LookMumFlyingCan

Bartłomiej Nowodworski 1st High School in Cracow

Final Design Review

Jakub Bubak, *Sebastian* Florek,
Mikołaj Gazeel, *Miłosz* Łagan

supervised by
Mgr. Piotr Gracjasz

1 March, 2021

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.

Table of contents

Abbreviations

ABS Acrylonitrile Butadiene Styrene. 10

ADS-B Automatic Dependent Surveillance - Broadcast. 2, 5, 7, 8, 9, 10, 11, 12, 15, 16, 18, 19, 23, 25, 31, 37

AGH AGH University of Science and Technology in Cracow. 6

API Application Programming Interface. 21

ASCII American Standard Code for Information Interchange. 18, 26

ASP Academy Of Fine Arts in Cracow. 6

ATC Air Traffic Control. 8

CNC Computer Numerical Control. 34

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. 3, 7, 9, 10, 11, 12, 16, 32

ICAO International Civil Aviation Organization. 19

ISM Industrial, Scientific and Medical bands. 8, 27

LNA Low-Noise Amplifier. 12

MCU Micro Controller Unit. 12, 18

PCB Printed Circuit Board. 2, 5, 14, 16, 17, 25, 26, 34, 37

PLT Personal Locator Transmitter. 8

PSU Power Supply Unit. 5, 11, 13, 14, 34, 37

RF Radio Frequency. 2, 5, 6, 8, 11, 12, 13, 17, 34, 37

RSSI Received Signal Strength Indication. 28, 37

SBC Single-Board Computer. 2, 3, 9, 12, 18, 23, 26, 27, 32, 37

SDR Software-Defined Radio. 3, 7, 8, 12, 16, 18, 32

SPI Serial Peripheral Interface. 16

SWD Serial Wire Debug. 16

TDMA Time-Division Multiple Access. 14

TTY Terminal. 16

UART Universal Asynchronous Receiver-Transmitter. 16, 26

USB Universal Serial Bus. 16, 32

USB 2.0 Universal Serial Bus High Speed. 16

VNA Vector Network Analyzer. 30, 37

VSWR Voltage Standing Wave Ratio. 27

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
- Accelerometer (see Secondary mission devices)
- Tests (see Test campaign)
- PCBs and schematics (see PCBs)

Changed

- The parachute size has been recalculated (see Recovery Systems)
- RF signal path redesign (see Figure 8)
- 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)

FDR (2021-03-01)

Added

- RF Board designs
- Performed tests
- Risk assessment
- Bill of materials
- ADS-B visualisation software
- Rocket launch details

Changed

- Outreach has been expanded
- Mission description has been organized
- New CanSat structure
- New revision of PSU PCB
- Ground support equipment has been expanded
- RF link details have been updated
- Test campaign has been developed

1 Introduction

1.1 Team organisation and roles

Team supervisor: Piotr Gracjasz

Team members (students of the Bartłomiej Nowodworski 1^{st} 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

The CanSat will be attached to a rocket and launched to an altitude of 3km, at which point it will be deployed and begin its descent. This is where our mission begins.

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 visualised using our software.

1.2.2 ADS-B Secondary Mission

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 [4] 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.

Risk 5.2

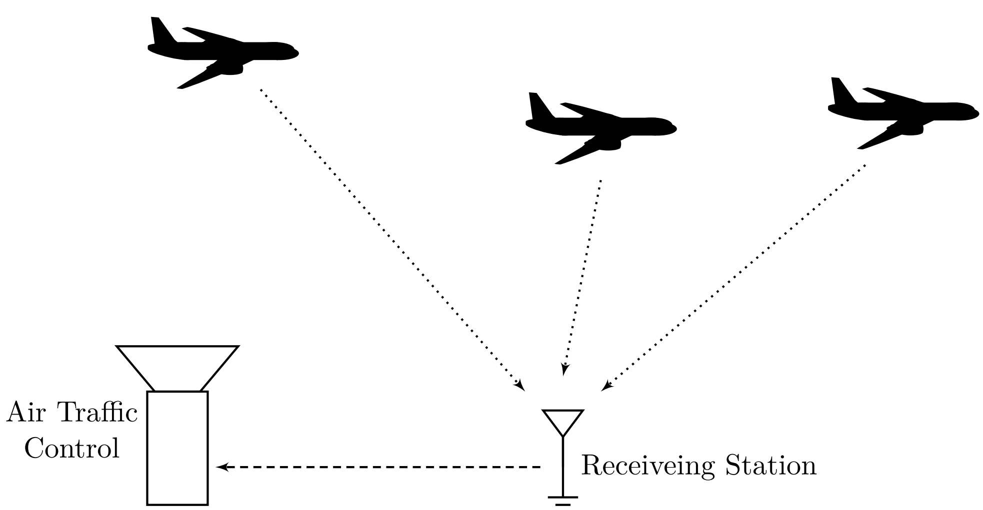


Figure 1: ADS-B overview

The mission The ADS-B 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 amount 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.

1.2.3 The emergency beacon mission

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.

The 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[1]), hidden away in a different part of the launch site. Our CanSat should detect and relay the signal containing its location to the responders and our ground station in real-time. The mission will be considered successful, if we locate the beacon.

1.2.4 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 as 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 in 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 essentialy indefinitely.

We are also investigating the possibility of creating a low cost flying Software Defined Radio, a platform capable of receiving technically any signal thanks to the SDR technology and on-board Linux processing unit. It would not be possible without the 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 be paid.

[1]Due to security concerns

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 reduce power usage and a special telemetry signal will be sent to increase the odds of CanSat retrieval by the recovery team.

In order to facilitate retrieving the CanSat after its landing a PWM controlled buzzer is implemented. After touchdown, it starts playing specially prepared melody, loud enough to be useful in the process of looking for the satellite.

