LookMumFlyingCan

Bartłomiej Nowodworski 1st High School in Cracow

Preliminary Design Review

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

supervised by
Mgr. Piotr Gracjasz

27 October, 2020

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. 8

ADS-B Automatic Dependent Surveillance - Broadcast. 4, 6, 7, 8, 9, 10, 12, 19

AGH AGH University of Science and Technology in Cracow. 5

API Application Programming Interface. 14

ASP Academy Of Fine Arts in Cracow. 5

BMS Battery Management System. 9

CNC Computer Numerical Control. 17

CTF Capture The Flag. 5

ELT Emergency Locator Transmitter. 6

EPIRB Emergency Position Indicating Radiobeacon Station. 6

ESA European Space Agency. 2

ESERO European Space Education Resource Office. 2

GNSS Global Navigation Satellite System. 7, 9, 10

ISM Industrial, Scientific and Medical bands. 7

LNA Low-Noise Amplifier. 9, 10

MCU Micro Controller Unit. 10, 12

PLT Personal Locator Transmitter. 6

PSU Power Supply Unit. 11

RF Radio Frequency. 5, 7, 9, 10, 11, 12, 17

SBC Single-Board Computer. 7, 10, 12

SDR Software-Defined Radio. 6, 7, 10

TDMA Time-Division Multiple Access. 12

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

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

Most commercial planes are fitted with the 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 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.

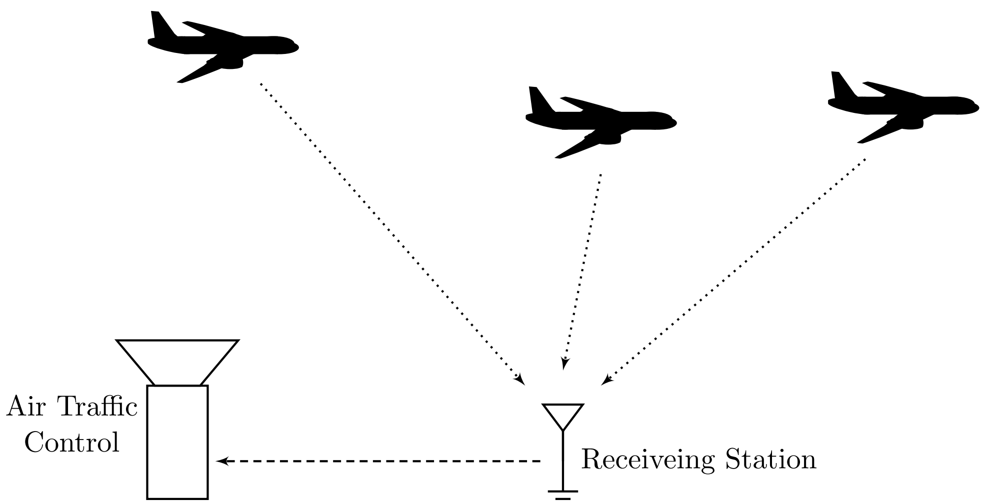

Figure 1: ADS-B overview

Globally, the Cospas-Sarsat system is a satellite-aided search and rescue initiative. 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 ADS-B coverage 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.

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 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 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 real-time 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.

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 Linux computer and the SDR will be measured to keep an eye on the thermals. Radio waves coming from the planes (ADS-B) and distress beacon (Cospas-Sarsat) will be processed by the on-board computer.

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 the other frequency in the ISM band). Our CanSat should detect and locate it relaying the signal to the responders and our ground station in real-time. Temperatures outside and of internal important elements such as Linux computer and the SDR will be measured to keep an eye on the thermals. Also, to demonstrate the functionality of an on-board ADS-B receiver, we will be sending live plane positions to a mock air traffic controller and creating a map showing the amount of planes spotted compared to its altitude. Such measurements might help dissect the exact implications altitude has on over-the-horizon reach due to RF waves refraction in the atmosphere. The altitude data will be supplied from a GNSS receiver and a precision pressure sensor.

