CANSAT

Team Air Thief

Created by Air Thief Team

Consisting of Maria Matuszewska, Aleksy Chwedczuk, Henryk Nowacki, Tymon Augustyniak, Mateusz Mazurczak

Supervised by Dr. Jakub Bochiński

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Final Design Review

Changelog

- All CanSat functional and environmental tests have been conducted and were successful. **System is ready for launch.** For more information see Test Campaign.
- All structures have been completed and tested in harsh conditions. Test passed. ✓
- All satellite components were tested both as separate devices and as an assembled CanSat. The tests confirm the ability of the vehicle to survive harsh conditions: temperatures below zero, high humidity and ground impact. The vehicle functioned flawlessly for the duration of the 7-hour test. ✓
- The 6V converter has been removed entirely. More information in section Secondary mission devices
- Ground equipment includes a laminar chamber to handle the collected microorganisms.
- One of the filters has been changed from F7 to F9. More information in section Current final method
- The relay has been changed to a N-Mosfet due to its size. More information in section Secondary mission devices
- We have developed a web-based User Interface and Python3 Flask middle-end to present in a human-readable way the data received from the satellite via comms to facilitate the interpretation of the state of the CanSat. Timestamps are now local.
- The RTC (Real-time clock) module on the POCU will not be used during the mission and, as such, will be unpowered and nonfunctional. That is because it is now obsolete but is part of the FeatherWing datalogger. The mass is negligible.
- The design of our document is augmented to be easier to read.

Abstract

The project consists of a primary and a secondary mission. The primary mission consists of measuring the temperature and pressure throughout the whole flight of the satellite. Thus, the CanSat is equipped with an additional sensor specified to take those measurements. The data obtained should be sent to the ground station every second to allow the team to analyze the information given and plot graphs that should facilitate the execution and organization of the secondary mission. It is important to notice that measuring both temperature and pressure, will allow us to identify the position of our satellite, as these two factors can be modelled to provide the height at which the system is placed at some point in the given time.

The secondary mission is designed to investigate microorganisms, at a designated height above sea level. To pursue this experiment, the satellite has been equipped with four filters enclosed in two sterile chambers, allowing the separation of the desired sample from any other contaminants. The air will be pushed through the sterile chamber described above with the use of a pump to increase the possibility of collecting the samples only at the desired height. The collected data will be specially prepared and transported to our on-site laboratory, where we will conduct various tests to ensure the viability of the secondary mission and possibly prove and analyze the existence of life in the lower troposphere. **Validity of this approach has already been confirmed by the team using experimental methods in the laboratory and on ground level. The next step is to launch the same equipment high into the atmosphere to sample microbial life there.**

Why is our mission worth pursuing?

Our idea appeared as an answer to the recently published studies of the possibility of microbes being present in the atmospheres of Mars[1] and Venus[2]. We would like to carry out a challenging method of exploration of extraterrestrial life: an atmospheric sample return mission. This mission, as a technology demonstrator, would test the viability of our new versatile method that could be easily adapted to numerous conditions present on multiple celestial bodies throughout the Solar System. Additionally, the results of our experiment, apart from promoting the idea that life is possible on other planets than Earth, could help understand better the life cycle of bacteria and fungi also here on Earth. Painting a big picture of growth and needs of simple microbiological organisms could help us understand how to fight the harmful ones and how to effectively make use of the neutral or beneficial organisms. Atmospheric sample studies of microorganisms are also a quickly growing field of microbiology, which is not particularly well-developed in Poland.

The ability to conduct air sampling studies upwards from a kilometer above a certain site is also particularly useful as a method of monitoring the spread of biocontaminants in the environment, even here on Earth. This is especially important around sites such as landfills, etc. According to various studies, the range of bioaerosol emission is considerable and may reach 1000 m – 1200 m from the border of such a site (Kaźmierczuk & Bojanowicz-Bablok 2014). The air sampling system we are developing can be used with a recovery system of choice (e.g., drone) to conduct just such studies. What is most exciting about our mission is the fact that collecting samples exhibits so much about the unknown - it gives us insight in the area that has not been studied much in the past apparently due to the lack of impact it would have on the growth of humanity. It is all doable and extremely exciting, and while it will be a considerable challenge, that is exactly what fuels our love and admiration for learning. Through this expedition we want to clearly state that no matter the conditions you are working in (like the pandemic we are currently in) there is always the possibility to contribute positively to the world.

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[1] Evidence that liquid water flows on Mars.
[2] Phosphine gas in the cloud decks of Venus.

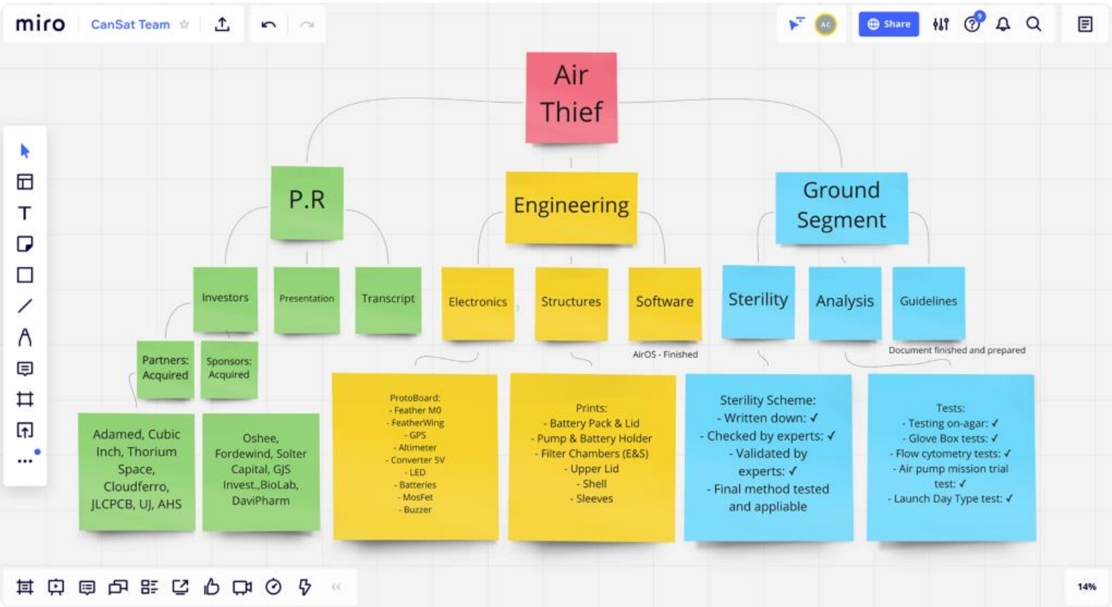
Introduction

Team organization and roles

Air Thief consists of 5 members apart from our supervisor:

- The Team Leader and main mechanical engineer is Aleksy Chwedczuk. For his final exams he takes physics, mathematics, and further mathematics. He is a pro designer and telescope constructor[3]. He, as well as the whole team, is mesmerized by the night sky.
- Air Thief's Vice-Leader and Sales Representative is Tymon Augustyniak. For his final exams he chose physics, economics, mathematics, and further mathematics. He is an excellent writer and is amazed by the world's unknowns. He designs and builds his own computers. His passion for drawing and sketching is extremely helpful for the project.
- Our electronics engineer is Henryk Nowacki. For his A-levels he is taking physics, mathematics, and geography. His understanding of various, complex electrical systems designing is outstanding. He is also interested in building and prototyping planes and gliders.
- The team's programmer is Mateusz Mazurczak. He studies biology, chemistry, mathematics, and further mathematics. Apart from programming he is fascinated by viruses and microbiology in general, which is quite helpful in carrying out the mission.
- The team's Biology Expert is Maria Matuszewska. She studies biology, chemistry, mathematics, and physics. She is also deeply passionate about astronomy and spaceflights. In addition, she is a quick learner which is advantageous.

The Air Thief team is supervised by Dr Jakub Bochiński – an excellent astronomer, designer, and a constructor of robotic telescopes. Our CanSat's mission is an intricate process which is time-consuming. Each of our team members dedicates at least 4 hours weekly for the project during our planned meetings. Apart from that all the members work on their own around 25 hours in a week not including lessons like physics, mathematics or programming that are helpful when designing a CanSat.



Miro Board

This is our Mind Map on Miro

For better effectiveness of the work schedule, the team was divided into smaller sub-teams that are responsible for specific tasks such as electronics, 3D-modelling, marketing, software, and design group that are all supervised by the Team Leader. In addition to that, a lot of the planning of our mission occurs on the Miro app, where we implement most of our ideas and divide work between each other. We decided to take inspiration from ECSS set of standards for space project management (i.e., ECSS-M-ST-10C) to have a firmer grasp of what we want to achieve in our mission, and how we want to accomplish it. The use of the ECSS standards (e.g., product tree, WBS, etc.) is essential, because thanks to its established norms it makes our project clear and available for future development.

Mission objectives

Our mission consists of two major steps: the first one is imposed by the Competition. This mission consists of measuring air pressure and temperature over the length of the whole flight. The CanSat will also have a backup mode, which is based on GPS altitude readings. The CanSat is programmed specifically to measure the desired variables every second to leave the team with as much data as possible. The parameters acquired should be transmitted as telemetry to the ground station to be further analysed. Graphs that would be useful in investigating the secondary mission's outcomes should be plotted. The secondary mission is our team's original idea; this is the notion of collecting an air sample from the designated altitude to then later measure and detect the number of bacteria and fungi present in our sample. The CanSat will consist of the main part, similar in all satellites, and additional sterile chambers equipped with 4 filters that are specially designed to separate microorganisms from any other contaminants.

[3] Website presenting a DIY telescope created by Aleksy Chwedczuk.

Moreover, our satellite was supposed to be equipped with a hygrometer, since the level of humidity might affect the filtration mechanism. The amount of water molecules present can decrease the permeability of the filters affecting the amount of data collected, however we have conducted a humidity test to ensure that during a short period of sampling, it has little to no impact as the filters used operate on a small surface area. Therefore, we have abandoned the idea of adding a hygrometer on board of our satellite as its absence should have no effect on the microbial collection. To analyze the collected data, we will be using flow cytometry[4].

The equipment needed to conduct this analysis has been provided to us by Adamed[5]. Prior to running this investigation, we will prepare our data accordingly to generally accepted protocols. Our team has contacted dr. Rafał Mostowy from Microbial Genomics Group, specialist Piotr Rózga and mgr. Edyta Żyła from the Jagiellonian University of Cracow – Faculty of biochemistry, biophysics, and biotechnology, and has gotten an official approval of the methods[6] of analysis used in our project.

The crucial part of our secondary mission is to perform numerous tests of the filtration mechanism and sample collection system prior to launching the satellite. That is to better visualize the results we should be expecting during the final analysis, to investigate the sterility level of the systems as well as the level of external contamination to be found. Additionally, the team will calibrate the cytometer appropriately prior to performing the qualitative and quantitative sample analysis based on the results of the tests obtained. Furthermore, during our control test we investigated the presence of duplexes as well as the microbes auto fluorescence which could affect the results of flow cytometric analysis.

An additional step will be required whilst investigating the samples – it is to use a fluorescence label specific for bacteria. The prepared samples should be assembled in a test tube with a bacteria specific dye to eliminate any errors that could occur due to unsterile handling of data. Each dye will re-emit light upon light excitation resulting in diverse colours, thus making the obtained results easier to read. We estimate that the results will be ready within 20 hours from the beginning of the experiment. On site, a glove box proof of the existence of bacteria will be conducted which is further explained in part Test Campaign: Secondary Mission Test. More thorough analysis of the probe will be conducted using a flow cytometer (available in the Adamed laboratory) after the end of the launch campaign.

Basic system objective

Element	Requirement	Mission type
Temperature sensor	Measuring temperature	Primary
Pressure sensor	Measuring pressure	Primary
Air pump	Pumping large amounts of air into the sterile chamber equipped with two filters	Secondary
Air filters	Separating microorganisms and contaminants	Secondary
Electronics	-	Primary and Secondary
Software	Programmed to take the primary measurements every 1 s. Programmed to start filtering the air at release of the satellite and closing the system after over 20% of the altitude magnitude covered by the satellite during the fall. Encoding & transmitting the collected information.	Primary and Secondary
GPS	Finding and relaying the coordinates of the satellite to the ground station	Primary and Secondary
YAGI Receiving antenna	Will enable receiving sent from the CanSat with important data from the sensors and the location from GPS	Primary and Secondary
Beeper	Will transmit audible 80 dB beeps to help find it.	Primary and Secondary
Ground station	Receiving the collected information, plotting graphs	Primary and Secondary

Primary mission: When will the launch be considered successful?

- The collected data parameters should be transmitted to the ground station at least every second.
- We should collect enough data to plot a graph.

Secondary mission: When will the launch be considered successful?

- The system should pump not less than 3 liters of air. We will perform post-landing pump health check.
- We should be able to collect any number of microorganisms considering the permeability of the filters.
- The temperature-regulating system should start cooling the satellite as soon as the temperature exceeds 23°C
- The CanSat's temperature-regulating system should maintain a stable temperature between 14-23 °C
- The pumping system should stop working before reaching one kilometer above Earth.
- The chamber should be tightly sealed, and the parachute should provide a safe landing so that the chamber does not burst when hitting the ground.

Secondary Mission: Glove box & Ground equipment part

- We should prepare the data prior to flow cytometry analysis.
- We should be able to successfully perform the cytometric analysis.
- We should procure proof of sterility of the equipment and show that inside the chamber no bacteria will be present by inserting a sterile agar plate inside.
- We should be able to successfully culture or detect microbes from our atmospheric sample to prove their existence.

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[4] Flow Cytometry protocols, Direct flow cytometry protocol, Cell surface staining, Filtering protocol
[5] Letter of Intent from Adamed. **We have already secured a professional sterile chamber for use during the mission.**
[6] Letter of Intent from a representative of Jagielloński University, mgr. Edyta Żyła

How will our secondary mission contribute?

Exploring the high-in-potential field might promote further investigations regarding extraterrestrial life similarly to the previous research on Venus and Mars. Our mission is intended to be a technology demonstrator for future space missions. Recently, scientists were able to prove that in Venus' atmosphere a chemical – Phosphine – was present.

Despite recent estimates from ALMA suggesting a 7x overreporting in the original paper, scientists consider microbes as a possible factor causing the presence of PH_3. To date, research conducted on this matter was only thanks to the use of telescopes, however it is already said that future space missions will be conducted to scrutinize this subject more.

Our mission would fall perfectly as an example of such a mission since we are analyzing microbes in the atmosphere as well. Some variables would have to be adjusted; however, this represents a possible solution for tests that will be conducted in Venus' atmosphere soon. Our project presents a new method of exploration of extraterrestrial life that could be easily adapted in the search for other variables in the atmosphere of a planet. We hope that our satellite will create a new trend in the scientific world and will be further continued by others.

Examining bacteria and fungi at a certain height might promote a more in-depth research regarding the growth and life cycles of such microbes. The knowledge about the microbes' life can have a big impact on the modernization of medicine. There are diverse research covering the topic of bacterial and fungi community in the troposphere i.e., **Airborne Bacteria in Earth's Lower Stratosphere**, **Free tropospheric transport of microorganisms**.

Microorganisms and viruses are ubiquitous on the surface of Earth. This is likely due to high-velocity, high-altitude wind currents in the upper atmosphere that evenly spread biological particulate matter. There are roughly 10^{30} microorganisms and 10^{31} viral particles on our planet. This field of research is undervalued and yet holds great potential for the development of modern medicine and search for extraterrestrial life – we have contacted a polish microbiologist and bioinformatician Dr. Rafał Mostowy and he believes that this proposed research is plausible and would hold value for the scientific community. It is a rather complex design and collaborating with companies is undeniable resulting in more future - related experience for the Air Thief's members.

CanSat description

Mission overview

We have designed and built a CanSat satellite that will be launched 2 km above the ground or dropped from around 500 m by a drone, depending on this year's regulations. The CanSat will descend at a speed of around 7 ms^{-1}. We will be using a parachute to slow down the fall of our CanSat to prevent it from falling out of the competition's set boundary, as well as to prevent it from breaking upon impact. To accomplish the primary mission, we will be using a pressure and temperature sensor to measure the temperature and pressure at the altitude we reach.

Our secondary mission's goal is to collect, filter through, and then determine if microorganisms are present in our sample. To do this, we will use an air pump to collect an air sample during the flight of the satellite. This air will then be pumped into a sterile container, which will be filtered through four air filters so that we can separate the bacteria and fungi from other unwanted particles i.e., dust. Although hard, we have developed and designed techniques which allow us to get the sample completely sterile.

After we retrieve the satellite, we are planning on detecting the microbes using flow cytometry. We also considered using the PCR method and the use of a fluorescent microscope, however, this proved insufficient and too costly. We also made sure that the mission concept is compatible both with Polish and European CanSat competition guidelines.

As this year the European final will take place without students on site, and SD cards with recorded data will be mailed back, we reached out to ESA to verify if the same could be done with a sterile sample container we plan to include in our mission. The reply was positive[7], and a special exception will be made for us, if we get to the finals, due to great scientific merit of the proposed mission.

Mechanical and structural design

Our main core of the satellite was designed using AutoCAD software – Fusion 360. This program allowed us to create a precise 3D-model that fits all components in the most efficient way regarding the space covered. We have decided to collaborate with Cubic Inch[8] to use their expertise and technologically advanced tools to print our main core of the satellite. This company uses Multi Jet Fusion technology provided by HP. Our final mechanical structure is now finished. It is composed of various substructures that all fit inside a cylinder in the size of a can. Our CanSat consists of:

- **The Outer Shell:** Its main objective is to be a protective layer that will absorb the impact while landing. Our team's components inside the satellite must be protected from any harm throughout the length of the flight, therefore the outer shell was designed as a strong protective shield. We have decided to create it on a base of an open cylinder on both ends, its dimensions are: 110 mm of height, 66mm of diameter.
  As mentioned before this part must be of great strength, therefore we have decided to use a 3mm width on the casing to ensure that nothing will happen to the inside body. On top of that, while printing we decided to up the number of layers and increase the infill to add additional strength to the structure. In the outer shell, there is an opening slot to ease the retrieval of the SD card, and two top and bottom holes, allowing us to add our top and bottom lid.

