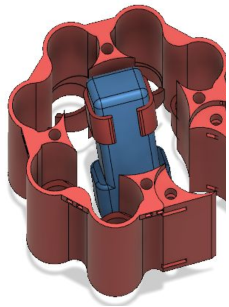


figure 20. pump attachment to the casing

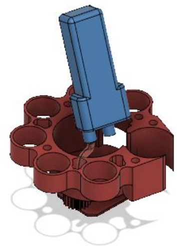


figure 21. intake and outtake pipe attachment to the casing

In the were we pumped 500 ml container we obtained following results (figure 22)

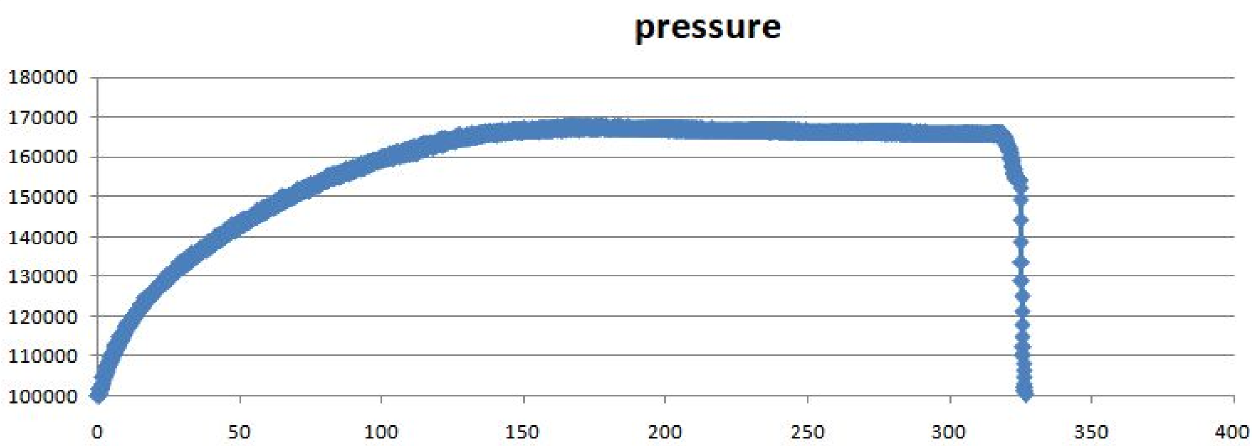


figure 22. - pressure in the container graph

Then we executed a test of pumping a real 4ml probe. The maximal pressure was the same as in the previous test. Was reached after about 3 seconds. The result is shown on the figure 23.

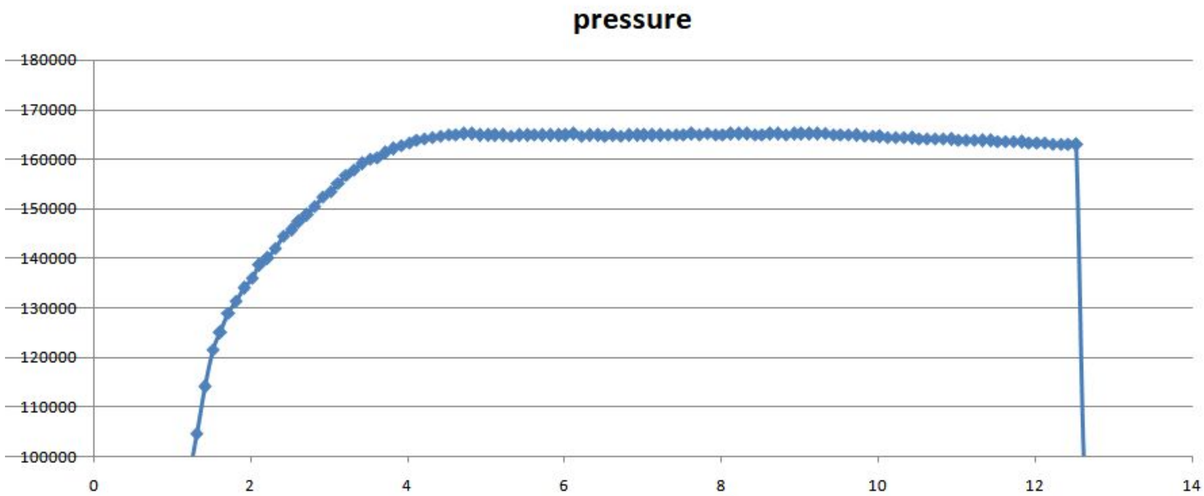


figure 23. - pressure in the probe graph

3.2.4. ***Probes***

They are containers for air samples. They are made of thin plastic and plastic closures. Probówka z aktywatorem krzepnięcia plastikowa, 4ml BIOMEDICO (figure 24.) model was chosen. Tubes are sterile, vacuum sealed, and used in blood collection systems. Filling is done by puncturing the stopper with a needle. After removing the needle, the hole seals itself. Their price is: 7.13 € for 100 pieces. It is important that the container (test tube) has no contamination, it should be as sterile as possible and empty of gases. The test tubes will be attached to the casing by pressing (figure 25. & 26.), so that they can be easily removed and the samples can be examined. To replace with new tanks, just remove the casing, take out the old ones and replace with new ones.

figure 24. probes photo

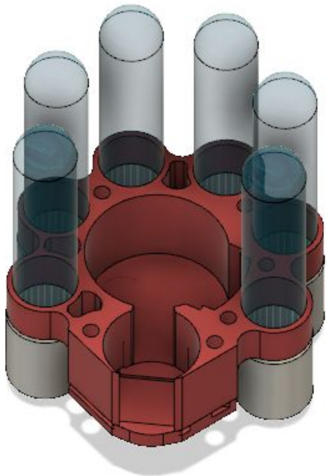


figure 25. probes attachment to the base

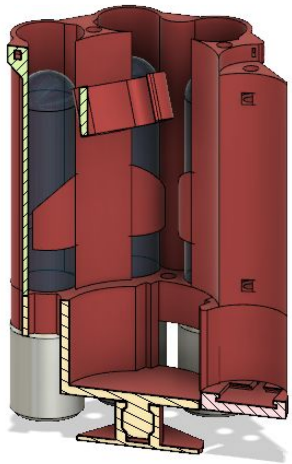


figure 26. probes attachment to the main casing

3.2.5. *Casing*

The entire casing (figure 27.) will be printed on a 3D printer, in addition, the most delicate elements will be additionally secured with a sponge.

The casing is designed to:

- provide the basis for mounting the satellite components,
- protect mechanical and electronic components from damage,
- prevent CanSat elements from moving, protect them from high G-force.
- protect the test tubes from breaking and, if they do break, protect them from injuring people who find OSACan after landing
- provide quick access to the CanSat interior, including the battery
- enable any mechanical elements to operate freely,
- protect the inside of the satellite from outside conditions (temperature, humidity, air momentum when falling)
- be as easy to print as possible

The casing has no bottom, as more space was needed for the movement of the arm with the servo. Figures 28, 29, 30 show 3 parts of casing. Reason for using 3 different parts is to ease access to inner elements. Except servo all mechanical and electrical components will be inside the main part as well as above CanSat Kit. To organise electronics in the main casing body there is a pump mount. Main part is designed to print without any support to make the print cleaner and to save on printing time.

The main part is connected with base by two screws and two metal, 3mm diameter wires.

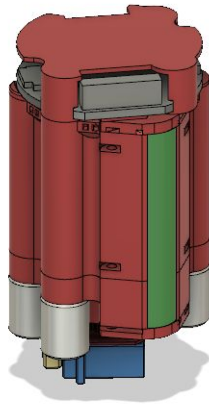


figure 27. casing

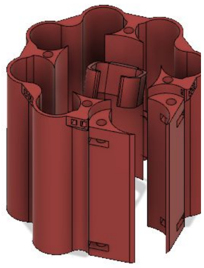


figure 28. main casing body

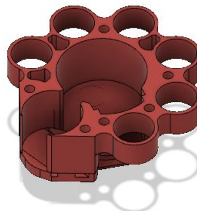


figure 29. base - probes casing part

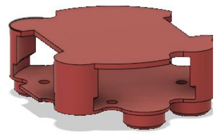


figure 30. main-top -electronics casing part

Battery mount:

To save on space and for better access to the battery instead of using a bought battery case we designed our own which is part of the CanSat case. The battery is located on the side of CanSat, because it's too big to fit inside . Two screws connect the bottom battery lock, base and main casing body (figure 31.). There are two more screws that connect the top battery lock with the main casing body. Two metal parts which convey energy from battery to electronic board are placed in bottom and top battery locks (figure 32.). We didn't use springs so ours CanSat won't reset over to load factors.


figure 31.