Risk 5.6

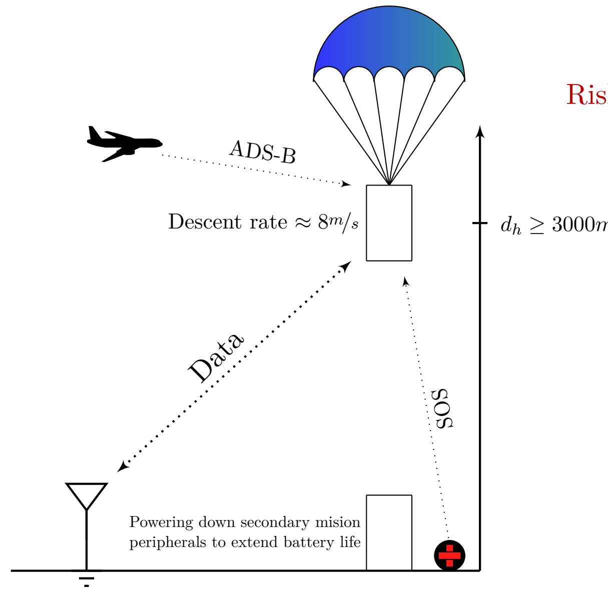


Figure 2: CanSat's deployment

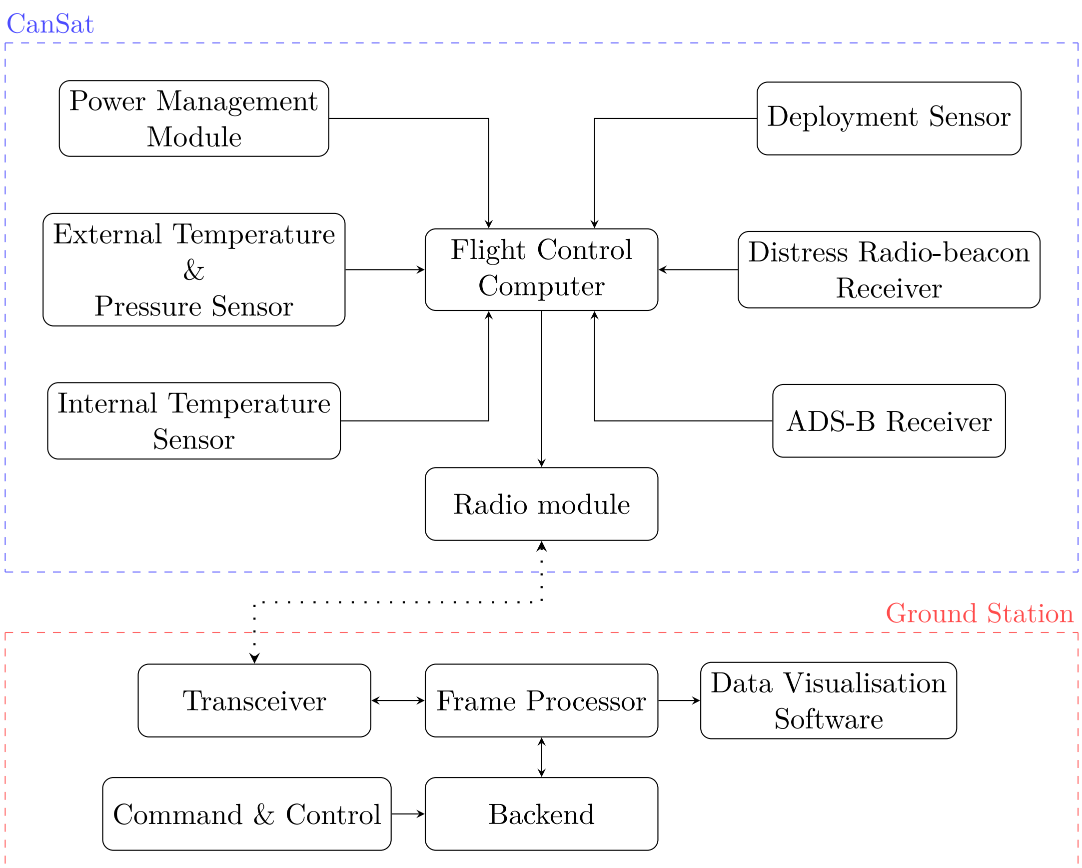


Figure 3: CanSat's overview

2.2 Mechanical design

Ready for flight

Risk 5.1

Components inside the CanSat are modularized into a top cap (GNSS module, environmental sensors, ADS-B antenna, and Cospas-Sarsat), a bottom cap (communication antenna), fibreglass tube, a battery, power supply assembly and 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 under the power supply PCB and firmly affixed to the Cansat's structure. The fibreglass tube encompasses the device providing lightweight protection of the internal components. It is slid over one of the caps and held by both of them in place over the internal components. 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

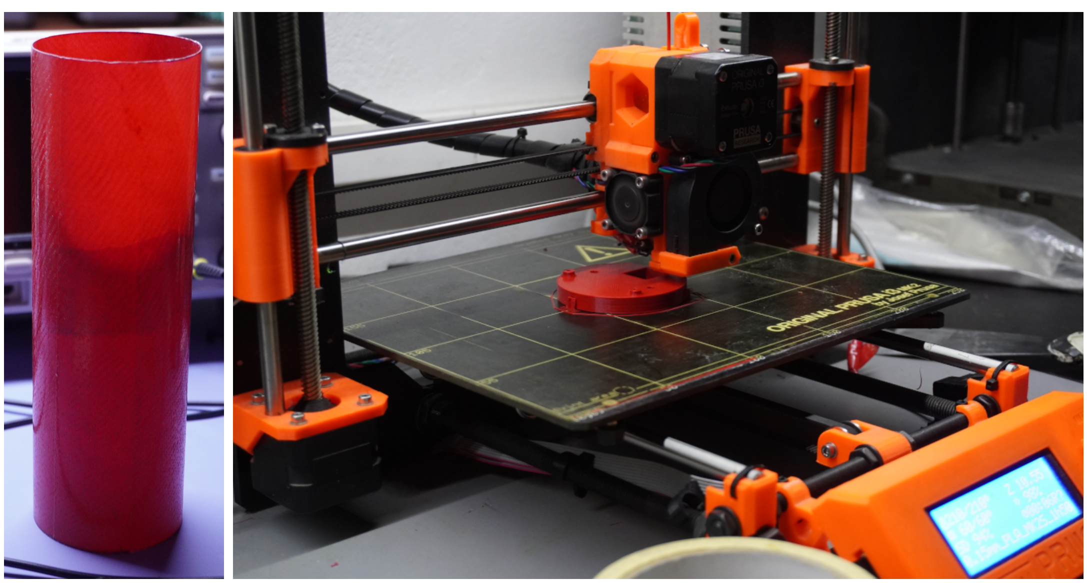


Figure 5: a: Fibreglass tube b: One of the elements being printed on a Prusa 3D printer

Part	Material	Quantity
Fibreglass tube	Fibreglass paste	10g
Caps	ABS	$2 \cdot 5$m of 1.5mm filament
Skeleton	3 M2 rods	1m M2 threaded rod
Fastners	M2 nuts	16 M2 nuts
ADS-B Antenna	Conductive copper tape	1m of 1cm tape

Figure 6: Bill of materials

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 7: CanSat's components weight

