LookMumFlyingCan

Bartłomiej Nowodworski 1^{st} High School in Cracow

Critical Design Review

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supervised by
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Abstract

This design document will provide ESA and ESERO with all important information on the experiment. During all experiment phases the design document is the only documentation for describing the experiment in detail. The chapters can have been modified and additional sections have been be added by the experiment team if appropriate. The design document will be one of the evaluating criteria for the jury of the European CanSat competition.

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Abbreviations

ABS Acrylonitrile Butadiene Styrene. 10

ADS-B Automatic Dependent Surveillance - Broadcast. 5, 7, 8, 9, 11, 12, 15, 16, 19, 26

AGH AGH University of Science and Technology in Cracow. 6

API Application Programming Interface. 18

ASP Academy Of Fine Arts in Cracow. 6

ATC Air Traffic Control. 8

CNC Computer Numerical Control. 23

CTF Capture The Flag. 6

ELT Emergency Locator Transmitter. 8

EPIRB Emergency Position Indicating Radiobeacon Station. 8

ESA European Space Agency. 2

ESERO European Space Education Resource Office. 2

GNSS Global Navigation Satellite System. 7, 9, 10, 11, 12, 15

ISM Industrial, Scientific and Medical bands. 8

LNA Low-Noise Amplifier. 12

MCU Micro Controller Unit. 12, 16

PCB Printed Circuit Board. 2, 5, 14, 15, 16, 23, 26

PLT Personal Locator Transmitter. 8

PSU Power Supply Unit. 5, 11, 13, 14, 23, 26

RF Radio Frequency. 2, 5, 6, 8, 11, 12, 13, 14, 15, 23

SBC Single-Board Computer. 2, 5, 9, 12, 16

SDR Software-Defined Radio. 7, 8, 12, 15, 16

SPI Serial Peripheral Interface. 15

SWD Serial Wired Debug. 15

TDMA Time-Division Multiple Access. 14

TTY Terminal. 15

UART Universal Asynchronous Receiver-Transmitter. 15

USB Universal Serial Bus. 15

USB 2.0 Universal Serial Bus High Speed. 15

Changelog

PDR (2020-10-27)

Changed

- We have changed the profile of the secondary mission. The CanSat will perform a mock rescue mission and capture the ADS-B and Cospas-Sarsat data

CDR (2021-01-15)

Added

- Project status section
- Added accelerometer (see Secondary mission devices)
- Tests (see Test campaign)
- PCBs and schematics have been added (see PCBs)

Changed

- The parachute size has been recalculated (see Recovery Systems)
- RF signal path redesign (see Figure 6)
- The introduction has been revisited to provide a clearer view of our mission objectives
- Fibreglass tubing was added around the CanSat (see Mechanical Design)
- Software environments have been updated (see Software)
- Weight has been recalculated (see Weight)

Project status

Assembly in progress

Finished:

– The flight computer, enviorment and PSU PCBs have been constrcuted, assembled and are working.

– The body has been constructed.

– The fibreglass tube has been constructed.

– SBC software has been prepared.

Yet to be completed:

– The RF board.

– Microcontroller software.

– Ground station software.

– Thorough testing.

1 Introduction

1.1 Team organisation and roles

Team supervisor: Piotr Gracjasz

Team members (students of the Bartłomiej Nowodworski 1st High School in Cracow):

- Miłosz Łagan - **Team Leader**
  - field of work: electronic and mechanical design, CanSat software
  - experience: 4 months of developer work in a fintech company
  - skills: design of mechanical constructions (Autodesk Fusion), electronic and basic RF circuits design (Autodesk Eagle / KiCad)
- Jakub Bubak
  - field of work: data visualization, ground station software, public relations
  - experience: broad experience in creating promotional materials, 3 years of programming, editing promotional materials for ASP Kraków and AGH
  - skills: film editing, programming, photography, algorithms, engineering
- Mikołaj Gazeel
  - field of work: ground station software, mechanical and electronics design, team's website
  - experience: 3 years of algorithmic theoretics, cryptography CTF challenge author, website design experience, related electronic experience through projects, broad experience in photography
  - skills: cryptography, algorithms, electronics, engineering design
- Sebastian Florek
  - field of work: mechanical and recovery system design, test launch engineer
  - experience: 3 years of model rocket design, winner of multiple polish competitions - S 6 S 9 S, 3rd place in the European Championships - S3,6,9 classes
  - skills: theoretical mechanical construction, model rocket design, recovery systems

We dedicate at least 2-3h to team meetings every week. Due to the COVID-19 pandemic and the lack of any equipment in our school, we are unable to do any work from there. Engineering is mostly done from our homes and Hackerspace Kraków.

1.2 Mission objectives

Our mission has two distinct objectives that coexist with each other on the CanSat. We plan to fulfill both of them.

1.2.1 Primary mission

While operational, our CanSat will measure its position using a GNSS receiver supplemented with precision altitude readouts from a pressure sensor. Temperatures outside and of important elements such as the Linux computer and the SDR will be measured to keep an eye on their thermal performance. The temperature and pressure data will be relayed to the ground station (see Communication), where it will be monitored for any deviations and visualsied using out software.

1.2.2 Description of the ADS-B system

Most commercial planes are fitted with ADS-B system transponders. It is a surveillance technology used by air traffic controllers to determine precision aircraft position using the Global Navigation Satellite System. During emergencies such as plane crashes the knowledge of an exact path the plane has traveled allows the first responders to go directly to the crash site. Unfortunately, the system is far from having 100% global coverage. Therefore, several 'dead zones' exist around the world in hard to reach remote areas such as Siberia, the Atlantic Ocean or Central Africa. In the case of an emergency, those sites being out-of-range of the ADS-B system result in a larger area to be searched by Search and Rescue, and the need of approximating the plane path using other data sources. Recently, there have been some projects [3] focused on providing 100% coverage such as GOMX-3 [1] or Aireon [2] company's plans to launch its satellite fleet over the Asia-Pacific region by 2021.

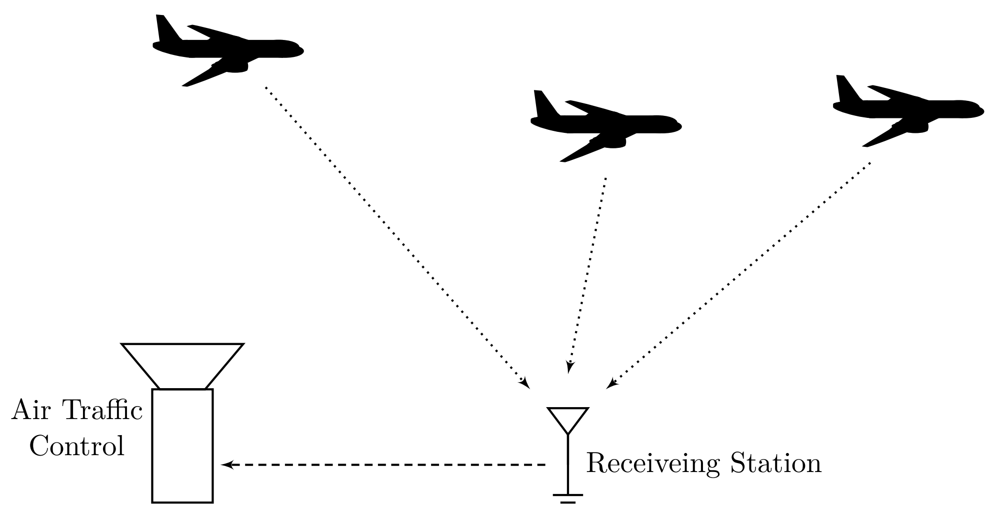

Figure 1: ADS-B overview

1.2.3 The ADS-B mission

This objective, is to monitor, receive, decode and relay ADS-B positional data sent by airplanes in radio range. The received data will allow the ATC to 'see' planes in places not covered by existing ADS-B network. The CanSat serves as a 'proof of concept'. It will not be ready to be deployed over large bodies of water (see above), but will be the base upon which any such future developments could be built. To demonstrate the functionality of an on-board ADS-B receiver, we will be sending live captured plane positions to a mock air traffic controller station and rendering a map showing the number of planes spotted compared to its altitude. Such measurements might also help dissect the exact implications altitude has on over-the-horizon reach, due to RF waves refraction in the atmosphere.

