UK CanSat Competition

Athena

Sutton Grammar School

Preliminary Design Review

Date: 08/12/23

Part 1: Introduction

1.1 Meet the Team

We are Project Athena, a 6-man team participating in the CanSat Competition from Sutton Grammar School.

Our Roles:

Team Lead/Coordinator: Responsible for scheduling meetings, arranging task lists and pushing deadlines. Also responsible for chairing meetings and communicating with different aspects of the team

Mission/Technical Researcher: Responsible for researching feasibility of mission and equipment needed. Once the plan is in motion, responsible for researching measurements required.

Media Manager: Responsible for directing the outreach programme, including all the project's social media accounts.

Software Programmer: Responsible for writing algorithms in code and handling how the data gets sent/received

Model Designer: Responsible for creating models online and physically of the CanSat\other parts

Electrical Engineer: Responsible for making sure all electronics are compatible and creating the circuits

1.2.1 Mission Objectives

Our overall mission objective is to simulate a mission to another planet and record data which will be sent back to ground and then stored/analysed.

1.2.1.1 Primary Mission

Our end goal of the primary mission is to take temperature and pressure measurements while the CanSat descends, we will also take VOC (Volatile Organic Compounds) and humidity measurements . These will all be sent down to ground stations and will act as extra data for comparisons/analysis.

1.2.1.2 Secondary Mission: Simulation of Renewable Energy Expansion Exploration Mission

Our goal of the secondary mission is to test if a planet will be suitable for renewable energy sources and if so, test which ones are possible and worth it compared to earth. The four sources we will be testing for are solar, wind, hydroelectric and geothermal. We selected this mission because right now, humanity is on the precipice of revolutionising how energy is produced so it is vital to figure out the more efficient ways.

The example which sparked this idea was when we saw an article about Mars being a possible source of geothermal energy and then discovering other planets got more wind or solar energy than Earth.

Before this mission, we had a previous idea of creating a machine-learning algorithm which detects space junk and the image then gets sent down to ground where it passes through a deconvolution algorithm to get rid of motion blur. However, while researching for parts, we discovered that the four cameras we needed to get a 360 view to detect the space junk were too much for a microprocessor to handle so we had to drop the idea. Luckily, we discovered this very early on as we tried to get a prototype as soon as possible which meant not much time/resources were wasted.

The process of the mission:

1. The shape and weight distribution (specifics detailed later) of the Cansat will make it go upright automatically
2. CanSat will begin the process of taking measurements and conversion
3. Readings from our sensors will be sent back to ground
4. An algorithm designed by us will return a report including:

a. Table comparing live values and hardcoded values
b. Reading - Time Graphs
c. The most likely to work sources

1.2.2 Measurements, Rationale and Methodology

Our sensors will be sending readings back to ground every second during the descent and upon landing it will be every 15 seconds. These intervals can be controlled from the ground station. The delay in taking measurements is to avoid unnecessary data from being sent as too many signals will cause interference.

Measurements and their uses:

- Light (Light dependent resistor):
  - The light intensity will be fed back to ground and will help determine if solar Power is viable/effective
  - It will also show the day/night cycle which will again help determine if solar Power is viable/effective
- Humidity (DHT20):
  - Will reveal if there are any bodies of water and possibly their size, this will determine if hydroelectric power is possible
  - High humidity suggests there is water underground which is required for Geothermal
- Air Pressure (BME 680):
  - This is required in the primary mission
  - We can analyse the effects of air-pressure on temperature, humidity and look for correlations
  - Calculate altitude (formulae detailed later)
    - Altitude readings give us another measurement to analyse data against and shows us the velocity of the CanSat as Altitude is a displacement reading and velocity is the derivative of displacement with respect to time
    - The velocity can then be used for a number of things detailed later
- Wind (Custom-made Anemometer):
  - Calculate wind velocity which shows if wind power is viable as wind turbines need a velocity between a certain range
- Temperature (BME 680):
  - Record heat patterns which will help scientists make informed decisions on if building these energy sources is feasible and if so, what maintenance would be required for protection
  - Required for Secondary Mission
- GPS (Adafruit PA1616D GPS):
  - This will be used to keep track of the CanSat and can be used for testing purposes as we can track the flight path
- Accelerometer\Gyrometer (MPU-6050):
  - Gives all around useful information such as the if the CanSat is descending correctly and hasn't reached an uncontrollable spin
  - Can be used for testing to track how the CanSat moves during flight
  - Can be used to calculate force the CanSat hits the ground to see if the parachute works correctly
  - Will be used to determine is geothermal energy is possible as we can detect earthquakes
- Volatile Organic Compounds (BME 680):

- This will be taken during the Primary Missions and will allow us to analyse any correlation of the readings with temperature, altitude or humidity

To analyse this data, we could potentially use more accurate and larger sensors and get readings from the launch site separately to see the readings from the CanSat comparison. For Primary Mission analysis, we are interested in seeing how the VOC readings change with altitude and also we want to know if temperature has an effect. From research, we found that an increase in humidity relates with an increase in VOC's so this could be a possible hypothesis we test out.