2.4 Electrical design

2.4.1 General architecture

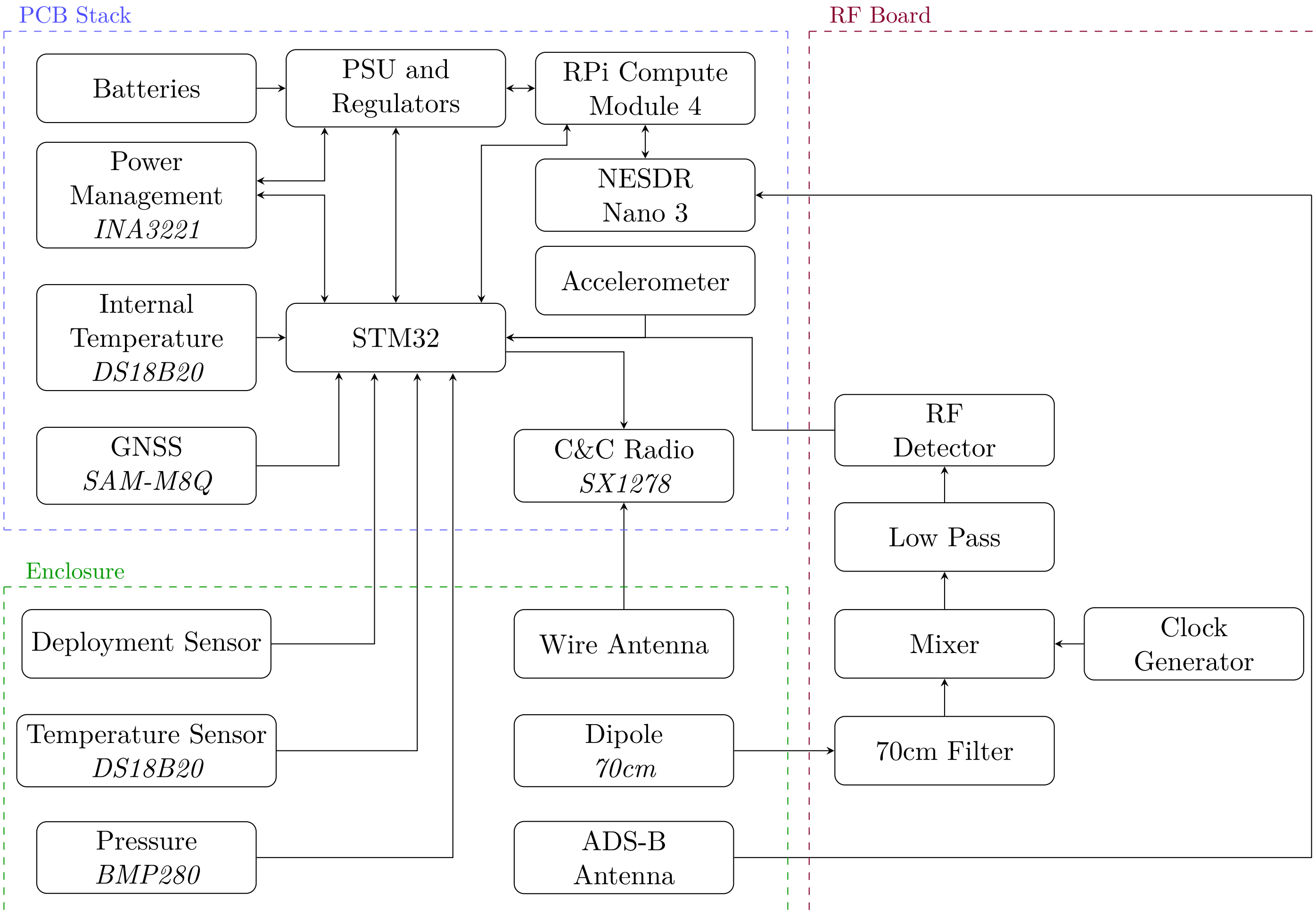


Figure 8: General electronic architecture

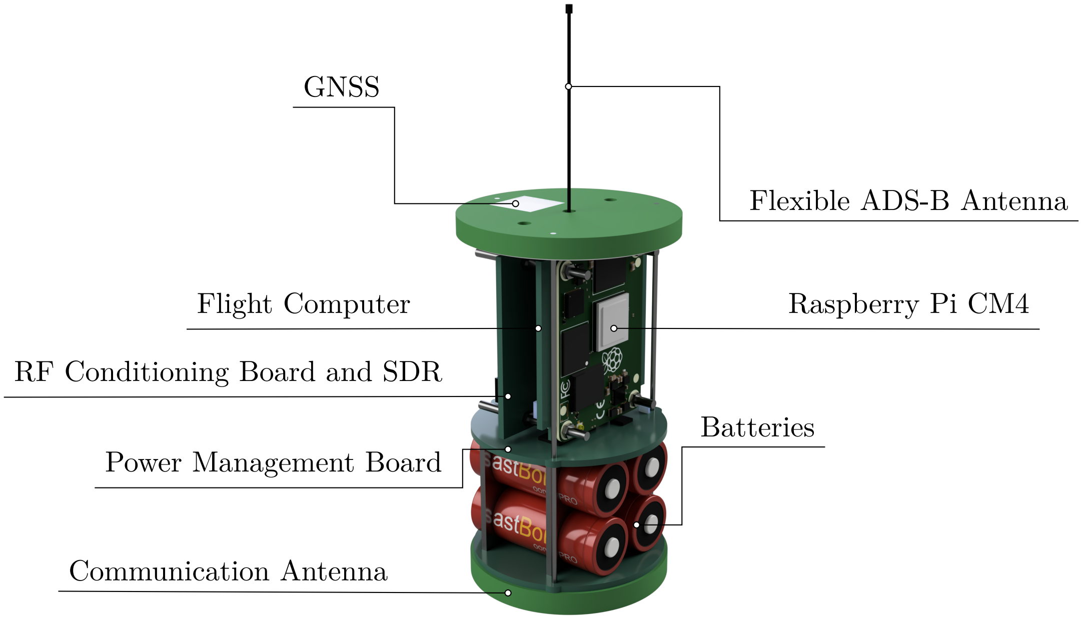


Figure 9: CanSat's side breakdown

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 will be digitized as 8bit IQ samples and sent through the USB interface Risk 5.5

(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 two A5973D buck converter ICs. They output BAT, 3.3V, and 5V voltages on buses. These 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‡

Risk 5.3

The 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_v2.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 11: Power draw calculations

*Maximal †Typical
‡on-board PSU

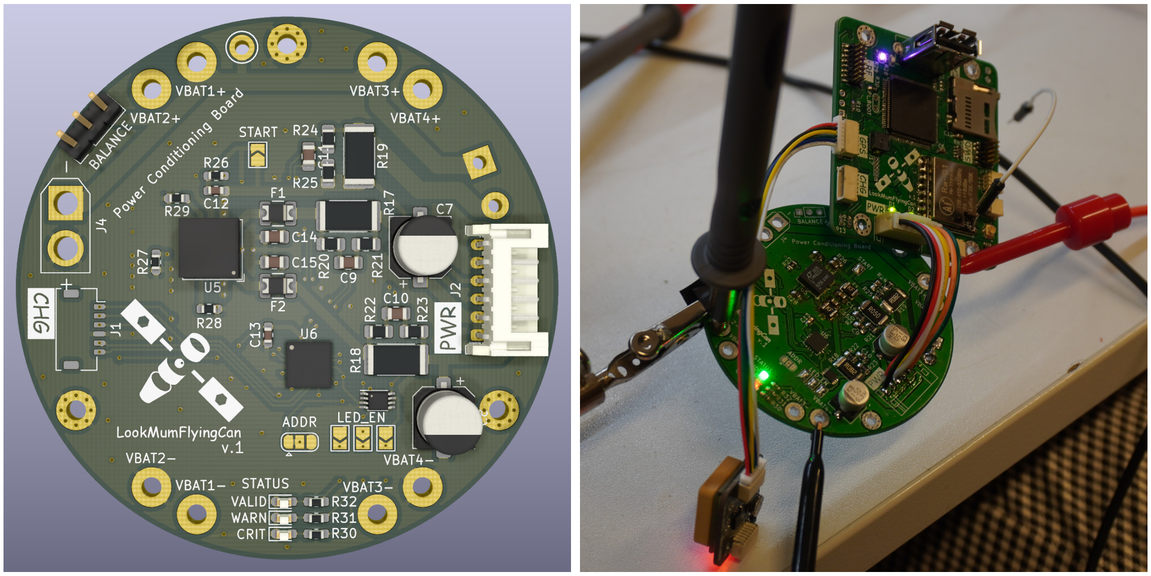


Figure 12: a: Old PSU PCB renders b: Old PSU being tested

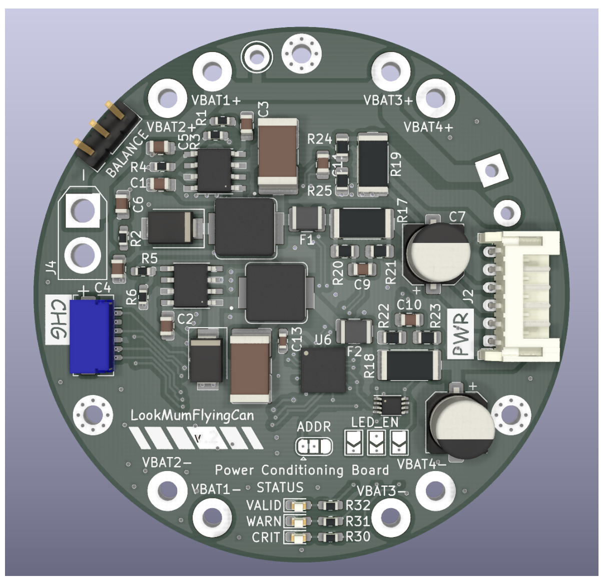


Figure 13: New buck-based PSU PCB

2.4.5 Communication system

Ready for flight

Risk 5.4

To download and visualise 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 one frame per 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	BASIC_TEL	Sync / sensor telemetry
2	DOWNLINK	ADSB_TEL	ADS-B telemetry
3	DOWNLINK	GNSS_TEL	Positional data
4	DOWNLINK	COSPAS_TEL	Emergency beacon telemetry
5	UPLINK	GS_COMMAND	Command & Control

Figure 14: 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 8, CR 4:6, BW 125kHz, CRC Enabled. Additional testing verified the chosen values.

We are using a STM32F407G Devboard equppied with a 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.