1.2.4 Description of the Cospas-Sarsat system

Globally, the Cospas-Sarsat system is a satellite-aided search and rescue system. It serves as a middleman between emergency responders and the people in need. A crucial part of Cospas-Sarsat are ELT(aviation), EPIRB(maritime), and PLT(personal use) distress radio-beacons activated in the case of an emergency , sending location and details about the sender. This information is shared with rescue teams, greatly speeding up the search process in any place on Earth.

Every year, dozens of distress signals are being sent and emergency response teams are being deployed to provide help to those in need. Some of those accidents happen in remote locations on Earth where emergency infrastructure is poorly developed thus slowing down the responders. We want to create a device that will be able to assist them directly by providing information about the target location in real-time.

1.2.5 The emergency beacon mission

During the launch campaign, we are planning to create a mock rescue mission. A mock distress signal will be sent from a test radio-beacon (on a frequency in the ISM band, not used by Cospas-Sarsat). Our CanSat should detect and relay the location signal to the responders and our ground station in real-time.

1.2.6 Objective summary

We are designing a CanSat that will be equipped with ADS-B and Cospas-Sarsat receivers to be used during ground or nautical rescue missions. Such device could be used an aid for the responders as well as to record plane paths filling in the gaps, in the ADS-B system. Our goal is to test the possibility of placing small cubesat-like relaying devices positioned on the Low Earth Orbit or on high altitude balloons. This will allow them to receive ADS-B signals with greater range, monitor Cospas-Sarsat radio beacons' activations and relay live data pretty much indefinitely.

We are also investigating the possibility of creating a low cost flying Software Defined Radio, platform capable of receiving technically any signal thanks to the SDR technology and on-board Linux processing unit. It would not be possible without recent introduction of Raspberry Pi Compute Module 4 which is a powerful and easily upgradable System-on-Module. Due to high power consumption of internal components, special attention to thermal performance and power management should to be paid.

2 Description of the CanSat

2.1 Mission Overview

CanSat will initially be in a low-power state. After being released from the rocket the CanSat will open the parachute and slow to a descent rate of around 8 m/s and start sending telemetry to the ground station. ADS-B and Cospas-Sarsat data will be captured, pre-analyzed, compressed and relayed by the onboard Linux SBC and a software-defined radio receiver in order to allow live data acquisition on the ground. Precise altitude data, required for the CanSat's mission, will be determined using a GNSS and a pressure sensor. Ground station communication will be performed using a two-way scheme.

After landing, the mission payload will be switched off to greatly reduce power usage and a special telemetry signal will be sent to increase the odds of CanSat retrieval by the recovery team.