Part 2: Project Planning

2.1 Project Timescale

Meeting Schedules:
We had a general meeting every Monday at lunch in school, and an after-school meeting every Wednesday.
Task Arrangement:
We grouped our tasks into Work Cycles, each lasting a week. Below is an outline of our work schedules, agreed at the beginning of every Work Cycle.

First Stage: 8/11/23 - 12/11/23
Aims:
- Begin Working on Preliminary Design Review, have Section 1 Completed (Achieved)
- Start learning technical aspects and concepts of the secondary mission (Not achieved, we had to change the mission after feasibility tests)
- Look into Fusion 360 as a modelling platform for our Satellite Design Blueprint Prototype (Achieved)
- Research in Mission Components that the team needs to purchase and produce a team report for a meeting on 13/11 (Achieved)

- Second Stage: 13/11/23 - 17/11/23
  Aims:
  - Continue Working on PDR, Begin Section 3 (Achieved)
  - Test out a basic model with Fusion 360, Cura and the 3D printer we acquired (Achieved)
  - Begin learning Onshape/Fusion 360 and start working on the model (Achieved)
  - Work on the precise plan of the mechanical landing system (Achieved)
  - Finish the Outreach (Section 4, by 19/11/23) (Achieved)
    - Have logo ready
    - Explainer posters?
    - Have TikTok, Instagram, Twitter, Reddit and Facebook up and running

- Third Stage: 18/11/23 - 25/11/23
  Aims:
  - Decide of parachute design and material (Not achieved, scheduling issues)
  - Address the problem of whether the Parachute can take 50N of force (Achieved)
  - Continue working on Section 3 of PDR (Achieved)
  - Try print out our first prototype by 27/11 (Achieved)
- Fourth Stage: 26/11/23 - 5/12/23
  Aims:
  - Finish off all sections of the PDR (Achieved)
  - Unfinished tasks from last week (Achieved)
  - Finalise topic lists of what members need to learn for programming the mission (Achieved)

Gantt Chart is Appendix 4 and Appendix 5

2.2 Team and External Support

<u>Team Skills:</u>
We are a highly dedicated team of 6, and one of two teams representing Sutton Grammar. The majority of us have previous experience from working on the Big Bang competition last year and so we have a strong team culture and bond between members. We are especially able to adapt to sudden changes of plans. Most notably, at the beginning of our project we had a really good secondary mission idea that would mean we had to spend about a week learning necessary skills for the mission. However, about four days in, when we were running feasibility studies we found that no equipment advanced enough was compatible with the Raspberry Pi Pico we were using. The Team Lead quickly coordinated multiple emergency meetings and we successfully managed to repurpose our secondary mission within 24 hours. The entire team also showed their efficiency and dedication through this incident and once again proved our strong team bond and adaptability.

<u>Technical Skills:</u>
The bulk of the team not only has previous experience working on the Big Bang Competition, in which some of the team had to learn an entirely new programming language for our project, but the team also has expertise in analytical skills and data handling. This would massively help achieve our objectives of the Secondary Mission, which requires us to process received data and determine whether our simulated environment is hospitable or not. As mentioned before, multiple team members can program in C/C++, Java and Python and are always keen on experimenting with different mediums of interpreting and constructing algorithms, functions and systems. Our lead electrical engineer is highly experienced with the Pico and its workings, having done many projects beforehand.

<u>Limitations:</u>
Our team is very strong on a lot of aspects, but one thing that the team is short on is someone who does graphic design. This is mainly regarding the outreach poster and logo designs, so it is not as much of a problem. Also, to learn the concepts needed to engineer our CanSat and program our missions, the team members need time to learn and master the concepts, as many are A-Level content and all our members are still doing GCSEs. However, the team is enthusiastic and very flexible, so this should not prove too much of a limitation.