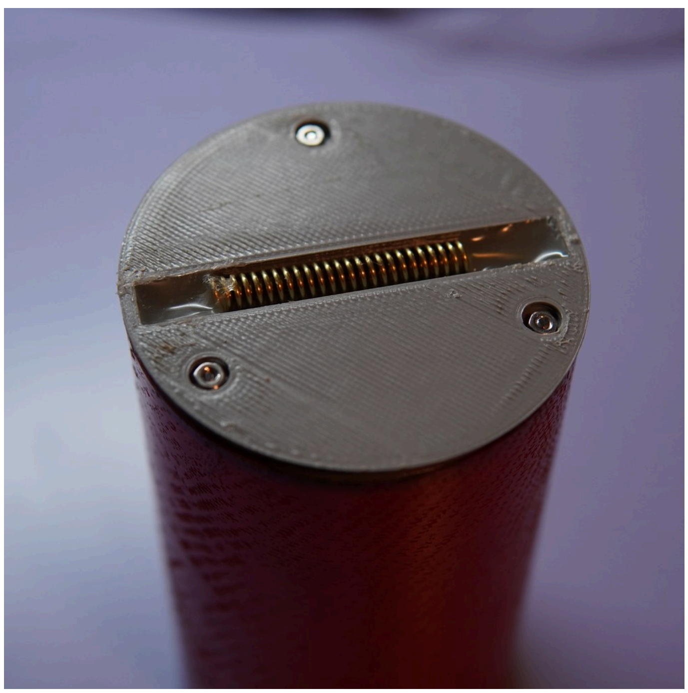


Figure 15: New bottom cap equipped with the communication antenna

Below is a list of all antennas aboard our CanSat

- The dipole made with jewelery line for Cospas-Sarsat reception is affixed to the top lid running along parachute strings.
- The communication antenna forming a spring-like monopole antenna is located in the bottom lid.
- The ADS-B antenna is built into the top lid consisting of a ground plane made with a copper tape and a vertical flexible monopole extending into the parachute compartment.

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

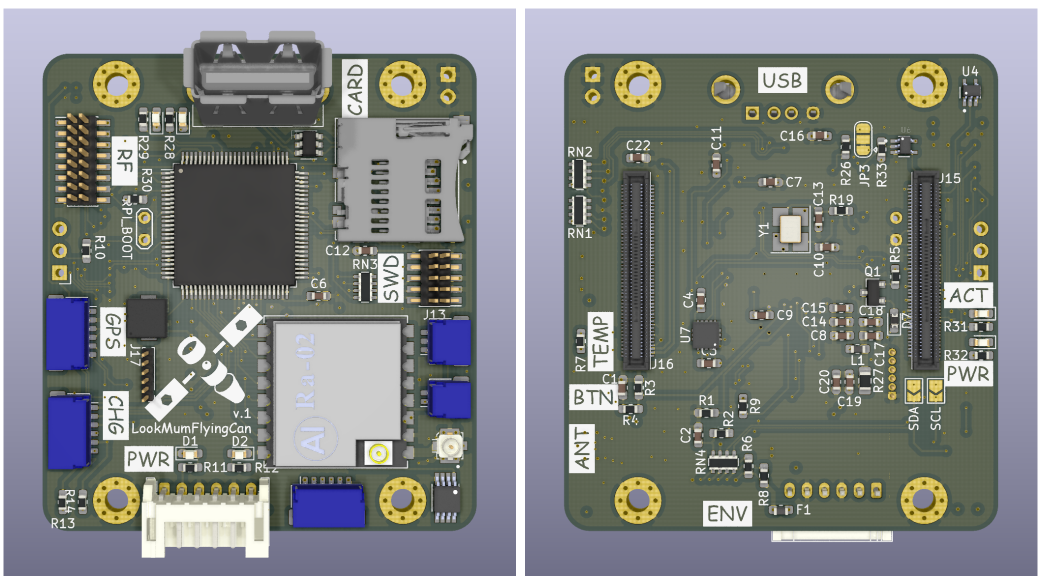


Figure 16: Flight computer PCB renders

Design documents are available at:
cansat_flight_computer_schematic_v1.pdf

2.4.7 RF PCB

Final prototyping

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 8).

Design documents are available at:
cansat_rf_schematic_v1.pdf

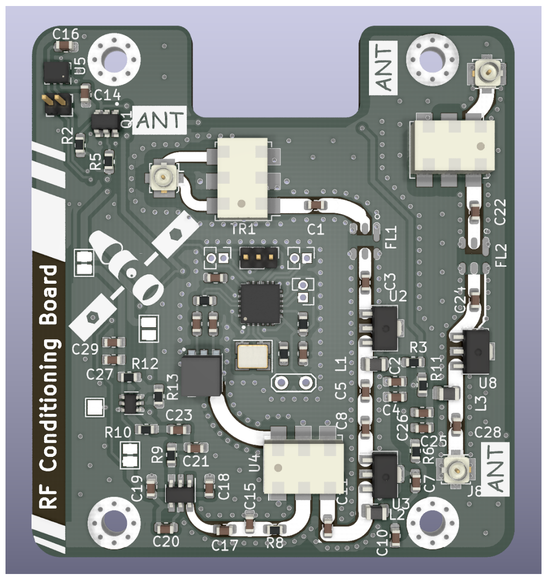


Figure 17: RF PCB render

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. The pressure sensing part of this board has been moved to the RF PCB.

Design documents are available at:
cansat_envboard_schematic_v1.pdf

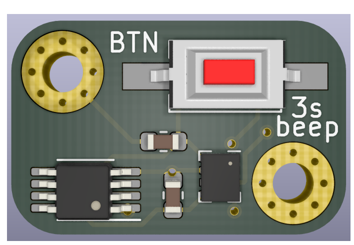


Figure 18: Env PCB render

2.5 Software design

Two distinct 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: C / HAL environment
(d) Ground station data processing: Rust / Python
(e) Mission control system: Python (PyQt, Matplotlib, NumPy)
(f) Public data visualization: Angular and NodeJS

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

The command & 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 any are 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.

Version control is being realised via git repositories on GitHub

2.5.1 SBC Software *Ready for flight*

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`.

The SBC is also used for buffering the data, since it has a lot more memory than any other component. It replies to fetch requests from the flight computer feeding data chronologically whenever needed. We have developed a simple ASCII based serial protocol for communication that balances speed and stability to our needs.

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.

2.5.3 ADS-B visualisation software

We have created propertiary software, that graphs all of the ADS-B data, below is a breakdown of operation.