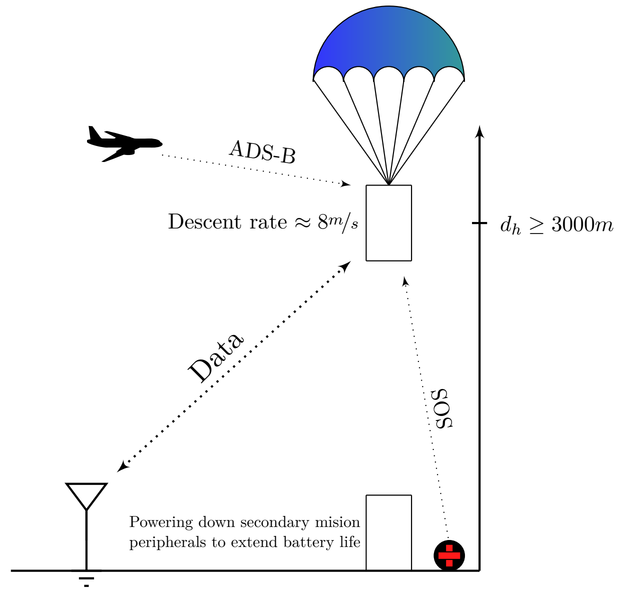

Figure 2: CanSat's deployment

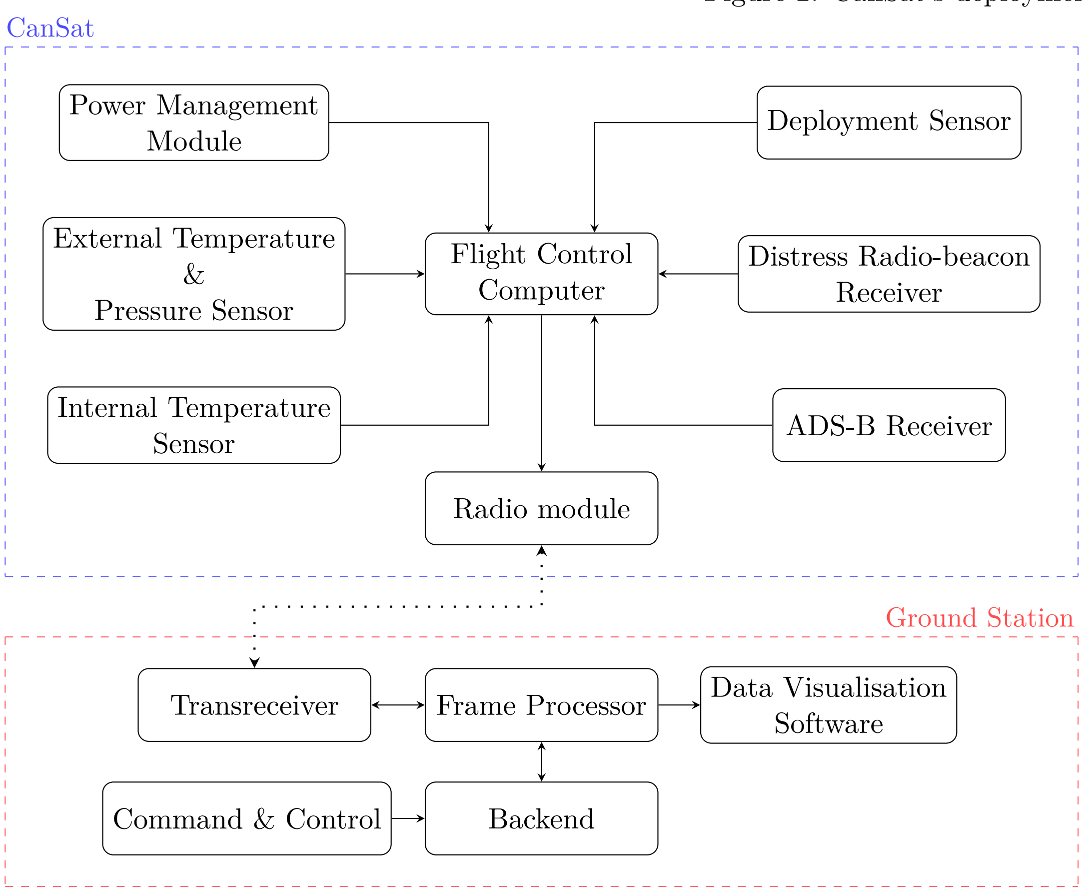

Figure 3: CanSat's overview

2.2 Mechanical design

Final prototyping

Components inside the CanSat are modularized into a top cap (GNSS module, environmental sensors and ADS-B antenna), a bottom cap (communication antenna), fibreglass tube, a battery and power supply assembly, a flight computer assembly (flight computer, Linux computer, RF board, SDR receiver). Most of the structure was 3D printed with ABS filament using a Prusa i3 MK2S printer. Individual modules are held together with M2 bolts running from the top lid to the bottom one. Batteries are placed in a specially designed 3D printed holder guaranteeing rigidity and good electrical connection. The fibreglass tube encompasses the device providing lightweight protection of the internal components. It is mounted using three screws to both lids and presses towards two o-ring seals making the CanSat water-resistant. Other holes in the structure are sealed with silicone.

Full Cansat's 3D render is available at:
a360.co/3jhvYEK - Fusion 360 online viewer

Figure 4: CanSat's render

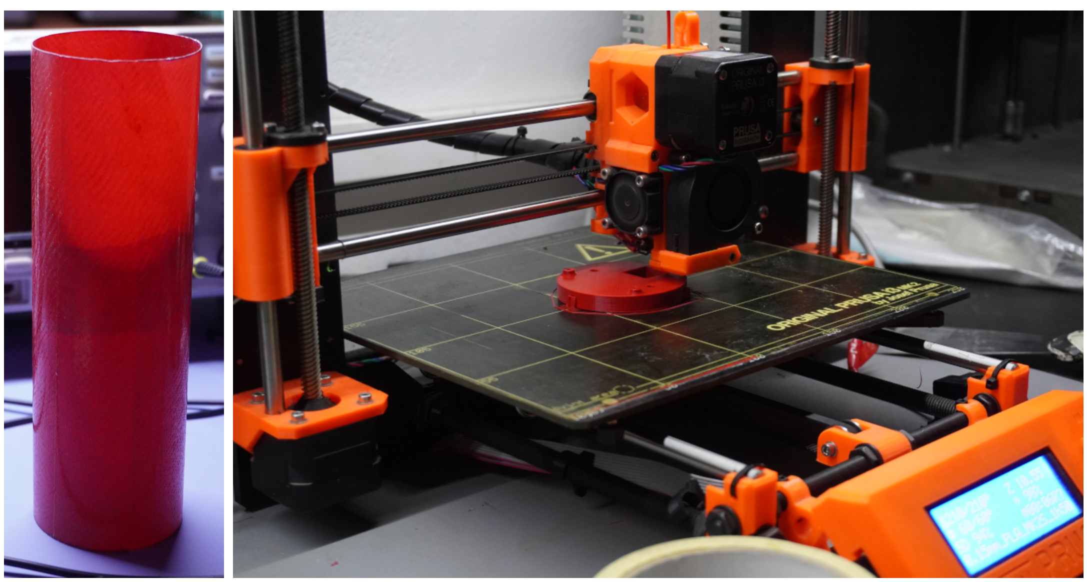

Figure 5: a: Fibreglass tube b: One of the elements being printed on a Prusa 3D printer

2.3 Weight

Component	Weight
Raspberry Pi Compute Module 4	15g
Flight Computer Board	15g
uBlox SAM-M8Q	7g
Nooelec NESDR Nano 3	12g
RF conditioning board	15g
Battery Assembly	155g
Enclosure and recovery system	100g
Total	319g