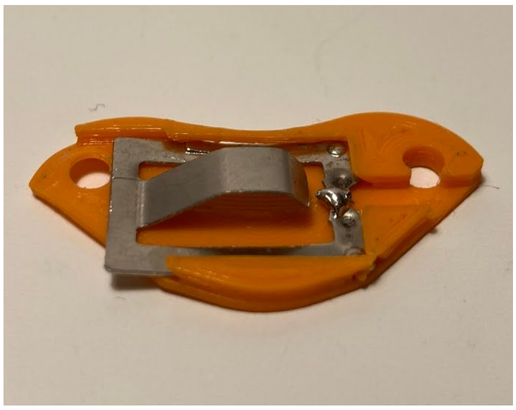


figure 32.

3.3. Electrical design

3.3.1. General architecture

The general architecture is presented on the following diagram. The concept of the microcontroller subsystem is based on ready-to-use CanSat Kit and pcba shield with additional elements.Elements are marked in:

- yellow - located in the main pcba (CanSat Kit)
- blue - pcba shield (to be developed)
- violet - outside pcba, mounted directly to the housing body.

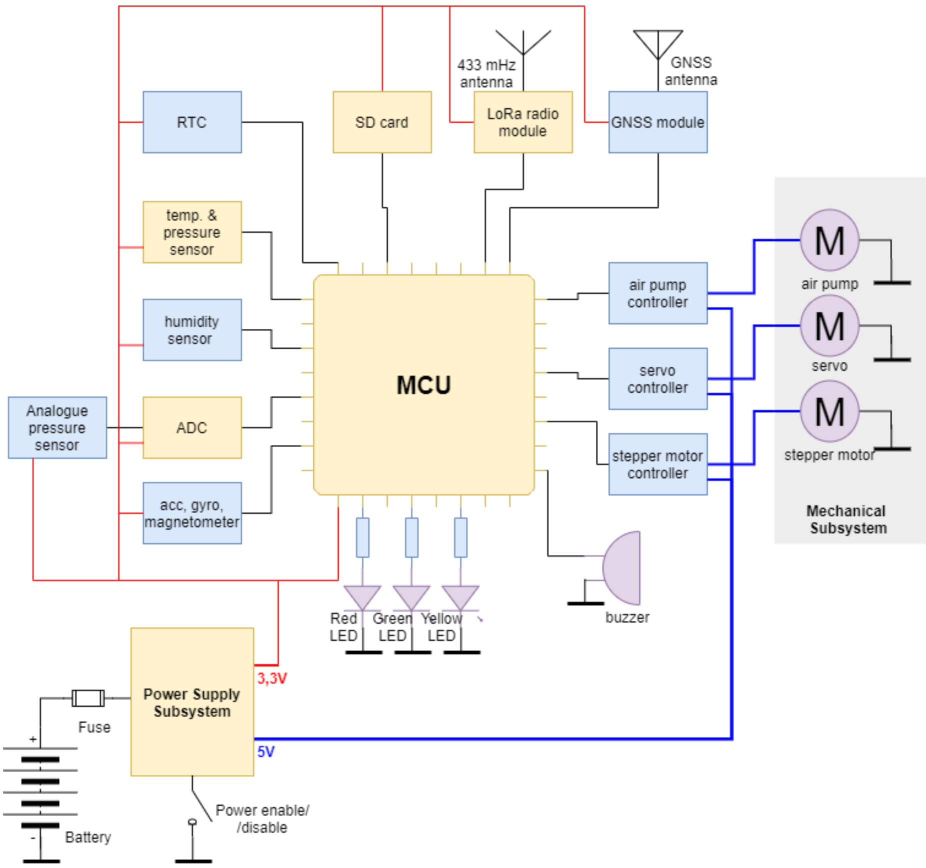


figure 33. electronics topology

Some elements are selected, other elements will be selected during the prototype phase.

3.3.2. *Primary mission devices*

- Temperature sensor: Model - LM 35 (figure 34)
  - Used for measuring temperature at certain height, will be mounted outside CanSat, so it won't be heated by inner devices
  - Temperature range - (-55*C)-150*C, Measuring in Celsius, Accuracy to 0,5*C, Voltage: 4V-30V
  - Price : 0,33 €
- Atmospheric: humidity, temperature and pressure sensor: Model - BME280 (figure 35)
  - Used for measuring atmospheric pressure and humidity at certain height
  - Atmospheric pressure range - 300-1100 hPa, Accuracy to 1hPa, Voltage 3,3 V
  - We are using this particular one because it is attached to the integrated circuit
  - Price : 8,85 €
- Radio module: model SX1278 RA-02 LoRa 433MHz
  - (described in 3.2.6.5.1, communication system Transceiver part of OSACan)

3.3.3. *Secondary mission devices*

- Pressure sensor: model - Honeywell SSCDANV030PASA3 (figure 36.)
  - was tested on version with SPI. It was decided to change it to the same sensor but with I2C, so it does not collide with SD card and LORA radio.
- Accelerometer, magnetometer, gyroscope - LSM9DS1 (figure 37.)
  - Used for checking weather the parachute is open or not
  - wasn't tested yet
  - will be used as a potential option
- AJK-B03V1405C pump
  - (described in Pumping System)
- Servo Hitec HS-55 - micro
  - (described in Servomechanism)

- stepper motor - 28BYJ-48
  - (described in Carousel)
  - was runned on different board, needs synchronization with CanSat kit and other units
- Location system
  - not selected yet ; dependable on other variables

figure 34. - temp sensor

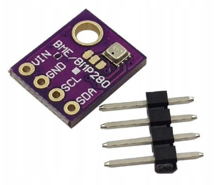


figure35. - BME280 sensor

figure 36. - analogue pressure sensor

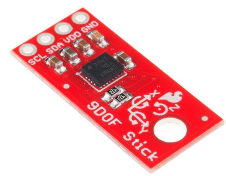


figure 37. - accelerometer, magnetometer, gyroscope

3.3.4. Electrical scheme

We started drawing the electrical schematic of the pcb shield in KiCad software. The preliminary version is presented in figure 38.

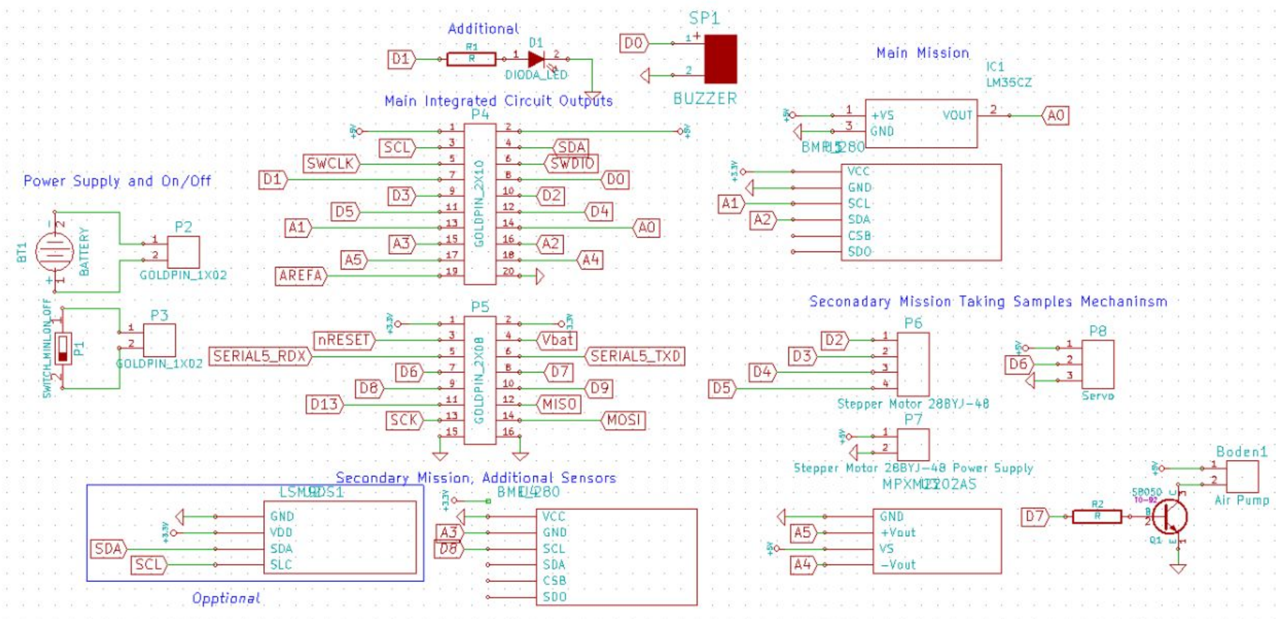


figure 38. - electrical schematic of pcb shield

3.3.5. Power supply

Batteries will be selected in the next phase of the competition to fit our demands after we conduct tests regarding the electrical modules.