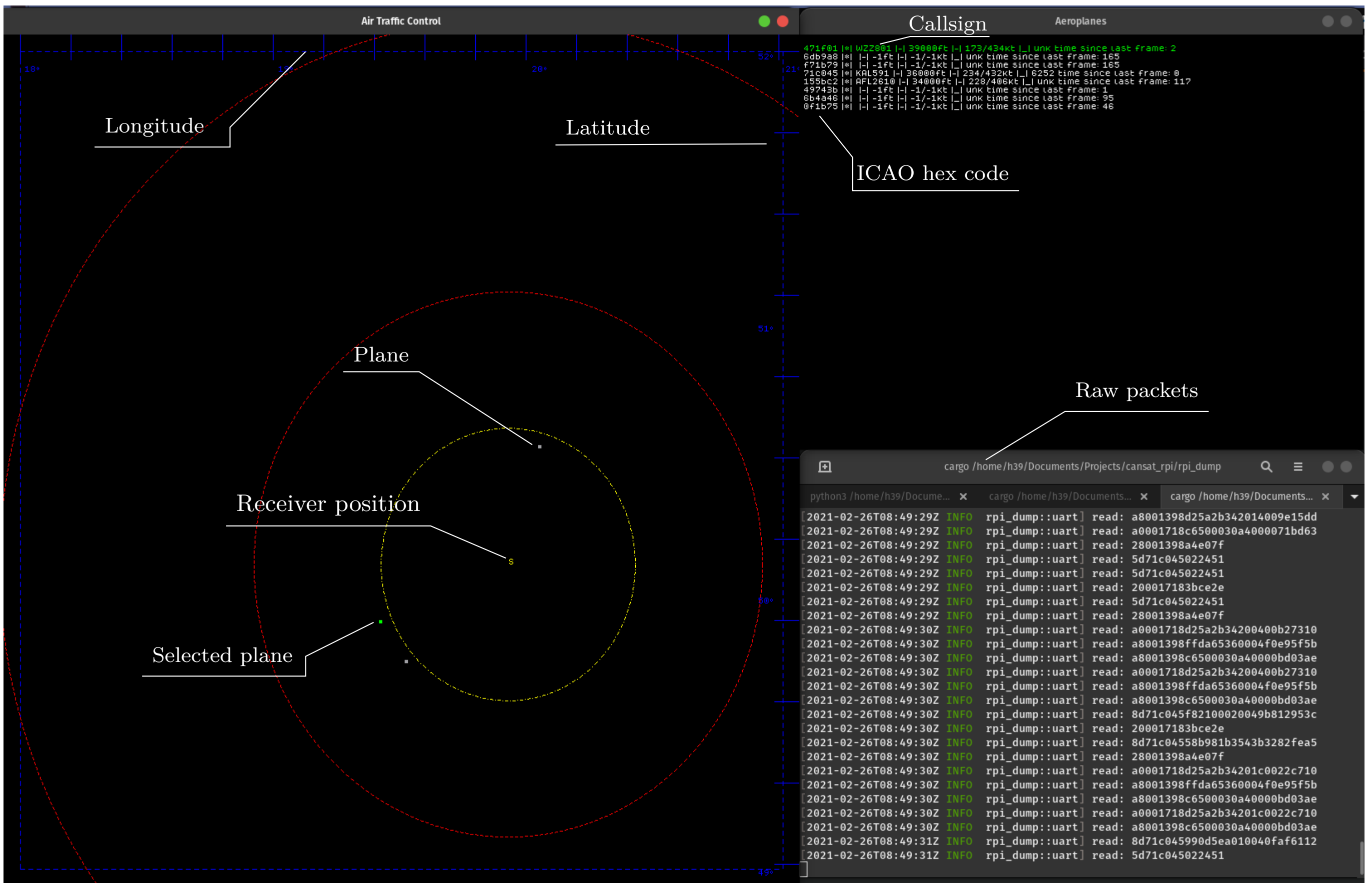


Figure 19: ADS-B software screenshot

2.6 Recovery system

Testing in progress

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 is made from Nylon 40D material and has a diameter of 30-34cm. Attachment is 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 density $\rho(z)$ – Air's exact density at z g – Earth's acceleration[‡]

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

From [5] 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 20: Parachute size calculation

INTENTIONALLY LEFT BLANK

[†]Gas in this case

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

3 Ground support equipment *Final prototyping*

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 visualisation 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.

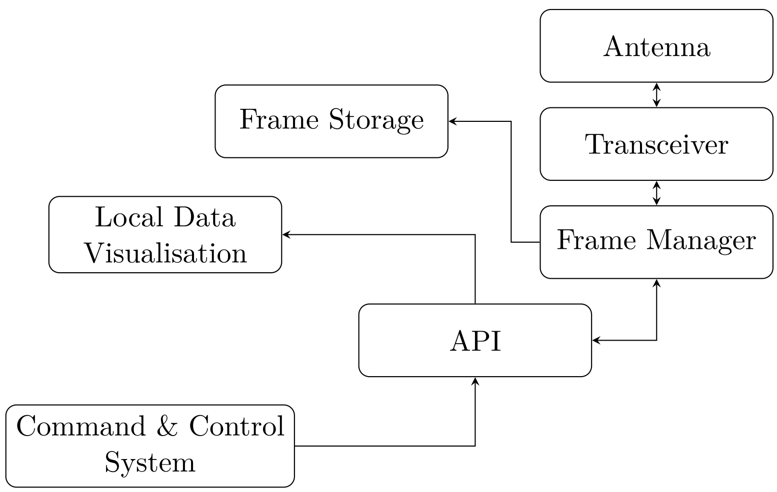


Figure 21: Ground station overwiew

3.1 Receiver setup

The data will be decoded by a module identical to the one on the CanSat, using a similar microcontroler. As a backup we have a LimeSDR device capturing the data alongside the main receiver.

Figure 22: Our antenna during reception tests

4 Test campaign

4.1 Primary mission tests

Testing in progress

4.1.1 Objective

To determine the accuracy of our 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 Pressure to altitude relation

Ready for flight

4.2.1 Objective

Determine whether we can rely on the pressure readouts to specify the device's altitude

4.2.2 Method

We will compare the readouts of the pressure sensor on different floors of a tall building, and compare them with the real altitude. To determine altitude data from pressure readouts we are using the barometric formula.

From [3]:

$$P = P_b \cdot \exp\left[\frac{-g_0 M(h - h_b)}{R^* T_b}\right]$$

Provided with the sea level pressure and a measured one it enables us to get precise positional data.

4.2.3 Acceptable results

The pressure to altitude conversion strays no more than 5m from the real altitude.

4.2.4 Results

We have compared BMP280 readouts on different heigths with ones taken by a Bosch PLR 50 rangefinder device with an accuracy of 2mm/m.

One of the tests were conducted with a height difference of 5.9m.

- Ground level - 1008.89 hPa
- Test level (5.9m higher) - 1008.17 hPa

The calculated data sugested 5.998m (1.6% error). It was consistent with other measurments with errors up to 3%.

4.3 SBC receiver subassembly *Ready for flight*

4.3.1 Objective

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

4.3.2 Method

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

4.3.3 Acceptable results

10-20% from the reference results.

4.3.4 Results

The 1/4 wave gorund plane antenna was tested alongside the CanSat's ADS-B antenna a ground plane relying on copper tape.

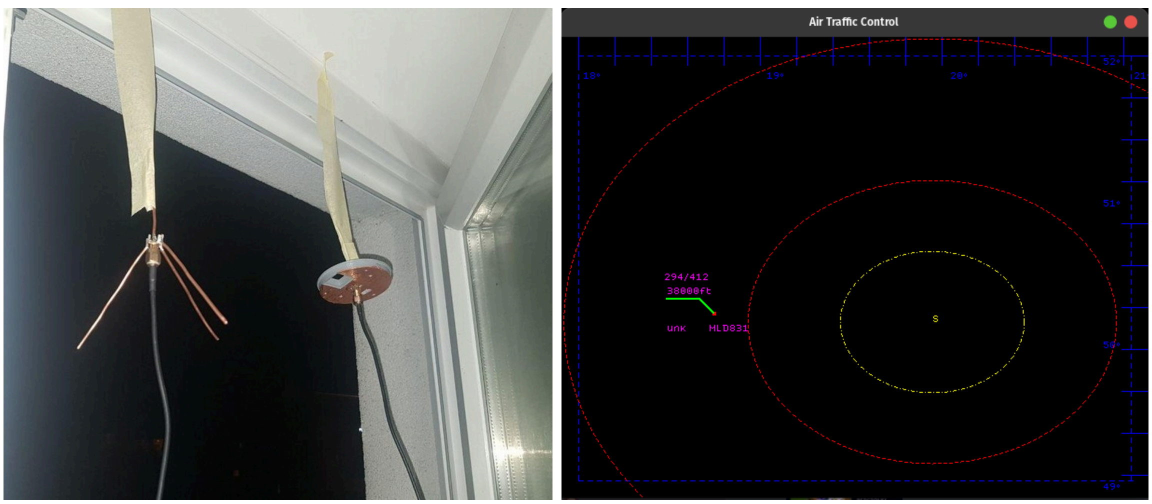


Figure 23: a: ADS-B antennas b: A plane found during testing as seen in our software

The tests have shown about 18% less in average packet count between the top lid antenna and reference ground plane.

INTENTIONALLY LEFT BLANK

4.4 Power usage test

Ready for flight

4.4.1 Objective

Test the power draw in all operating modes.

4.4.2 Method

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

4.4.3 Acceptable results

Minimal 10 hours of operational time.

4.4.4 Result

Primary mission devices are performing as predicted. Secondary mission peripherals use around 600 mA when activated - three times less than anticipated.

4.5 Parachute tests

Ready for flight

4.5.1 Objective

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

4.5.2 Method

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

Figure 24: One of the tested parachutes

4.5.3 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.

4.6 Test launch

Testing in progress

4.6.1 Objective

Test the mission under close to launch campagin conditions using a built rocket. Test the recovery systems. Designate the velocity of the satellite.

4.6.2 Method

We have built a rocket capable of reaching 450m and deploying the CanSat.