Figure 6: CanSat's components weight

2.4 Electrical design

2.4.1 General architecture

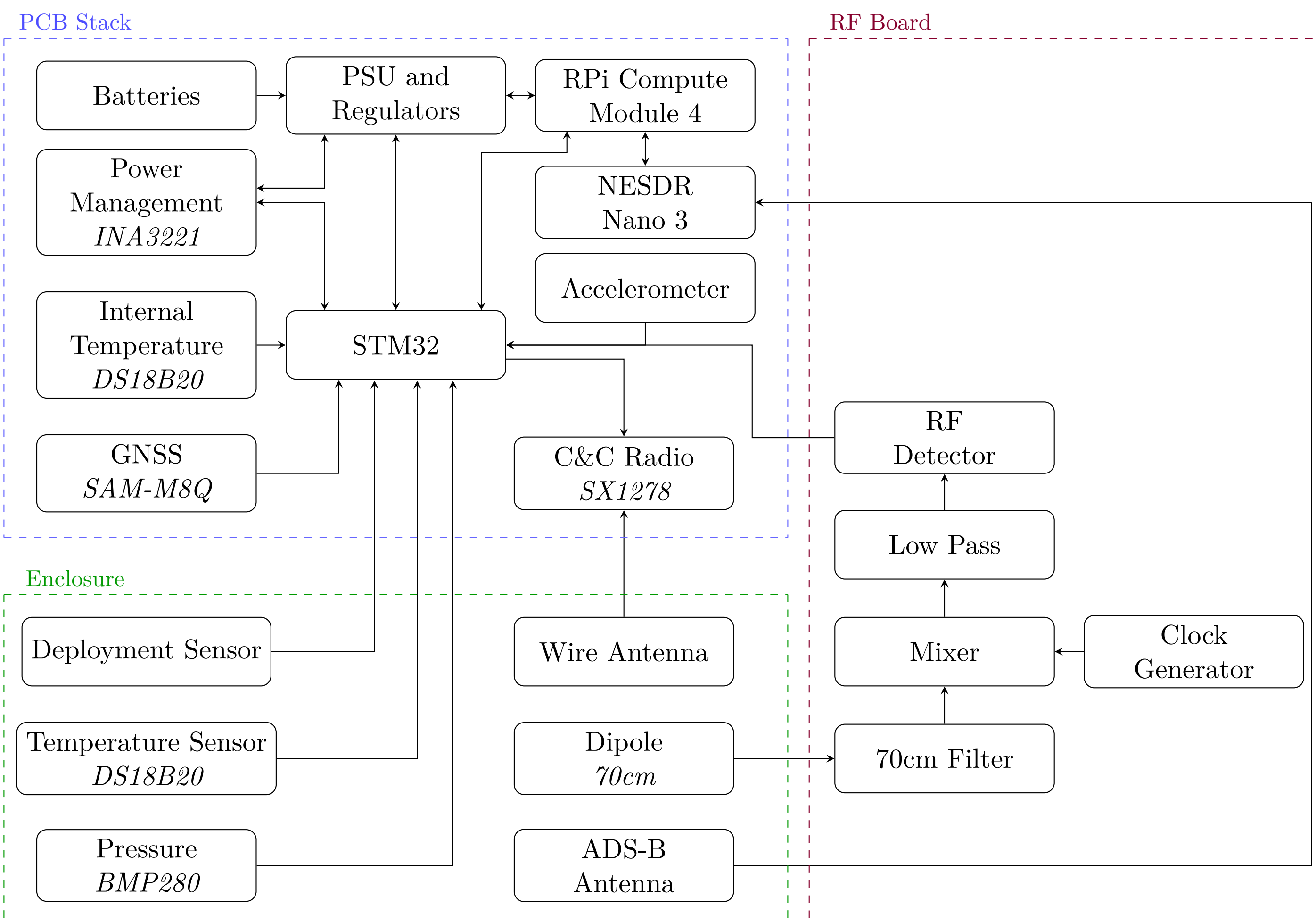

Figure 7: General electronic architecture

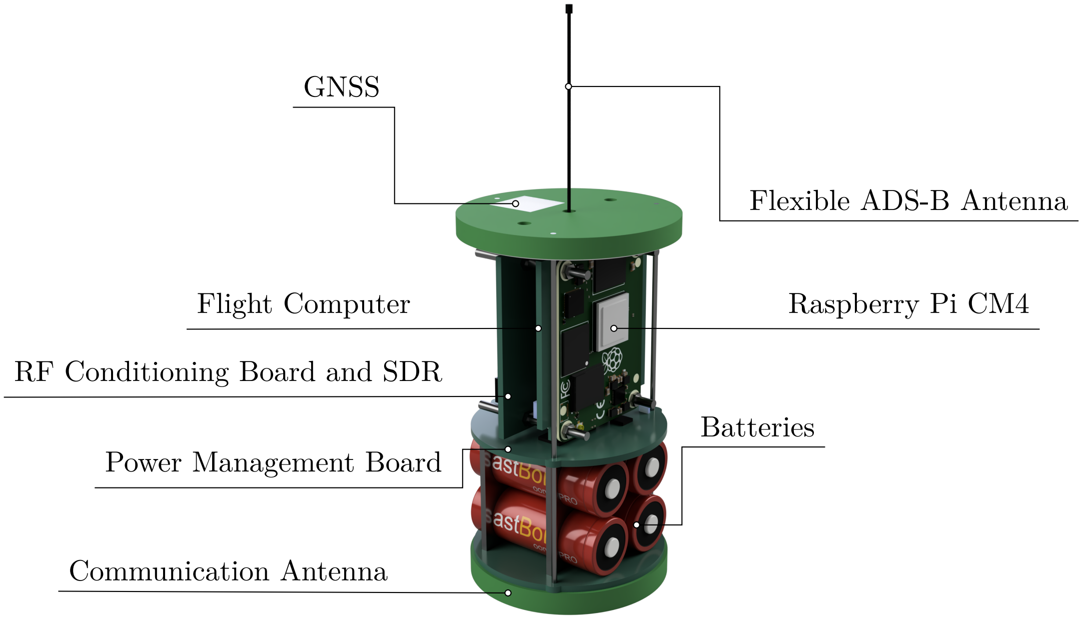

Figure 8: CanSat's side breakdown

2.4.2 Primary mission devices

(a) MCU - **STM32F407VGT6**: high speed microcontroller capable of live data handling, interfaces with every other component inside

(b) Radio module - **SX1278**: enclosed in the Ra-01 module, creates a radio link to the ground station

(c) Temperature sensors - **DS1820B**: captures data about outside/inside/SDR receiver temperatures

(d) Pressure sensor - **BMP280**: high precision sub-meter altitude sensor, used to assist the GNSS receiver

2.4.3 Secondary mission devices

(a) Software-defined radio receiver - **Nooelec NESDR Nano 3**: captures up to 2MHz of bandwidth between 30 and 1700 MHz. The data is be digitized as 8bit IQ samples and sent through the USB interface

(b) Linux SBC - **Raspberry Pi Compute Module 4**: processes data coming from the SDR; the data stream will be used to capture ADS-B signals and Cospas-Sarsat distress beacons

(c) RF conditioning board: contains RF signal paths for wireless receivers, increases selectivity, reduces out-of-band interference:

- ADS-B: a sharp SAW 1090MHz filter with an LNA
- Cospas-Sarsat: a 70cm band filter, RF detector/demodulator circuit

(d) Antennas: quarter-wave 1090MHz ground plane, two 433MHz dipoles

(e) GNSS module - **uBlox SAM-M8Q**: high precision and short hot start time (around 1s), supplements height data captured by the barometer and captures CanSat's position increasing the odds of a recovery

(f) Accelerometer - **MMA8451QR1**: will be used during mechanical tests

(g) SD card: stores captured data with timestamps for a later review

2.4.4 Power supply module

Testing in progress

Four on-board 2000mAh 18500 batteries connected in a 2S2P array are used to power the CanSat feeding into a LTM4622 DC-DC converter IC. It outputs BAT, 3.3V, and 5V voltages on buses, which currents and voltages are monitored with an INA3221 monitoring IC. In a case of a power anomaly it will raise either WARN or CRITICAL signal notifying the microcontroller about a potential failure. During normal operation the GOOD signal will be sent.

Device	Power draw*	Voltage
STM32F407	109 mA	3.3 V
uBlox SAM-M8Q	32 mA	3.3 V
SX1278†	10/120 mA	3.3 V
DS18B20	$4 \cdot 1$ mA	3.3 V
BMP280	< 1 mA	3.3 V
Raspberry Pi Compute Module 4	1.5 A	5 V
Nooelec NESDR Nano 3	300 mA	5 V
RF conditiong board	30 mA	BAT‡

An ability to monitor power information in real time will ensure that we have enough energy to fulfill our mission.

We use four KEEPPOWER ICR18500-200PCM 2000mAh batteries with built-in protection circuits to ensure safe operation.

Design documents are available at:
cansat_psu_schematic_v1.pdf

ALL OF THE CALCULATIONS BELOW ARE THEORETICAL

Predicted power draw and batteries:

- Battery capacity: $2 \cdot [2 \cdot 2000\,\text{mAh}/3.3\,\text{V}] = 4000\,\text{mAh} \cdot 7.4\,\text{V} = 29.6\,\text{Wh}$
- Operational: 296 mA@3.3 V
- Secondary mission peripherals activated: 296 mA@3.3 V + 1.8 A@5 V

At 91% efficiency

$$P_o = 0.967 \cdot 1.08 \approx 1.05\,\text{W} \quad \wedge \quad P_s = 9.97 \cdot 1.08 \approx 10.7\,\text{W} \tag{1}$$