We tested power only using bench power supply and 3xAA in the minus temperature. Batteries lasted about 8 hours.

3.3.6. Communication system

3.3.6.1. General description

The following assumptions were made for the communication system:

- communication between the satellite and the ground receiving station is one-way, that is from CanSAT to the ground station
- communication takes place in the 433 MHz public band
- the radio layer of communication will take place with the use of ready-made LoRa modules
- power cannot exceed 20 dbm (as required)
- the satellite antenna must fit in the assumed dimensions of the satellite, it must extend to a certain length along with the parachute deployment.

To achieve the goal it is necessary:

- Equipping the satellite with a LoRa micro-transmitter with an antenna.
- Building a ground receiving station with a directional antenna.

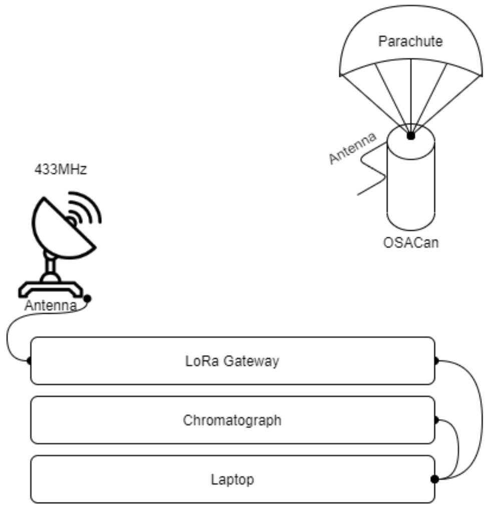


figure 39. - communication scheme

3.3.6.2. **Transceiver part of OSACan**

Characteristics

- CanSat Kit with HDP16A (compatible with SX1278) LoRa 433MHz module:
    - Range: 10-15km, Sensitivity: -148dBm, Transmission speed: up to 300kbps, Working frequency: -148dBm, Supply voltage and work: 1.8-3.7v, Working temperature: -40 - +80 ℃, Communication protocol: LoRa, RF transmitter power: + 20dBm (100mW) at 433.00 MHz, Communication: SPI, CS Line: PIN11, Price: Included in the CanSat Kit price

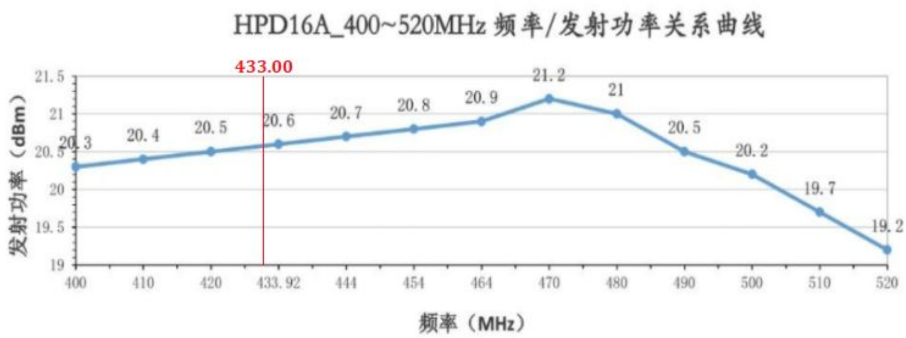


figure 40.

- Antenna: wire antenna, length $\lambda/2$ = 347 mm ($\lambda = c*T = c/f$, where c = 299 792 458 [m / s] is the speed of light, T is the period, f = 433 [MHz] is the frequency), soldered directly to PCB
- the necessary software ensuring the transmit of messages.

Prototype details:

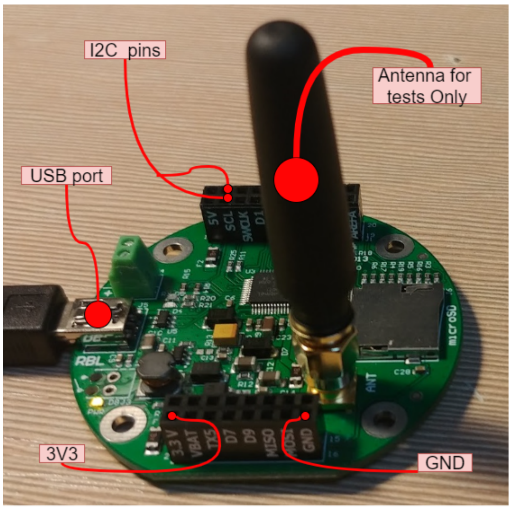


figure 41. -CanSat board

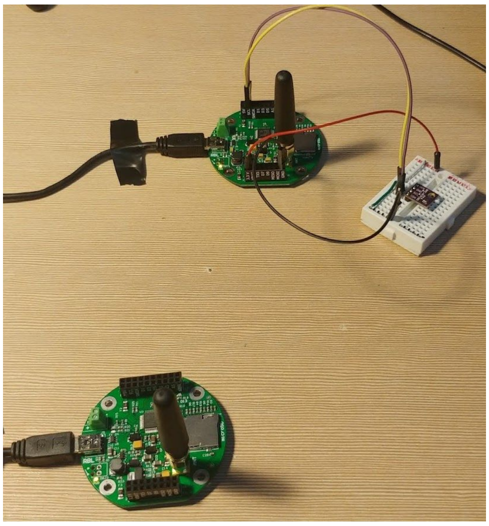


figure 42. - communication between two CanSat boards, sending data from BME280

We designed a prototype of communication using two CanSat boards and antennas (figure 42). The antennas are used for home tests only and designing software. Model used a 433M-ANT401 antenna (instead of wire antenna) connected by SMA connector soldered to the PCB.

BME280 sensor was connected to the circuit using I2C as shown on figure 43 on breadboard (figure 44).

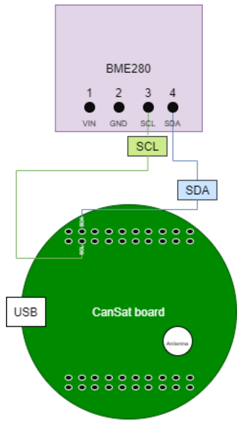


figure 43. - BME290 connection

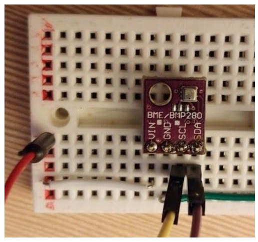


figure 44. - BME280 on breadboard

Software setup enables maximum output radio power:

```
write_register(SX1278_REG_PA_CONFIG, SX1278_PA_SELECT_BOOST | SX1278_MAX_POWER | SX1278_OUTPUT_POWER);
write_register(SX1278_REG_OCP, SX1278_OCP_ON | SX1278_OCP_TRIM, 5, 0);
write_register(SX1278_REG_LNA, SX1278_LNA_GAIN_1 | SX1278_LNA_BOOST_HF_ON);
write_register(SX1278_REG_PA_DAC, SX1278_PA_BOOST_ON, 2, 0);
```

For test purpose transmitter sends example messages including: timestamp (ms), temperature (C degrees), humidity (%), air pressure (Pa) from BME280 sensor

3.3.6.3. **Ground Receiving Station**

Characteristics:

- CanSat Kit with HDP16A (compatible with SX1278) LoRa 433MHz module **(the same parameters as in transceiver)**
- handmade 9-elements directional antenna (reflector x1, dipole x1, directors x1),
- antenna cable (50 Ohm) ended with SMA connectors (male / female),
- the necessary software ensuring the receipt of messages,

3.3.6.3.1. Ground station directional antenna

A sensitive receiving radio circuit is required over long distances. One way to increase the sensitivity is to use an antenna with a good gain. Antennas with directional characteristics work well in such applications, we decided to go with the Yagi antenna:

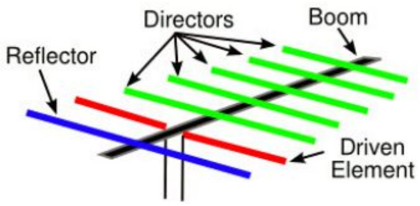


figure 45. - Yagi antenna scheme

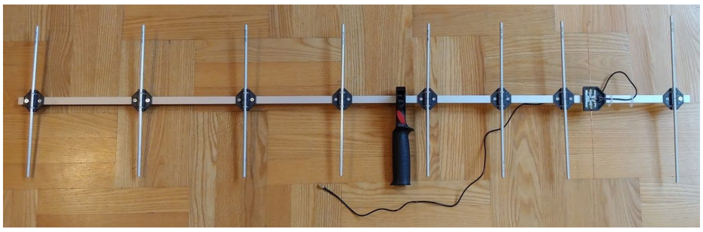


figure 46. - OSATeam ground station Yagi antenna

We decided to build such an antenna ourselves from scratch. It was built of a boom made of the square aluminium profile 15 x 15 [mm], it was equipped with transverse active elements made of the aluminum tube fi 6 [mm] and dipole made of the copper straight wire 1,5 [mm^2]. Precise parameters of elements are shown below:

Element:	Reflector	Dipole	Director #1	Director #2	Director #3	Director #4	Director #5	Director #6	Director #7
Length:	333 mm	tbd	314 mm	311 mm	308 mm	306 mm	304 mm	302 mm	300 mm
Position: (from reflector)	0 mm	166 mm	218 mm	342 mm	491 mm	664 mm	857 mm	1065 mm	1282 mm
Distance : (from prev. element)	-	166 mm	52 mm	124 mm	149 mm	173 mm	194 mm	207 mm	218 mm

The construction and dimensions was calculated using “Yagi Una Antenna Calculator”.

Materials were bought in a hardware shop. We measured them and cut them ourselves so they fit requirements. Also we needed to isolate directors and dipole from the boom. To do it we printed such isolation pieces on a 3D printer. These construction elements are shown on figure 47 and figure 48.

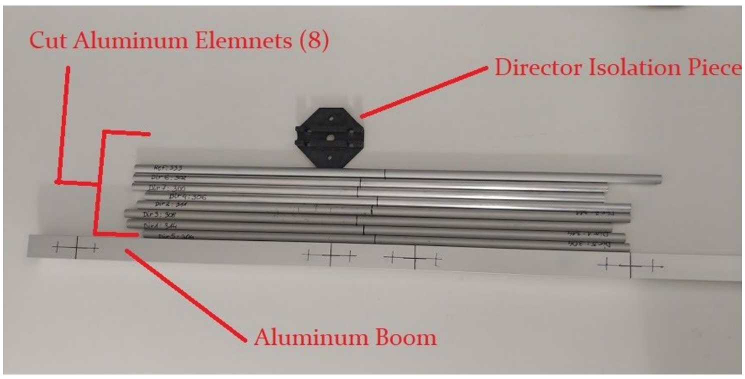


figure 47. - antenna’s construction components

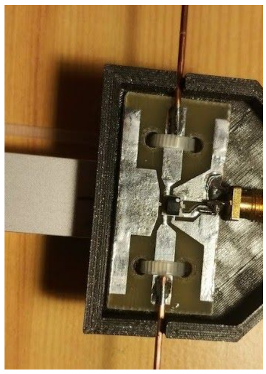


figure 48. - balun pcb and enclosure

The most important construction element is **dipole with balun** (figure 49)**.** It is used to fit the impedance of the antenna. We plan to use copper tubes with bigger diameter (3-5 mm) to stabilize the structure. However, for tests thisl dipole is sufficient. The balun is made of the special plate and transformer JA4220-ALC Coilcraft to strengthen the signal.

Connection between Gateway and antenna is done by SMA-SMF/50/1 cable (figure 50). Cable is connected by SMA directly to CanSat Board .

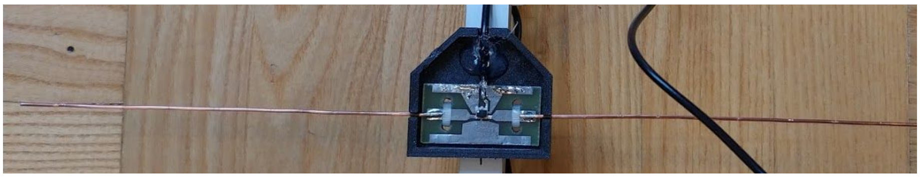
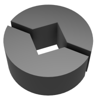


figure 49. -dipole with the balun

figure 50. - SMA

To ease using the antenna we designed a special holder. It consists of a 3D printed adapter (figure 51) and drill holder (figure 52).



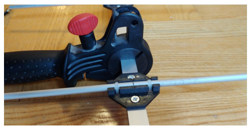
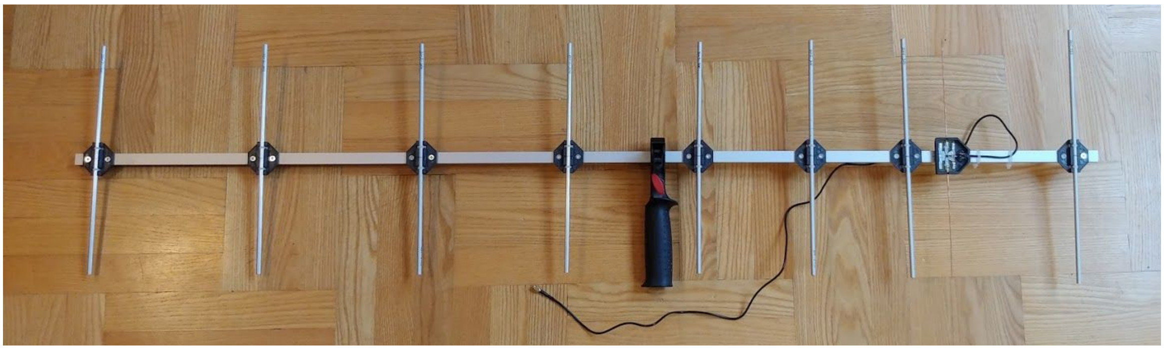


figure 51. - 3D project of adapter

figure 52. - drill holder with adapter mounted to antenna

Results of finished Yagi Ground Directional Antenna are shown below on figure 53.



3.3.6.4. Sending/receiving tests

- First test was done in a desk environment. Two CanSat boards were put within about 300 [mm] space between each other as shown on figure 54. With following parameters: Bandwidth 125000, SpreadingFactor 9, CodingRate 4_8. The test lasted 6,75 hours with RSSI about -17.
- The tests were done before checking accuracy of the used BME280 sensor, because it wouldn't affect results of sending and receiving tests.
- Data was uploaded from a BME280 sensor. The main aim was to send and receive data and save it on a personal computer disk as a .txt file. Then convert it to a .csv file, show collected data on graphs. In excel data was checked if any of the measurement was missing using a simple line of excel code shown in figure 55. Fortunately there wasn't any data missing, the test was completed successfully. Example results are shown in the folder on google drive.

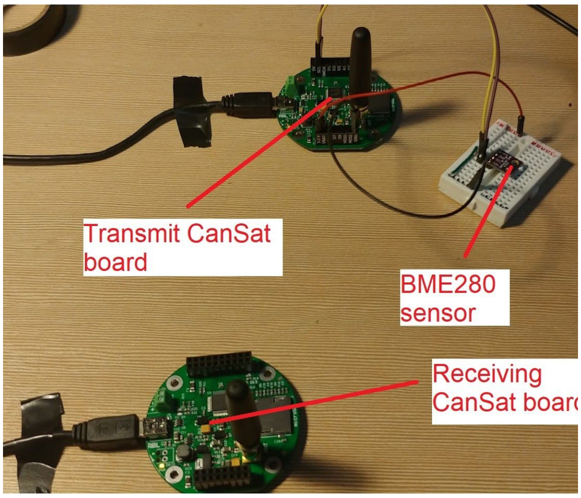
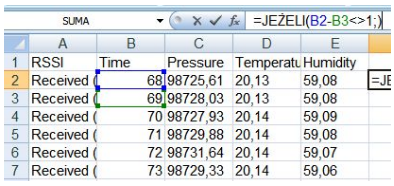


figure 54. - CanSat boards communicating


SUMA =JEŻELI(B2-B3<>1;)

	A	B	C	D	E
1	RSSI	Time	Pressure	Temperatu	Humidity
2	Received (	68	98725,61	20,13	59,08
3	Received (	69	98728,03	20,13	59,08
4	Received (	70	98727,93	20,14	59,09
5	Received (	71	98729,88	20,14	59,08
6	Received (	72	98731,64	20,14	59,07
7	Received (	73	98729,33	20,14	59,06

figure 55. - checking if any data is missing

3.3.6.5. **Communication system range tests (urban built in space):**

To test the range of the OSATeam antenna we needed to put a transmitting CanSat board on a very high place. Because of unpredictable weather we built special casing.