Figure 25: a: Rocket body b: Top cone

The ejection system is realised via a balast of black powder, that is set off when the rocket reaches its service ceiling. It creates negative pressure that drives a piston which ejects the CanSat. Afterwards the CanSat will perform a mock mission from a lesser altitude, than the one at finals.

4.6.3 Acceptable results

The CanSat successfully deploys and begins it's mission, we recieve all telemetry and ADS-B data, the CanSat lands and starts broadcasting its location. Telemetry reception throughout the entire recovery. Buzzer activates on landing. Parachute deployment and proper speed reached.

4.6.4 Unexpected delay

On the day we scheduled our test launch one of the internal flight computer PCB traces failed, rendering our test unrealizable. We suspect a possible mechanical or thermal stress fault on internal power layer caused by a high density connector replacement. Furthermore, we were unable to replace the PCB with a newer revision due to unexpected components delivery delays caused by the Texan drop in temperatures "Desperate for Light and Warmth, Texans See No End for Winter Storm." [6].

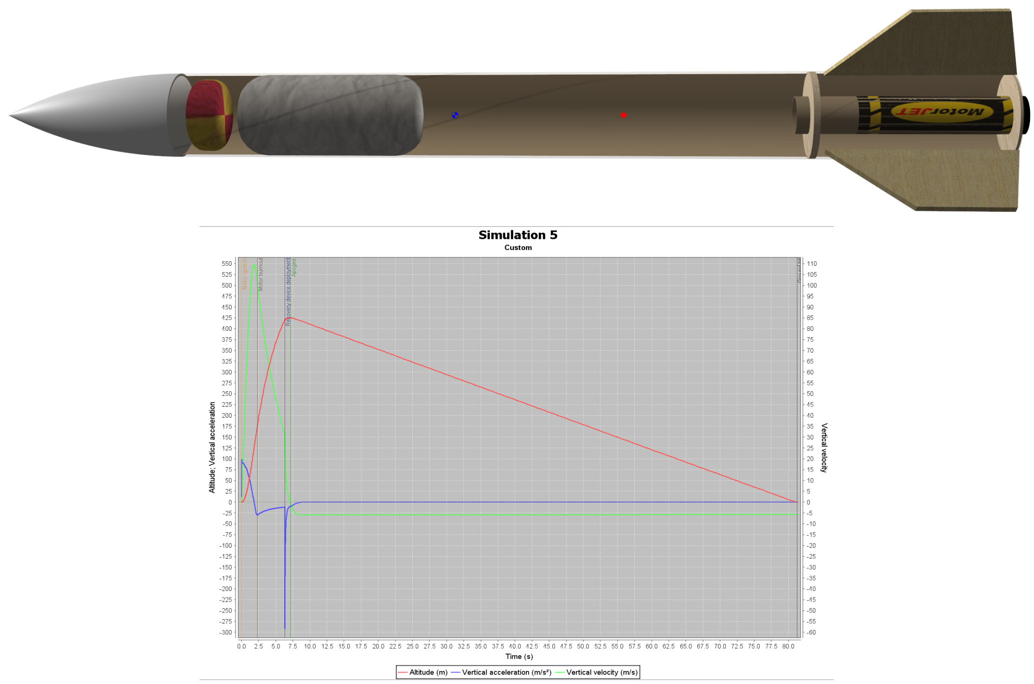


Figure 26: a: Render of the rocket b: Altitude calculations

4.7 SBC interface tests

Ready for flight

4.7.1 Objective

Test the UART interface between the flight computer PCB and SBC.

4.7.2 Method

Perform data exchange between the SBC and flight computer.

4.7.3 Acceptable results

The SBC has a stable serial connection with the flight computer, the data exchange is successful.

4.7.4 Results

We have created a two way, ASCII based communication scheme in which the SBC queues the data and sends it over after receiveing a fetch request from the flight computer. The ideal balance between speed and stability was found to be `115200` bauds. Mock communication was performed for a duration equal to flight time, and no lost bits were detected.

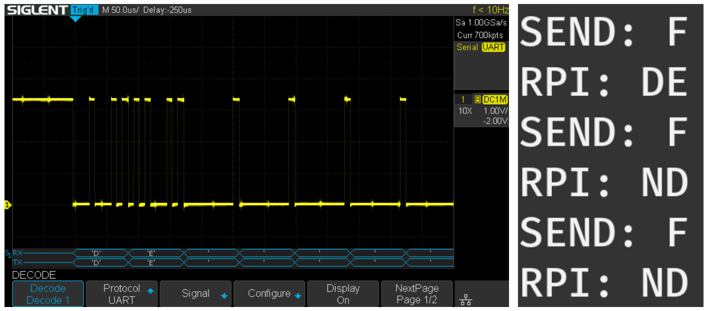


Figure 27: a: Oscilloscope showing `DE` packet sent by the SBC b: Two-way communication log

4.8 Ground station antenna tests

Ready for flight

4.8.1 Objective

Find the optimal antenna for our ground station.

4.8.2 Method

To characterise our antennas we used NanoVNA and NanoVNA-Saver software. Usage of the VNA enabled us to get precise data about their performance. We have captured a 20MHz data span with a center frequency of 433MHz in averaging mode and calculated S11 and Smith chart plots.

4.8.3 Acceptable results

The antenna should be directional, resonant in the ISM band and have VSWR lower than 1.5.

4.8.4 Results

We have acquired a folded dipole 7-element yagi-uda antenna, with the following characteristics. Marker 1 indicates the best antenna match at 430 MHz. Our band of interest is located between marker 2 (433 MHz) and marker 3 (434MHz).

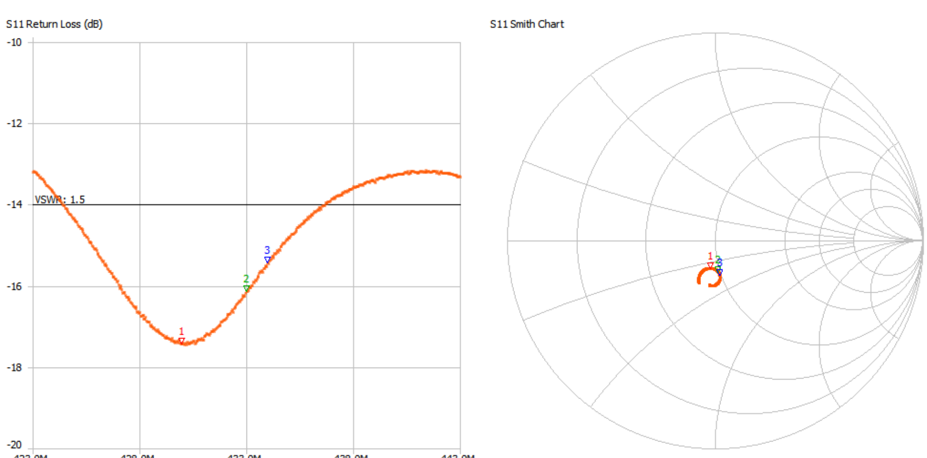


Figure 28: a: Return loss diagram b: Smith diagram

4.9 Ground station reception tests *Ready for flight*

4.9.1 Objective

Test the range and quality of the ground station to CanSat radio link.

4.9.2 Method

Have the receiver set up and distance the trasmitting board to find the maximum range of our transmitter.

4.9.3 Acceptable results

At least 2km of range and less than 10% lost frames.