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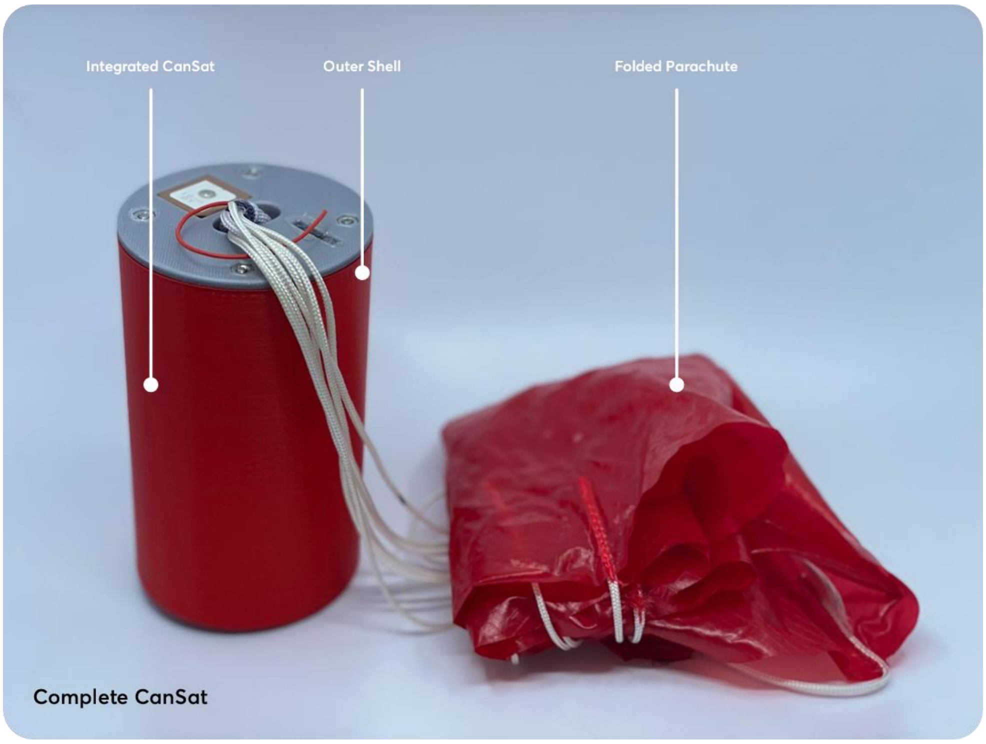
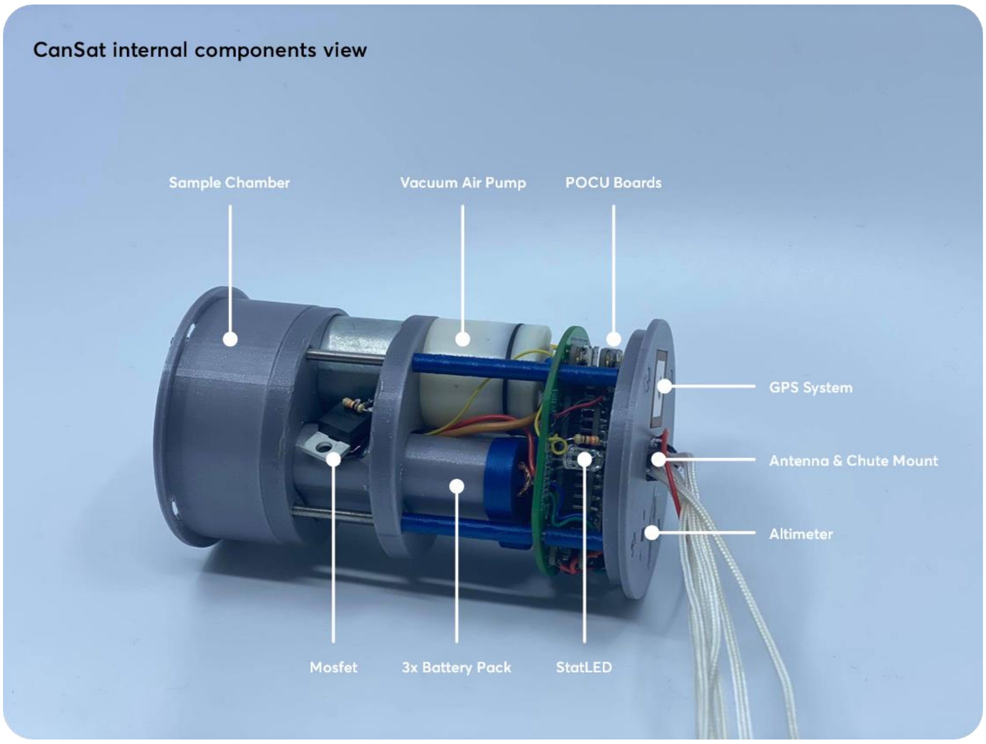
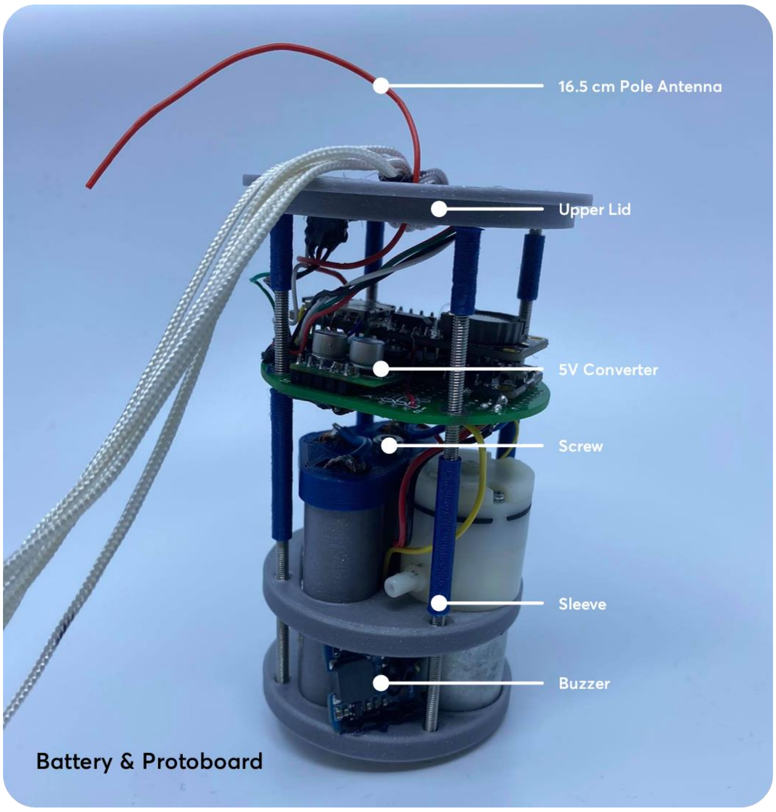
[7] **Screenshot** of mail from ESA.
[8] **Letter of Intent** from Cubic Inch.



- **The Upper Lid:** A crucial part of the mission as it holds most of our components in place. We have placed slots for the GPS, the sensor and created a parachute mounting part. As our components must not fall out of the structure throughout the duration of the mission, we use various ways of holding them into one place.
  1. The GPS has been mounted in a tight fit slot that fits the GPS size perfectly, on top of that we have decided to ensure its safety by adding a layer of ethylene-vinyl acetate (EVA) copolymers (commonly used in hot-melt adhesives) by glue gunning the component into its slot.
  2. When it comes to the sensor, it must have been placed with access to the outside of the CanSat as it must obtain measurements of temperature and pressure at the given altitude, therefore we have placed it on the upper lid, with a special hole for the measuring part. Additionally, we fixed it to the upper lid with the help of tiny rods and two hex nuts. Similarly, to the GPS, we have also glued our component into the structure. Finally, the upper lid is the place where we mount our parachute, to do that we have cut out two semi-circles separated with a bridge through which the parachute's ropes pass through. As the parachute passes through the semicircles, it loops back and is later passed through the bottom of the lid creating a node.
  3. The infill on the upper lid was adjusted to rectangular so that the LED can be easily visible through it. This was done to fulfill the ESA requirement for an on-board status ON/OFF, this will help us to minimize the risk of sending a turned off CanSat on the rocket. Color codes for diode are available in **Software Design**, and will be shared with Recovery Squad as part of handling procedures.



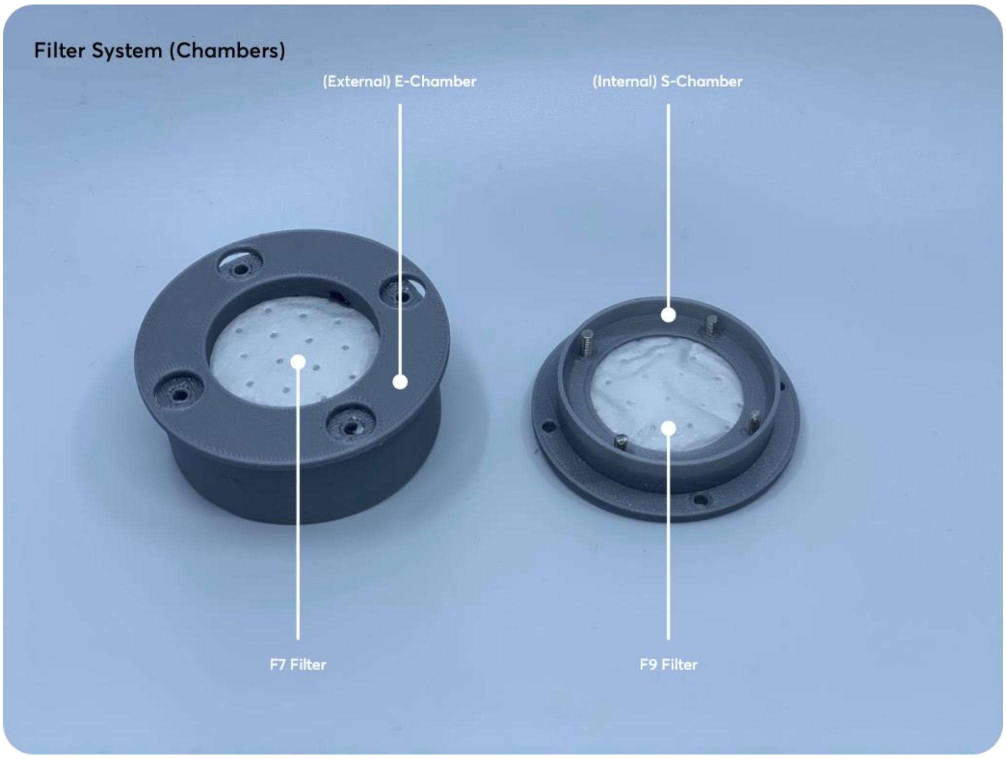
- **The Battery Pack and Pump Holder:** Our satellite is powered by three batteries which must fit into one holder that must not take too much space. To save space and allow us to expand our collecting chambers, we have created a structure that places our batteries and pump in the same holder.
    1. The battery pack was created with three slots, one for each battery. We have also created tiny rectangular holes on both the top and bottom side of the holder to create tight electrical contacts with the help of cables, which were later soldered. On top of that, to make sure that the batteries are unable to lose contact in flight or during the acceleration while in launch, we added a screw in the battery holder lid which makes sure that the top lid of the pack stays in place.
    2. The pump is placed right next to the battery pack on two circular holders into which they are inserted. To pump the air through the filters we have added a tube that goes from the inlet of our tube to the outer filter chamber. This means airflow first passes through the sampling array and only then thorough the pump. This design ensures any potential contaminants in the pump do not enter the main section of the filtration system.



Battery & Protoboard

- **Protoboard and electrical components:** We have placed all other electrical components, such as the POCU, the datalogger, the 5V converter and the LED onto our Protoboard (from CanSatKit) by soldering the components. In order not to damage our board and the components on it we have added sleeves throughout the whole CanSat structure to minimize collisions between different substructures. The sleeves will absorb part of the force or impulse and will prevent unwanted collision between the battery pack container and the Protoboard.
- **The Filter Chambers:** As we need two filter chambers, one within the other, we have decided to use the external one as our bottom lid of the CanSat. The structure consists of two parts, one fitting inside the other as a small package.
    1. To maintain the filters in place, we have designed rings that are to be put between the filters and between consequent parts. On top of that we reinforce the holders of the filters (rings) with a layer of glue to keep it in place.
    2. The filter chambers are also equipped with sleeves to ensure that the filters are not touching each other. For sterility purposes, both chambers are surrounded by a thin layer of Aluminum or Mylar foil to ensure the protection of microorganisms inside the inner chamber during the irradiation process.

Filter System (Chambers)



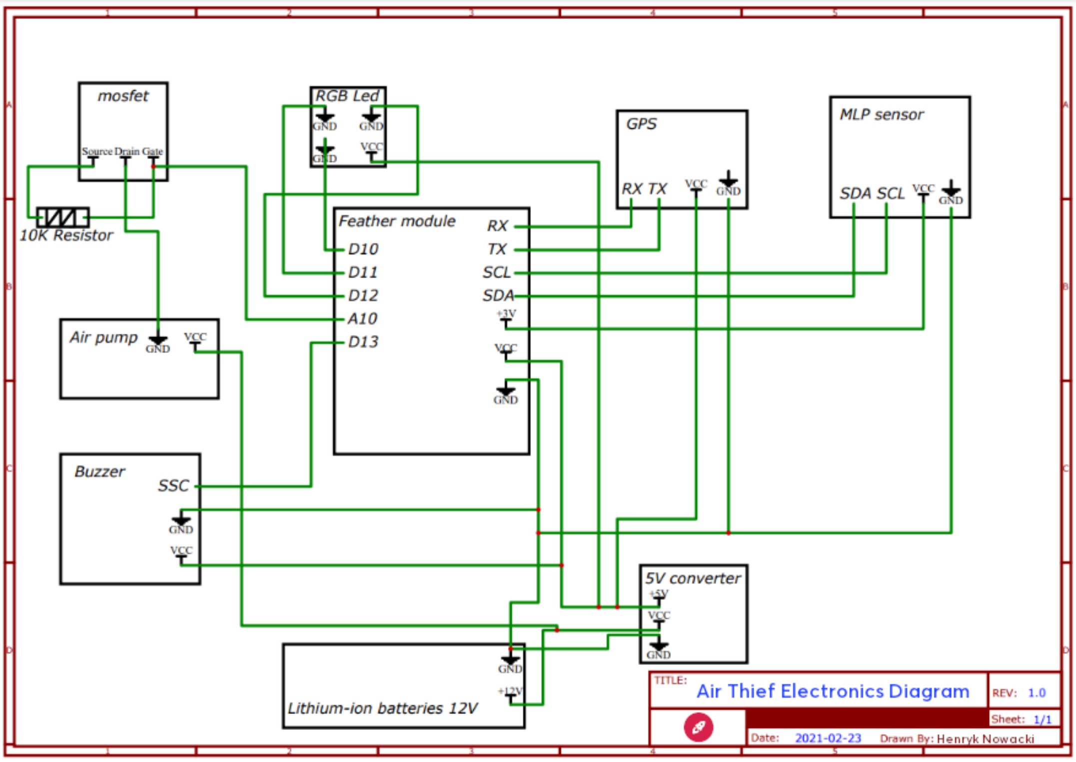
The whole CanSat is integrated together in a plug-in method, which means all components are plug-in compartments which are easy to retract if needed. Our satellite is integrated with the help of four 3 mm Ø rods that hold the satellite together, these are assured not to move with a system of hex nuts. All substructures of the satellite contain holes in their faces to pass the rods through them, which provides us with great strength and stability of the system. On top of that, we maintain distances between structures with the help of sleeves, which even more allow us to make sure none of our components are moving.

Electrical design

General Architecture

Our CanSat is made up of a couple specific components, each has its one role in the mission. The components chosen here are finalized by the Final Design Review. The main controller board is the brain of the operation; it is used for measuring the primary and controlling the secondary mission. The processor used will be a Feather M0 module that involves an ARM Cortex M0 microcontroller known from Arduino Zero with an integrated radio module (LoRa) for communication purposes. The core of our primary mission will be an MPL temperature and pressure sensor, which will record the data every second to give us an accurate depiction of the altitude of the CanSat. This will be calculated using the hypsometric formula, more information in Test Campaign: Primary mission tests. Also check out the YouTube video for a summary.

This sensor suits our mission well, because of its high level of accuracy. The core of our secondary mission will be the NW Air Pump which will be used to push air from a high altitude through a series of filters. This air pump, after testing showed that the amount of air that it can pump is sufficient for finding small organisms and bacteria. Furthermore, the power converter that was initially used for powering the pump was not strong enough and it needed to potentially be changed for a one that could supply more power. To power the NW Air Pump with 12 V and 500 mA the pump will be directly connected to the batteries which can supply more power, also a step-down converter (**D24V22F5**) will be used to power the main controller with 5 V and 700 mA. The converter powering the pump was removed after testing due to the current limit being reached (500 mA) and the motor not reaching its highest power possible. To power the CanSat a lithium-ion 750 mAh 3x batteries are used and the voltage is stepped down for the other components. To turn on the pump a Mosfet is used for safety; in case of a short in the motor the motherboard will not be damaged. It is particularly important for our secondary mission that the CanSat will be found due to the physical sample that we need to analyze in a lab; a GPS module is used to determine the coordinates of the CanSat, and these will be sent to the ground station and superimposed on Satellite Imagery from MapBox©. To help with finding the CanSat after landing an 80dB buzzer is used, if the CanSat is hard to find visibly it can be also found using sound.



Air Thief Electronics Diagram

Shows the intricate inner workings of our CanSat designed by Heniek. :)

Primary mission devices

The primary mission is a part of the criteria that is obligatory for each CanSat; this is the task of recording pressure and temperature. We are using an MLP pressure and temperature sensor to measure the parameters with a set interval of one second, and the measurement & software will be processed by an ARM Cortex M0 microcontroller on a feather module. The data is transmitted through a radio connection made between the CanSat and the ground station. It is important to realize that the sensor needs to be placed in the correct spot for the pressure and temperature measurements to be correct, due to the heat emission from the electronics it needs to be isolated and a certain amount of air flow needs to be available for the sensor to reliably measure the temperature across the altitude. Therefore, the sensor needs to have line of sight out of the CanSat and have separation between the other electronics for example Styrofoam or air which are great insulators.

Secondary mission devices

The secondary mission will be conducted using almost all electrical components. The electric air pump was connected to a power converter (through a relay) that drops the voltage from 11.1V to 6V due to the requirements of the motor, however since the FDR report we have decided to connect the pump directly to the batteries so the pump can work harder to push more air through the filters to collect as much bacteria as possible, also we have changed from a relay to a Mosfet due to its more compact size this helped us save space which was very precious. The Feather controller controls the air pump using a Mosfet that will protect the motherboard in case of a short in the motor.

The main controller will be powered by a converter that steps down the voltage from 12V to 5V due to the Feather's requirements, a 3V converter build into the Feather module will supply power to the MLP sensor that will measure the altitude at which the CanSat now is in time, this will be used to turn off the air pump at a certain height. There are no real parameters or measurements made by the electronics; the focus of the secondary mission will be to collect a sample of bacteria and small organisms and bring it to the ground for testing.

The changes implemented to the electrical components of the secondary mission were changing out the relay for a Mosfet due to it being more compact as we realized in the design stage space in our CanSat is valuable due to the pump and the filters taking up a lot of space and not using a 6V converter in testing we realized that the pump only needs to work for 2 minutes therefore we can go over the recommended voltage to increase the airflow of the pump. In testing no problems were observed. ✓

Power supply

The power supply is 3 lithium-ion batteries in series to step up the voltage to 12.6 V → 11.1 V and a total capacity of 750mAh [as it is connection in series]. Each of the batteries will have a voltage of 3.7 V and a capacity of 750 mAh. From the calculations given the lifespan of our CanSat would reach almost 7.5 hours, it can withstand the long waiting time for launch and the recovery of the satellite. Assuming worst case scenario 2 h of waiting for launch, we would have 5.6 hours to find our CanSat. We have exceeded that working time in the Final Trial. ✓

Battery capacity: 750 mAh

Calculations: $E = Q \times V \div 1000 \rightarrow 12.6\ \text{V} \times 750\ \text{mAh} \div 1000 = 9.45\ \text{Wh}$

Battery capacity is thus: 9.45 Wh

Calculations example: $A \times V \times T = W \times h \rightarrow 5\ \text{V} \times 0.04\ \text{A} \times (1 \div 60) = 0.004\ \text{Wh} \therefore T = W \times h \div (V \times A) \rightarrow 9.122\ \text{Wh} \div (0.19\ \text{A} \times 5\ \text{V}) = 7\ \text{h}$

We thus get: 7 h battery life for 5 V Converter component.

Component	Consumption during secondary mission	Consumption During flight	Power during recovery of the satellite	Power in W Consumption during pre-laumch & post-launch ground phases
Air pump	0.148 Wh	0	0	0
Converter 5V 1A	1/300 Wh	0.018 Wh	0.04 A x 5 V = 0.2 W	0.04 A x 5 V = 0.2 W
MPL sensor	-	-	-	-
Mosfet	0	0	0	0
buzzer	0	0	0.095 A x 5 V = 0.475 W	0
RGB Diode	0	0	0	0.025 A x 5 V = 0.125 W
Feather + LoRa	0.012 Wh	0.055 Wh	0.125 A x 5 V = 0.625 W	0.125 A x 5 V = 0.625 W
GPS	0.04 Wh	0.022 Wh	0	0
Total power			1.3 W	0.955 W
Power Consumption	0.233 Wh	0.095 Wh	9.122 Wh ÷ 1.3 W = 7 h	9.122 Wh ÷ 0.955 W = 9.6 h
Work duration	60 sec	5 min 21 sec	7 h	9.6 h

Communication system

Our communication system is one-directional, as there is no need to send any commands since the vehicle is autonomous. Because the LoRa can transmit circa 20.4 characters every second, we have about 19 bytes to work with every transmission. Thus, GPS coordinates are sent in two chunks; Lat or Lon, meaning we get complete GPS lock every 2 seconds (see diagram below).