90 minutes of all systems being powered

$$10.7\,\text{W} \cdot 1.5\,\text{h} + 1.05\,\text{W} \cdot t_o = 29.6\,\text{Wh}$$
$$t_o = \frac{29.6\,\cancel{\text{W}}\text{h} - 16.05\,\cancel{\text{W}}\text{h}}{1.05\,\cancel{\text{W}}}$$

$$t_o \approx 12.9\,\text{h} \tag{2}$$

Figure 10: Power draw calculations

*Maximal †Typical
‡on-board PSU

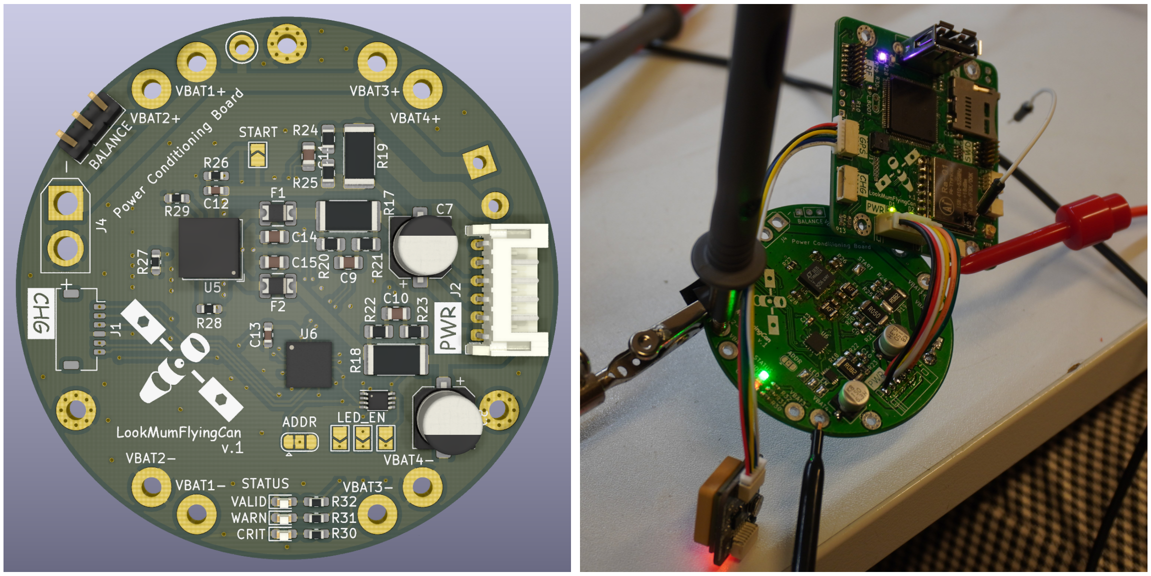

Figure 11: a: PSU PCB renders b: PSU being tested

2.4.5 Communication system

Assembly in progress

To download and visualize the secondary mission data in real-time, the link between a ground station and the CanSat will be realized in half-duplex mode. To prevent collisions our system will use a TDMA scheme consisting of five-time slots per frame with two frames for one second. Slots 1, 2, 3 and 4 will be dedicated to a telemetry downlink. The last 5th slot will be used for a Command & Control uplink allowing us to fine-tune automatically chosen secondary objective settings.

The CanSat will be responsible for the synchronization of each frame. It will be implemented in a form of a special packet containing on-board time reference and a unique frame number.

Slot	Direction	Packet	Details
1	DOWNLINK	SYNC	Sync / senosors telemetry
2	DOWNLINK	BASIC_TEL	Senosors telemetry
3	DOWNLINK	RESERVED	Reserved
4	DOWNLINK	RF_TEL	Secondary mission telemetry
5	UPLINK	GS_COMMAND	Command & Control

Figure 12: Frame breakdown

Communication will be achieved using the Semtech LoRa protocol due to high interference resistance, selectivity and great sensitivity thus resulting in a ultra-long range data link. We have chosen the following modulation parameters: SF 7, CR 2, BW 125kHz, CRC Enabled. Additional testing is required to verify chosen values.

We consider using the CanSatKit board containing SX1278 IC as a ground station unit. It should have adequate data speeds, sensitivity, and error correction functionalities. Our CanSat will be equipped with a 433MHz antenna whereas the ground station will be fitted with two high gain seven-element 433MHz band Yagi-Uda antennas.

2.4.6 Flight computer PCB

Ready for flight

A 4-layer impedance controlled PCB manufactured by JLCPCB. It connects various modules and components via SH connectors, serves as a base board for RPi CM4 System-on-Module and interfaces with the RF board.

Interfaced components list:

(a) Linux computer - ADS-B data UART & TTY console UART & USB 2.0
(b) GNSS receiver - UART
(c) Power supply - I^{2}C for power monitoring & GOOD, WARN, CRITICAL flag signals
(d) Environmental sensors - I^{2}C for BMP280 & OneWire DS18B20U
(e) Temperature sensors - OneWire for two DS18B20 sensors
(f) Programming interface - SWD
(g) RF board - SPI & I^{2}C
(h) SD card
(i) USB - SDR receiver

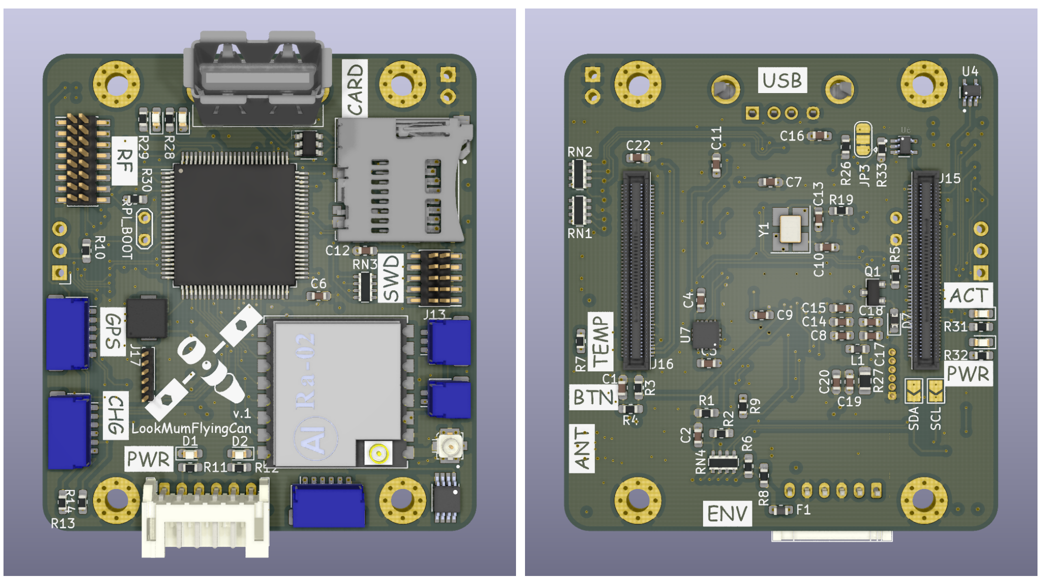

Figure 13: Flight computer PCB renders

Design documents are available at:
cansat_flight_computer_schematic_v1.pdf

2.4.7 RF PCB

Planning in progress

This module is responsible for conditioning RF signals coming from ADS-B and Cospas-Sarsat antennas. Placing it in the signal path will allow us to improve signal-to-noise ratio and increase receiver selectivity. Board architecture is presented on (Figure 7).

2.4.8 Environment PCB

Ready for flight

This board contains the CanSats on/off switch as well as the outside pressure and temperature sensors. It is currently mounted outside the CanSat but the pressure sensor will have to be moved inside due to dynamic pressure skewing.

Design documents are available at:
cansat_envboard_schematic_v1.pdf

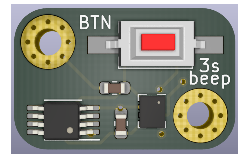

Figure 14: The env board render

2.5 Software design

Two definite sections of software will be written differentiated by the different programming languages used, one for low level fast programming and the other high level frontend programming.