2 Description of the CanSat

2.1 Mission Overview

After being released from the rocket the CanSat will open the parachute and activate secondary mission peripherals. It will 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 communication 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.

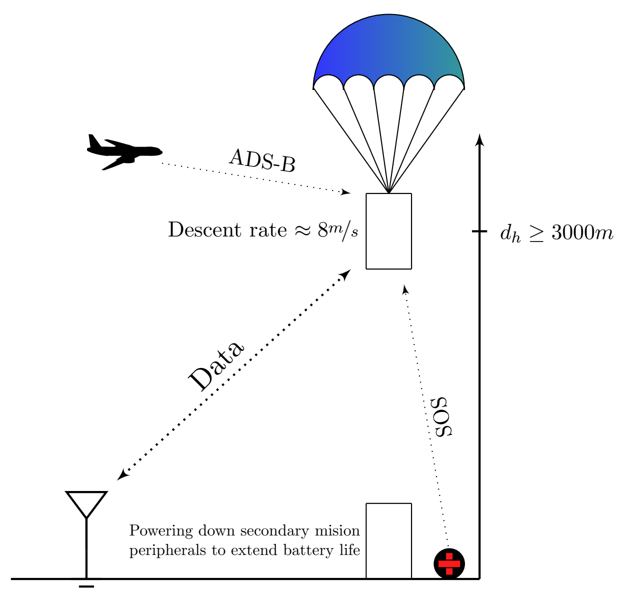

Figure 2: CanSat's deployment

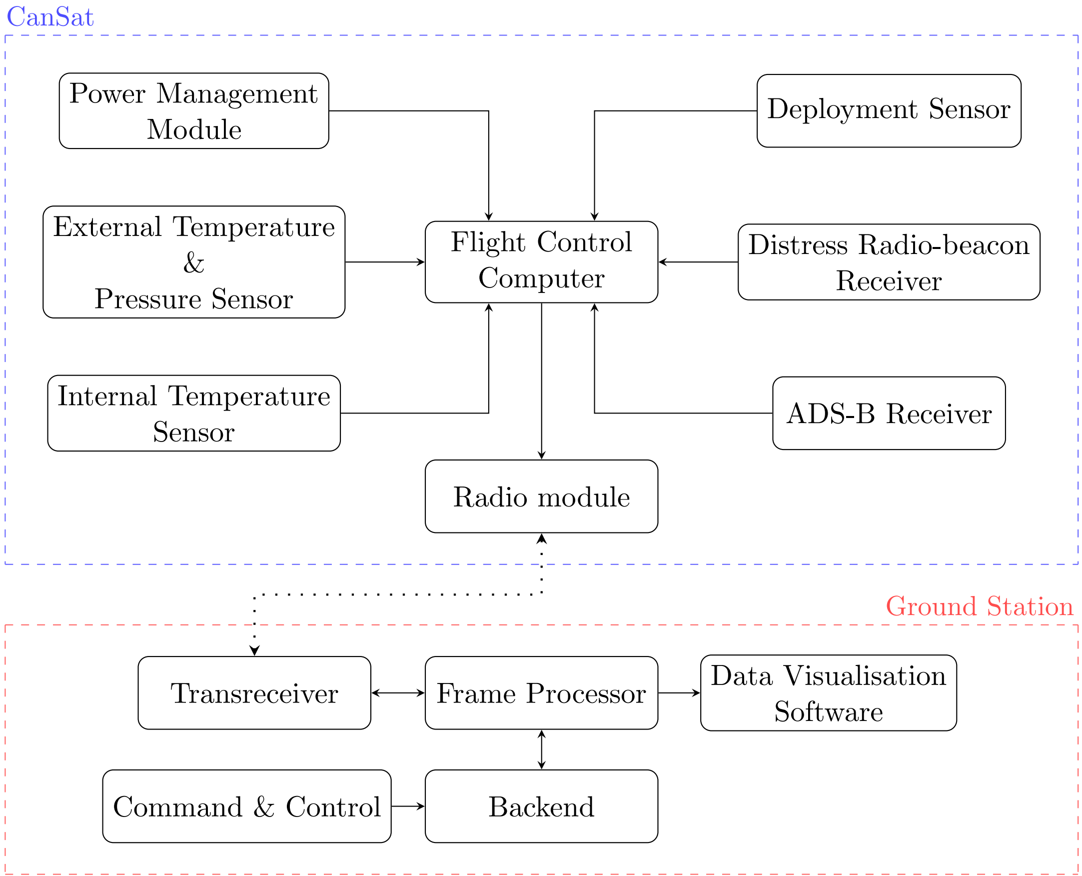

Figure 3: CanSat's overview

2.2 Mechanical design

Components inside the CanSat will be modularized into a top and bottom cap, battery and power management assembly, and a flight computer assembly. Most of the structure will be 3D printed with ABS filament using a Prusa MK3 printer. Individual modules will be held together with M2 bolts running from the top lid to a bottom one. Batteries will be placed in a specially designed 3D printed holder that will provide rigidity and good electrical connection. The enclosure will encompass the entire device and will be mounted via three screws to the lids and will press towards two o-ring seals making the CanSat water-resistant. Other holes in the structure will be sealed with silicone.

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

Figure 4: CanSat's render

Component	Weight
Raspberry Pi Compute Module 4	30g
Flight Computer Board	10g
uBlox SAM-M8Q	15g
Nooelec NESDR Nano 3	18g
RF conditioning board	15g
Battery Assembly	150g
Enclosure and recovery system	100g