AirOS Message Example

Total: 20 chars. Unit length on diagram corresponds to1 char. Uses arbitrary encoding scheme, GPS data is sent in 2 steps. X/Y Coord selects stream, 8 chars of GPS coordinate shortened for diagram simplicity.

Our communications array is composed of a receiving Radiora YAGI 270 antenna on the Gstat and a 16.5 cm pole antenna on the Can. The transmitters are two RFM96 Feather M0 modules, one of which is connected to the Gstat Laptop via USB, the other one is integrated as part of the POCU. While selecting our antennas we got help from the company Thorium Space which is a partner of our mission. Representatives from the company: Seweryn Ścibior, Przemysław Radzik and Marcin Niewiarowski[9] provided great help and transmitted their knowledge to our team. Additionally, executives from Thorium Space suggested calculating the distance that the receiver can reach.

To make the calculations we used a site called the link budget calculator which gave us an approximate range of 15 km. During the comms range test, we found that in natural foliage conditions we reliably receive data at 3.3 km range. During the Final Trials, the CanSat operated for 5 h while transmitting with no greater than 1 second packet loss.

[9] Letter of Intent from Thorium.

Software design

Changes in FDR:

- The GPS will not use much power when in lock-acquisition mode, thus it can be always running. Because the POCU code is already extremely complex and redundancy is handled very well and there are backup chains, the GPS can simply run in also Standby mode and can be used as a backup when altimeter fails, however altimeter is still prioritized.
- There is now code for the ground stages post-sampling, which controls the Buzzer module that is responsible for signaling the presence of the CanSat to the search teams. Additionally, the diode color is green if the sample is acquired.
- There are now error modes and error handling, correctly implemented duty cycles and redundancy. The CanSat can work with any onboard failure including LoRa chip malfunction, SD card malfunction, Altimeter failure or GPS data corruption. The ground station stores all the transmissions for data recovery as a backup and the CanSat SD also does that. The sample can likely be collected even after complete nonessential instrument failure, if we have Altimeter data or GPS altitude lock.
- The programmer has realized just how wide the error margin provided by the battery capacity onboard the CanSat is, and thus there are no more redundant methods of higher power efficiency that could cause software problems. We no longer delay the POCU when in Standby mode, as there is no reason to: during the Final Trials, the CanSat was stuck on top of a tree for 4 h and total runtime was circa 6 h on battery. There were no problems observed whatsoever. Even the pump functioned after the entire test was conducted.

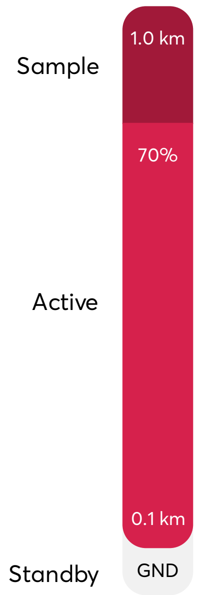
The primary onboard computing unit for our CanSat is an Adafruit M0 that supports Arduino. It is going to run all the programs necessary for the functioning of the CanSat and all onboard equipment and experiments. The flight plan for individual atmospheric Microbiome soundings can be fine-tuned, which is helpful. The data will be recorded to a MicroSD card, which will probably have such high storage capacity that it will be virtually infinite for our purposes (16 GB, around 30 PLN). The program has 3 main modes, controlled based on the current altitude measured by the temperature-pressure sensor. It also has 8 error modes that allow it to transmit data about ongoing problems with the CanSat, if any were to occur and enables better debugging and in-flight fixing. This means that if the SD were to fail, the OS continues to run correctly and simply will retry turning on the card every duty cycle (1 sec to 3 sec depending on type of error). This is going to ensure the correct data is always transmitted and minimum power is consumed. If the Adafruit sensor detects an anomalous result, the GPS reading is taken instead, if available and otherwise TELErr (telemetry error) is set. Our reasoning is that since the primary mission is so important, relying on it for data is quite sensible and when GPS has lock, the data there is amazingly precise.

RGB Diode Color Codes

AirOS debug & status color information

Modes that the OS will use:

- **Standby:** When the satellite is waiting on the launchpad and when it has landed post-experiment are similar flight conditions and require a similar approach. Thus, Standby mode is active when the CanSat elevation reported via the Adafruit array is less than 100 meters AGL. During this mode, the CanSat is running all the tests as normal. The buzzer is on while in this mode only if the Sampling flag has been set, meaning that the vessel has entered sampling altitude at least once. The buzzer pulses at an optimal frequency that can be heard from a large distance (2700 Hz). The diode shows error states: Blue if it is nominal (NULErr - no errors), Yellow if SD has issues (insert SD), Red if there are other errors, and Green if the Sampling flag is set. White on Standby signifies the CanSat is not exiting setup, suggesting continuity error for hardware such as sensors.
- **Active:** When the satellite is in flight, above 100 meters AGL, it constantly calculates its position and AGL via the GPS and Adafruit sensors. [This means sampling occurs at 1000 millis intervals.] These parameters are then transmitted to the ground station, so that a flight profile can be determined. If the altitude were to increase or decrease, Sampling or Standby modes would be engaged, respectively. Sampling mode is entered if we have the correct altitude (ALT_MIN) and if our sink rate is over 3 ms^{-1}. This is the least error-prone method that we have tested. Linear regression in-situ is too heavy and averages-over-time give launch latency. Precise data about Temperature and Pressure are written to the SD card only.
- **Sampling:** The pump powering the secondary experiment is enabled. It runs constantly until the CanSat goes below a set value of the mission altitude (0.5 km for a 2.5 km mission, for instance, this is configured pre-launch). That way the sample is collected from the correct experimental band that was being sampled (for instance one that has the lowest height of 0.5 km). During Sampling, the Active activities are also conducted. If the sampling altitude is passed and the CanSat begins heading down again, Active, and then finally Standby modes are engaged. When Sampling mode is entered for the first time [since last boot], a system-wide flag is set that is later used to determine whether the Buzzer should be turned on while in Standby and if the diode should be Green.



Flight States

Example flight states & vertical AGL.

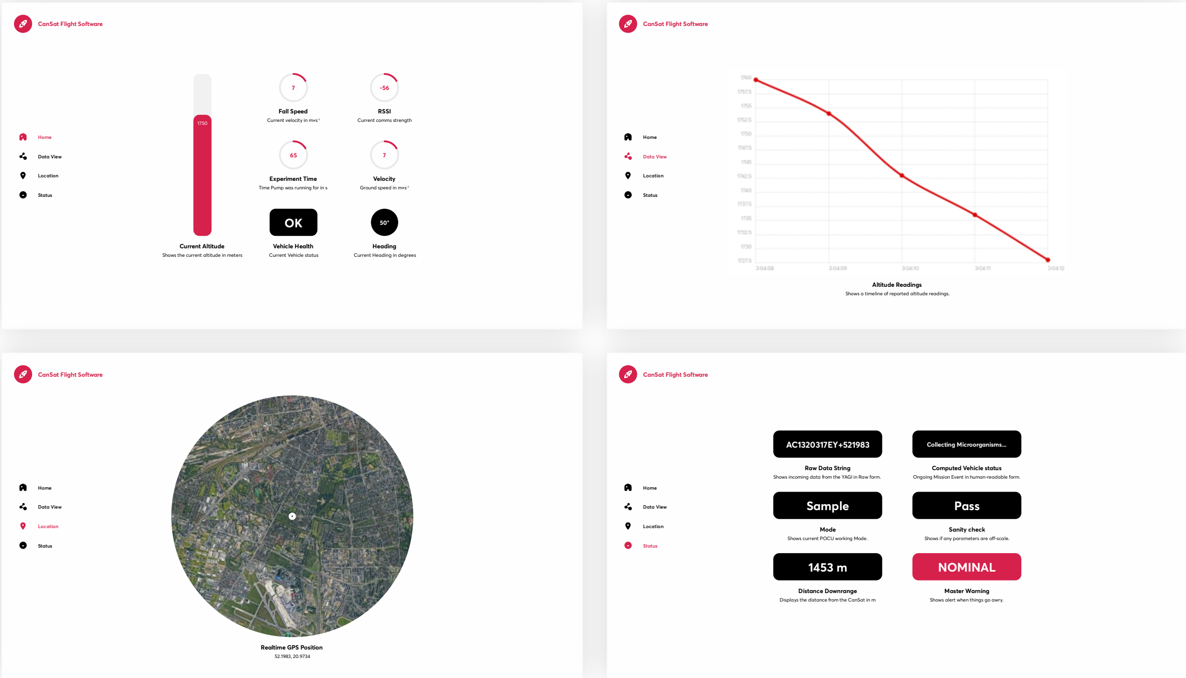
The data recorded via the MicroSD card, and the outgoing transmissions sent out via radio will have a specific format that will minimize their size, enabling higher efficiency. This format is gone over in detail in the Manual inside the AirOS file in our GIT and it is too long to talk over here but is summarized in the Communication System section. The ground station program has been coded in JS for the frontend, and in Python3 Flask for the backend. The ground station Feather M0 is coded in Arduino and connects via the USB. If You want detailed information about software design and UI usage, there are videos going over both[10] on our YouTube platform, and code is available on the GIT.

[10] Air Thief channel contains Flight Software UI design video and Software Design video.

User Interface

The user interface is based on Goost Design v4 guidelines that the programmers have developed over 3 years of designing easy to use UI for laboratory equipment and websites. The UI has certain rules: all data must be shown instantly when it arrives (no animations for raw data such as graphs and the central part of a circle display), other elements have 0.2 s long animations that reduce fatigue after prolonged use. The frontend of the CanSat Control Software is split into 4 screens. The Home screen shows general data such as altitude, vertical and horizontal velocity, inbound RSSI, Sample Time and current vehicle health and heading.

It is styled in the spirit of SpaceX mission UI, however with a different design. The Data View shows 60 seconds of historical altitude readings using chartist JS, the Location view uses MapBox to display a cached map detailing where the probe is now located (Błędów Desert is shown, of course). The Status view shows most important statuses and system variables for debug during mission flight, such as incoming YAGI raw string. If the CanSat is experiencing an error, a nice alert sound remix is played on loop to alert the team.



AirOS Flight Software UI

For image quality reasons, these are vector previews created in Adobe XD. The real software at work can be seen in the UI video.

Recovery system

The recovery system used with the CanSat is a simple parachute like the one in the demo CanSat. It has a hole in the middle of it to help with stabilization issues. The speed of the fall in our case is crucial due to the sample we are collecting in the clouds. It needs to be slow enough so that the CanSat has time to collect the sample, and fast enough so it does not fall too far from the launch site due to the increased risk of not being able to find it. From our calculations and tests, we are estimating that the speed will be around 6.5 ms^{-1}.

The parachute we decided on is the Rocket-model Klima GmbH 55cm Parachute - it is a parachute that fulfils all our requirements, as it is light and durable, made from a sturdy polymer, which ensures us that it will not tear and detach from the CanSat. Moreover, it has an adequate surface area, that being of 2376 cm^2. Furthermore, it is already colored red and so it will not need to be coated red afterwards - this will help us in finding and recovering the CanSat after its mission. The suspension lines that are connected to the parachute have a length of more than 16.5 cm to be able to connect the monopole antenna to them. The hole in the top of the parachute was calculated by us, same goes for the area of the parachute. The size of the parachute was calculated with the maximum weight and a falling speed of 6.5 ms^{-1} which gives us 1952 cm^2, which was calculated using the formula:

$$s = (2 \times m \times g) \div (v^2 \times c \times d)$$

Furthermore, another part of the recovery system is the audio and radio signals sent out by our CanSat after landing on the ground; it is important to note that the monopole antenna will be unable to send a signal if it lands in a certain position, therefore the most recent GPS coordinates sent by the satellite during the fall will be relied on for finding it. Also, the CanSat will beep at a constant rate with a sound about 80 dB, which can be heard for around 50 m if there are no obstructions. This sound will be produced by a buzzer. Moreover, the CanSat cover, and parachute will be in a bright color, such as red, to help with finding the satellite. To compensate for the area as well as a lack of a hole, we cut out a hole in the middle of our parachute with a 5.8 cm radius. This means that from the original parachute, which has a surface area of 2376 cm^2, we subtracted 105.68 cm^2, meaning the remaining area is 2270.32 cm^2. A hole in the middle means that during freefall, the CanSat will be more stable as air is flowing through the parachute. This may seem larger than the area that we have stated, but after the parachute drop tests we have conducted, we have deduced that this will be the best option for our CanSat, as it was the closest to achieving the speed of 6.5 $m \times s^{-1}$ in the conditions we conducted our tests in.

Ground support equipment

Changes in FDR: The POCU handles only basic data processing and categorizing. Additionally, there is more data saved to the SD as the write speed is over 10 times greater. The Ground station also backs up radio transmissions. ICAR (inflight CanSat added redundancy) pings are a liability and have been removed. Instead, we use optimal data compression in the radio transmissions that enable us to get all the data sent out every second without the need for complex async ICAR or other fancy methods of communication that break our duty cycle.

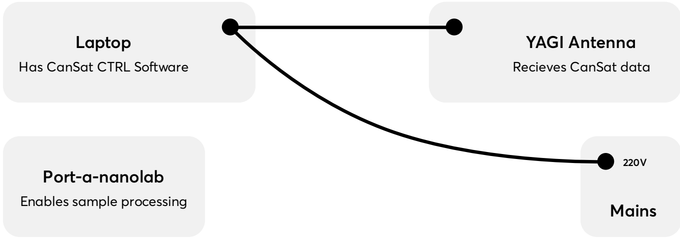


Diagram of Gstat
This is how the Groundstation will look.

The ground station is composed of these important things:

- Laptop running the backend and frontend for the communication with the satellite. The frontend handles the display of data on screen and the issuing of commands to the CanSat, and the backend communicates directly and writes to files, etc. The frontend is written in JS. The backend works in Python.
- A YAGI omnidirectional antenna that will send and receive data from the CanSat. It is connected to the Laptop.
- A power supply for the laptop and the antenna. This is a backup, as there is most likely mains power *in situ* at the launch site.
- A port-a-nanolab with materials applicable for the final selected procedure [if needed, consult detailed procedure report for fully written-out action plan etc.]:
    1. Lab safety equipment (hazmat-type suits, glasses, face masks, face shields, gloves)
    2. Flow cytometer in Adamed's Laboratory (letter of intent signed and link available below)
    3. Cytometry prep kit
    4. Professional glove box
    5. Self-adhesive foil
    6. Isorapid spray or ethanol
    7. Set of tools to open the chambers
    8. Tip or inoculating loop or cotton swabs
    9. UVC lamp
    10. Sterile swabs
    11. Sterile agar plates
    12. Transportation box
    13. Plastic zipper bags
    14. Standard amateur-grade light microscope & Immersion oil.
    15. Accurate scale and other basic measurement equipment

Sterility Scheme

Introduction

The sterility of the system is pivotal as any level of contamination is a potential threat to the reliability of the experiment. Collecting biological data shall be done with special care regarding keeping the system isolated from the environment. Extra steps should be carried out to prevent contamination and minimize the measurement error. The sterile chamber used in the experiment (either glove box or laminar chamber) should be built in a sterile environment.

The final components should be additionally irradiated with UVC light and cleaned with ethanol or "Isorapid" spray. The irradiation of the filters is especially vital to the experiment. No microbes should be found on their surface before opening the system for the measurement. Numerous designs have been taken into consideration to find the most efficient and suitable option for the experiment. A video going over all the most important information can be found here.

Sterility by UV-C Radiation
The lamp is sterilising the filters pre-flight.

Method 1: Doubled filters

One of the first alternatives to the design is to double the number of filters used during the procedure. The collecting chamber would consist of 4 filters: two of the F filters i.e., F7 and F9 and two of the Hepa 12 filters. The more permeable filters i.e., F7 and F9 would be placed at the inlet of the chamber. This should theoretically prevent extra contamination of the surface of the capsule. The F filters allow slightly bigger molecules that are still smaller than 10 μm pass through it. Examples include cement dust, fly ash, bacteria, and germs on host particles. The outermost layer of the F7 filter would be removed before sealing the data collector in a sterile matter and sending it to the analysis room. Decreasing the number of microbes from the surface of the chamber will significantly increase the reliability of the experiment.

On the other hand, doubling the Hepa 12 filter, which has a notably poorer permeability, would prevent ground-level microbes from entering the chamber from the outlet of the airway system, indicated by the placement of the pump, the activist of the system. Hepa 12 filters let through particles smaller than 1 µm. These filters will serve as a barrier that will not allow the collected microorganisms to escape further into the airflow system yet will allow the pump to push the air through the system.

The outermost filters (H12 and F7) are for additional support of the system. It should promote a more aseptic environment lacking at least 90% of external microbes. The exterior layers of filters should be directly attached to the outer cylinder with no crevices or bigger openings left. The area of connection should be tightly sealed.

Method 2: Thin separating wall

Another mechanism can be used to acquire the desired sterility. This option consists of a special mechanism that would close both the inlet and the outlet of the chamber by placing a thin wall over them. Either a miniature motor would rewind a string connected to the wall on a cylinder in a similar manner DNA is wrapped around histones, to move the wall and cover the inputs of the collection room. Covering the surface of the filters would partially increase the sterility of the system.

Although such a mechanism would fail to maintain a certain level of cleanliness throughout the transportation of the chamber to the laboratory. This problem could be solved by permanently attaching the wall to the capsule, therefore removing, and transferring both at the same time, only separating them when in the laboratory.

An alternative way of moving the wall is to use a resistor. Current would be supplied through the resistor, which would heat up, severing the wire. The wall that was primarily attached to the string would be released to cover the inputs of the chamber. This method of placing the separator might be inaccurate, which can lead to leakage and contamination of the sample.

Method 3: Pressure-regulating system

Additionally, the satellite can be equipped with a pressure regulating system. The idea is to create a significantly higher pressure on board of the satellite to the pressure outside in the interest of neutralizing the force exerted by the pressure outside on the inlet of the chamber. This would require programming the barometer to take measures at least every 0.1 seconds to maintain a stable gradient and to enable the creation of pressure on board of the satellite equal or higher to the external pressure. The method described above requires high precision and has no room for errors.

Method 4: Calibrating

The next suggestion is to calibrate our analysis to the level of microbial contamination on the ground resulting from the free flow of polluted air through the airways and the filters. This method is highly unreliable as different levels of microbial contamination can be found even within the range of 10 m^3. Calibrating the system to the number of microorganisms found near the ground is tantamount to the creation of a notable measurement error and is not recommended.

Method 5: Flexible hose

Furthermore, a system consisting of a flexible hose at the input of the chamber could minimize levels of biological pollution. The system based on a flexible hose would allow for the collection of microorganisms only when the air would be pushed through. When there is no forced air passing through the H-cylinder (i.e., the flexible hose) the collection of microorganisms is minimal or near zero and the contamination gradient is extremely low. This means that external microbes would not be able to enter the system in notable amounts. As the pumping system would be turned off the collection should stop.

This system might prevent nearly all entry of contaminants from the ground level. To collect the data the hose should be pinched as close to the inlet of the chamber as possible, where the gradient of contaminants should be exceptionally low. It is highly probable that this is the procedure that will be carried out when collecting samples. Another way of using an external hose or rather an external ring could be used.

Based on the same mechanism, an externally attached ring could enable sealing the inlets from the outside with the help of e.g., parafilm lowering the biological pollution. Although both mechanisms are an external segment to the satellite and both are =meant to minimize contamination, one, the ring, would enable attaching another part to seal the system after landing and the other, the flexible hose, would lower the contamination gradient due to its length and other properties.