4.9.4 Results

An interactive map of our reception test can be found here. We have conducted a receiver test during which, the following packet statistics were observed:

Correct packets	1339
Partly corrupted packets	39
Unrecoverable packets	154
All packets	1534
Failure rate	7.9%

Figure 29: Reception test statistics

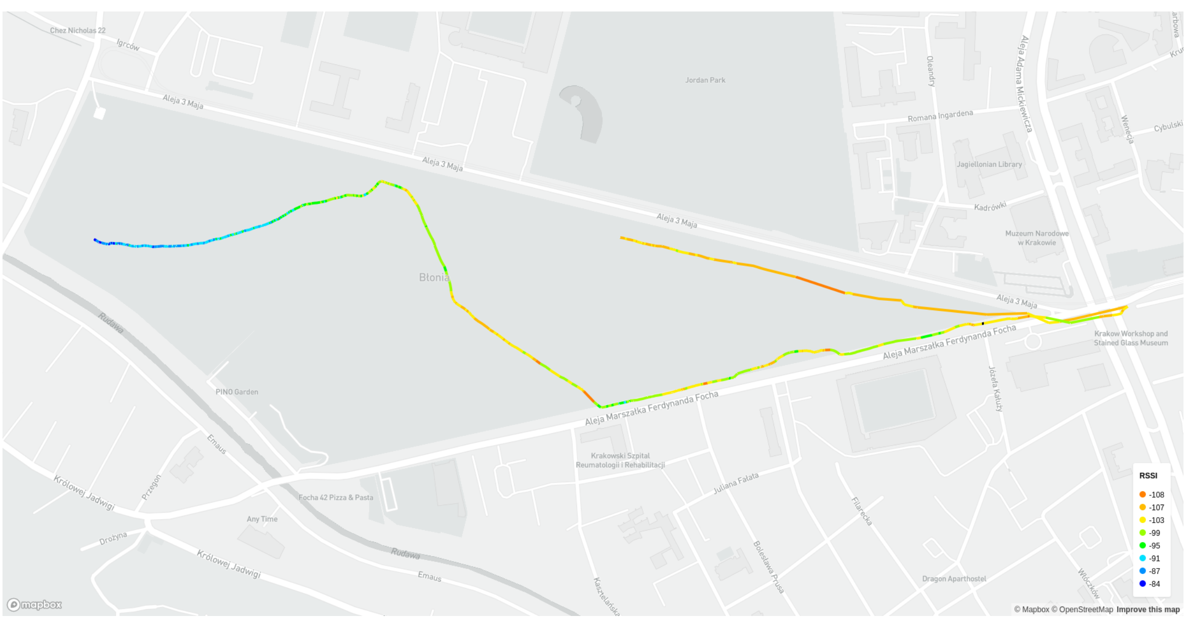


Figure 30: Receiver test path plotted map, with RSSI

4.10 Auxilary tests

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

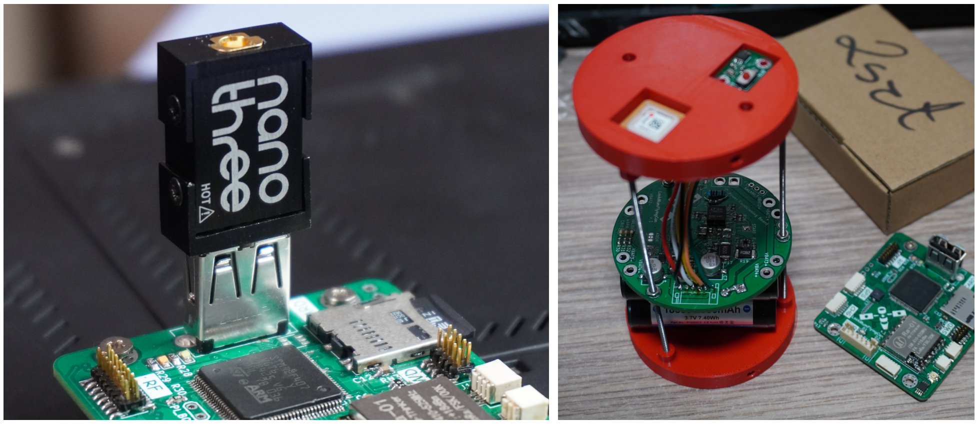


Figure 31: a: Nooelec NESDR Nano 3 radio b: The CanSat as seen from the top

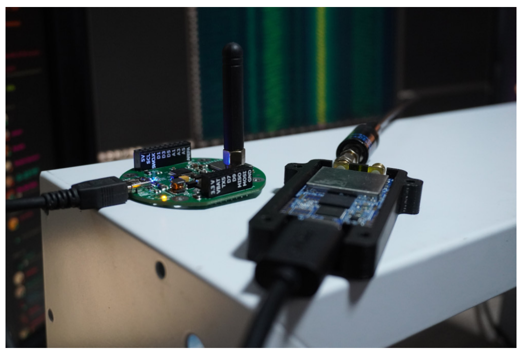


Figure 32: Old base station reception test with the use of a mock CanSat (LimeSDR Mini)

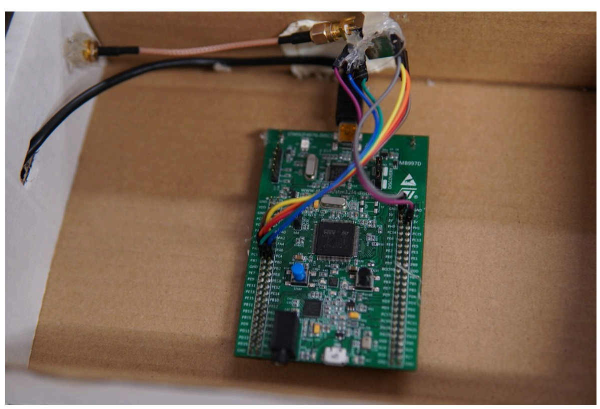


Figure 33: New STM32 base station

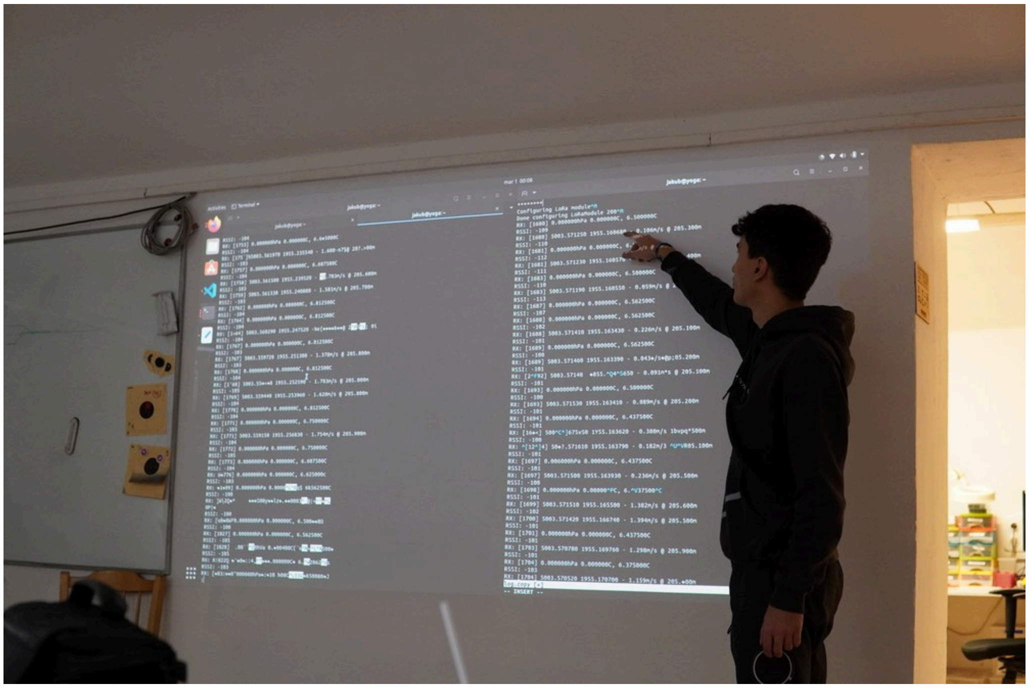


Figure 34: Reception data analysis

Figure 35: Testing the antenna with a VNA

5 Risk assesment

5.1 Mechanical failure

Risk Due to the high stress forces our CanSat experiences during the launch, the enclosure may fail.

Assesment We have distinguished two types of mechanical failures that may take place:

1. Fibreglass tube jettison
2. Skeleton failure

The fibreglass tube may become free of its harness by either breaking into two pieces or breaking the holding points in one of the caps. In any case this risk is not a big threat to the mission since the CanSat can continue its flight as normal. The tube serves only as a protection barrier against environmental effects, we would only loose static pressure information.