Figure 5: CanSat's components weight

2.3 Electrical design

2.3.1 General architecture

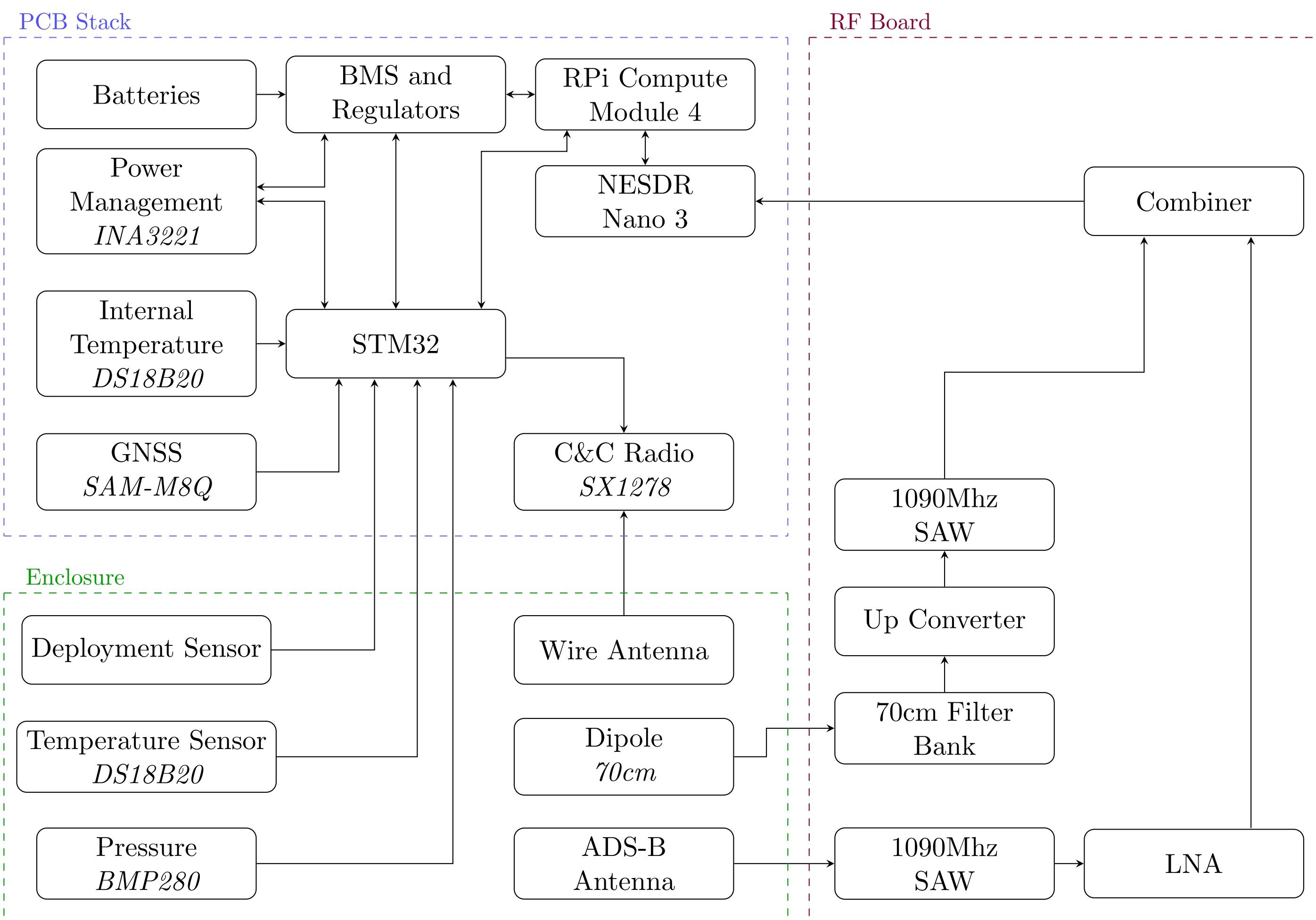

Figure 6: General electronic architecture

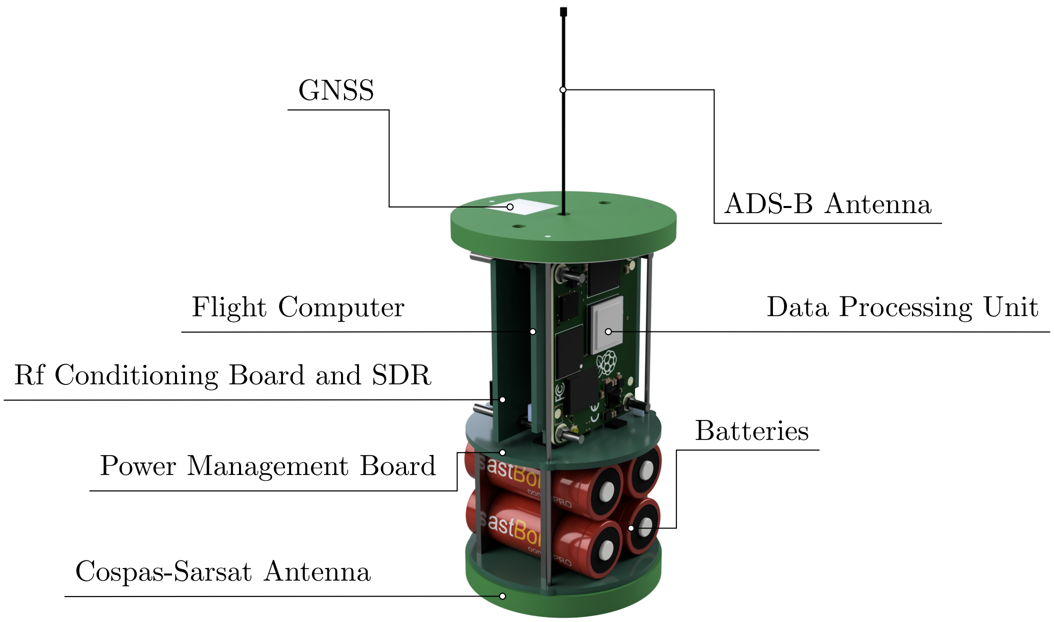

Figure 7: CanSat's side breakdown

2.3.2 Primary mission devices

(a) MCU - **STM32F407**: high speed microcontroller capable of live data handling

(b) Radio module - **SX1278**: enclosed in the Ra-02 module, creates a radio link

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

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

2.3.3 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

(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 receivers, increases selectivity, reduces out-of-band interference:

- ADS-B: a sharp SAW 1090MHz filter with an LNA
- Cospas-Sarsat: a 70cm band filter, upconverter, and a 1090MHz filter

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

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

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

2.3.4 Power supply

Four on-board 2000mAh 18500 batteries connected in a 2S2P array will power the CanSat feeding into a 5V and 3.3V buck converters. BAT, 3.3V, and 5V buses will be monitored with an INA3221 voltage monitoring IC.