Method 6: Double chambers

The latest design consists of two chambers, one within the other. This method would create a sterile environment and provide additional mechanical support, therefore, the collected data could be transported inside the outer capsule and opened only when in the laboratory. The idea is to build a double-layered chamber which inputs would open only at the designated height. The outermost box would close before the actual collecting capsules inlet would be covered, in a matter like a cabinet either with sliding doors system or double doors, to prevent the collection of data from a different altitude.

On the other hand, the inner chamber should open first, before the enclosing container, to eliminate the contamination of the outer surface of the second filters, so the filters are located on the inside. The inner box would be closed off via a thin wall moved via a string controlled by an engine like in one of the examples described above.

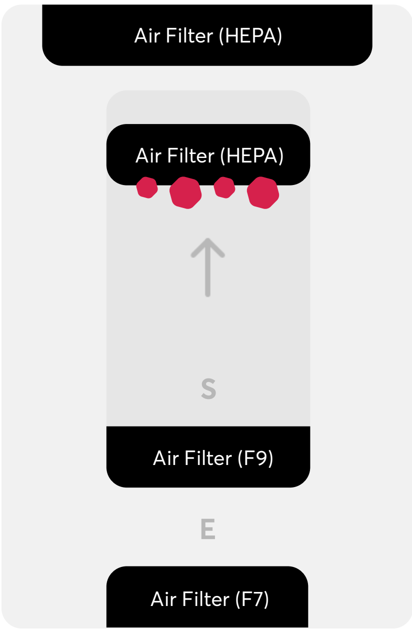
Another interpretation of Method 6 consists of placing both chambers within one another with the layers of filters attached to their inlets to ease the disassembling of the components prior to carrying out the analysis. This interpretation ignores the possibility to operate on the closing times of both chambers, therefore, significantly facilitates the execution of such design during an actual mission.

Summary

All the methods and mechanisms are lacking certain traits. It would be most beneficial to link the ideas given above. Combining certain ideas has resulted in an exceptionally reliable design that enables desirable sterility of the system. After landing the satellite is assumed to lie on the ground for a minimum of 30 minutes and up to 4 hours. Considering the above conditions, the chamber must be protected from environmental contamination and must be easily removable from the body of the satellite. The latest design allows for the detachment of the outer and inner chamber altogether, which will significantly simplify the process of transporting the data aseptically, in a sealed container, to the laboratory.

Current final method

Currently, the final method of keeping the system of the experiment sterile consists of 4 main elements. Firstly, the diameter of the cylindrical S-chamber i.e., the innermost collecting chamber has been decreased. This change is necessary for the addition of an extra outer layer to the collecting container i.e., the E-chamber. Looking from inside out the collection chamber looks as follows. The central cylinder of the satellite, the actual collecting S-chamber, is equipped with two filters: one F9 at the inlet of the capsule, which is the bottom of the satellite, and one Hepa 12 at the outlet of the chamber according to method 1. Method outline is accessible here.



Sampling Device

Airflow causes microbe collection on lower filter

The order of the filters in the S (transition to) E cylinder from the inlet to the outlet goes as follows: a layer of double F filters that prevents the remaining two from sticking and therefore, decreasing their permeability. The second central and the outermost filters on the other side of the S (transition to) E chamber are Hepa 12. As we move further from the center, we will see a thin layer of aluminum foil. This will later come in handy when sterilizing the E-cylinder prior to opening it in the laboratory to reveal the S-chamber with the samples collected.

Foil acts as a barrier to stop UVC radiation from damaging our collected samples within the S-chamber. This procedure should significantly reduce the number of unwanted microorganisms from the exterior surface of the chambers. The S-chambers outer lining is tightly attached to the E-chambers filters creating a tube or a channel of airflow. That decreases the chances of the chamber being dislodged during takeoff, which would not have a detrimental effect anyway. The filters are Hepa: on the inner lining of the S-chamber and the inner lining of the E-chamber. On the other hand, the F filters are placed on the outer lining of the S-cylinder, but the inner lining of the E-cylinder. To the inputs of the E-cylinder, an external ring will be attached accordingly to method 5. The ring (H) allows for sealing the system.

The remaining error resulting from any microbes that could have possibly entered the system should be accounted for in post analysis accordingly. This method allows the satellite to be left on the ground for about 4 hours or more. Finally, the E-cylinder with the S-cylinder are easily detachable from the satellite to be further packed and sealed in a sterile container. It is of most importance that the joined E and S chambers are easily detached from the main body of the satellite as little distress as possible should be done. Prior to sealing the chambers in a plastic container, the outer surface should be cleaned with Isorapid to prevent any extra biological pollution. Samples prepared using this method could be safely transported to the analysis room for further analysis.

Further analysis procedures

After collecting the satellite from the landing site, it will be transported further to the analysis room. A glovebox or a laminar chamber will be used to ensure aseptic conditions whilst working on the removal of the double protective layers and transferring the microorganisms into a growth medium.

There are two possibilities of working with the UVC lamp and the sterile box. Firstly, the glove box could be equipped with a UVC sterilizing lamp, an easy-to-use foil dispenser, a set of tools to open the chambers, a liquid disinfectant, an empty, small box, and a laminated, sterile nutrient agar all INSIDE the sterile glove box. Secondly, the glovebox could only have the laminated and sterile nutrient agar plates, a liquid disinfectant, an empty, small box, and a set of tools to open the chambers inside the box, but the UVC lamp would be placed outside. Placing the UVC lamp outside the glovebox will significantly facilitate the part of covering the lamp after using it to eliminate any threats resulting from operating with UVC radiation.

Isorapid sterilisation

The isorapid spray was used to sterilise the components pre-flight.

The first method of placing the UVC source inside the box will be used according to the results of the previous tests. Nonetheless, after collecting the main cylinder of the satellite and transporting it to the extraction site in a plastic bag the E-cylinder should be thoroughly cleaned with "Isorapid" spray. Only after disinfecting the exterior of the main E-cylinder and the filter inputs could the board be placed inside the pre-disinfected UVC light glovebox. The next step is to irradiate this chamber with UV light for at least 20 minutes. After the 20 minutes have passed, the E-cylinder should be opened with the tools provided within the glovebox. No removed parts, nor waste elements can be disposed of at this time although, they will be placed within a disposal container. The glovebox must not be opened until the microorganisms on the agar plates show signs of life, meaning they can be transported further to the laboratory or until the probes will be sealed with a parafilm which is commonly used for long term storage of microbiological samples which will allow for further sample transportation. When the E-cylinder is opened the system should be once again sterilized with UVC to ensure no microorganisms are trapped in between the chambers. Precisely, right before the irradiation process, the inner filters of the S-cylinder should be cleaned with an alcohol solution very lightly.

At this point, the sealed agar plates can be opened and placed within a preferable distance from the cylinders. Now, the S-cylinder can be opened, and the collected samples can be transported to the agar plates. It is of most importance that the whole glove box remains untouched at this point. The box should be placed in a warm environment of around 30 °C to promote the growth of the microbes or, if the probes will be sealed with parafilm they can be safely transported to the incubator outside the glove box.

After 10-17 hours of incubation the colonies should be ready to go to the laboratory for further analysis. To ensure that no external contamination occurs, the probes with ready colonies should be carefully placed inside the previously prepared small container for transportation. Only after carefully closing the small, transportation box can the glovebox be opened. The methods described require a lot of precision and skills when operating with sharp and delicate objects at the same time in big, rubber gloves. Therefore, numerous tests have been performed to learn how to accurately operate on this system to ensure the highest efficiency of the experiment possible.

Trade-offs

Parachute

The importance of a parachute in our CanSat mission: The parachute plays a significant role in our mission, as we require our CanSat to not accelerate after it initially deploys from the rocket, as our mission is to collect a sample of air from as high of an altitude as possible. It is safe to say our mission greatly depends on the parachute to do the job it is set to do. Our CanSat will weigh 330 grams, and we want it to travel in a speed range of 6 to 7 ms^{-1}, as we believe this will give our CanSat an adequate amount of time to collect the desired air sample. Our mean velocity would be 6.5 ms^{-1} - we use it in our calculations as it is the perfect middle in our range: 6 to 7 ms^{-1}. If we are to use the parachute without altering its shape or mass, we are estimating our speed to be:

$$S = (2 \times m \times g) \div (v^2 \times c \times d)$$

where **S** is the surface area of parachute [m^2], **m** is the mass of CanSat (mass of satellite + mass of parachute) [kg] → 330g = 0.33 kg, **g** is the gravitational acceleration [ms^{-2}] → 9.81 ms^{-2}, **v** is the speed of CanSat [ms^{-1}] → 6 to 7 ms^{-1}, **c** - aerodynamic resistance, dependent on the shape of our CanSat, it is circular so → 0.785, **d** - density of the air [$kg \times m^{-3}$] → 1.

$$S = (2 \times 0.33 \times 9.81) \div (6.5^2 \times 1 \times 0.785) = 1952 \text{ cm}^2$$

This value, **1952cm^2**, would be optimal for our CanSat, as we want to achieve a falling speed of 6.5 ms^{-1}, as we believe this speed is the most adequate for our sample data collection. Furthermore, this speed prevents us from moving too far away from the launch site.

Rocket-model Klima GmbH 55 cm Parachute

After a lot of research, our team concluded that the Klima GmbH 55 cm will be the most appropriate parachute for our mission. Klima GmbH 55cm has a diameter of 55 cm, which makes it the optimal parachute for our mission. This is because we want an appropriate surface area (calculated from area of a circle – $\pi \times r^2$), which, considering the parachute is almost perfectly circular - is equal to, 27.5^2 which is approximately 2376 cm^2. Because our CanSat (with the mass of the parachute) will weigh 330 g, and we want our CanSat to travel with the speed ranging from 6 to 7 ms^{-1}, this is an optimal surface area. We can denote this from our equation. If we are to use the parachute without altering its shape or mass, we are estimating our speed to be:

$$S = (2 \times m \times g) \div (v^2 \times c \times d);\ v = [(2 \times m \times g) \div (c \times d \times s)]^{0.5};\ v = [(2 \times 0.33 \text{ kg} \times 9.81 \text{ m} \times s^{-2}) \div (0.785 \times 0.2376 \text{ m}^2 \times 1)]^{0.5} = 5.89 \text{ ms}^{-1}$$

The speed **5.89 ms^{-1}**, however close to our expected mean, would exceed our range. Additionally, it would be too slow and that would mean our CanSat would be more probable to land a further distance from the launch site. Not only is this a burden for us, as we want to collect our data as soon as possible, but also because we do not want to leave the adequate area, as it may result in our CanSat colliding with an unforeseen object. How we can use this model to our benefit: The ideal value for the surface area for our parachute as calculated above is a 1952 cm^2 - this is close to the surface area of the 55 cm Klima parachute, as its surface area is 2376 cm^2.

There is a way for us to adapt the structure of this model of a parachute for it to reach our expected speed as close as possible. Also, this manufacturing method will allow us to add stability to our falling CanSat. This would consist of cutting a hole in the center of the parachute to evaluate the surface area from the measured to the designated one. Not only would this give us the adequate speed but would allow our CanSat to be more stable whilst in freefall. This hole would take away 2376 cm^2 - 1952 cm^2 → 424 cm^2 of the parachute, with a radius of 11.62 cm. Also, allows us to estimate for how long the can will fall - this is crucial, as we want our can to be in the air if possible, without being derailed out of the adequate landing area. Furthermore, we can estimate how far the Can will land from the launch site - this is assuming that we correctly assume the velocity (and angle) of the launching rocket.

Appropriate weight: The weight of this parachute makes it our deal for our mission - it is light - around 10 grams. This is important since we want to maximize the possible weight of the CanSat itself. When it comes to the payload this parachute can sustain, the manufacturer states that the recommended payload weight is from 200 to 300 grams, however this value does not take into consideration the margin error manufacturers use to make their equipment as reliable as possible. We assume that this parachute would be able to withstand a 10% higher mass of the payload. The parachute comes in a designated, bright crimson color - a color the team established would be most appropriate when it comes to searching for the CanSat after it has landed from its mission - recovering the CanSat is a crucial part of our mission, and having a radiant color comes in handy when the terrain is mostly toupee and sepia color palette - such as the launching site of the competition. In terms of the material, this parachute is made from light, soft, and tear-resistant material, making it resistant to air drag exerted by the free fall. Moreover, the fact that the parachute is tear-resistant is paramount for our parachute, as the landing site is packed with trees, which creates a possibility of our CanSat colliding with or even landing on a tree. We do not want our CanSat to fall off from our parachute, and so the fact that it is sturdy and can handle a firm pull affirms us that the CanSat will still be intact alongside the parachute.

Rocket-model Klima GmbH 45 cm Parachute

The smaller counterpart of the GmbH 55cm parachute, the 45cm model is an alternative for if we choose that we want our CanSat to fall at a greater speed than with the 55 cm parachute. Similarly, to the previous parachute it is almost perfectly circular so we can use the formula of the area of a circle – **π × r²**, so $(22.5)^2$ will give us the surface area of the parachute → 1590.43 cm^2. With that in mind, we can calculate the speed of the CanSat whilst in freefall.

$$v = [(2 \times 0.33 \times 9.81) \div (0.785 \times 0.1590 \times 1)]^{0.5} = 7.2\ ms^{-1}$$

This speed is too fast for the speed of our CanSat, as we want the speed to be below 7 ms^{-1}, and above 6 ms^{-1}. This was a parachute we wanted to use in the beginning, however, after we decided on the speed, we quickly noticed that this parachute was inadequate, so we ruled it out. We want our CanSat to fall slower, as we want to collect a sample from the high altitude, which would be impossible with this speed. Moreover, a collision during landing at this speed may be dangerous to the structure of our CanSat and potentially damage some of its inner components.

Rocket-model Klima GmbH 70 cm Parachute

The other best alternative was the Klima GmbH 70 cm Parachute. We chose it if the GmbH 55cm Parachute did not fulfil our requirements and made our CanSat fall too fast. Again, to calculate its surface area, we used the formula **π × r²** → $(35)^2$ = 3848.45 cm^2, and by using our formula, we can deduce that.

$$v = [(2 \times 0.33 \times 9.81) \div (0.785 \times 0.384845 \times 1)]^{0.5} = 4.63\ ms^{-1}$$

This speed is too slow for our desired range, between 6 and 7 ms^{-1}. Although this speed is not an obstacle when it comes to collecting our sample, as in theory, the slower we go, the easier it is for us to make an accurate sample - however, it does hinder our landing distance significantly, to the point where we would not be able to reach our CanSat in the designated time. Moreover, there would be a possibility of the CanSat being unrecoverable, as it would mean we would not have access to the location it landed and may even be a hazard to the environment. Additionally, our mission is not complete without the analysis of our air sample, which must be retrieved from our CanSat post landing.

However, we can overcome this by changing the area of the parachute. We could theoretically do this by cutting a circle in the center of the parachute. Since we know from our previous calculations that the surface area, we need to get to have a speed of 6.5 ms^{-1} would be 1952 cm^2, this would mean the surface area of the hole that we would need to cut out would equate to 3848 cm^2 – 1952 cm^2 → 1896 cm^2. After we realized that the hole, we would need to make would require us to cut out almost half of the surface area of the parachute, we decided to stick with the 55cm variant.

Sensor

The importance of the Barometer in our CanSat project: The barometer plays a particularly important role in our mission - it helps us determine the altitude of the CanSat, which is crucial for our secondary mission to be able to collect the sample at the right height, as it consists of taking a sample of microorganisms at a high altitude.

Furthermore, it gives us the speed that it is falling at, helping us determine if the parachute has deployed properly. It also needs to have an integrated temperature sensor for the CanSat to meet the requirements of the primary mission, which is to measure temperature and pressure during the flight. This will also be used to measure the height that the CanSat is at, because the decrease in pressure and temperature can help us determine what height we are approximately reaching.

Computing the current altitude is simple - we will calibrate the CanSat by informing it what ground level pressure is, and then use a hypsometric formula to compute the current altitude. The expected precision will be better than 0.3 meters. The barometer is an electrical component that will provide us with essential information - giving us its current altitude as well as speed of the falling CanSat. Therefore, we need to ensure that it will work for the entirety of the flight. Furthermore, a particularly important factor of the sensor is its energy usage, the smaller it is the further it increases our CanSat's lifetime.

From a software standpoint the accuracy of the sensor is significant - if there are large variations in the computed altitude, an average of a greater number of points must be taken, which increases processing time slightly, and decreases precision when the CanSat is changing its y-height rapidly.

Selecting a precise sensor is important, and there are additional methods available for combating these problems - for example, an array will store the last n-many measurements (n ≅ 30). Whenever the value of the current altitude needs to be utilized in the code, the average value is taken. In our code, we do not use these methods as they can lead to errors, slow reaction times to rapid changes in parameters and other issues.

Additionally, there would need to be discrete points defined in code that are mode-switch altitudes, and whenever such an altitude is passed and the switch is about to occur, the CanSat waits another sampling period (500 millis), and only then changes mode. That way, we are never too late to change mode, but we are also not wildly oscillating between modes and causing problems. For simplicity reasons we will be referring to the sensors with their number in the figure below.

Component	Precision of measurements	Battery	Operating temperature range	Pressure discrepancy	Temperature accuracy	OS and Software standpoint
MPL115A2	50 meters	6 μA	-40 to 105 °C	± 1000 Pa	± 1 °C	The precision is lacking slightly – everything else is adequate
BMP388	0.5 meters	3.4 μA	0 to 55 °C	± 40 Pa	± 1 °C	Good. Slightly worrying temperature range
MPL3115A2	0.3 meters	7 μA	-40 to 85 °C	± 5 Pa	± 3 °C	Sufficient all-around.

Sensor number 1

Firstly, there is the precision of the height measurement in the first sensor - it has the highest inaccuracy ranging at 50 meters which is quite a significant amount. Furthermore, due to our requirements from the sensor it will not be used in our CanSat project. We need it to be able to detect a certain height, around 2 km from the earth surface so a (50 m × 100%) ÷ 2000 m = 2.5% error can be calculated. This is an error that is acceptable, however, the discrepancy in the height measurement is too high and cannot be used with our CanSat. Secondly, the power consumption by the sensor is almost negligible. It consumes only 6 μA of power - this is 0.6% of an amp. This is sufficient and will help us increase the run time of our CanSat. Thirdly, the operating temperature range is very wide (-40 to 105 °C) and will not be a problem, as the temperature drops by 6.5 °C per kilometer in the troposphere - it will not fall below 0 °C assuming the temperature is over 20 °C on the day of launch. A wide range ensures that everything will work, and that the temperature of the system will not affect our process.

Sensor number 2

The second sensor on the other hand has a remarkably high accuracy in height detection at 0.5 meters - this is very impressive and accurate, which is needed for the CanSat's height measurements. The power consumption is defined as 3.4 μA per Hz, which means that for every Hz the sensor sends to the micro controller consumes the given number of amps, so for instance if the sensor is sending 7 Hz then the power consumption will be 7 × 3.4 = 23.8 μA This is also a ridiculously small amount, almost negligible, only 2.4% of an amp.

Furthermore, the range of the operating temperature is a lot smaller (0 to 55 °C) than the first and the third sensor, which leaves it at a disadvantage due to the temperature dropping lower in the higher parts of the atmosphere. Since we are going to be testing it in winter, the temperature will drop below 0 °C at a certain height. The temperature reaches close to zero after the launch of the CanSat in its apogee, which is possible due to the drop of °C per km is 6.5 °C. The sensor would not be able to collect data.

Sensor number 3

The third sensor has the best height resolution from all 3 sensors at 0.3 meters. This kind of accuracy is great, as it gives very precise information about the height from the ground. This sensor is great for our CanSat project giving fully accurate height measurements which is important as the sample needs to be taken from a certain altitude, therefore the sensor needs to give information about how high the CanSat is to ensure the microcontroller turns off the pump. Furthermore, the battery usage is also exceedingly small at only 7 μA, which means that this would be a viable option to choose due to the low power consumption.

Conclusion

After analyzing the barometers, we have found that all the sensors we chose are very compatible with our project. However, we picked one for the prototype we built - after we test the code and verify everything is working correctly, we will experiment with another sensor to see which one is the best in the real mission.