We are using:

(a) CanSat MCU : C / HAL environment

(b) CanSat SBC: Rust

(c) Ground station transceiver: Arduino environment

(d) Ground station data processing: Python

(e) Mission control system: Python (Pandas, Matplotlib, NumPy)

(f) Public data visualization: Angular and NodeJS

Version control is being realised via git repositories on GitHub which will be linked in future document iterations.

The on-board processor will store and backup data onto the SD card included within the probe and also send data through the radio link to our ground station.

The command and control software will allow us to monitor: the position of the CanSat, on-board temperatures, ADS-B airplane data and Cospas-Sarsat beacon status and location (if is any activated). These details will be displayed in real-time using our data visualization frontend (Command & Control and radar ATC-like view) and later parsed to an interactive dashboard to be released to the public.

2.5.1 SBC Software

Final prototyping

The Linux machine has a `systemd` service that demodulates and outputs raw ADS-B data from the SDR IQ stream. This is achieved using a well known demodulator (`dump1090`), and a layer of connection software that takes the output data of `dump1090` and forwards it to the UART port as well as provides an interface for restarting and tuning the demodulator. This is achieved via low-level manipulation of processes and `libusb`.

2.5.2 Data management

The captured data, as well as mission-critical data, will be simultaneously stored on an 8GB SD card and sent to the ground station. Data will be stored in form of binary files, each spanning 10 seconds of mission time. The worst-case scenario is about 1-2KB/s of data. This SD card will allow for $\approx$ 1000h of data capture time. This will be sufficient as our mission lasts up to 10h.

We use an Kingston UHS-I series industrial grade micro SD card, which is resistant to extreme weather conditions (temperature from $-40°$C to $85°$C). The manufacturer guarantees that the card would work even with 5g acceleration.

2.6 Recovery system

Final prototyping

A parachute is used to recover the CanSat after its deployment and is affixed with 8 strings with length of 40-45 cm each connecting the parachute to the device. It will be made from Nylon 40D material and will have a diameter of 30-34cm. The attachment will be possible thanks to two holes in the upper lid element.

F_d – Drag force F_g – Gravitational pull $z(t)$ – Position according to time

$\dot{z}$ – First integral of z (velocity) $\ddot{z}$ – Second integral of z (acceleration)

ρ_a – Air's approximate desnity $\rho(z)$ – Air's exact density at z g – Earth's acceleration‡

C_d – Air's drag constant A_p – Area of the convex hull

From [4] we deduct that:

$$m\ddot{z} = F_d - F_g \quad \wedge \quad F_d = \frac{1}{2}\rho(z)A_pC_d\dot{z}^2$$

This combined gives: $\ddot{z} = \dfrac{\rho(z)A_pC - d\dot{z}^2}{2m} - g$

Since we do not want the CanSat to accelerate we fix $\ddot{z} = 0$

$$\therefore \quad \dot{z} = -\sqrt{\frac{2mg}{\rho(z)A_pC_d}}$$

$$\therefore \quad A_p = \frac{2mg}{\dot{z}^2\rho(z)C_d}$$

Here some approximations have to be made: $\rho(z) = \rho_a$ and $\dot{z} = 8\dfrac{m}{s}$

$$\therefore \quad r = \sqrt{\frac{2mg}{\dot{z}^2\rho C_d\pi}}$$

$$r = \sqrt{\frac{2 \cdot 0.319kg \cdot 10\frac{m}{s^2}}{64\frac{m}{s} \cdot 1.2\frac{kg}{m^3} \cdot 0.8 \cdot 3.1415}}$$

$$r \approx 18cm \therefore d \approx 36cm$$

Figure 15: Parachute size calculation

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† Gas in this case

‡ Not accounting for the integral error $\leq \pm 1\%$

3 Ground support equipment

Programming in progress

Ground support equipment will include:

(a) The main antenna for receiving and transmitting data to the CanSat
(b) One small computer/server dedicated to data decoding, storage and hosting an API
(c) Networking equipment to create a small LAN network through which the API can be accessed
(d) A backup database storage computer/server
(e) Two computers running frontend applications; one for real-time data visualization and another for command and control

The decoding server will store data in a database and host an API to allow frontend software to interface with the database and receive events from the decoding software.

The Frame Manager program has already been finished, it is a dynamic distributor of frames, applications can ask to be added to the subscriber list and whenever a frame arrives the manager sets off hooks and forwards frames to all of the applications. It also supports queuing messages to a serial port to be sent to the satellite.

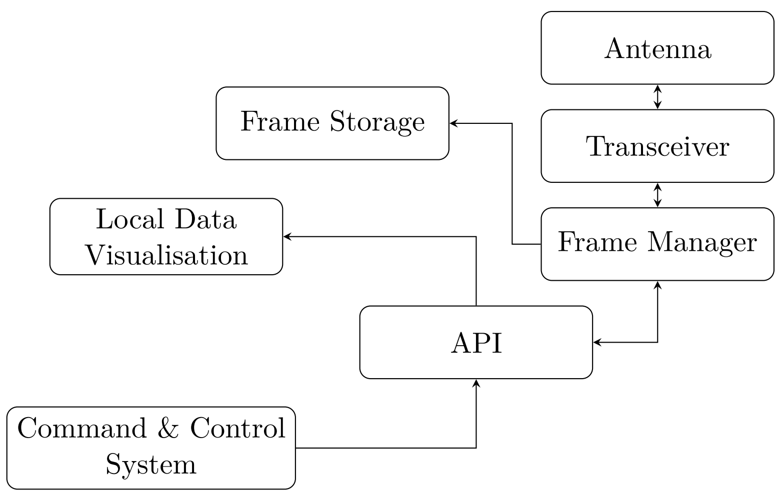

Figure 16: Ground station overwiew

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4 Test campaign

4.1 Primary mission tests *Testing in progress*

4.1.1 Objective

To determine the accuracy of out temperature sensors and static pressure sensors

4.1.2 Method

The pressure sensors invulnerability to velocity (which in turn creates dynamic pressure), can be shown simply by measuring the impact that velocity has on our readouts. We deduct from Bernoulli's principle that the value of dynamic pressure is characterised by: $q = \frac{1}{2}\rho v^2$ (that is assuming that air is incompressible which is of course not true, but for approximations sake we assume that it is, since it takes a lot of work to compress air). This, as can be easily seen, tells us that since the density of air ρ is static the dynamic pressure, q is $q \propto v^2$. The temperature sensors accuracy will be tested via comparing it with a known working termocouple.

4.1.3 Acceptable results

The impact of velocity on the pressure sensor is negligable. The temperature sensor yields results similar to the thermocouple.

4.2 ADS-B receiver subsystem *Testing in progress*

4.2.1 Objective

Test the reception quality of the ADS-B subsystem by recieving positional data from planes in range.

4.2.2 Method

We will compare the on-board receiver signal reception with a reference 1/4 wave ground plane antenna.

4.2.3 Acceptable results

10-20% from the reference results.

4.3 Power usage test *Testing in progress*

4.3.1 Objective

Test the power draw in all operating modes.

4.3.2 Method

Measure the current on all power lines and calculate the power draw during powered off, idle, secondary mission operation and shutdown states.

4.3.3 Acceptable results

Minimal 10 hours of operational time.

4.4 Parachute tests

Ready for flight

4.4.1 Objective

Designate the descent velocity of the satellite. Find an optimal folding method for the parachute to be reliable.