We will use four KEEPPOWER ICR18500-200PCM 2000mAh batteries with built-in protection circuits.

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‡

ALL OF THE CALCULATIONS BELOW ARE THEORETICAL

Predicted power draw and batteries:

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

At 91% efficiency

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

90 minutes of all systems being powered

$$10.7\,\mathrm{W} \cdot 1.5\,\mathrm{h} + 1.05\,\mathrm{W} \cdot t_o = 29.6\,\mathrm{Wh}$$

$$t_o = \frac{29.6\,\cancel{\mathrm{W}}\mathrm{h} - 16.05\,\cancel{\mathrm{W}}\mathrm{h}}{1.05\,\cancel{\mathrm{W}}}$$

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

Figure 9: Power draw calculations

*Maximal †Typical
‡on-board PSU

2.3.5 Communication system

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 a synchronization burst, on-board time reference, and a unique frame number.

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

Figure 10: Frame breakdown

We consider using similar architectures for both parties - STM32F4 series MCU with the SX1278 module. 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 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. The choice of these languages is yet to be made.

Currently we consider:

(a) CanSat MCU : HAL / Mbed environment

(b) CanSat SBC: Rust / C++

(c) Ground station transceiver: HAL / Mbed environment

(d) Ground station data processing: Python and Redis DB

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

(f) Public data visualization: Angular and NodeJS

Version control will be realized 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.

2.4.1 Data management

The captured data, as well as mission-critical data, will be stored on an SD card and sent to the ground station. The SD card will be about 64GB. The worst-case scenario is about 1-2KB/s of data. This SD card will allow for ≈ 8500h of data capture time.

2.5 Recovery system

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

$$\begin{aligned}
\vec{D} &- \text{Drag force vector} & C_d &- \text{Drag force constant} \\
\vec{V} &- \text{Speed vector} & p_d &= \frac{pv^2}{2} - \text{Dynamic pressure} \\
\rho &- \text{Fluid}^{\dagger} \text{ density} & g &- \text{Earth's acceleration}^{\ddagger} \\
d_s &- \text{Parachute diameter} & m &- \text{Mass of the object} = 325g \\
& & S_d - &\text{Area of the body perpendicular to} \\
& & &\text{the speed vector relative to the fluid}^{\dagger}
\end{aligned}$$

$$\begin{aligned}
p_d &= \frac{1.2\frac{kg}{m^3} \cdot (8\frac{m}{s})^2}{2} = 38.4\,Pa \\
F_c &= mg = 0.325kg \cdot 10\frac{m}{s^2} \approx 3N \\
S_d &= \frac{|\vec{D}|}{p_d \cdot C_d} = \frac{3N}{38.4\,Pa \cdot 0.83} \approx 0.095m^2 = 950cm^2 \\
\pi r^2 &= 950cm^2 \implies r \approx 17cm \implies d_s = 34cm
\end{aligned}$$

Figure 11: Parachute size calculation

INTENTIONALLY LEFT BLANK

† Gas in this case

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

3 Ground support equipment

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) A router 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.