The sensors need to be accurate enough for us to detect the CanSat being at a height of 2 km to turn off the pump that is taking a sample of the air, which all 3 of them can do. They also need to be able to measure the temperature on the high altitude, which only two are suitable to due to the second sensor having too short of a range between (0 to 55 °C). This is a problem because we will be testing them in the winter, when temperatures will fall below 0 °C. That is why we picked the third sensor as the one we will use in our final prototype. Due to its high accuracy in height measurements and low power consumption.

Buzzer

The buzzer plays an important role in retrieving the CanSat from the terrain. For example, if the CanSat was to be stuck in a tree. In a situation like this, it could be hard to spot just by looking, however, the sound would be an indication that a CanSat is near. Retrieving the CanSat after it lands is essential for our secondary mission due to the sample we collect in the air. We need to retrieve the sample to test it for microorganisms as this is mandatory for our secondary mission.

Component	The sound generation	Loudness	Power consumption	OS and Software standpoint
Grove – module with passive buzzer	Constant voltage supplied	80 dB	95mA at 80 dB	It works and has been coded, and implemented correctly already
Active buzzer module	Signal wave supplied	Not supplied	30mA	It is overcomplicated, nevertheless usable

Because the buzzer does not have any complicated function, we picked only two different ones. They are both used to create sound; however, one is controlled by a constant voltage at one tone and is simple, robust and can be heard from a large distance away.

Because of the way multithreading is handled natively in Arduino (in fact: it is not) the buzzer will be interrupted for about 30 millis every second when the system is sampling and writing data anyway, even if multithreading is implemented. This is to assure the correct sampling rate amongst other things. If a melody would be played the voltage would need to change. However, for the second buzzer to generate a sound it needs to be supplied by a constant wave generated by the microcontroller. This increases code complexity, as additional libraries would have to be imported. Due to the nature of this mission, this is not going to be much of a problem. It is however not a necessity and thus rendered obsolete.

Buzzer 1

The buzzer generates a remarkably high pitch. We believe this is appropriate for our CanSat - the loud sound helps us hear it from a distance, which gives it a higher probability of it being found due to the CanSat not only being easily seen due to its bright color paint, but also able to hear it even when it is in a less visible area. The 95mA at max volume of amperage consumption is high, however it could be reduced using a siren like sound, which would mean the consumption could be decreased to 50% consumption or even lower. This would be done by turning the speaker off for a short period of time and then turning it back on, so it would generate a beeping sound. This would decrease the amount of power used, solving the issue of high-power consumption.

Buzzer 2

This buzzer is a cheap alternative. Unfortunately, the volume of the speaker was not mentioned in the packaging, and so we will have to test if it is not louder than Buzzer 1. On the other hand, the power consumption of the unit is smaller than the previous buzzer only at 30 mA. This gives it its potential for our project because the longer run time of the CanSat, the more time there is for it to be found, which again is especially important for the sample that we collect for the secondary mission. Nonetheless, this would be only used if the amperage consumption would need to be decreased.

Conclusion

The two buzzers are both good options for our CanSat. They have different advantages which help solve problems that may possibly occur, giving us a higher variety of choices. We are going to test the two buzzers to compare the battery usage, which is crucial for the runtime of the CanSat, as well as the loudness of the speakers, because the louder the sound the bigger the distance you can hear it from, again increasing the probability of it being found. From the information we have from the data sheet of the two components we can deduce that the first speaker is probably going to be louder due to the higher consumption of energy, however we cannot be sure due to the lack of information about the loudness of the second speaker supplied by the manufacturers.

LEDs

The LED light serves an important precaution for our CanSat mission, as it gives us the option of knowing what mode it is at a given moment. For example, a mode called "waiting for launch", which would be on when the CanSat is being placed into the rocket and is on the launchpad waiting for the rocket to start. This solves the problem of the CanSat being turned off before launch due to the diode signaling the correct color. This could be understood by anybody due a small sticker on the CanSat showing which color of the diode signals which mode.

No.	RGB diode	Power usage	OS and Software standpoint
1.	LED 8mm RGB WS2811	50 mA	Unfortunately, due to the way this thing is operated and the way Arduino functions, it is not usable. That is because creating more system interrupts and slowing down loop() even more is not recommended. Use a small and simple led that has 4 pins.
2.	LED 5mm RGB	25 mA	This diode is easier to program and does not possess the disadvantages listed above, that is why it is superior to alternatives.

Conclusion

We have selected to use the 5mm RGB. Thanks to the lack of subroutines in assembly needed to be written in the code, and because of the way Arduino handles multiple threads, using such a diode is beneficial. We will be able to correctly utilize amazingly simple millis()-based delay control and thus achieve millisecond-perfect measurement timeframes, additionally handling all components such as the air pump correctly in the main loop() and keeping it free from bloat.

Air Pump

The air pump plays one of the most significant roles in our secondary mission, as its roles to pump air through a filter, simultaneously capturing microorganisms from the air at the designated altitude. The pump should have a good flow rate of air to ensure we filter as many microorganisms as possible - this would make detecting them much easier.

Furthermore, it is important to ensure that the power consumption by the pump is not too high - the power consumption being too high would result in the decrease of the lifetime of the CanSat. Furthermore, it is also important to retrieve the CanSat because the sample that is collected at our designated altitude needs to be taken to a lab and analyzed.

Secondly, another important factor is the weight of the pump - this is due to the limit of weight on the CanSat that is mandatory for every team (300g - 350g). A third important aspect that should be mentioned is the space taken by the pump due to the restricted size of the CanSat, meaning we have limited space that needs to be managed properly.

Element	Battery consumption	Rate of flow	Volume of the pump	The weight of the CanSat
NW Air Pump	400 mA at 6V for 60s	3.2 l × min-1 at 5V to 6V	29.4cm3	62g

The pump will be controlled by simply activating or deactivating a relay, that functionality ultimately boils down to setting voltage to high or low on a certain pin. The code handling that will be in our main routine, and any logic connected to it will run every time the altitude is checked (that way mode-switching is processor-friendly).

The power consumption of the pump can be calculated: 1/60 × 400 mAh = 6.8 mAh. This is a low proportional to the size of the battery installed in the CanSat, being at a capacity of 2250 mAh. The power used by the pump only amounts to (6.8 × 100%) ÷ 2250 = 0.4% of the battery capacity, which is almost negligible - this is sufficient as it increases the runtime of the CanSat. The flow rate of the pump is given by the manufacturer at 3.2l at 5V to 6V. This flow rate is ideal for the size and weight of the pump. This is the best that we can find for the application of our CanSat, this is due to the small size and weight.

The volume of the pumps casing with the motor amounts to (29.4 × 100%) ÷ 393 = 7.4% of the total volume available in the CanSat. This is an exceedingly small percentage of the volume of our CanSat, making it very space efficient. The weight of the pump is specified by the manufacturer at 62g and the percentage of the total weight of the CanSat is (62 × 100%) ÷ 330 = 18.8%.

This amount is also quite small, which is adequate for the CanSat due to the limited weight being set as mandatory for all CanSats starting in the competition. The pump will only be turned on for a short sampling period, while the CanSat is nearby apoapsis and 1 km above surface level.

Conclusion

In conclusion, the pump we chose for our CanSat is suited for its mission due to low battery usage, which is needed to ensure a long battery life of the CanSat. The percentage volume taken up by the pump is only at (29.4 × 100%) ÷ 393 = 7.4%, this amount is exceedingly small, which is a good advantage of the pump due to the restricted size of the CanSat that is mandatory for all.

This leaves more room for the batteries which are the biggest part of the CanSat and ensures that there is space left for all the other components. Lastly the percentage weight of the CanSat is small, only at (62 × 100%) ÷ 330 = 18.8%. This small percentage gives us the information that the pump is not taking much of the CanSat's weight. This is crucial due to the biggest component used, which are the batteries.

Converters

No.	The converter	Power consumption	Voltage conversion	Max. A
1.	D24V10F5	40 mA	12.3 V to 5 V	1 A
2.	D24V5F6	40 mA	12.3 V to 6 V	0.5 A

The voltage supplied by the batteries to the CanSat is 12.3 V. This voltage is too high for all the CanSat's components - to solve this problem, two converters are used to step down the voltage for all the components of the CanSat.

The usage of 2 different converters is due to the two different voltages that need to be supplied to the components. The first one is the voltage required for the pump to work (6V), and the second voltage is the one used for all the rest of the components, for example the microcontroller, the barometer, and the led RGB diode. The converters will supply power to the devices, which in turn will be controlled by our POCU. The converters make it easier to control those devices, as the correct voltage can be supplied directly without the need for any complex circuitry.

Converter 1

The converter is used to convert the voltage from 12.3V to 5V. This voltage is used for all the components except the pump, as it has a higher voltage requirement. The total power consumption by these components is 920 mA - smaller than the maximal amperage of 1A provided by the converter. Furthermore, the power usage by the converter is small, and from calculations (40 × 100%) ÷ 1320 = 3.03%.

Converter 2

The second converter is used to convert the 12.3V to 6V being used to power the air pump. The power consumption by the pump is 400mA, which is also under the maximum power that the converter can provide, making the converter suitable for its job. The power consumption by the converter is the same as in the first one - the percentage value of the total consumption of power is (40 × 100%) ÷ 1320 = 3.03%. This small percentage ensures that the efficiency of the converters converting the voltage is extremely high, at only 3.03% power loss.

Conclusion

The two converters are crucial for the power supply of the CanSat as they convert the voltage supplied by the battery to specific voltages required by different components. This is done at a 96.97% efficiency, which is great for the life span of our batteries.

Battery

The batteries are one of the most important parts of the CanSat as the power all the electronics on board, meaning that the whole CanSat mission is dependent on them. That is why we need to ensure that they can power the whole CanSat for at least 6 to 10h - they are important regarding finding the CanSat after it has landed, especially for our secondary mission which relies on a sample that is collected mid-air, which needs to be taken to a lab and examined.

The most important factor of the batteries is their capacity - they need enough power to support the CanSat for at least 6 to 10h, and after choosing and calculating the batteries we have settled at 2250 mAh supplied by 3 batteries with a capacity of 750 mAh to give a voltage of 12.3V. From this we can calculate the run time that has been estimated to last around 10 hours.

Conclusion

The batteries we chose for this project are well suited for their function - they can power the CanSat for almost 10 hours, which is a lot and enough time to find the CanSat after it lands. This is especially important for our mission due to the sample that is being collected by the secondary mission, which later will be taken to a lab and tested for microorganisms.

The POCU will use power only when needed, and it will oversee managing what is currently running and draining power and what is in standby mode or turned off. Each mode will affect what is currently running.

Mosfet

In the electrical design a change has been made, the relay was exchanged for a Mosfet. The reason for the swap was due to the space that the relay took and due to the amount of space taken by all the components, if we tried to use the relay, we would not be able to fit the CanSat in the 115 mm required by the rulebook. Moreover, the relay was not working reliably sometimes not turning on.

Furthermore, we were discussing between using a N-channel and P-channel Mosfet, the difference between the two came down to electrical function of it. These two types are not much different from each other and both would have worked for our purpose, however due to the more simplistic electrical circuit of the N-channel Mosfet needing only one resistor we chose it over the P-channel where the circuit evolving it is much more complicated and it would add more weight to our CanSat.

GPS

The role of a GPS module in our CanSat is to measure height from the ground and the position of the CanSat, this information will be relayed to the ground station thru the radio and then used to find the CanSat. This is especially important for our CanSat due to the sample that is collected by the secondary mission, this needs to be tested for microorganisms. The GPS will allow exceptionally fine telemetry for our CanSat. As knowing the altitude is not enough for locating the satellite, we also need the longitude and latitude.

The GPS will most likely lose signal in the final few meters AGL, however that is also when the comms array will fail to uplink to our gstat, and so it is irrelevant. By extrapolating the general trajectory, horizontal and vertical speed of the CanSat, we can extrapolate where we need to search for it and then locate it using the radio and finally our ears.

GPS	Power consumption	Precision in y-axis	Component of power consumption
Beitian Dual BN-220 GPS	50 mA at 5V	2m	(50 × 100%) ÷ 1320 = 3.8%

The GPS is an especially important component of the CanSat, it helps locate the CanSat by sending its current location to the ground station just before it loses connection giving us an approximation of where it landed. This is important due to the need of retrieving the CanSat because of the sample that needs to be taken back to the lab.

The important part of a GPS for our project is its power consumption, we need to ensure that it does not take much of the power due to the long-required battery life. From calculations (50 × 100%) ÷ 1320 = 3.8%. The GPS uses only 3.8% of the total power consumption. Furthermore, the horizontal precision of the antenna is 2m.

This is more than sufficient for our purpose; we do not need an exact location but an approximation and when the CanSat is close enough the buzzer should be able to give the CanSat's location away. To increase redundancy in the GPS and other experiments, all data that can be recorded *in situ* is saved to a microSD card.

This includes GPS telemetry and other data such as what experiments are active (and error logs where needed). All this raw data enables us to process the nascent data on the POCU, but also later the gstat laptop and in post-processing.

Conclusion

The GPS module has an especially important role in the retrieval of the CanSat - it is going to send the location of the CanSat before landing to make finding it easier. This is essential to our mission, due to the sample that needs to be collected and tested for microorganisms in a lab. Furthermore, the power consumption of the unit is small and can be tolerated, also from percentage calculations **(50 × 100%) ÷ 1320 = 3.8%** we can tell that the GPS does not take up much of the total power consumption, only 3.8%.

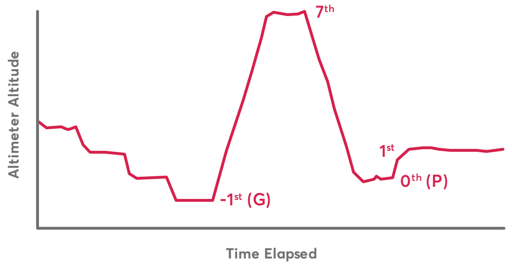
Moreover, the horizontal positioning precision is particularly good for our application - 2 meters is exactly accurate and will be enough to determine the landing area of the CanSat. During the ground stages of the mission the buzzer is going to be modulated, reaching resonant frequency, and theoretically allowing it to be heard even in windy conditions. That way even if the CanSat falls into the ground, a 30m auditory radius is still achievable.

Test campaign

Primary mission tests

Altimeter - The altimeter we are using currently is the Adafruit MPL3115A2 variant, which can measure the T in Celsius and the p in kPa. As this component is especially important for the correct execution of the entire mission, several tests were conducted. First, the ground pressure p_0 was calculated and noted. The hypsometric equation was used:

$$AZE = [(p_0 \div p)^{1.0/5.257} - 1] \times [T + 273.15] \div 0.0065$$

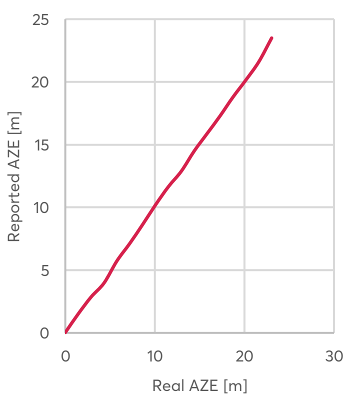


Data feed from Altimeter

Higher-quality recreation of original screenshot. Shows data from elevator trip. Elevator stopping points of interest are indicated.

The resulting **AZE** [m, Above Zero Level] was used to check if a 60 cm change on a ruler was observed on the detector. The precision of this detector enabled it to get a correct mean increase of around 60 cm ± 20 cm. The detector correctly identified the altitude change and allowed us to get a valid reading almost instantly (<1 s after lifting FlatSat). The second test that was conducted was checking how good the data would be in a theoretical situation of flight. On a windy day, while performing GPS test simultaneously, a window was opened, and the altimeter was placed outside. The pressure changes on the altimeter during this test were small enough to give a precision range of ± 220 cm, which is acceptable for an in-flight state.

Adafruit Altimeter Data vs Real AZE



The final test that was conducted was checking if the programmer can do math and that the hypsometric equation is correctly applied. To conduct this test, the FlatSat was carried to the bottom of a flight of stairs and the altitude was set to 0 (by setting current pressure as base pressure). Then, the CanSat was carried up 0.5-floor intervals (equivalent to 1.44-meter elevation changes, as there are 9 stairs, and each has 16 cm in height) up to an altitude of 17 meters (6 floors). The results were obtained by accumulating 10 data points and taking an average (the code was smart in that it used gradient-descent to find where the altimeter stabilized and then sampled next 10 300-millis intervals). Finally, the data was plotted, and a near-perfect linear relationship was found, which is a particularly good sign! The graph shows a linear correlation and a plot of both the real and measured altitude at a datapoint.

We have additionally computed the BMP-280 plot, as it was used to auto validate the Adafruit readings; there is a very slightly anomalous set of results centering on the 7th datapoint, which is probably attributed to thermal fluctuations in the building, but we are unsure. We have also attached a log of how the altitude changes during use of an elevator that is set to stop at each floor (yes, people were a bit angry). We have ridden to the 7th floor from G (garage) level, and the raw data looks particularly good.

GPS - The GPS used is a Beitian Dual BN-220. This GPS can connect quickly to satellites and get a position lock. It is a crucial component of the mission, as most telemetry systems, due to the nature of our mission (live specimen sample recovery). The GPS was thus tested rigorously. The first test was the speed at which the satellite could acquire a new lock when off. The GPS automatically attempts to quickly acquire a lock the moment it is turned on, and it must do this whenever it is power washed, that is because it is a simple and robust component. To test this characteristic, the GPS was unplugged for 3 seconds, then reconnected and a script using TinyGPS++ measured how long it took to get a valid position lock (within about 100 meters of our current location, using Pythagoras' theorem to determine distance downrange). It always took below a minute. This is a good result. It means that the satellite is always going to be able to acquire a lock before touching down, since it will probably need to be released from the carrier rocket before initiating lock acquisition, and the fall time is long enough that the GPS can lock and transmit telemetry before touching down and the pole antenna becoming nonfunctional.

The second test was the precision test. The GPS was left to run for over 3 minutes (fall time till gstat ← sat comms cut-off) and when it had acquired about 7 satellite locks, the position was recorded. The results are good - the precision is within 20 meters, which is acceptable considering the CanSat does not use some Wi-Fi connection to get precise locations - it is comparable to a medium-quality smartphone device. The image shows a test result selected at random - our position is shown in blue and the reported GPS location is shown in red. This GPS is good overall, it is a component that reports precise locations, can acquire a lock quickly, and is able to remain locked even when moved from outside into a building and back out. The only foreseeable problem for this small device is power usage. We can always add more batteries, however. [To parse the location from gibberish-GPS to normal human coordinates we employ the amazing TinyGPS++ library that supports parsing all the data that our GPS can 'Serial' to our FeatherWing POCU.]

Real retrieval of CanSat using GPS
On the left is the feed from the OS, on the right is what roughly was the location of the CanSat (saved from Aleksy's iPhone)

During CanSat recovery on a trial day, we lost sight of the CanSat and used the GPS position to find it again. It was within 5 meters from the predicted position.

Air Pump - The air pump is an especially important component, as it is what enables the live sample collection at the correct altitude. Thus, optimal operation of the air pump is essential for the secondary mission to go successfully. The air pump model used by us is a NW Air Pump. To determine the flow rate, stated as 3.2 l/min, we used a small plastic bag that contains 0.5 cubic decimeters. The total time needed to fill this bag was found, this test was repeated 3 times T = {9.5, 10.3, 9.6} and an average of 9.8 seconds was calculated. This amounts to $60 \div 1 \times (0.5 \div 9.8) \approx 3.06\ l{\times}min^{-1}$, which is close to the amount stated on the datasheet. The pump was subsequently turned on to work for about a full minute (if it will run for during the real flight possibly) to check roughly how much heat it would generate. No observable temperature increase was detected. Our objective was to check whether the pump can pump enough air to enable effective sample collection, as a large enough volume of air must be pushed through the filters to collect enough biological sample matter. Objective satisfied.