figure 56. - protective box

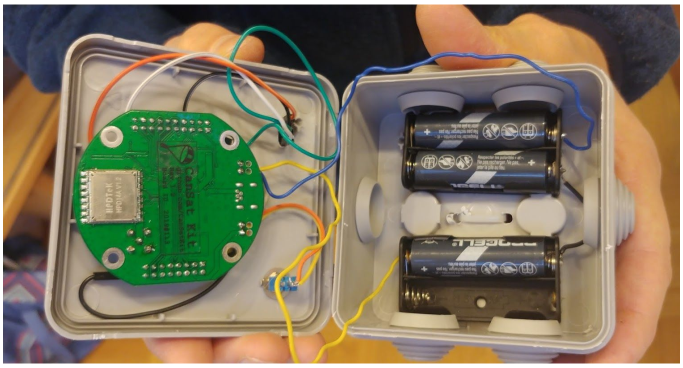


figure 57. - inside of the protective box

We used a protective waterproof box where we put a CanSat board with an antenna with an independent power supply consisting 3 AA batteries (total 4,5V).

figure 58.- protective box with CanSat board on the roof in the centre of Cracow

figure 59. - RTL-SDR USB stick

To analyze waves we used an RTL-SDR USB stick and SDRsharp software. This combination allowed us to check the strength of the signal. Depending on the environment analyzer showed us different dBm, as its logarithmic scale, closer to “1” the better. Software shows readings on the graphs.

Signal quality:

dBm	Classification
-30 dBm	incredible
-67 dBm	very good
-70 dBm	good
-80 dBm	bad
-90 dBm	unuseful

Distance: 400m, urban environment, obstacles, transceiver not covered, directional antenna

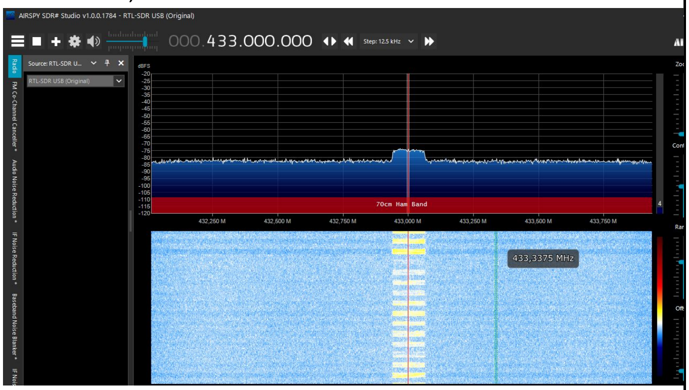
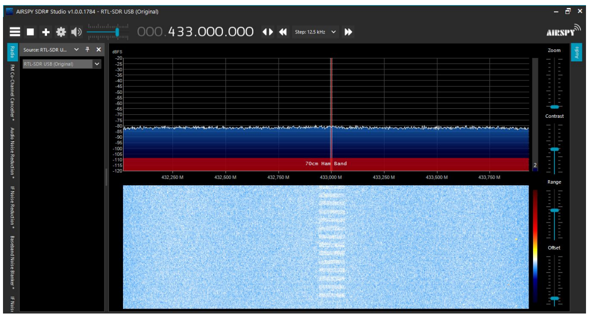


figure 60. - 400m

At the shown distance we could get a signal rated up to -74 dBm. This makes quite a good signal. All the data could be collected. Quality depends mostly on the angle of where the antenna was pointing.

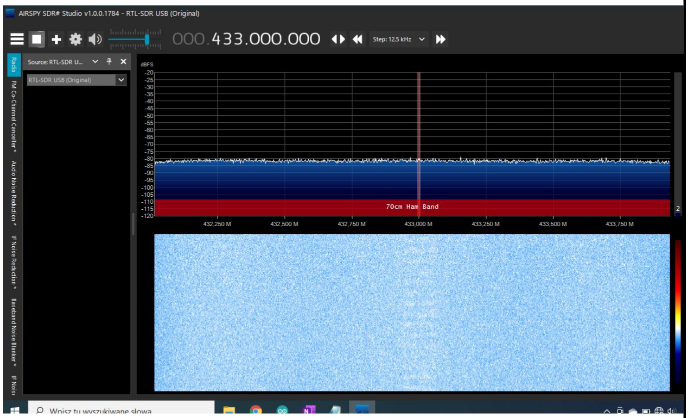
Distance 500m, urban environment, obstacles, directional antenna



figure

figure 61. - 500m

At the shown distance we could get a signal rated up to -81 dBm. At this rate we shouldn’t miss any data, although it isn’t obvious. We believe that tenement building with thick walls was the main problem. We were losing signal when the angle was perfect.

	Distance 600m, urban environment, obstacles, directional antenna  figure 62. - 600m	At this distance the signal was barely visible (rate close to noise level). Most data was missing.
	Further away from transceiver we couldn't get any signal	

3.3.6.5.1. *Conclusions and recommendations*

The antenna should have worked better, we expected a minimum 3 km of range. We decided to analyze our antenna. We used NanoVNA V2 Vector Network Analyzer (figure 63). Results were unsatisfying. We found a problems:

1) holder: we decided to put it in the middle of the antenna (figure 65). It came out this was messing with readings. Fortunately it isn't put there permanently and can be easy dissabled.
2) transformer: while making antenna balun with transformer must have been hit at certain point. It damaged the transformer (figure 64) so the signal wasn't good as expected
3) Dipole should be moved closer to the reflector. We decided to build mechanizm so it can be adjusted easily.
4) Dipole wires should be thicker so it can't be damaged as easily as it is now.
5) Final tune to be done is to put cable, so it wouldn't interfere with the dipole and elements

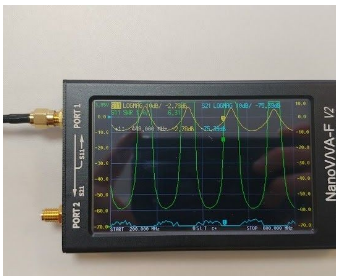


figure 63. - readings from our antenna on NanoVNA analyzer

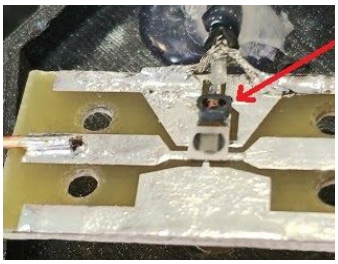


figure 64. - damaged transformer

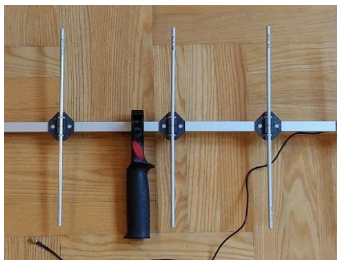


figure 65. - holder problem

- The signal strength test will be performed, whether we achieve the assumed radiation power, but also whether we do not exceed the permissible amount of emitted power as well as electromagnetic disturbances. Such tests are performed in anechoic chambers designed to measure EM emissivity. The necessary measuring equipment (chamber, carrier wave generator, exposure emitter, analyzer) is beyond our reach, we intend to reach a professional laboratory (AGH, Sponsor)