<u>External Support</u>
Our team has an expansive external network, including plenty of the team members' family friends being engineers. One of them, a mechanical engineer, helped guide us to the idea of our exterior design of the CanSat and introduced us to the roly-poly mechanics behind the design. Another, a meteorologist, helped us come up with the methodology for our wind and solar measurements, which we are taking for our Secondary Mission.

At the same time, our peers have significantly helped us in the project as well. As one of our team's weaknesses is poster and logo designing, we outsourced to one of our classmates to help design our logo (which can be seen on the cover). On top of that, we worked with another team from our school who is also part of the Competition and we traded services. One of their members was experienced at drawing so she drew our sketches for us and in return, one of our members knew how to code in LaTEx so he coded their maths equations into their document. The team also has advisors in upper years who have experience in mechanical design, and will help us peer-review our reports and designs in order to help us further improve and add to our output.

2.3 Risk Assessment

Physical:

Short Circuiting: Exposed wires can contact other parts of the circuit, causing high current draw, breaking the affected components and/or causing unintended side-effects. To mitigate these risks, we will be securely mounting each component and using heat shrink tubes to isolate electrical connections.
Soldering/3D Printing fumes: Soldering and 3D printing can release toxic fumes that are harmful to the lungs. To mitigate this risk, we will be soldering in a well-ventilated area, using a fume extractor and using non-lead solder. When 3D printing, we will be printing in a ventilated area and avoid using filaments that produce an excessive amount of fumes.
Soldering/3D Printing burns: Solder and 3D printing filament melt at 200°C, which can cause burns if touched. We will avoid contact with the 3D printer nozzle while the machine is in operation and will take care when soldering by keeping a perimeter around the solderer where no-one else is allowed.

Technical:

Time Constraints: We decided to take part in this competition in mid September and we hadn't anticipated the amount of school work we will be faced with. This is because our team has just started their GCSEs and most are taking 11, with some taking 12. This has led to an unforeseen rise in work and this rise will only increase as we approach our mocks. To mitigate this risk we have done two things. Firstly we chose our Secondary Mission as something which is achievable without the need to dedicate an extraordinary amount of time. Secondly we have also planned our tasks with a generous amount of buffer time which will greatly help when our work suddenly increases.
Size/Weight Constraints: Due to the nature of our secondary missions, size and weight is extremely important and there is a chance that some electronics don't fit in which has the potential to render parts of the missions impossible. To combat this, we have selected electronics which will be the first to be cut if need be as their removal affects the mission the least. There is also a significant risk that our 1200mAH battery does not fit. We discovered this through modelling in CAD and we found out that it is a very close fit. For this reason we have identified another battery which we can use as it is smaller due to it being only 750mAH but this will be a last case resort.
Anemometer not working: A quarter of our secondary mission relies on detecting wind speed but there is a significant chance that our anemometer will either not detect velocity accurately due to its size or break on impact due to its intricate design. This is probably one of the greatest potential risks so we will start making the anemometer in mid-December and we will try to get a working prototype done by the end of December.
CanSat is prone to breaking: There is a risk that the 3D printed parts may be damaged during the launch. To mitigate this risk, we will be using high impact PLA printed at a high infill level and 3+ layer walls. We will also design the parts in a way that allows them to be printed in an orientation where the stress applied is parallel to the layers of the 3D print, lowering the chance of layer separation.
Defective Components: There is always a risk that a part we order comes with an issue, therefore we will have spare sensors on the launch day and will design the electronics in a way that lets them be replaced quickly.