POCU [Feather & FeatherWing] - The POCU is essential for our mission, this is obvious since it controls all mission equipment and can process inputs, encode, and transmit the data and store it on the SD card (via FeatherWing SD module). The POCU in our mission is the Adafruit Feather M0. This is a SAMD board that can interpret Arduino C. To enable interfacing with the board the device that is uploading must have the Adafruit SAMD board library. This library takes an exceptionally long time to download, so a mirror link was used to acquire it. After successfully installing and configuring Windows drivers for Adafruit Feather M0, a simple Blink program was uploaded to the device.

The onboard LED was observed to blink rapidly and the Serial opened via the USB connection was also working. The next test was to connect a device to the TX1 RX1 line and use Serial1 to read from it. A GPS module was connected (one tested previously). The Serial1 feed was forwarded to Serial. It was observed that the GPS is correctly read as the GPS native communications were observed on screen (as char -> int values). After using TinyGPS++ to parse that data it was confirmed that that part of the board is fully functional. The last test was checking if the pins were working. A LED was connected to a digital pin and the output was set to HIGH in code. The LED correctly lit up brightly (as no resistor was used). This concluded preliminary testing of the Feather M0 as it seems that it is fully operational. The data collected during the CanSat flight must be stored on some type of storage medium, for instance a SD or MicroSD card.

In our case the device that will be used is the FeatherWing Datalogger, that has a builtin RTC module (Real-time clock) that is powered by a small watch-battery such as CR1220 (for statekeeping). That way any data recorded can instantly have timestamps (not in millis since power-on but real actual time) attached to it. Additionally, the FeatherWing Datalogger has a MicroSD slot built in, and this MicroSD is going to record all the data captured during the mission. To test the FeatherWing module, a battery was inserted into the RTC slot (to allow RTC testing). The Adafruit library RTCLib was used to initialize an RTC connection (it was installed from a mirror because Adafruit has terrible servers), set time to the current date and time, and every 1000 millis the time was printed - it was being reported correctly. Next, the MicroSD card was tested - the 5GB card was first formatted [FAT32 & Rufus as it supports formatting only also] to remove all unnecessary data. The example Arduino built-ins program for SD cards was first used to confirm that everything is working appropriately. Afterwards a test was conducted where the altitude values for 10 seconds of sampling (around 30 samples) were stored on the SD card, coupled with the timestamps. The data was then read and stored as a text file on the Laptop that was powering the POCU. After reviewing the data, it was observed to be readable.

Circuitry [General, includes converter] - By testing all components we have been able to show that everything is functional, including the 5V converter. Conversely, if there were any problems with the wiring or function of the auxiliary circuit components, we would have been unable to verify the function of the Pump, Relay, POCU, etc. When it comes to the pump, since the electronics were redesigned to use a small N Mosfet instead of a Relay that occupied too much room, the components were retested by uploading a program to the POCU to turn on the Pump. The pump turned on without causing any problems, signifying full functionality of the Mosfet system and the Pump.

Buzzer - The buzzer will be used to notify the Ground Search Team about the position of the satellite using a high-pitched pulsing sound. It is a Seeedstudio Grove buzzer that beeps at 1 ms delay. That way, it is not annoying to anyone, and additionally it is audible in a large range and not blocked by the sound of wind. This ensures that, even in hard conditions, finding the probe will be a straightforward task and thus the likelihood of retrieving the sample will be greater. We conducted a simple test to check the auditory detectability of the radiant signal emitted by the buzzer. We went outside and placed a buzzer, then walked a known distance away (30 m) and checked if the buzzer was still distinguishable, irrespective of the direction of our ears. It turns out that the buzzer is detectable in a >50 m range. Thus, it has passed this test. This device has been selected because it has acceptably low power usage, it is audible for a large distance and can be controlled using an approachable library. Of course, there exist larger and louder models, but this device, as opposed to the essential LED, is mostly just an additional luxury… [It will be running only while POCU is in STANDBY mode, but only after SAMPLE mode has been entered at least once during this session. That way it is not on when waiting for liftoff, which would annoy everyone's ears too hard.]

LED - The Status LED of our CanSat is important - it allows us to easily determine the on/off state of our satellite and avoid a situation in which one person will unknowingly, accidentally turn off an already data-recording satellite. Because of this, it is also mandatory at the European level of CanSat. The LED used in our project is a simple red ~660nm diode. Before making the switch to this specific component, we were using a high-grade LED that could accept 18 million color combinations and was overly complicated for our purposes. Because of the way Arduino supports multithreading, or rather the lack of such support, this LED was not usable as it caused the system to hang every cycle, which was very undesirable and unavoidable. Thus, we switched to a normal 3color LED. It accepts a voltage of 5V on three digital Arduino pins, through a 220-ohm resistor. The component was tested by observing its behavior while conducting AirOS software tests - the LED is always on during ground phases and has the color according to current mode. During flight, the LED is off. During sampling, the LED is also off. It is thus easily possible to determine the current OS state by looking at it, in accordance with the table in **Software Design**. It was observed that the component always worked correctly and is thus functional. Such an LED solution, both from the software and hardware standpoint, is best. The LED is cheap, provides bright, noticeable light, it is easily determinable which OS state the CanSat is in, also the LED can be quickly replaced in case a fault is detected, since it requires only 4 soldering points. It can be argued that putting so much thought into an LED component is redundant, but this is the only ubiquitous status-giving component of a CanSat.

Secondary mission tests

All the tests were conducted under strict rules that would guarantee the team's safety and the optimal conditions to improve and accelerate the growth of microorganisms i.e., bacteria and fungi. The conditions were changing throughout the experiments according to the results of previous tests, which allowed us to fully adjust them to our current needs. Before conducting all experiments, the collection method was tested. For this a Q-tip and the filters from air conditioning were used.

The microorganisms were collected from the surface of the filters firstly using a dry Q-tip and then using a slightly wet Q-tip. The microbes collected using a dry Q-tip were observed to grow more rapidly and in bigger amounts, therefore for any need of collecting microbes in the experiments this method was used. The first experiment was easy to conduct. A freshly grated bacterial colony was placed inside the sterile box for both experiments with the position of the UVC source changed. Both experiments were conducted twice and gave fairly similar results between one another. Notwithstanding, the colony irradiated with UVC lamp placed within the box [colony 1] showed a significant difference when compared to the colony irradiated with UVC outside the box [colony 2].

Agar plates

The microbes that have been cultured.

After the irradiation session the colonies were once again transferred and sewed onto new agar plates, after 24 hours in optimal conditions the first colony did not show any signs of viability, whereas the second colony had slightly more new microbial colonies. The effect of UVC on microbes was tested separately. The results came out positive as both trials proved the effect UVC has on microbes. The sowed colonies that were irradiated before allowing them to grow did not survive.

On the other hand, the colonies that were irradiated after growing them in optimal conditions showed some irregularities as to what the scientific publications say, therefore an additional test had to be done. After adjusting the conditions, the irradiated and grown colonies could not grow any further. Therefore, all tests were marked as successful. All tests investigating the effectiveness of ethanol and UVC on killing microorganisms proved that both procedures provide sterile conditions and are enough to prevent contamination and unwanted growth of microbes. Although, an additional test was conducted that showed that Isorapid is a better disinfectant than ethanol, therefore in all following tests Isorapid was used instead. To test the level of protection from UVC that foil gives, a simple test was conducted. The test successfully showed that foil is enough to protect the microbes from dying of UVC.

The colony covered with foil proceeded further growth, yet the uncovered colony stopped developing. To confirm the reliability of the experiment, the same was done with freshly grated colonies. The results of this experiment confirmed that a layer of aluminum foil can protect from UVC light as the uncovered colony was unable to develop in contrast to the colony that was covered with foil. The sterility of the chamber had to be tested for, because the team is new to operating in such conditions, therefore the test was to show that we can maintain aseptic conditions. The test was successfully executed. The sterile plate was placed in all setups described previously (that is in the sterile box) and showed no presence of microorganisms after leaving in optimal conditions for microbes to grow in. The packing and transportation methods experiment was successfully executed. The sterile plate, sealed with parafilm left outside the sterile glove box, yet inside its transportation box, for 36 hours in a warm environment showed no signs of microorganisms grown after thoroughly investigating the plate under an optical microscope.

The test for the effectiveness of growing microbes was attempted, but within 24 hours no bigger colonies managed to grow outside the laminar chamber therefore, in normal conditions (25 °C and undefined level of humidity) in contrast to the colonies left within the sterile box in which the conditions were altered for the growth of bacterial colonies (35 °C, 50% humidity), therefore this trial proved that the conditions within the box allow for more rapid growth of microorganisms. An additional test was conducted to see if we can prepare an adequate suspension that could be used for further introductory analysis i.e., flow cytometric analysis.

The optimization of preparation methods is crucial for conducting successful analysis. With the help of Adamed an Escherichia coli bacteria suspension was prepared in a formaldehyde-based fixation buffer with a Hoechst 34580 dye for DNA staining. We were able to obtain reasonably applicable results based on which further methods were developed with the use of PFA 3% fixation solution and **SYBR Green stain**, propidium iodide and **Hoechst 34580**.

Further tests

To make sure that the collection system works appropriately several tests were conducted with the help of multiple prototypes of the chambers. To determine whether the limited time of extra air flow through the system is enough to collect microbial samples several tests were conducted. Prior to all experiments the chambers were thoroughly disinfected with the help of UVC irradiation and an alcohol solution.

The tests were conducted as if a real mission was performed apart from the fact that all experiments were laboratory based. Thus, after collecting the samples for an appropriate period (up to 3 minutes depending on the device used) the inlets to the collecting chambers were sealed with parafilm and the rest of the procedure was performed according to the instructions given in the report.

Additionally, all tests were accompanied with a control growth test relying on opening a sterile packed agar plate for 15 to 20 minutes (airborne bacteria and fungi spore assessment) in the same environment as the other experimental plate to check whether the results obtained were not just contaminants from the air that could have affected the test in between operating on the chambers. Firstly, the air was pushed through the four layers of filters for 3 minutes by one of the team members. The chambers were disinfected under a laminar chamber and the microbes were collected from the surface of the inner H12 filter.

The remaining inner Hepa filter was pressed onto an agar plate to provide extra information if the other sampling method failed. Both plates were placed inside an incubator set for 35 °C for 20 hours. As expected, the results were positive although the agar plate onto which the filter was pressed had a significantly higher number of microbial colonies present. Secondly, the pump was used to pull the air towards it through the whole system for 2 minutes. The rest of the procedure was performed identically.

The results were positive. We were able to observe microbial colonies present on the nutrient agar plate however, the visible number of colonies was lessened, which did not impact our outcome. Similarly, the plate onto which the filter was pressed had more colonies which, in this case, displayed more variety especially in color and odor. The test was performed three times in the same room, to ensure that the diversity was not due to leakage, a malfunction in the prototypes design or unsterile handling of chambers or pump. All tests showed the same results, varying slightly in the number of colonies and their characteristics which might be due to change in the environment and mass air flow.

Lastly, the same test was done with the help of a vacuum. The samples were collected for approximately 25 seconds as the vacuum used pushed significantly more air than the pump used during the mission. Although the test was conducted 4 times, only a few microbial colonies were present on the agar plates after the experiment. It is assumed that the colonies were only present due to ineffective cleaning and disinfecting of the vacuum as after pressing the end of the vacuum pump onto an agar plate a marginal number of microbial colonies was present.

Therefore, the results of this investigation were excluded from our data booklet mainly due to lack of precision and reliability of the results. To test whether we would collect any microbes without the help of a pumping system the previously disinfected prototype was left on a table for 2 minutes. Afterwards, the CanSat was sealed with parafilm, cleaned from the outside under a laminar chamber and disassembled until the inner filters were visible. The samples were taken and transferred onto an agar plate which was later sealed and placed in the incubator in the same conditions. After 20 hours of incubation no microbial colonies were observed therefore, the pumping system is said to be an appropriate tool to help with the collection of microbes.

Maintaining the sterility of the system for a long period of time

For the tests regarding the maintenance of sterility level of the system several prototypes had to be built. Additionally, as the tests were conducted inside a building, there were no real air movements that could possibly push air through the system. Therefore, a random error was considered when studying the results of the experiments. For every test, at first, the prototypes were built separately and discarded after use until a reusable prototype was made that allowed for numerous uses after sterilizing with UVC and an alcohol solution. The pattern of the investigation looked as follows. The chambers were sterile prepared before each test and were placed outside the laminar chamber (inside a closed room with little air movements which fundamentally means that during the real mission, taking place outside, the actual time of maintaining the system sterile will slightly decrease) for a certain amount of time i.e., 60, 120, 150, 180, 210 and 240 minutes.

Starting over again after the stated time passed. The chambers were then placed under the laminar chamber (or in a clean room when it comes to the second prototype model), cleaned rigorously according to the procedures that is: from the outside, layer by layer with frequent UVC irradiation sessions and cleaning with an alcohol solution until the innermost chamber was revealed. When the H12 filter from the inner chamber was visible it was sampled from using a Q-tip and, likewise the previous experiment, the remaining of the filter were pressed onto the plate. Additionally, a control test was performed which consisted of placing an opened agar plate for the same amount of time as the current investigation next to the chambers. Both agar plates were sealed with parafilm and placed in the incubator set for 35 °C for 20 hours. All tests were conducted twice for reference. The tests lasting up to 150 minutes and one out of the two trials until 180 minutes were all marked as successful. The second 180-minute trial showed a marginal number of bacterial colonies. We assumed that it might have been due to leakage of the chambers thus, a failure in building this component.

AIR THIEF

CanSat Sterile Assembly Guidelines

Students Allowed on Launch Site

Preparing and disinfecting the equipment

Assembling the CanSat under the laminar chamber

Packing and transporting the CanSat

Handing over the satellite to the competition staff

CanSat Launch & Landing

Preparing the tools and disinfecting the equipment beforehand

Disinfecting and sealing the satellite

Packing and transporting the CanSat to the analysis room

Sterilizing workplace and preparing laminar chamber and the equipment

Sterilizing and disassembling the CanSat

Sampling from the inner filters and transferring the samples onto agar plates

Sealing the agar plates and incubating the collected microbes

Sending the samples to the laboratory for further cytometric analysis

Students NOT Allowed on Launch Site

Preparing and disinfecting the equipment

Assembling the CanSat under the laminar chamber

Safely packing the Cansat in sterile zip lock bags and transportation container

Sending container to competition staff

CanSat Launch & Landing

Preparing the tools and disinfecting the equipment beforehand

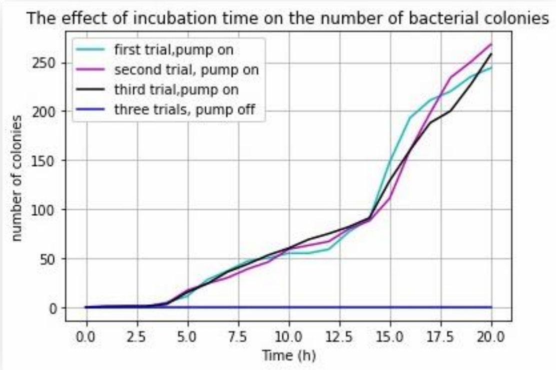
Disinfecting and sealing the satellite

Safely packing the CanSat

Sending the parcel to the team

To test whether it was a simple mistake done when building the chambers or a malfunction in the design of the system four tests were performed. One on the previous, fully sterilized prototype, the second on a newly built prototype, the third using the disposable prototype with one of the F7 filters exchanged for an F9 filter and lastly using the reusable prototype. As suspected, the first test did not work properly therefore, based on the positive results from the newly built prototype it was said that it is due to a malfunctioning component. It is noteworthy that the prototype with one of the filters being F9 displayed no colonies after 30 hours of incubation whereas, the one with double F7 filters showed no bacterial colonies after 20 hours however it did show roughly 5 colonies after incubation time of 30 hours. Regarding the above we will be using the F9 filter during our mission. Lastly, the reusable system was tested.

This time the results were satisfactory thus, we have conducted a follow up test. Next, 3 separate tests on the reusable prototype were conducted for 180 minutes. The results showed that an average of 4 colonies were present on the agar plate after 20 hours of incubation in 35 °C. (The results were as follows: 2 visible colonies on the first plate, 5 visible colonies on the two remaining plates). The results of this investigation showed that a systematic error will have to be considered during the final sample analysis. The remaining tests for 210 minutes and 240 minutes were performed using the disposal prototype version. None of the tests came out positive using the F7 filters however, when tested for the second time using the F9 filters, the number of colonies decreased. We have developed new ways of caulking the system and the first tests were conducted using an additional layer of silicon glue/sealant.



Growth of bacteria collected

From the inner filters after 2 min of Pump ON

Only the tests lasting more than 180 minutes were taken into consideration when sealing the system with a silicon glue. The disposable prototype, when sealed with silicon, passed the tests for 210 minutes as it showed a repetitive number of colonies i.e., 6, 7 and 7 for the remaining tests. The results for all 210 minutes tests were burdened with a systematic error: an average of 6.7 visible colonies were present. Lastly, the test for 240 minutes was conducted twice for reference using the disposable prototype, sealed with a silicon sealant. Surprisingly, after 20 hours of incubation for 35 °C on both agar plates 10 colonies were visible. A systematic error will once again be taken into consideration during the final mission.

An easy test was conducted to see if a formerly sterilized zip lock bag will maintain a sterile environment within. Under a laminar chamber, the zip lock bag was sterilized (the plastic was not affected by UVC light therefore, the tests could be carried out further) and a pre-bought, sterile agar plate was placed opened in the plastic bag for 2 hours all under a laminar chamber. Later, the bag was put in an unsterile room outside the laboratory to expose it to external factors it might come across during the transportation to the launch site. Two trials were performed, and both were executed successfully. Therefore, this method of transportation will be used during the actual mission. Additionally, if the teams will not be allowed for the launch and will have to send the sterile packed segments of the satellite to the competition staff the zip lock bag with its content will be placed within a plastic container/box to provide mechanical support and prevent tearing of the plastic bag which would introduce unwanted contaminants.

Time [min]	Number of visible bacterial colonies after 20 hours of incubation			
	Trial 1	Trial 2	Trial 3	Trial 4
150	0	0	0	0
180_A	0	$3_\star$	0	-
180_B	6	0	0	2
180_C	0_{FR}	2	5	5
210	6	7	7	-
240	10	10	-	-

180_A - First round of tests; $3_\star$ - malfunction of the prototype; 180_B - Tests following the malfunctioning 180-minute test: trial 1 → previous, fully sterilized prototype, trial 2 → newly built prototype, trial 3 → disposable prototype with one of the F7 filters exchanged for an F9 filter, trial 4 → reusable prototype; 180_C - Second round of tests performed using the reusable prototype only; 0_{FR} - First round of tests using the reusable prototype.

Tests of recovery system

To test durability, we decided to drop different weights from different heights onto the parachute while it was under tension. We decided on heights of 20 cm, 50 cm, 100 cm, 200 cm, and 400 cm, respectively. We used weights of 20, 50, 70, 100, 150, 200, and 250 grams. We are analyzing the impact the weights have on a stretched parachute. We are rather positive that the parachute can withstand more pressure, nevertheless, we want to initiate testing with a test that will not put too much stress on the parachute as we do not want to strain it at the very beginning. This ensured us that the parachute is tearproof to a certain degree, however, further tests to prove this will be conducted.

To test the velocity at which our CanSat is falling, we decided to drop our test CanSat from a drone. This allowed us to control the altitude and moment at which the CanSat is launched into freefall. To do this, we needed a drone that would be able to lift our payload, which consisted of our CanSat, which weighs 330g, as well as a device created to drop our CanSat on command. Our test payload was CADed by Henryk and fit the requirements of the CanSat - 115 mm high, and a diameter of 66 mm. It also had a handle through which we could thread our parachute.