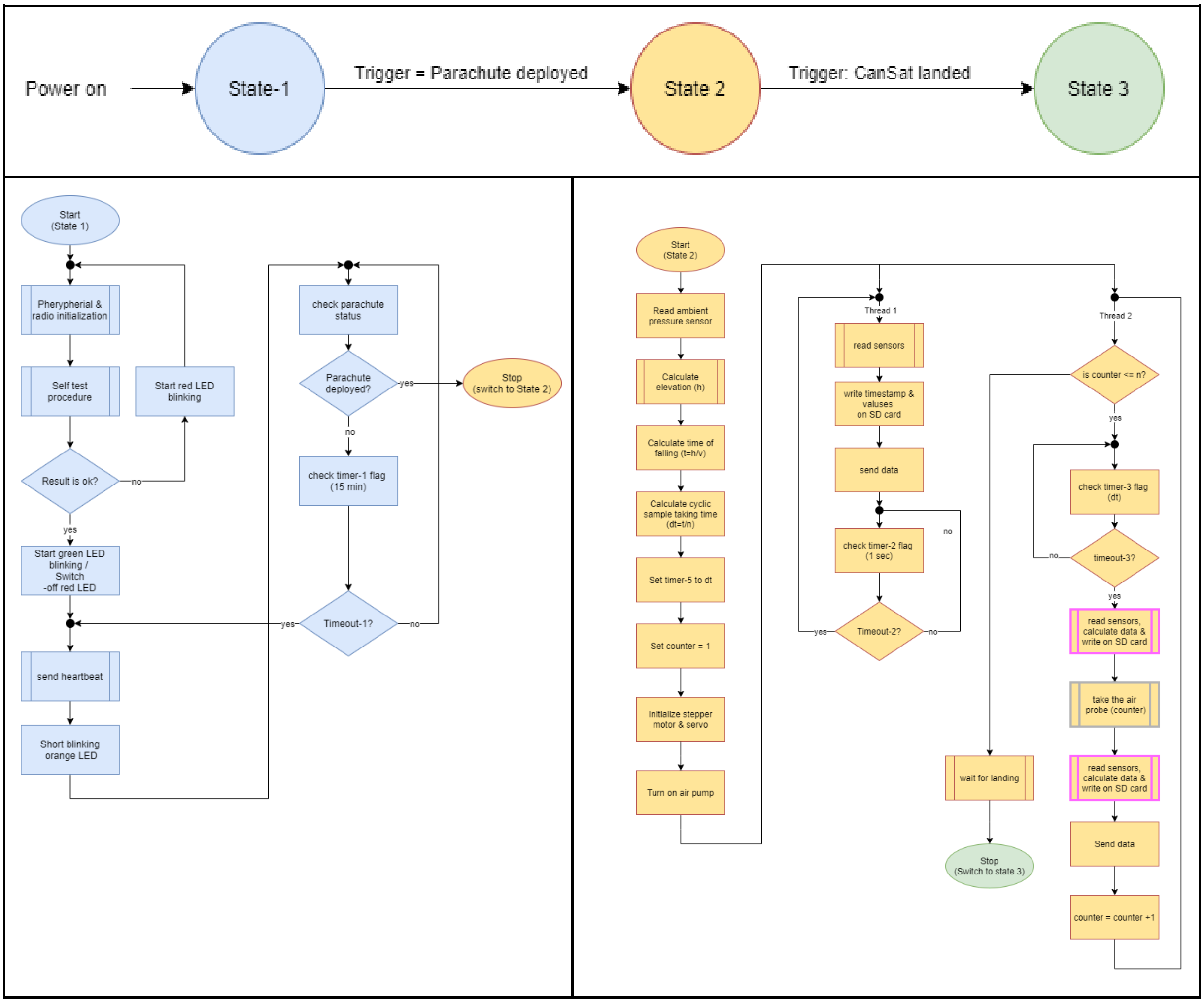
- The maximum achievable range of CanSat under different conditions is measured:
    - In open space - expected measurement 10 km
    - in urban built-up space - expected measurement 3 km
    - measurements should be consistent with the calculations of Fresnel zones
- Additionally, a range and communication test will be performed during: freefall, a balloon or a drone flight. Ultimately, communication with CanSat should be up to 3 km vertically, it will probably be difficult to reach this height, however based on measurements at a lower altitude and the theory of wave propagation in the atmosphere, we plan to estimate the result .

3.4. Software design

Software should cover the support of CanSat Kit Hw v.1.4 and our additional shield with planned pheripherials. Our team will develop the software on microcontroller using the Arduino toolchain.

The preliminary software architecture is described in figure 66:

- state-1: CanSat in this state is waiting for deployment. No primary and secondary activities, due to battery capacity limitation. Main loop is waiting for trigger signal (parachute deployment)
- state-2: satellite realizes primary and secondary missions. This is the crucial part of our software. Details on Diagram. We assume that the unit runs in state-2 no longer than 10 minutes. After the landing it finishes missions and goes to next state
- state-3: unit send periodically the GPS position to the ground receiving station and switch on the buzzer.



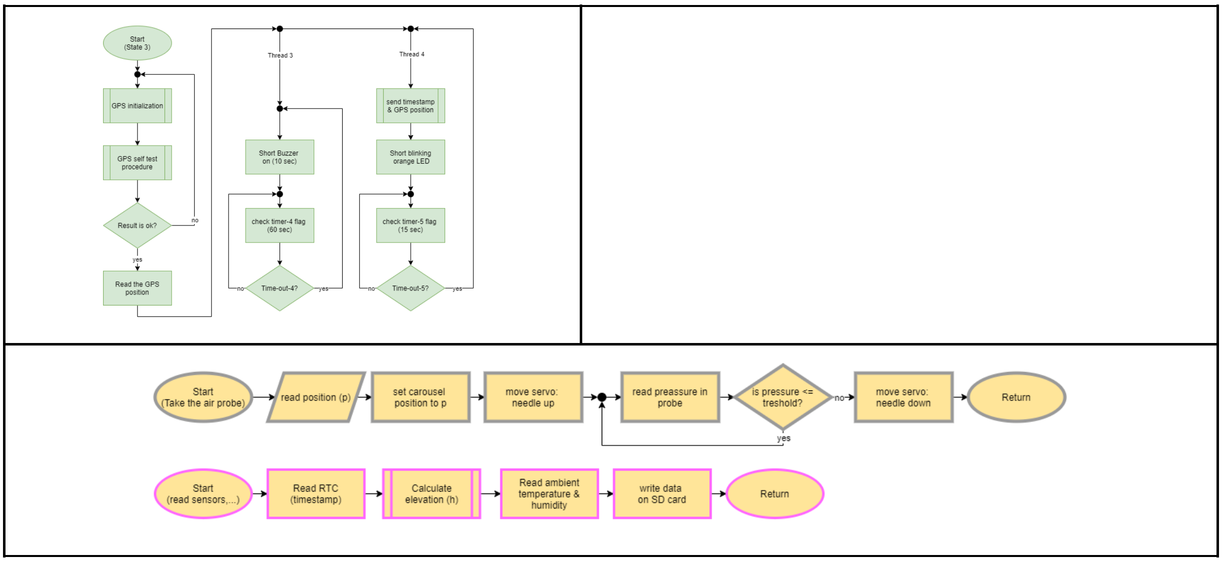


figure 66. - software design scheme

3.5. Recovery system

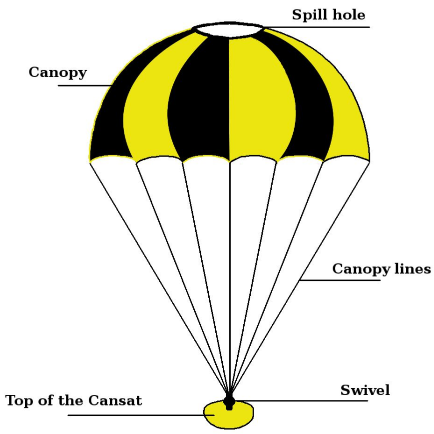


figure 67.

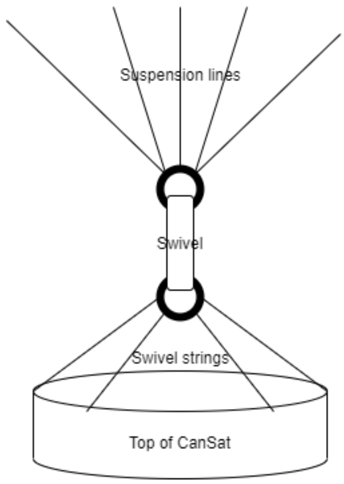


figure 68.

As a recovery system we have decided on using a parachute. The drag force, which can be easily calculated, will allow our precious cansat to fall with targeted speed. We did not want our cansat to drift too far into the distance, however we needed for our probes to land relatively safely so we decided on terminal velocity equal eight meters per second. Using the terminal speed equation we can figure out the area of the chute. Out of the most popular parachute canopies such as square, cross or round canopy the last has the highest drag coefficient thus will assure the lowest area. In the middle of the canopy there will be located a spill hole that will keep the chute from tilting sideways. The ratio between spill hole area and canopy area will measure 1/20. Furthermore we will be connecting canopy lines to the cansat using a ball bearing swivel that will help prevent line entanglement. The length of the canopy will be 20% longer than the canopy radius.