4.4.2 Method

Measure the velocity a 325g CanSat representative model reaches when falling from 10m. Test different parachute diameters.

Figure 17: One of the tested parachutes

4.4.3 Results

The parachute with a 32cm diameter reaches about 8m/s, which is the satisfactory speed. We have been successful in defining a reliable folding method.

4.5 Recovery systems tests

Testing in progress

4.5.1 Objective

Test the recovery systems. Designate the velocity of the satellite.

4.5.2 Method

Perform a mock mission from a low starting altitude. Check the parachute descent rate as well as buzzer activation on landing.

4.5.3 Acceptable results

Telemetry reception throughout the entire recovery.
Buzzer activates on landing.
Parachute deployment and proper speed reached.

4.6 Auxilary tests

- ~~The CanSat was empirically tested to be invulnerable to overvoltage conditions~~

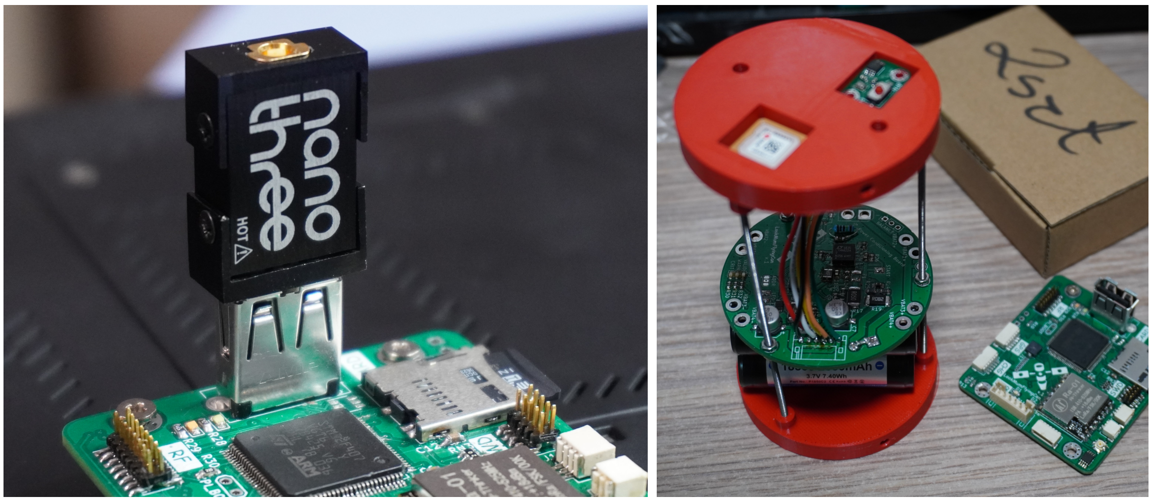


Figure 18: a: Nooelec NESDR Nano 3 radio b: The CanSat as seen from the top

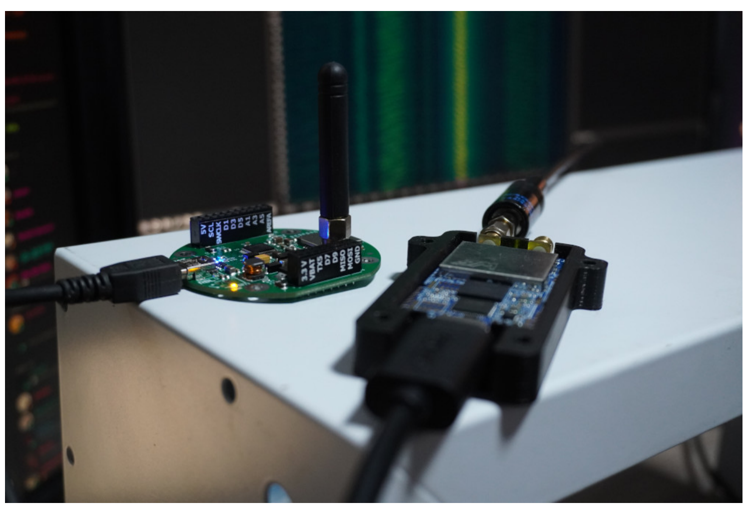


Figure 19: Base station reception test with the use of a mock CanSat (LimeSDR Mini)

5 Project planning

We use Jira Software to prepare a schedule and manage work units for our CanSat project. We have set up two entry types - Tasks and Epics. Each task contains basic info about what needs to be done, the priority and an assignee. Our tasks among others include public relations such as creating a Facebook Fanpage and contacting sponsors. They are grouped together into Epics - milestones that track progress on task subsets. So far we have created them for PDR, CDR and FDR lasting according to the competition's requirements and Epics related to public relations.

5.1 Time schedule

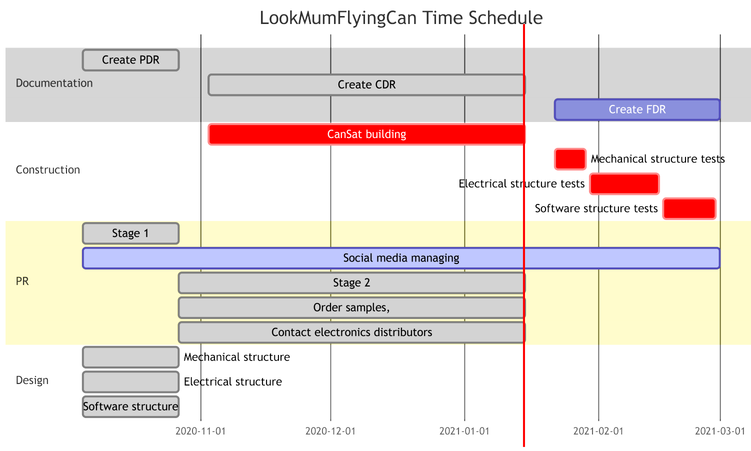


Figure 20: Time schedule

5.2 Task list

The extracted full task list created with Jira Software is set out below:

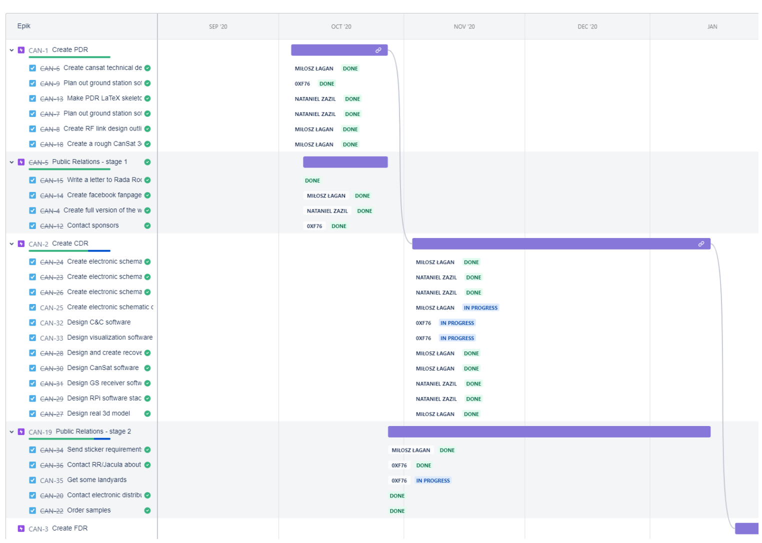


Figure 21: Jira roadmap

5.3 Resource estimation

5.3.1 Budget

We are using the following exchange rates: 1 USD = 3.85 PLN, 1 EUR = 4.57 PLN.