Initially, we had one handle, however, after a few tests, we realized this is not how we should attach our parachute. The parachute we are using has 3 strings (that is how it came out of the box), so we decided to later CAD a CanSat that has three threads equally distributed on the edge of the CanSat. This would, theoretically, give it more balance, in comparison to one thread in the center, which gives it equilibrium momentum and makes the CanSat spin, potentially resulting in the strings from the parachute being wound up. The CanSat is lifted via a DJI Mavic drone with a custom holding mounts at the center of the gravity. Moreover, the drone provides video and height measurement of the falls, which allows us to multiple drops at different heights. This device was designed by Henryk, our mechanic of the team. The apparatus consisted of a 3D-printed arm, as well as a servo. It allowed us to drop our CanSat from the drone when it was necessary, using just a switch of a button - the servo was controlled by a controller, previously used for RC cars.

The dropping mechanism is composed of 4 components: a small battery 4.7V, a radio receiver, a handheld transmitter, and a servo. The line holding the CanSat in place is hooked on to a servo arm, the line can be released by a single switch on the transmitter moving the servo arm and letting the hooked string fall off. This in turn enables the parachute to open and the CanSat to fall.

This was especially useful, as we had no time constraints when it came to adjusting the position of the drop. It hung one meter below the drone from a wire, as the bottom of the drone could not have anything covering it, as if this would make it go into landing mode. The wire could not be too short, as the device would oscillate with a higher frequency, one that would make the device unstable and not prone to launch. We flew the drone to an altitude of 30 meters. We firstly had to find a field that was rather flat and devoid of tall bushes and trees, so that our drone and CanSat do not collide with anything in their proximity. We checked the direction of the wind, to check in which direction we should expect the CanSat to land. Furthermore, we decided on recording the drop from both, the drone's and ours, perspective - it would show us how the parachute opens and give us a more incisive view on the freefall in general.

Our trial test was not a definite success - the drop apparatus was using a servo that we found was inadequate to our payload - we were using a 6g servo, which was not giving us enough power to hold the loadout properly. We found this problem as after we pulled the drop switch, the parachute was released, however, the CanSat was still attached to the drop apparatus. We retrieved back to our "base of operations" and made necessary attachments to the drop apparatus. After that, everything went smoothly; the table on the right shows our results. We decided to add 2 meters to our calculations as the strings that we hand the drop apparatus, as well as the distance from the parachute to the CanSat, was approximately 2 meters.

Height [m]	Time to land [s]	Average speed [ms^{-1}]
32.0	5.00	6.40
42.0	6.50	6.46
52.0	10.0	5.20
62.0	9.00	6.88
72.0	12.0	6.00
82.0	10.0	8.20
102.0	15.0	6.80

This means, without considering that the parachute needs to first attain terminal velocity, its average velocity throughout the experiment was 6.56ms^{-1}, and when not using the values that we found were anomalous, we would get 6.51 ms^{-1}. This is surprisingly close to our designated altitude, which we have previously stated to be 6.5ms^{-1}. We previously equated that this parachute will give us the speed of $v = (20.33 \times 9.81) \div (0.785 \times 0.2376 \times 1) = 5.89\ ms^{-1}$. This result, however, was derived from a formula that takes into consideration the density of air at a given altitude of 2 km. This difference, however, is much greater and cannot be caused just by this. This is not bad news, and we will continue to gather more data the next day - this time with more variables of the 55 cm parachute.

We changed locations, as we thought there is a safer and more appropriate field to conduct our tests on. Unfortunately, there was more wind than before. We also adjusted the decoy we were using as our CanSat. Initially we had one handle from which the parachute was attached to, however, Henryk CADed and 3D-printed another version, which had three handles going along the edge of the circumference of the can. Since the parachutes we were using all had 3 strings that were connected to the parachute at both ends, we looped them around the handles to attach them to our decoy CanSat. The second parachute we tested was another rocket-model Klima GmbH 55 m parachute, however, beforehand, we had cut out a hole with a 11.6 cm radius; meaning the hole subtracted a surface area of about 424 cm^2. When we subtract this surface area from the original one - this being 2376 cm^2, we get 1952cm^2. This is the area which was derived from the equation $s = (2 \times m \times g) \div (v^2 \times c \times d)$ to get a surface area that would give us the speed of 6.5ms^{-1} according to this equation.

Our first test began as we launched the drone into the air with our drop apparatus - attached to it was our CanSat with the new parachute. Our results, that can be seen on the right side, have an average fall velocity of 6.64 ms^{-1}. We discovered that this parachute was very gullible to the intensity of wind, so the speed at which the CanSat depended strongly on the direction and intensity of the wind. This means that, on a windier day, it may fall at a speed faster than desired, which would make it inadequate.

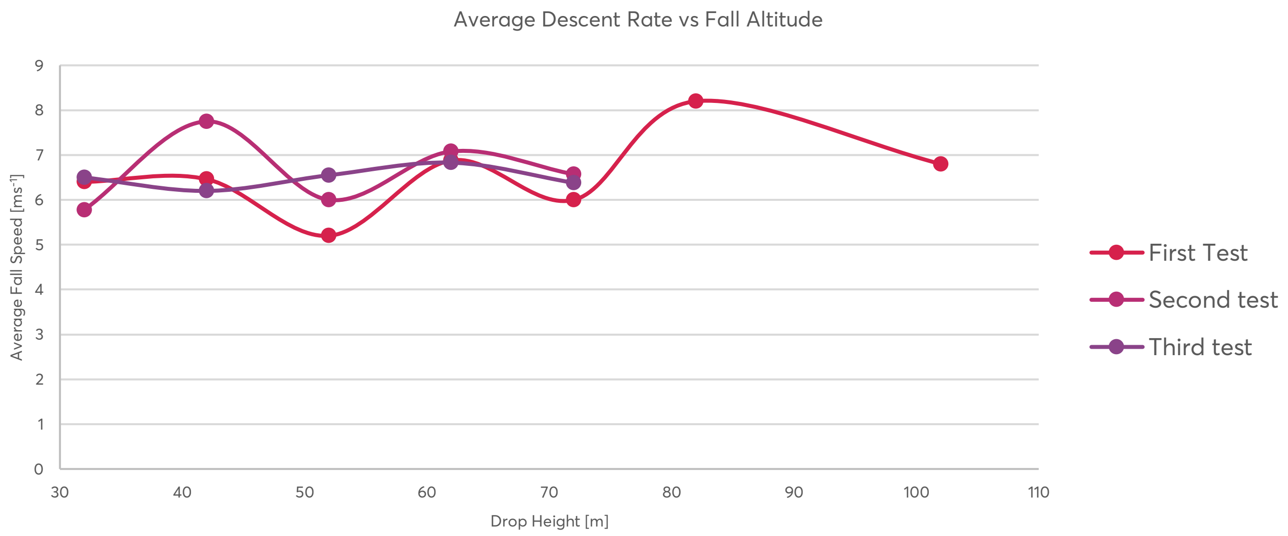
Height [m]	Time it takes to land [s]	Average speed [ms^{-1}]
52.0	9.00	5.78
62.0	8.00	7.75
72.0	12.0	6.00
82.0	13.0	7.08
92.0	14.0	6.57

We discovered that this parachute was very gullible to the intensity of wind, so the speed at which the CanSat depended strongly on the direction and intensity of the wind. This means that, on a windier day, it may fall at a speed faster than desired, which would make it inadequate to use. However, on a day with less wind, this version of the parachute may seem more appropriate as it provides more stability to the parachute and the CanSat.

The third parachute we tested on was yet again a rocket-model Klima GmbH 55 cm parachute, however, this time, it had a hole in the center with a 5.8 cm radius. This means that from the original parachute, which has a surface area of 2376 cm^2, we subtracted 105.68m^2; the remaining area we got was 2270.32 cm^2. The first test of that parachute was a failure - due to unknown circumstances, the parachute failed to open and our CanSat fell. However, after that, tests went rather smoothly. The average is 6.49 ms^{-1}.

Height [m]	Time it takes to land [s]	Average speed [ms^{-1}]
52.0	8.00	6.50
62.0	10.0	6.20
72.0	11.0	6.55
82.0	12.0	6.83
102.0	16.0	6.38

After assessing, we believe this parachute is optimal as the speed it reaches is adequate, and from our observations, the cut-out hole creates a lot of necessary stability for the CanSat. Thus, this parachute will be dedicated to our CanSat. The other two also come really close to our desired speed, however, the first parachute lacked stability, and the second one we tested was a little bit too fast, as well as is the easiest to rip, as the length of the center to the edge is too short. This one (with the 5.8 cm radius hole) seems to fulfil both our requirements for being steady as well as satisfy us with the speed it achieves in freefall. **Here** you can find a video of our testing procedure. On top of the separate test on a demo version of a satellite, we have concluded tests of the full mission with our final version of the Air Thief where the fall speed detected, computed, and recorded on our SD card was exactly in our calculated range at about 6 ms^{-1}.



Tests of folding of the parachute.

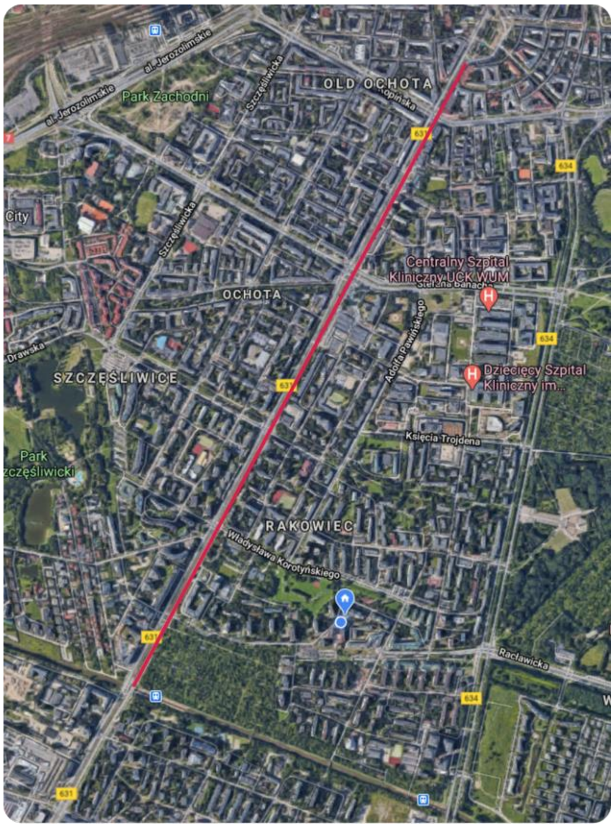
To fold the parachute, it is enough to: straighten the parachute as much as possible, fold the parachute in half - repeat this process twice, and make sure to align corners. Fold the ropes, onto the surface of the parachute - (make sure not to tangle them). Next, you want to loop them back around and bring them back facing the shell of the satellite. Lastly, roll around the ropes, and place it in each structure. You can see this is done here[11]. We have conducted tests of the folding of the parachute, which gave us incredible results that can be seen in **our YouTube video**, where we can see that the parachute is being deployed fully and almost instantly right after dropping our CanSat from a drone at an altitude of around 100 m.

Communication range tests

To transmit the data from the POCU to the ground station we will be using two Feather M0 LoRa RFM96 boards, one with a 16.5 cm pole antenna that is the POCU and another one that is connected to the ground station and reads data from a YAGI antenna that is connected via a female antenna adapter to a surface-soldered uFL connector. To check that we would be able to pick up the CanSat signal at an acceptably large range, we positioned a car nearby a long main road in Warsaw that was over 3 km long. We were in the car with the laptop because of thermal considerations.

The antenna was positioned parallel to the ground [on top of old toilet paper rolls that provided adequate cushioning]. A team member walked away from the vehicle, maintaining comms range via a phone. We carried the POCU of the CanSat along with a Microsoft Power bank that supplied the POCU with power. The OS was at maximum transmitter strength and was sending enumerated Hello World packets with a length of 20 bytes, which is what the OS will normally be transmitting.

We checked how far the POCU could travel until no packet was received for over 30 seconds. At 1.5 km we still received data from a CanSat at no elevation [placed on pavement]. At 2.5 km we still had over 75% packets, which varied because of foliage near the road and because of cars and streetlights causing random error. At 3 km we started to sometimes lose signal but still had a lot of data [50% packet loss avg.], and occasionally had 0% packet loss for ~5 consecutive seconds. At 3.3 km we lost comms for 30 seconds, which finished the test. This is an exceptionally good result given that we were aiming for a 2.5 km range and should be sufficient. [Any signal with RSSI < -89 dBm was not received because incomplete packets were rejected in this test. Check AirOS manual or Software Engineering for information on encoding.] The route shown on the map is roughly what was traveled, length is estimated.



Primary comms range test Route

Total range was about 3 km, signal lost ultimately on top side of path when buildings obscured the transmitter. About half way in we still got data from surface elevation. Secondary tests of fully integrated hardware using drone confirm these results.

We have also conducted testing of the range of the signal with the use of a drone. We have attached our satellite to the drone and decided to see how the strength and stability of our satellite changes with how far away we distance ourselves from our base. The test might have been affected by the electrical fields created by the engines of the drone, however, our tests still showed great results of 1.5km range without any sign of loss of signal or of its stability. We believe that this range could be greater if it were not for the weather conditions on the test day.

[11] Video showing parachute folding technique.

Energy budget tests

The craft battery is composed of three 3.7V Li-Ion cells that together have a combined voltage of 11.1V, which is later processed using converters. To check how long our craft can run in continuous mode (lifespan) without intermittent charging, the batteries were first charged to full and everything was plugged in correctly. After conducting the Final Trials by dropping the CanSat from a drone in a simulated CanSat Finals environment and having the CanSat get stuck on a tree for 4 hours. As a result, we know that 6 h on battery life after performing mission is achievable, we can infer that obviously 6 hours before achieving secondary mission also is achievable since after the 6 h period the pump was still functional at full power. This means that if we had continued the test, most likely the 7 h total calculated theoretical duration would be exceeded. CanSat has passed this full systems health test.

Requirements of the CanSat competition (Mass, Dimensions & Fall Speed)

Our team made sure to fulfill the CanSat competition rules. We also made sure to include a margin error in our final CanSat as we do not know what uncertainties the scaling tools that will be used by the jury have. Our CanSat has a height of 114.8 mm, this was measured with calipers which are precise to the nearest 0.01 mm. We have also made sure that the diameter of our satellite does not exceed the competition's threshold being at 66 mm. The diameter recorded by the team technicians once again using calipers (0.01 mm resolution) has shown a value of 65.5 mm, which is nominal. We have managed to get our CanSat to fall at the required velocity of around 6 ms^{-1}.

Lastly when it comes to requirements of the jury, we have checked the weight of the satellite which must have been between 300 g and 350 g. The weight has shown a value of 348 g while using a scale that has ± 1 g accuracy. We are happy to announce that our satellite has successfully passed all the requirements of the competition in terms of mass and dimensions.

Testing in accordance with *ECSS-E-ST-10-03C 1st of June 2012*

As our team works in accordance with the ECSS-E-ST-10-03C, we decided to go through the "Space segment equipment test sequence" (Figure 5-1). We have decided to tailor down the segment so that it fulfills the needs of our mission. In this, we will include the following tests: physical properties, full functional & performance test, humidity test, acceleration test, and audible noise.

As the Physical Properties test was already mentioned (find more information in Requirements of the CanSat competition).

The full functional & performance test was conducted, and the team had to face a launch day type of situation. The team emphasized the importance of doing everything (integration, ground base and collection) by themselves and as much as possible in field conditions.

The jury was imitated in person by our project supervisor Dr Jakub Bochiński. The team started this test by setting up the ground segment of our mission - the base going through all methods of sterility talked about earlier.

We have prepared our CanSat for flight in a sterilized laboratory and we have managed to ensure sterility during the satellite launch conditions too. We later conducted a dropping test from an altitude of 300m, the CanSat was elevated with the help of a drone and all safety measures were met. The CanSat has passed all missions tests put forward by the team: communication systems, altitude check, GPS location, Pump turn ON/OFF mechanism, fall velocity, recovery system and finally collection of samples.

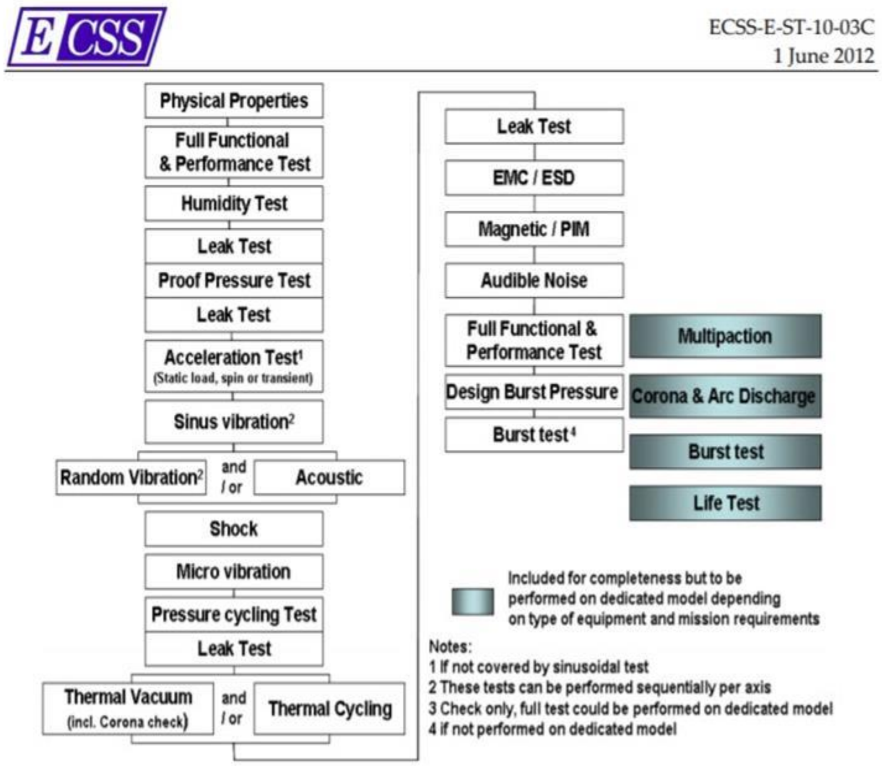
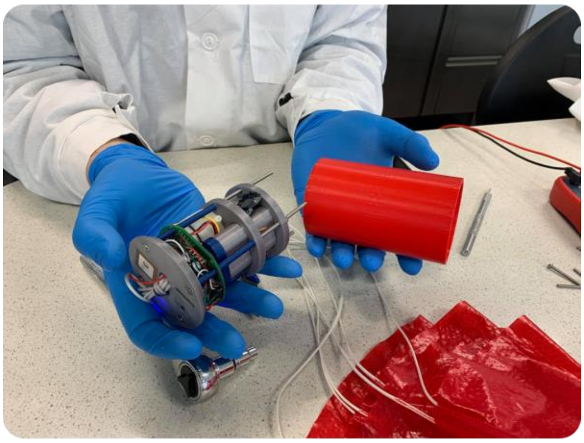


Figure 5-1: Space segment equipment test sequence

After the satellite had landed, the filter chambers were retrieved in accordance with our sterility scheme and were transported to the lab. Once in the lab, microbiological analysis was conducted which has shown bacteria growth on agar plates.

The humidity test was conducted as a proof that our CanSat is not affected by weather conditions. We have managed to conduct various tests of the effect of the landing spot on our CanSat. We have landed with it on snow, water surface and dust and the CanSat has shown absolutely no problems, all systems were nominal. Just for the sake of our argument, we have also conducted a test in hyperbolized conditions in comparison to launch day. We dropped the satellite while it was snowing and once again no issues came up.

The team decided to check the ability of the satellite to survive acceleration and eventual bumps during transportation. We have placed the CanSat itself with no supports in the trunk of the supervisor's car and decided to check its status post-test. We were accelerating and brusquely braking to provide actual proof of survival and once we returned to base the CanSat was still in standby mode and had not initiated the mission. This shows great potential as our team has ruled out some main problems some teams might encounter while accessing the launch pad location. The acceleration tests were also conducted to prove the ability of the satellite to survive high G forces that will be present in the launch of the rocket. Although our test is unable to portray the same conditions, we believe the satellite's core is strong enough to withstand the acceleration of the rocket. The team has also conducted an audible noise test in a natural environment which means with all side noises of the city. After landing the CanSat initiates the buzzer which in sequences provides sound for it to be easier to be found. The team members decided to land the satellite, locate it thanks to GPS coordinates and try to measure how far away from the landing location team members were able to hear the buzzer. The test came out positively as the team members were able to hear the buzzer from around 10m which will facilitate the localization of the satellite.