- Air density approximation ρ = 1.225 [kgm3]
- Gravity acceleration approximation g = 9.81 [ms2]
- Cansat mass approximation m = 0.35 [kg]

$$V = \sqrt{\frac{2 \times m \times g}{C_d \times \rho \times A}}$$

$$A = \frac{2 \times m \times g}{C_d \times \rho \times V^2};$$

$$A = \pi \times (R_1)^2 - \pi \times (R_2)^2$$

$$A = \pi \times (R_1)^2 - \pi \times (R_1)^2 \times 5\%$$

$$A = \pi \times (R_1)^2 \times 95\%$$

- Drag coefficient for round type canopy Cd = 1.3
- Terminal velocity of Cansat V = 8 [ms]
- Pi constant approximation π = 3.1415
- A - area of the canopy
- R1 - radius of the canopy
- R2 - radius of the spill hole

$$R_1 = \sqrt{\frac{A}{0.95 \times \pi}}$$
$$5\% \times A = \pi \times (R_2)^2$$
$$R_2 = \sqrt{\frac{0.05 \times A}{\pi}}$$

Parachute will be made out of:

- swivel: Swivel Bushido LUX 2/0 (figure 69.)
    - weight: 3.4 [g]
    - price: 1.99 €

  Swivel will be hitched with 4 strings, attached to the top of CanSat (scheme 7). The reason for using a swivel is to make sure lines will not muddle.
- canopy fabric: ripstop nylon fabric 1.5 x 1.5 [m] (figure 70.)
    - weight: 64.42 [g/m²] - (parachute canopy itself will weight around 9[g])
    - price: 9.83 €
- canopy lines: SHIMANO EXAGE 150m/0.16mm (figure 71.)
    - price: 3.70 €
- Connectors : KÓŁECZKO ŁĄCZNIKOWE KOSTAL CZARNE 10mm 25SZT (figure 72.)
    - price: 0.48 €

figure 69.


figure 70.

figure 71.

figure 72.

Making process:

The parachute shape was selected to be a regular octagon because of its eight corners.The parachute size was calculated and drawn twice onto the fabric. Further the pieces were cut out with excess and after being sewn reversed. The area of the spill hole was decided to be 5% of the whole parachutes area. Connectors were attached to the parachute's corners. Lastly the eight lines were measured and connected to the swivel.


figure 73.


figure 74.

Testing:

Ballast of 300 grams was attached to the parachute. The parachute was dropped from a 15 meter cliff while being recorded from two perspectives. Then the footage was analyzed in "Tracker" made by physlets. (figure 75.)

Observations:

- Parachute opened and the lines didn't entwine
- Parachute flew down to fast reaching about 18 m/s of vertical velocity
- Parachute reached terminal velocity and stopped accelerating

Conclusions and improvements:

- Spill hole has served its purpose stabilizing the flight
- The area of the parachute is to small
- Our calculations were not correct probably because of wrong selected value of the drag coefficient
- More parachutes will be made using corrected calculations

figure 75.

3.6. Ground support Equipment

The ground support system will consist of the following components:

- Laptop
- A ground receiving station, consisting of:
  - directional antenna,
  - antenna cable (50 Ohm)
  - LoRa Gateway,
  - the necessary software ensuring
  - the receipt of messages,
- spare battery pack for CanSat
- optional laboratory facilities
- portable chromatograph,
- data analysis software.
- basic set of tools and spare parts.

3.6.1. Laptop

Any model with Linux or Windows, suitable computing power and a USB input. It will have special software installed to present the data collected on the mission.

3.6.2. Ground receiving station

(described in communication system)

3.6.3. *Chromatograph*

The chromatograph is a very expensive device, we are not going to buy it. We decided on borrowing it from one of the sponsors or from the university[1 2 3]. That is the reason we do not have a specific model inscribed yet.

An alternative is also to deliver the collected gas samples to the sponsor's laboratory or the university (if the loan approval could not be obtained).

3.6.4. *Basic set of tool and spare parts*

4. TEST CAMPAIGN

4.1. PRIMARY MISSION TESTS

4.1.1. Measurement tests

weren't executed because of lack of access to AGH lab.

- **pressure sensor test**: this will involve exposing the used sensor to a pressure change and comparing the results with a reference device. A special pressure chamber will be used for this type of tests, from the AGH laboratory. In the event that such equipment is not accessed, the target and reference sensors will be inserted into a sealed container where the pressure will be increased by a compressor or both sensors will be taken upwards where the pressure will decrease with increasing altitude. It is estimated that the test will last 6 hours, which is the assumed maximum time that CanSat should be found after a fall. The test will be considered positive when both sensors show the same pressure without measuring errors. - weren't executed because of lack of the access to AGH lab reference devices.
- **temperature sensor test**: it will consist in checking whether the target device and the reference device will show the same temperature within 24 hours

4.1.2. Data download tests

- weren't executed yet.

- After positive results of the measurement tests, the data download system will be checked. The device will be turned on successively longer and longer periods and left for measurements. After this time, the collected data on the SD card will be validated for completeness and the occurrence of errors.

4.1.3. *Sending/receiving tests*

PASSED, details described in 3.3.6.4

4.2. Secondary mission tests

atmospheric temperature, pressure, humidity measurements tests using BME280

- We tested readings of the BME280 sensor connected via I2C line Probes were sampled every 1 second and were sent via USB to the terminal program on the laptop. The laboratory setup was very similar to described in 3.2.3.2, but we used a CanSat board.
- The test lasted 7 hours, no samples went missing, intervals were kept at 1 sec.. The results from the BME280 sensor were reliable relating to the weather station and room temperature. The results are shown on figures 76, 77, 78

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[1] WGGiOŚ: Laboratorium chromatografii gazowej," *Agh.edu.pl*, 2019. http://www.wggios.agh.edu.pl/badania-naukowe/laboratoria-i-aparatura/laboratorium-chromatografii-gazowej/ (accessed Jan. 12, 2021).

[2] Laboratorium Chromatografii i Spektrometrii Mas | Jagiellońskie Centrum Innowacji," *Jagiellonskiecentruminnowacji.pl*, 2021. https://www.jagiellonskiecentruminnowacji.pl/laboratoria/laboratorium-chromatografii-i-spektrometrii-mas/ (accessed Jan. 12, 2021).

[3] Laboratorium Zagrożeń Pyłowo-Gazowych i Klimatycznych - KGHM Cuprum," *KGHM Cuprum*, 2018. https://kghmcuprum.com/o-nas/zaklady-badawcze/laboratorium-zagrozen-pylowo-gazowych-i-klimatycznych-nl-3/ (accessed Jan. 12, 2021).

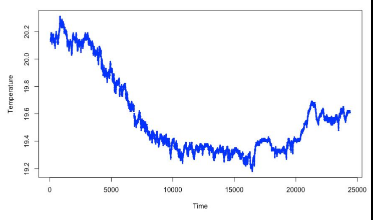	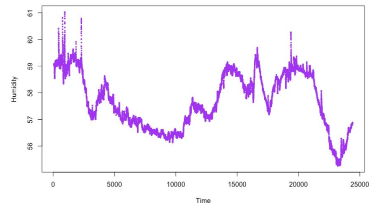	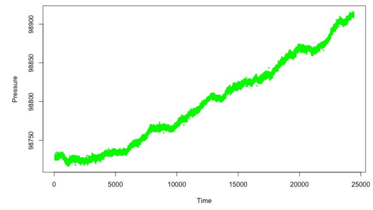
figure 76. - temperature graph	figure 77. - humidity graph	figure 78. - pressure graph

  - the same test was repeated in an external environment on the roof
- pressure in the pumping unit using a Honeywell pressure sensor connected via SPI line.
  - with the same frequency as BME280
  - in the preliminary test we changed pressure manually using syringe
  - secondly it was tested together with a motor pump test described in 3.2.3.2
- location **-** weren’t executed yet.
- Sting System tests, ***--> PASSED, details described in 3……..***
- saving data to SD card tests: **-** weren’t executed yet.

divided into measurements tests (pressure, humidity, location), Sting System tests, saving data to SD card tests:

4.2.1. Measurement tests

- **Analogue pressure sensor test**: (described in 4.1.1 - Measurement tests, pressure sensor test)
- **Humidity sensor test**: will be tested in an airtight container where the humidity will be increased by the evaporating water. The measurement should be the same as on the reference sensor.
- **Location test**: the measurement from the GNSS system will be compared to that from a smartphone.

4.2.2. Sting System tests

The test consists of a mechanical system test and general endurance tests.

- -mechanical system Tests::
- -stepper motor with gear in terms of precision and speed of rotation
- -the servo will be checked together with the arm. The needle should hit the rubber opening of the test tube precisely without breaking
- -pumping system: tubing system, pump and tubes must be tight. In a closed system, it will be tested whether the appropriate pressure will be achieved (0.5 atm). Additionally, it will be measured whether this pressure is obtained in a timely manner.