The three M2 rods holding the structure together may burst, under *tremendous* stress, in that case our mission is doomed. This is very unlikely since the rods themselves are made of steel and the mounting points have greater resistance to stress. We currently see no way of alleviating this risk.

Conclusion Minimal

5.2 Lack of data sources

Risk Due to outside factors there may not be any airplanes in range of our CanSat, meaning that there will not be any ADS-B packets to collect.

Assesment Due to the COVID-19 pandemic, the density of planes in the air is minimal, since our mission depends on airplanes as data sources, this is very detrimental. To add salt to injury, the new location chosen for this years finals is a relatively low traffic area. This results in a low number of data points for our mission.

We see no way of alleviating this risk, as we have no way to influence the traffic or the time and place of the launch campagin.

Conclusion Severe

5.3 Power depletion

Risk The CanSat may deplete all of its power reserves before the end of the mission.

Assesment This should not take place since our power draw during deployment would drain all power reserves in a time much greater than the entirety of the descent. The only way for this to occur is if the CanSat becomes operational much before actual deployment, this also should not take place due to our deploment detection switch. We have a power monitorig circuit, able to sense abnormal power usage, and disable the offensive components to conserve power.

Conclusion Minimal

5.4 Lack of signal

Risk We may not be able to receivie from, or transmit anything to, the CanSat.

Assesment We have ensured every step of the way to keep all of our signals separate, to stop as much interferance as we can. Our downlink tests clearly show that there is no interferance impedeing the radio module.

Conclusion Minimal

5.5 SDR connection failure

Risk The SDR may disconnect from the SBC's USB port, leading to complete receiver loss.

Assesment The SDR device is very sensitive to certain position factors, and as such will need to be affixed with utmost care so that it does not disconnect during the descent.

Conclusion Medium

5.6 GNSS alignment failure

Risk The GNSS may fail to align for a relatively long time, leading to the lack of positional data during the beginning of the deployment.

Assesment Before the launch the GNSS will be aligned and updated with current satellite positions, which will allow for a warm start during deployment. The manufacturer claims that such a warm start will allow the GNSS device to align in approximately 8s, this has been confirmed by out empircial tests. The GNSS is equipped with a top facing directional antenna. During deployment the antenna may not be facing upwards for small periods of time due to high amplitude pendulum-like movement of the CanSat, this will temporarly disturb our location readings.

Conclusion Medium

6 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.

6.1 Time schedule

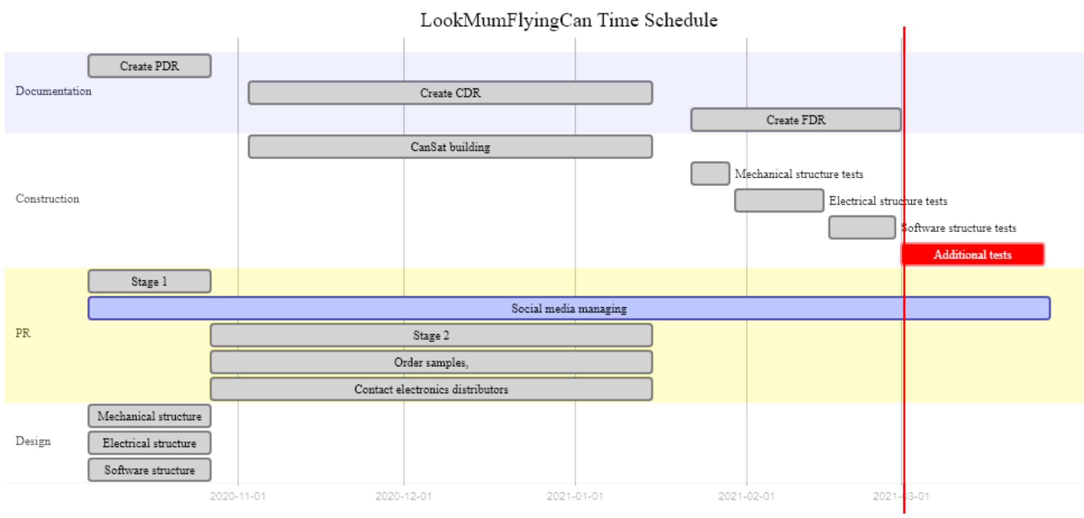


Figure 36: Time schedule

6.2 Task list

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

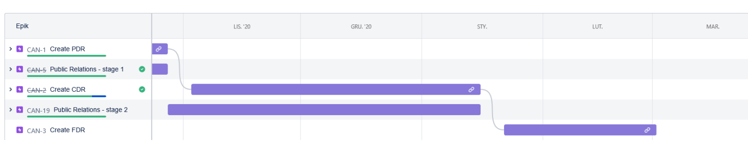


Figure 37: Jira roadmap

6.3 Resource estimation

6.3.1 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 38: Budget table

6.3.2 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. 1$^{\text{st}}$ 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.

6. Batkiewicz - Sponsors merchandise.

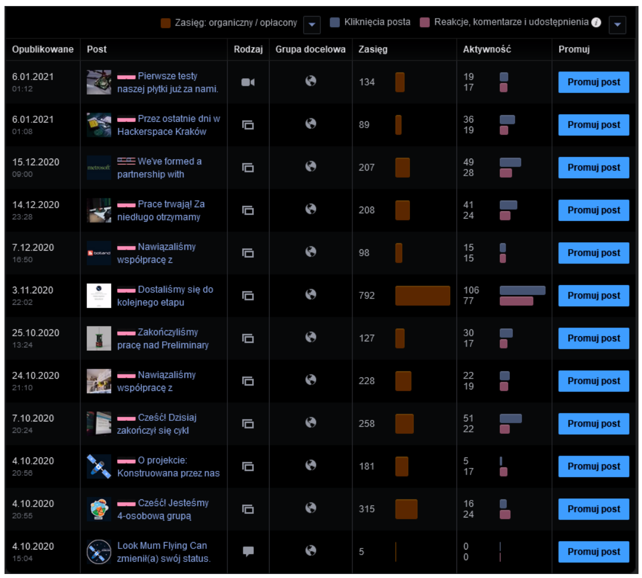
7. Mini-Circuits - Provides technical support and knowledge in developing our satellite. Supplies our team with qualitative electronic equipment.

Figure 39: Sponsors

Appendix A Outreach programme

Due to the COVID-19 pandemic, all of our outreach is performed using the internet. As such we have been unable to organize any person to person events, and have tried to do as much as we can online.

We have created a team website (lookmumflyingcan.com) and a fan page on the Facebook platform (facebook.com/lookmumflyingcan), that has gathered over 1000 views, and over 100 followers. 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 40: Fan page outreach statistics

We have contaced 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 (github.com/LookMumFlyingCan). It is used for collaborative work on our project and to host public-facing services (webpage, data visualisation software).

We have contacted 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 have been invited to host an online discussion about our project before all Polish Hackerspaces. Our goal is not only to present our work, but also to zero in on ADS-B and Cospas-Sarsat problems and provide prospective solutions.

Radio Pryzmat has agreed to host an interview with us on their reccuring show «Operacja Styl», and the date has been set for 2021-03-10

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

A.1 VisualCan

We are creating a public web-service that displays mission information about all of our launches. VisualCan allows people to explore our findings with ease and without installing any software. The framework of choice is Angular. We hope that this can fabricate a stronger bond between our team and people interested in our mission. The software provides data collected from our test launches and represents them in a user-friendly way.

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 41: CanSat's Characteristics

List of Figures

References

[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] Mário N. Berberan-Santos, Evgeny N. Bodunov and Lionello Pogliani. “On the barometric formula.” In: *American Journal of Physics* 65 (1997), pp. 404–412. DOI: https://doi.org/10.1119/1.18555.

[4] 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.

[5] 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.

[6] Will Wright and Campbell Robertson. “Desperate for Light and Warmth, Texans See No End for Winter Storm.” In: *The New York Times* (2021). URL: https://www.nytimes.com/2021/02/17/us/texas-winter-storm.html.