Integration of sterile CanSat

The CanSat is now being assembled in the Cleanroom and is sterile.

Project Planning

Time schedule

Task	Due Date
Filters ground pre-test	20-21.10.2020 (Completed)
Filters final ground test	12.2020 (Completed)
Finish Preliminary Research Paper	Beginning of March 2021
Finishing touches to final research paper	Near FDR
Creating Social Media	10.2020 (Completed)
PDR pre-design	18.10.2020 (Completed)
Dividing Writing Tasks Regarding PDR	17.10.2020 (Completed)
Verifying PDR elements	21.10.2020 (Completed)
Reaching out to companies	12.02.2021 (Completed)
Scheduled meetings	Ongoing
Presenting the project to possible investors	15.03 (Completed)
Buying and gathering products	As fast as possible (Completed)
Meeting with Thorium	16:00-18:00 22.10.2020 (Completed)
Establishing communication	25.10.2020 (Completed)
PDR submitting	10.2020 (Completed)
Prototyping the Satellite	10/11.2020 (Completed)
Designing the satellite in CAD	10/11.2020 (Completed)
Finishing touches to final (CDR) satellite structure design	02.2020 (Completed)
CDR dividing writing tasks	11.2020 (Completed)
CDR pre-design	20.12.2020 (Completed)
Satellite structures check up	End of 01.2020 (Completed)
Start of building the satellite	Beginning of 02.2021 (Completed)
Finishing touches to satellite	20.02.2021 (Completed)
Testing the collection method from the chamber	02.2021 (Completed)
Final Communication System Test	02.2021 (Completed)
Final Satellite Structure test	02.2021 (Completed)
Final Ground Segment Test	02.2021 (Completed)
Final Communication System Test	02.2021 (Completed)
Verifying CDR elements	25.02.2021 (Completed)
CDR submitting	15.01.2021 (Completed)
Exam Session	*14-18.12.2020 (Completed)*
Christmas Break	*21.12-06.01.2021 (It was too short)*
CDR submitting	15.01.2021 (Completed)
Landing test	01.2021 (Completed)
FDR dividing writing tasks	Completed
FDR pre-design	Completed
Verifying FDR elements	Completed
FDR submitting	01.03.2021
Final satellite check-up	08.03.2020
Laboratory organization	02.2021 (Completed)
Launching the satellite	March 2021
Sample collection and analysis	End of March 2021
Results	April 2021

Task list

State	High Level Task	Lower-Level Task	State
Done	Writing PDR	Overall design	Done
		Dividing work	Done
		Checking Specific Parts	Done
		Submitting PDR	Done
Done	Writing Final Research Paper	Overall design	Done
		Dividing work	Done
		Contacting Professors	Done
		Checking data	Done
		Checking Specific parts	Done
Done	Filters Ground pre-test	Choosing and buying filters	Done
		Assembling the filters	Done
		Collecting data	Done
		Investigating data	Done
		Comparing obtained data to theoretical data	Done
Done	Outreach Program	Creating Instagram account	Done
		Creating Facebook account	Done
		Creating project's website	Done
		Advertising project and companies	Done
		Creating brochures	Done
Done	Presenting the project to investors	Creating a presentation & Writing a script	Done
		Q&A regarding the mission	Done
		First trial of presenting	Done
Done	Satellite	Prototyping the satellite & designing the CAD	Done
		Buying materials	Done
		Building the satellite's skeleton & frame	Done
		Assembling electronics	Done
		Programming the satellite	Done
		Designing the parachute	Done
Done	Ground tests	Satellite's test from a drone	Done
		Filters final test	Done
		Parachute test	Done
		Overall test	Done
		Checking the measurements	Done
Done	Writing CDR	-	-
Done	Writing FDR	-	-
Done	Gathering primary sensor data	Choosing sensors	Done
		Testing Altimeter	Done
Done	Establishing communication	Choosing radio module	Done
		Testing radio module	Done
		Choosing antenna design	Done
		Designing antenna	Done
		Testing antenna	Done
Done	Structuring clean chamber	Making the inside of CanSat sterile	Done
		Placing a sterile case inside CanSat	Done
Done	Collecting samples at ground level	Preparing and analyzing microbes	Done
		Checking if method of collection is successful	Done
		Checking if method of separation is successful	Done
Done	Minimization of sample uncertainties	Reducing unsterile surface area of satellite	Done
		Calculating the possible number of microbes commonly found near the ground	Done
Done	Locating the satellite	choosing GPS module	Done
		choosing GPS antenna	Done
		testing GPS module and antenna	Done
		testing minimal height, accuracy, and reliability of the GPS module	Done
Done	Landing of the satellite	choosing a parachute	Done
		testing parachute's durability, rate of fall and ability to deploy reliably	Done
		testing the stability of CanSat's base	Done
Done	Picking an onboard computer	testing the onboard computer	Done
Done	Casing of the satellite	choosing a material	Done
		CAD model for casing	Done
		testing the casing	Done
Done	Testing the reliability of the glovebox	Testing the level of sterility	Done
		Testing the effect of UVC and Isorapid/ethanol	Done
		Testing the growth rate	Done
		Testing transportation methods	Done
		Testing the collection method from the surface of the filter	Done

Resource estimation

Budget

Product	Price [PLN]	Availability
Radiora Yagi 270 Antenna	441.50	Received ✓
NW Air Pump 5V-6VDC Miniature Vacuum Pump	57.00	Received ✓
Accumulator; Kinetic; MS-AL-14500K; 3,7V	61.30	Received ✓
Product 'Filtr do Rekuperatora F7 Mata Włóknina Filtracyjna'	13.00	Received ✓
Beitian Dual BN-220 GPS GLONASS	37.92	Received ✓
Protoboard from CanSatKit	10.00	Received ✓
Raketenmodellbau Klima GmbH	58.54	Received ✓
Pololu 5V, 2.5A Step-Down Voltage Regulator D24V22F5	37.40	Received ✓
Diode: LED 5mm RGB	0.90	Received ✓
MPL3115A2 - digital barometer, pressure, and altitude sensor 110kPa I2C 3.3V module - SparkFun SEN-11084	63.22	Received ✓
Grove - module with passive buzzer - Seeedstudio 107020109	12.12	Received ✓
Feather M0 + radio module (integrated) 433MHz RFM96 LoRa - Adafruit 3179	192.50	Received ✓
FeatherWing datalogger - RTC PCF8523 + microSD Shield for Feather - Adafruit 2922	55.82	Received ✓
N-Mosfet	14.90	Received ✓
3D Printing cost [1x filament roll]	150.00	Received ✓
Total onboard CanSat [=267.52 EUR]	1206.12	Checked ✓

External support

We have contacted an overall of 100 companies from around the World. The companies were mainly from Belgium, Poland, USA and Switzerland, France and three other countries. As of the 28th of February 2021, we have received a positive response from 7 partners: Adamed, Thorium Space Technology, Cubic Inch, JLCPCB, Akademeia High School, Cloud Ferro, and the Jagiellonian University of Cracow. We have also managed to gain sponsorships from 6 companies: Fundacja OSHEE, Fordewind, Solter Capital, BioLab Invest, DaviPharm & GJS Investment. All the partners agreed on collaborative work with the Air Thief Team and provided a letter of intent.

Adamed agreed upon helping us with the ground segment of our mission including the provision of specialized equipment, private workshops, and a letter of intent together with an acceptance of our analysis. Thorium Space Technology gave us a helping hand regarding our satellite communication system and officially approved of our telemetry system. Cubic Inch has confirmed the collaboration with our team regarding using 3D technology to improve the overall design and functioning of the satellite. Cloud Ferro has proposed to support the team substantively mostly by giving us access to CREODIAS and the possibility to work with the company's specialized teams. Finally, we have received an official acceptance letter of the methodology used in our project from dr. Rafał Mostowy and mgr. Edyta Żyła. Our team has also received two negative responses from Planet Partners and Blue Dot Solutions. Planet Partners has already started working on the ECR project therefore is unable to support our mission. Blue Dot Solutions does not have enough budget and personnel to take on a new project. The team is satisfied with the number of partnerships it has gained, and therefore decreased the amount of action taken in that field.

Fundraising Scheme

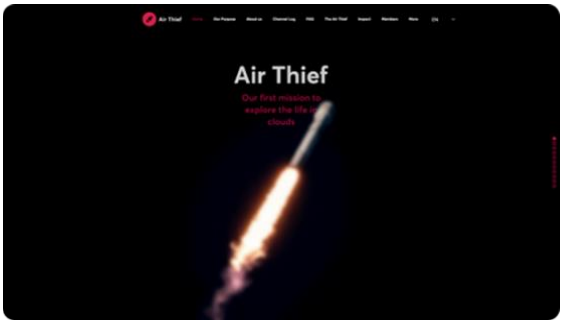
The Air Thief team needed to get the most out of our sponsors as we want our final CanSat to be as reliable as possible. We also need the biggest budget possible as our research is costly, and with more money to spend, we can get more accurate results. It also allows us to choose and test the best possible version for each component of our CanSat. Initially, we were given 1000.00 PLN by the school as a head start to plan our CanSat. However, we soon realized this is not enough, as we were not aiming at just building the CanSat but building the best CanSat for fulfilling our mission. This means we would need to spend a few times more than the final CanSat budget, which is held at 2,000.00 PLN. We soon reached out to a plethora of companies - 100 in total. Most of these were national companies, however, some were companies that we reached out to with a multinational range. In total (for now), we have received 6 positive responses and garnered around 15,000.00PLN. The companies we reached out to were chosen by us based on our research - we wrote to firms that we believed would be intrigued by our project and willing to sponsor it. This process was, unfortunately, more complicated than anticipated as it was a big challenge for us to present ourselves to these companies. Moreover, it was extremely time consuming and difficult for our team to assemble the CanSat together, so the trial model has taken more time than predicted to be completed.

Companies:

- **BiolabInvest** is a Polish company focused on creating new biotechnology as well as pharmaceutical products. They are a company which often finances smaller start-ups that aim at creating new and innovative ways of creating a healthier world - therefore we considered Biolab to be an extremely appropriate sponsor for us.
    1. Our contact was done primarily through the exchange of emails with the company's CEO. These emails were sent from one of our members, Tymon's email, where the Air Thief email was CC.
    2. The company was first to respond out of the many that we concurrently informed, which we were grateful for as we always awaited their response because of the field they are working in. The amount they were willing to give us was 1,000.00 PLN.
- **The Oshee foundation** is a Polish foundation which mainly focuses on creating and supporting initiatives that lead to creating a better and healthier lifestyle in the future, as well as helps people in need. We considered writing to them because we believe our project is a project that has the potential to help scientists and researchers in the future.
    1. Our contact was conducted primarily through email; we got in touch with one of the employees of the company, and after proposing them our project, they kindly agreed to support our project.
    2. The amount they were willing to give us was 2,000.00 PLN.

- **GJS investment** is an investment firm which takes interest in anything that is willing to help the economy and the people. On the internet, we have found data that told us that it also supports medical and pharmaceutical research, and because of the nature of our project, we decided to try to reach out to them and see if they would be willing to sponsor us.
  1. Our contact was conducted via email. After we sent over our pitch, the person we contacted asked us questions about our project, for example if our research can be used in medical or business purposes.
  2. We were more than happy to explain to him how we believe our project has the potential to be a big development in pharmaceutical research. After this, the company has agreed on sponsoring us. The amount they were willing to give us is 3,000.00 PLN.
- **Fordewind** is a private equity firm, which invests mainly in start-ups. Its investments span from investing in companies such as Carsmile, Sales & More, as well as Verdeat. We believe the company was an adequate choice for investing in us as our project is innovative.
  1. Our contact was conducted via email. After we sent over our pitch, the person we contacted had a few questions regarding the financial situations of our project.
  2. After we provided answers to his questions, he was glad to sponsor us. The amount they were willing to give us is 2,000.00 PLN.
- **Solter capital** is a private equity firm, which invests in different businesses from various sectors, such as Bakalland, Cenatorium, MTM Broker, and Wiko. We reached out to them as we believed they would be interested in sponsoring our project, as we believe it has the potential to be a big development in pharmaceutical research. After this, the company has agreed on sponsoring us.
  1. Our contact was conducted via email.
  2. After we sent over our pitch, the person we contacted was more than happy to sponsor our project. The amount they were willing to give us is 2,000.00 PLN.
- **DaviPharm** is a firm from the pharmaceutical branch that manufactures high-quality generics and that produces over 300 high-quality medicinal products that are distributed in Vietnam. We believe that this company would be interested in collaborating in such an innovative project. Additionally, a partnership with an international company will allow us to expand even more our reach and allow us to touch even more students around the world. We believe that this partnership will allow us to expand our ability to provide knowledge and present our mission to the World.
  1. The contact was conducted via email. We reached out to the company and presented our ideas and course of action by which the board was overly impressed. We were granted with a sponsorship from the side of DaviPharm.
  2. The amount they were willing to support our project with is 1,000.00 USD, which gives around 4,000.00 PLN.

Outreach program



One of our main sources of reaching out to others is the Air Thief website - it is the main place which keeps our project up to date and shows what we are currently up to. It also clearly depicts the objective of our project, how we want to get there, as well as what we will do to get there - this is made clearly by the FAQ section as well as the Air Thief section of the page, which both answer any doubts and questions the viewer may have about the project. They also contain specific details such as the measurements and 3D model of our CanSat, as well as the models of the components that we will be using, and of our reports that have been written during our research - this is something we strive for, as we want our project to be open-source. Moreover, we have created an entire tab dedicated to the open-source actions taken by the team.

We have a YouTube video summarizing our Outreach program, and also a video regarding Air Thief in general. All our software is available on an open source GIT repository under a Free for Academic Use License.

You can see their materials from our YouTube channel with instruction videos as well as our GitHub repositorium. Furthermore, the page also contains a blog tab, which keeps viewers updated on our progress with research and other outreach, like the Facebook page - this is useful as it is an easy way for the website viewers to see what we have worked in most recently. The page also contains a tab with all the team's members, which not only makes it clear that this is a project done by 5 high-schoolers, but also gives a reference to where to contact us if any questions arise.

Moreover, all our partners and sponsors are represented on the page, as they are our main sources of support, and we believe it is only right to proudly mention them when displaying our work. The website also acts as a guide of reaching out to us via email or other social media, if the need arises. It is the easiest way of educating yourself about our project, as well as reaching out to us if need be, especially when it comes to things such as organizing webinars and interviews.

Another platform on which we share our progress is Facebook. We chose Facebook as it is a useful social platform to distribute the latest news about our project to people who are keen on being updated - most people who view our page are not sponsors, but rather the younger generation who took interest in our project.

Facebook is a media checked every day by most teenagers, that is why we believed it was a worthy investment of our time. It is a source that keeps our followers up to date, with posts regularly uploaded every week, regarding every update from progress to our research to new articles and interviews conducted with us. Sharing our experiences and day to day activities or struggles allows other people to have an insight into our project, time management and team organization. Facebook allows the team to try out ideas shared by the rest of the community, scientists can share their thoughts and help to expand the Air Thief's possibilities.

One of our partnering companies, Thorium Space Technology, mentioned us on their Facebook page ThoriumSpace, which is a great way of spreading Air Thief team's knowledge and promoting our project. The team is satisfied with the promotion of our project on Facebook as we have reached over 200 people that like our page through this media outlet.

We have also branched out into using YouTube as a platform on which we educate our viewers. We have conducted a handful of instruction videos; every video talk about a different aspect of what each team member is working on. We release two episodes a week on average, mostly on Mondays and Thursdays. The videos consist of each member introducing themselves, and then going into detail about their line of work, and approximate to about 5 minutes. Apart from that, we release videos that are crucial in explaining some technical aspects of the CanSat such as the way we must fold the parachute for it to open approximately instantaneously. Additionally, we also try to remain active with our testing content, where we publish videos regarding the tests we conduct and the way we must prepare them. This idea came to us as we strive for more educational value in our project. We do not only wish to win this competition, but we would also like to teach and inspire as many people as we can through our experience, we have gained thanks to CanSat.

Our high school is represented in the CanSat competition by two teams: Green Can & Air Thief. Both our teams decided to collaborate and donate a makerspace full of components and tools for a potential workshop for future teams. Our school has shown interest in continuing to encourage students from our school to take part in the CanSat competition, therefore we have decided to ease their job by presenting them a full set of components needed for completing the primary mission of each CanSat and provide them with the tools needed to pursue their dreams. We are also planning on continuing mentoring younger students throughout this project. As we are aware that our team was particularly lucky to have easy access to 3D printers thanks to two members owning them, we have decided to fund a Prusa MK3S to our school's Physics Lab with our leftover money.

After contacting numerous media outlets, we had a few positive answers. An article that has already been published about our project on kosmonauta.net (**article**). Another article will be published soon on 3-lab.pl.

Both articles touch upon the objective of our mission as well as why we set out to accomplish it in the first place. It also touches They also upon mention another goal of our mission, this being the accessibility of it - all our work is publicly available in the article, which will hopefully lead to even greater interest in the website's viewer base. We want to reach out using articles as we believe that the media outlets we are using and will be published in have an audience that would be interested in our project. It will help us garner more exposure as well as intrigue, interest, and possibly inspire other readers to hopefully try something similar or get invested in the life in clouds, as one of our main goals is gaining exposure to educate our audience.

Moreover, we want to reach out to a younger audience in the form of a webinar. The team organized a webinar for the younger classes to teach them about the CanSat competition, as well as what our team is creating and how we are doing it. All the members of our team participated, as we all wanted to put as much input into the Webinar as possible. Mainly, however, we wanted to do this as inspiring a younger generation of scientists is one of our main goals when it comes to our overall objectives. The CanSat competition as well as our objective touch on a multitude of different subjects, which means a larger pool of people may be inspired. Whether it encouraged listeners to take part in the CanSat competition in the following years or piqued the interest of viewers about the life in clouds, we believe our webinar was a successful message to the youth. We have added a form on our website that allows anyone to request another webinar in the future. Moreover, the team organized another webinar, this time to answer any unanswered questions - this webinar was open to anyone and was meant to help better understand the CanSat project as a whole - it also definitely motivated other viewers to participate in the competition in the future. We dedicated most of our time to answering viewers questions.

We are currently talking about our project in other outlets, such as the school newspaper or a radio interview, all for the purpose of further educating and informing more people about projects such as ours, and how and why we are participating in them. The team will have an audition in Radio Szczecin. We will have a special audition just for us, organized by Ms. Dorota Zamolska on her Sunday program - the audition is scheduled post-launch. We have reached out extensively, however, many outlets would prefer to engage with us after we have launched our CanSat. As the project is open-source Air Thief's has shared the **PDR report** and **CDR report** on Scribd. We are planning on sharing the rest of our reports on this platform, as it allows for downloading and using the documents uploaded.

We have also created a GitHub page to extend into the open-source aspect of our project. We have described with further detail every technical aspect of our CanSat. We have also made it easy to follow and included guides, as well as given links to download the work we have done over the last few months. We really want this project to be as accessible to everyone as possible, and the GitHub page allows for just that. We believe giving access to the work we have done to the public may further inspire the future generation as well as more research in these fields of study. We want our mission to be an aid to future missions - giving easy access to it online makes this goal more possible than before.

Furthermore, we will also be having an interview with a well-recognized YouTube channel, Astrum - a channel mainly focused on space travel. The channel has a huge audience of over 543,000 subscribers - this gives us the potential of a huge audience being exposed to our project. YouTube is a platform most often used by the younger generation, so it reinforces our goal of educating and inspiring a younger audience. The interview is scheduled between 25.02 and 11.03.

END OF DOCUMENT

'Dare Mighty Things'