4.2.3. Endurance tests

- **Drop resistance test**: OSACan will be attempting a crash test. Under normal conditions, when the parachute opens, no element, including the casing, should be damaged, especially important when yanked when the parachute is unfolded as well as when hitting the ground. Also, all internal components should not move, the electronics should work continuously. To test this, CanSat prototypes will be dropped from a height sufficient to achieve the descent speed (from a tower or drone). A fall test without a parachute is also planned, from a height such as to obtain a falling speed 2-3 times faster than assumed. Optionally, it is envisaged to add a 3-axis accelerometer to the electronics board (if within budget and weight constraints) to record any G-force.
- **Long-term G-force tests**: during rocket transport, G-force up to 20G may occur. In order to simulate such G-force, we plan to perform an experiment consisting in placing the satellite model on a carousel or string, introducing the satellite into rapid rotation. It is possible to achieve the required overload due to the centrifugal force.

G - gravitational acceleration
ω - angular velocity
R - string length
n - quantity of rotations
t - time of rotating

$$G = \omega^2 R$$
$$G = \frac{4\pi^2 n^2}{\Delta t^2} R$$

- **Shock resistance test**: CanSat will be put into a special shaker (AGH equipment). Ultimately, during long-term shocks (tests on the order of 1 hour), no element is to be damaged, slipped out or significantly moved.

4.2.4. SD card test:

will be tested for correctness of writing, storing and reading data (test program)

4.3. Tests of recovery system

details described in *3.5 Recovery system*

- **Parachute deployment test**: this will consist of mounting the parachute to a load equal to the weight of the CanSat, and then dropping it from ever greater heights. Initially, it will be thrown from buildings and hills. When tests at higher altitudes are required, a drone will be used to drop it, to which a specially designed CanSat detachment system will be connected. Ultimately, the parachute must fully open within the specified time. to make any possible amendments, the testing process will be recorded and analyzed on this basis.
- **Parachute test for various weather conditions**: parachute with the weight attached will be dropped during: rain and / or wind. The test result will be recognized as successful only if the parachute is fit for reuse
- **The flight path and its speed test**: The dummy-mass model during the fall will be recorded and then analized in *Tracker by Physlets* in terms of flight stability and falling speed. Additionally, the moment of opening the parachute from the analysis should be consistent with that of the accelerometer.

4.4. Communication system range tests

--> necessary to repeat after improvements, described in 3.3.6.3.4

4.5. Energy budget tests

The power supply system must guarantee the supply of the entire system for the duration of the mission, according to the recommendations, we expect that the battery will last for 8 hours of operation, but we divide this time into the following periods (modes):

1. from satellite activation to deployment (Basic Mission functionality enabled) - 4 hours
2. from deployment to landing (full functionality enabled: primary + secondary mission) - up to 10 minutes (down from 2,500 km by parachute)
3. From landing to being found (Basic Mission functionality with GPS data enabled) - up to 4 hours

In order to test whether the capacity of the selected type of battery that will be determined at a later stage - is appropriate, we will perform:

- measurement of current consumption by systems and components in modes 1,2, 3 and calculation of energy consumed
- checking the actual capacity of the battery by loading it with a simulated resistive receiver
- under normal conditions
- at low temperatures (the battery
- may lose its properties)

Maximum device operating length test under real conditions, covering all 3 modes

- we assume that the battery will be discharged to a maximum of 80%, and the voltage of cells connected in series will not drop below 5V.

4.6. Test equipment:

- reference sensors (pressure x2, humidity, temperature),
- phone - gps,
- recommended sensors inside the satellite (accelerometer, battery voltage)
- digital multimeter
- Power Supply

5. Project Planning

5.1. Time schedule

For the project schedule we plan to use the web Gantt tool https://app.teamgantt.com/ . The basic tasks were divided into a few week periods and planned, the effect is shown on figure 79. Main steps are:

- Ideation - finished
- Design - work-in-process
- Prototyping - work-in-process
- Tests (prototype) - to be defined (tbd) in details
- Construction (Run A) - tbd
- Test campaign (Run A) - tbd
- Construction (Run B) - tbd
- Test campaign (Run B) - tbd
- Competition - we hope to participate

Run A will be the first of our construction, probably with a set of mistakes. Run B means the second and final construction, improved after Run B. We plan to order the whole BOM twice to support both Run A and Run B. At the same time we plan to carry out activities related to:

Outreach programme:

figure 79.

5.2. Resource cost estimation

5.2.2. ***Budget***

Cansat:	Ground station:
● Probe 7.13 € ● Swivel- 1.99 € ● canopy fabric - 9.83 € ● canopy lines- 3.70 € ● connectors: 0.48 € ● Temperature sensor - 0.33 € ● Pressure and atmospheric sensor - 8.85 € ● 28BYJ-48 stepper motor : 1.94 € ● motherboard - 38.19 € ● Servo Hitec HS-55 - micro - 12.91 € ● case - 1€ ● electric pump AJK-B03V1405C - 1.02 € ● GPS module - not selected yet sum: 87.37 € + the cost of a GPS module	● Antenna needs rebuilding , cost tbd

5.2.3. ***External support***

5.2.3.1. **Goals**

We plan to start our outreach program to get funds, access to equipment and laboratories and also professional technical support.

Our actions will contain following activities:

- Firstly ask for support in the circle of family, friends and their closest,
- Secondly we will try to reach sponsors conducting regular activity on different communication channels and social media (details described in next section: "Outreach programme")

Our goals are to realize following achievements:

- get funds 1000.00 €,
- get access to laboratories and equipments,
- find the experts in mechatronic to ask for review of our ideas.

We got in touch with following institution and hope to improve our relation:

- AGH University of Science and Technology (al. Mickiewicza 30, 30-059 Krakow, Poland)
- Fideltronik Poland Sp. z o.o., Engineering Centre (ul. Cystersów 19, 31-553 Kraków, Poland)

5.2.3.2. **Accomplishments**

- We got 66 EUR from closest relatives for a good start.
- We got 220 EUR from our school Principal
- Our first sponsor we reached is Fitech Sp. z o.o. (Grupa Fideltronik), ul. Kościelna 5, 34-200 Sucha Beskidzka. They declared significant financial support (amount is confidential, as was requested by sponsor)
- We are in touch with another sponsor: CanPack, 31-358 Kraków, ul. Jasnogórska 1
- We have declared access to Chromatograph from **AGH University of Science and Technology** (al. Mickiewicza 30, 30-059 Krakow, Poland).

5.2.3.3. **Outreach programme**

We plan to public project status, progress and news at least twice per month.

At present, we have established the website and took care of the logo (presented on the document header)

We plan the promotional activities at the school, due to pandemic limitations, remotely.

Our outreach actions performed and media coverage are shown in the picture below (figure 80.).

We started a page on Facebook on which we uploaded a few posts connected to the progress of our cansat.

https://www.facebook.com/osacan.eu

We also built and set up a website at https://osacan.eu/

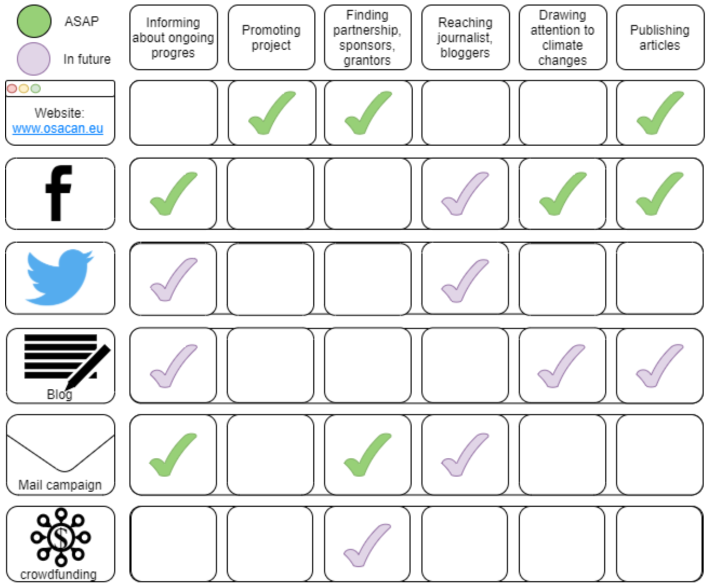

figure 80.

6. CanSat characteristics

Estimated characteristics	Figure
Estimated height of the CanSat (main space) and its parachute (additional space)	114.4 [mm] - main space 40[mm] - additional space
Diameter of the CanSat	65.6 [mm]
Mass of the CanSat	tbd
Estimated descent rate	6 [m/s]
Radio transmitter model and frequency band	SX1278 RA-02 LoRa 433MHz
Estimated time on battery (primary mission)	5 [h]
Cost of the CanSat	87.37 €