Device	Price (Original)	Price (PLN)
Nooelec NESDR Nano 3	29.95 USD	118.87 PLN
Raspberry Pi Compute Module 4	169 PLN	169 PLN
Flight computer board	79.07 USD	295.31 PLN
Enviorment board	2.03 USD	7.58 PLN
RF conditioning PCB	$\approx$ 15 USD	$\approx$ 57.75 PLN
PSU PCB	15 USD	56.03 PLN
KEEPPOWER Batteries	175.88 PLN	175.88 PLN
Enclosure Materials	20 PLN	20 PLN
Total	198.17 EUR	900.11 PLN

Figure 22: Budget table

5.3.2 External support

We've reached several companies and organizations asking for financial and utility support.

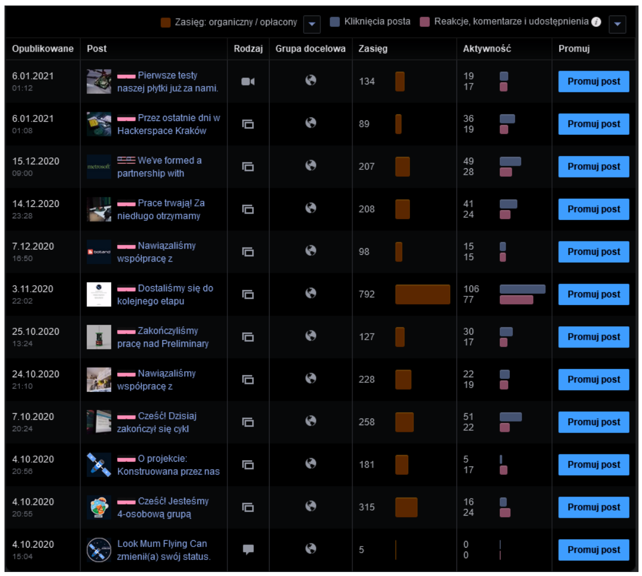
So far our confirmed supporters are:

1. Hackerspace Kraków
   - Provides electronic laboratory, machining equipment (such as Prusa 3D printer or CNC milling machine), and various tools that can be used while building and testing our CanSat project.
2. 1st High School Parents Board
   - Provides initial funding allowing us to start prototyping as soon as possible.
3. Botland
   - Provides discounted electronic equipment for our CanSat project.
4. Metrosoft
   - Provides broad expertise in various fields which will aid us in developing a Linux software stack required for real time aircraft and beacon data processing. Futhermore, Metrosoft provides essential financial support for our project.
5. BTO
   - Provides discounted li-ion batteries for our project.

Figure 23: Sponsors

Appendix A Outreach program

We have created a team website (lookmumflyingcan.com) and a fan page on the Facebook platform (facebook.com/lookmumflyingcan). The fan page is being used as a communication medium where we share information about our progress in a form of text posts with pictures and short videos. In this place, various milestones achieved during our development process such as a successful test launch will be shared. The website serves as a landing page containing basic information about our project for potential sponsors and the public. Visitors are be able to read about our team/mission goals and see promotional materials (eg. video clips).


Zasięg: organiczny / opłacony | Kliknięcia posta | Reakcje, komentarze i udostępnienia

Opublikowane	Post	Rodzaj	Grupa docelowa	Zasięg	Aktywność	Promuj
6.01.2021 01:12	Pierwsze testy naszej płytki już za nami.			134	19 17	Promuj post
6.01.2021 01:08	Przez ostatnie dni w Hackerspace Kraków			89	36 19	Promuj post
15.12.2020 09:00	We've formed a partnership with			207	49 28	Promuj post
14.12.2020 23:28	Prace trwają! Za niedługo otrzymamy			208	41 24	Promuj post
7.12.2020 16:50	Nawiązaliśmy współpracę z			98	15 15	Promuj post
3.11.2020 22:02	Dostaliśmy się do kolejnego etapu			792	106 77	Promuj post
25.10.2020 13:24	Zakończyliśmy pracę nad Preliminary			127	30 17	Promuj post
24.10.2020 21:10	Nawiązaliśmy współpracę z			228	22 19	Promuj post
7.10.2020 20:24	Cześć! Dzisiaj zakończył się cykl			258	51 22	Promuj post
4.10.2020 20:56	O projekcie: Konstruowana przez nas			181	5 17	Promuj post
4.10.2020 20:55	Cześć! Jesteśmy 4-osobową grupą			315	16 24	Promuj post
4.10.2020 15:04	Look Mum Flying Can zmienił(a) swój status.			5	0 0	Promuj post

Figure 24: Fan page outreach statistics

We are planning to contact Radio Pryzmat and local newspapers such as:

- Gazeta Krakowska
- Kraków Nasze Miasto
- Gazeta Wyborcza Kraków
- Dziennik Polski

We have also created a professional contact email under our domain (team@lookmumflyingcan.com). Another point on our outreach list was to create a GitHub Organisation (https://github.com/LookMumFlyingCan). It is used for collaborative work on our project and to host public-facing services (webpage, data visualisation software).

We're going to contact SFI Academic IT Festival in order to take part in an episode of their podcast. We think it's the best way to reach as many young people interested in STEM as possible.

With support from Hackerspace Kraków, a place where people can freely share their knowledge, we are planning to showcase our work and mission goals during a short talk. We are also considering giving a presentation within our high school and making a demonstration during the school's open day.

When we have more tangible developments we want to contact The Hackaday magazine.

Appendix B Characteristics of the CanSat

Characteristic	**Figure**
Height of the CanSat	113mm
Diameter of the CanSat	65.4mm
Mass of the CanSat	$\approx$ 319g
Estimated descent rate	$8\ {}^{m}/_{s}$
Radio transmitter model and frequency band	SX1278, 70cm
Estimated time on battery (primary mission)	12.9h
Cost of the CanSat	$\approx$ 198.17 EUR

Figure 25: CanSat's Characteristics

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[1] Gilles Nies, Marvin Stenger, Jan Krčál, Holger Hermanns, Morten Bisgaard, David Gerhardt, Boudewijn Haverkort, Marijn Jongerden, Kim G. Larsend, and Erik R. Wognsend. "Mastering operational limitations of LEO satellites – The GomX-3 approach." In: *Acta Astronautica* 151.1 (2018), pp. 726–735. DOI: https://doi.org/10.1016/j.actaastro.2018.04.040.

[2] Karen Marais, Ph.D. *Environmental Benefits of Space-based ADS-B: Study.* School of Aeronautics and Astronautics, Purdue University, 2016, pp. 1–15.

[3] Raymond Francis, Ronald Vincent, Jean-Marc Noël, Pascal Tremblay, Daniel Desjardins, Alex Cushley, and Matthew Wallace. "The Flying Laboratory for the Observation of ADS-B Signals." In: *International Journal of Navigation and Observation* 2011.973656 (2011), pp. 1–3. DOI: https://doi.org/10.1155/2011/973656.

[4] Travis Fields, Jeffrey LaCombe, Eric Wang. "Path Planning of a Circular Parachute Using Descent Rate Control." In: *AIAA Aerodynamic Decelerator Systems (ADS) Conference* (2013). DOI: https://doi.org/10.2514/6.2013-1324.