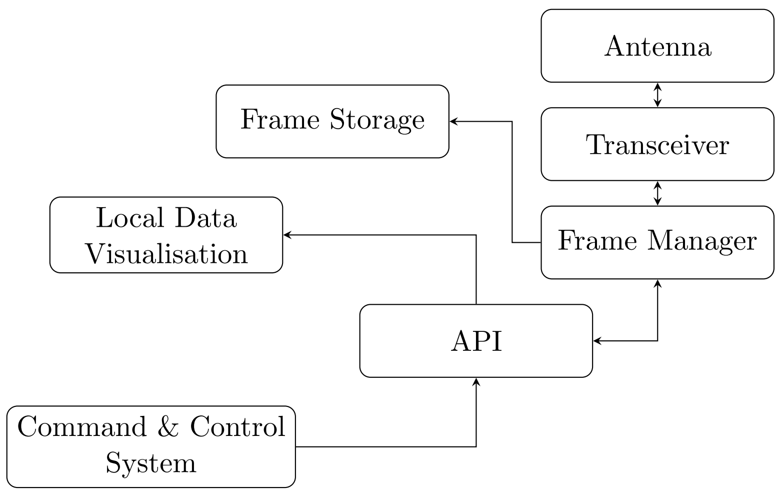

Figure 12: Ground station overwiew

INTENTIONALLY LEFT BLANK

4 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.

4.1 Time schedule

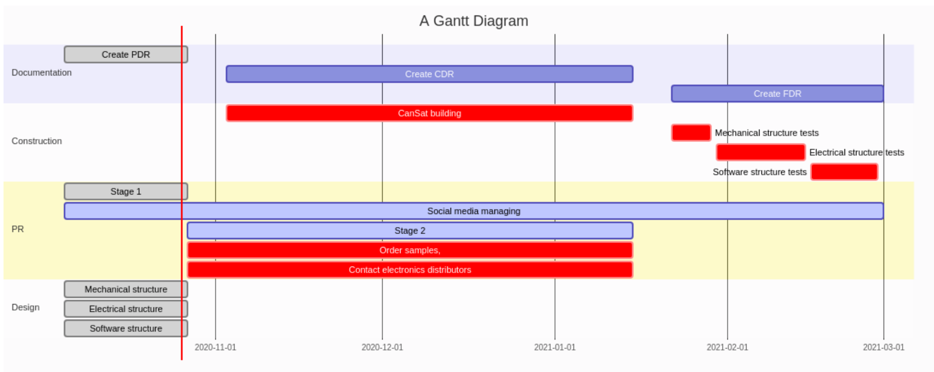

Figure 13: Time schedule

4.2 Task list

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

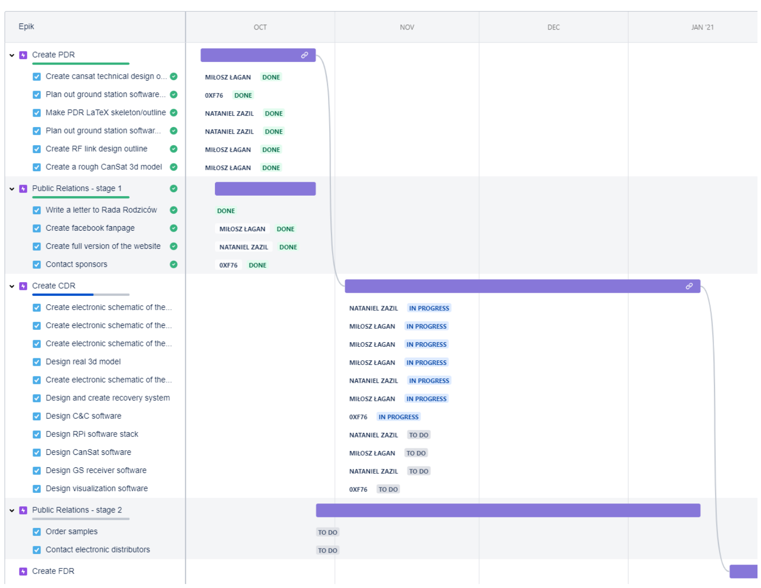

Figure 14: Jira roadmap

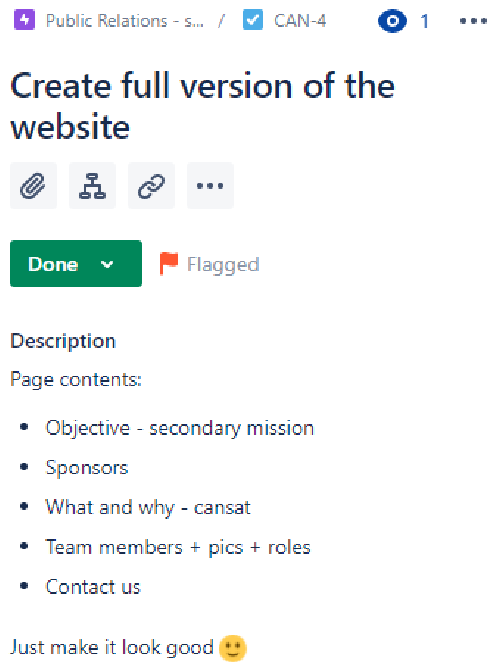

Figure 15: Task elements

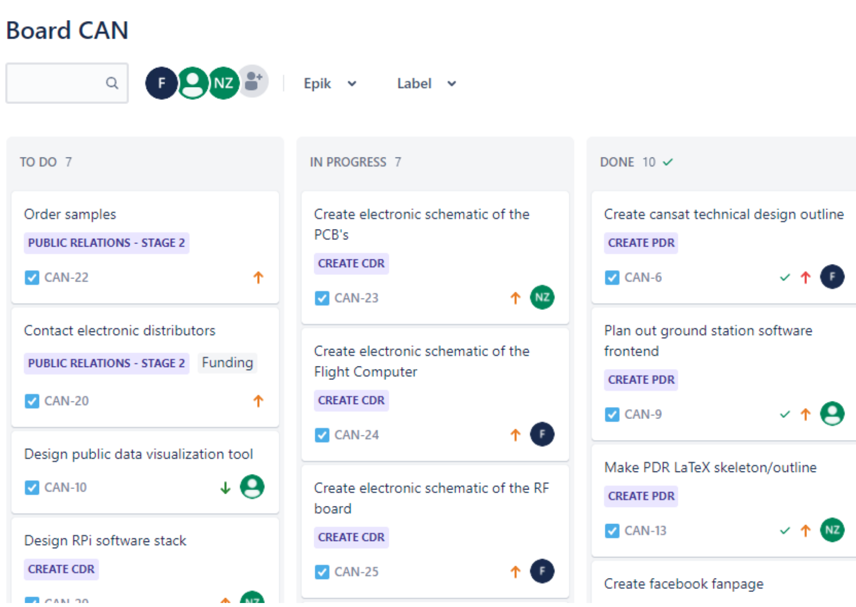

Figure 16: Board view

4.3 Resource estimation

4.3.1 Budget

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

Device	Price (Original)	Price (PLN)
STM32F407	10 USD	38.5 PLN
uBlox SAM-M8Q	≈ 100 PLN	≈ 100 PLN
Ra-02 (SX1279)	3 USD	11.55 PLN
DS18B20	2 USD	7.7 PLN
BMP280	2.5 EUR	9.6 PLN
RPi Compute Module 4	140 PLN	140 PLN
Nooelec NESDR Nano 3	30 USD	115.5 PLN
RF conditioning board	≈ 15 USD	≈ 57.75 PLN
PCBs	15 USD	57.75 PLN
KEEPPOWER Batteries	124 PLN	124 PLN
Enclosure Materials	40 PLN	40 PLN
Total	158.75 EUR	702.35 PLN

Figure 17: Budget table

4.3.2 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

Figure 18: Sponsors

Currently, we lack a founding surplus. The funds from the Parents Board will be just enough for one CanSat and some basic R&D. We plan building two models - one as a backup.

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 will be used as a communication medium where we will 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 will serve as a landing page containing basic information about our project for potential sponsors and the public. Visitors will be able to read about our team/mission goals and see promotional materials (eg. video clips).

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

- Gazeta Krakowska
- Kraków Nasze Miasto
- Gazeta Wyborcza Kraków

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.

Appendix B Characteristics of the CanSat

Characteristic	**Figure**
Height of the CanSat	115mm
Diameter of the CanSat	66mm
Mass of the CanSat	≈ 340g
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	≈ 150 EUR

Figure 19: 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] 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`.