Part 3: CanSat Design

3.1 Mechanical Design

<u>Uprighting System</u>

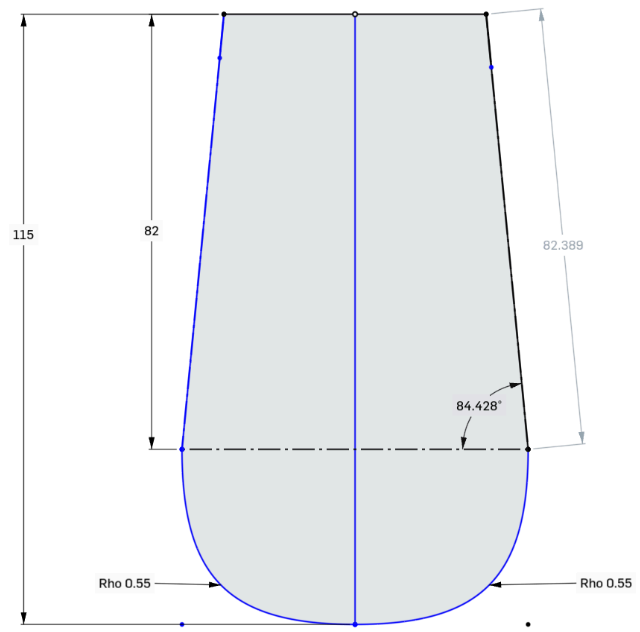
Our secondary mission relies on our CanSat being upright after landing. This is for two reasons: to increase the amount of light our solar panels take and to get more accurate measurements. Our uprighting system relies on the CanSat's centre of gravity. Our CanSat will have a hemispherical bottom with a cone on top and the centre of gravity will be in the bottom half, over the supporting point. The hemisphere will have a flattened bottom to help reduce impact pressure and to give the CanSat a stable platform to balance on, however for calculations sake we will approximate the bottom half to a perfect hemisphere. If the CanSat lands on its side, the centre of gravity would be shifted away from the support point. This would produce torque as the gravity acts on the centre of gravity. After rocking for a bit, the CanSat will finally upright. However, this system adds extra limits to our CanSat. After consulting a mechanical engineer one of our team members knew, we were informed that the weight ratio of the top half to bottom home should be at least 1:3. Assuming our CanSat (without parachute) weighs roughly 320g, the top half can weigh at most 80g and the bottom has to weigh at least 240g. To get our bottom half to meet the weight requirements, we will add a dense object at the bottom. As our centre of gravity also has to be roughly in the centre (horizontally), the weight distribution has to be evenly distributed around the z axis. This means we will need to do a lot of testing/moving parts around to get a centre of gravity in the correct place.

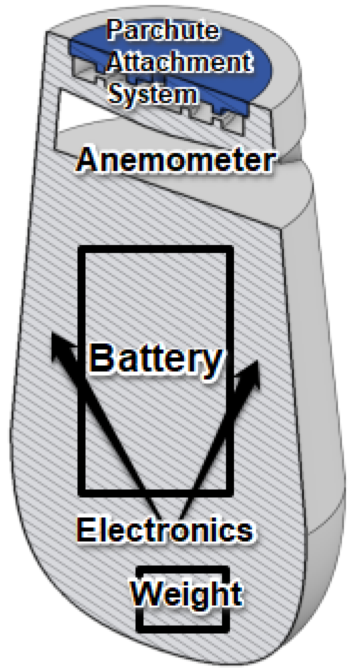
Our original idea for the uprighting system was to have legs which extend from the walls of the CanSat through a servos system. However we decided against this as the aforementioned mechanical engineer advised us that in any object/mechanism, the moving parts should be kept to a minimum. This will decrease the chance of failure which is especially important for missions far away from the Earth as a single mistake can cost billions of dollars and waste years of work.

However this uprighting system has a lot of size and weight constraints which could render parts of the missions impossible. There is also a risk that the hemispherical part cracks under the impact force as the pressure that the bottom faces is a lot due to Pressure = F/A and a relatively smooth sphere coming in contact with a flat line has a small Area of Contact which leads to the high pressure. For these reasons, we have another possible uprighting system in mind in case of our prototyping failing due to the aforementioned reasons. The system is similar to the legs extending system but in this design, the legs are flush in the walls and have a spring pushing them outwards. The legs are held together in the middle by some mechanism. When the CanSat is descending, by using a servo we will let go of the legs through the mechanism which will be then pushed outwards by the springs. These legs will be wide which means unless the CanSat is swinging a lot and the CanSat nearly lands upside down, the legs will force it to become upright. The spring will also act as shock absorbers and upon impact the legs will move outwards as they aren't stiffly connected which acts as a further cushioning system. We haven't sorted out the details of this design due to this only being a possibility in case something goes wrong with the previous design. The reason the previous design is being chosen instead of this one is because this leg design is rather more complicated and we want to keep it simple.

Another possible problem is that during a hypothetical earthquake that the CanSat measures, our readings could be inaccurate as the CanSat will shake with the ground, causing the accelerometer to read inaccurate data. If we find that is a significant risk we have another possible design. This design is similar to the previous one. Again, there will be legs flushed into the wall but these legs will extend once the CanSat has landed and uprighted itself using the system we are currently planning to use. We will have a servo in the middle of the bottom of the hemisphere with rope attached to it, the other end of the rope will be connected to the top end of the leg by travelling on the outside of the CanSat. The servo will turn, tightening the rope and pulling the leg down. This will create a stabilised structure for the CanSat and the tightened rope will make sure the legs stay in place.

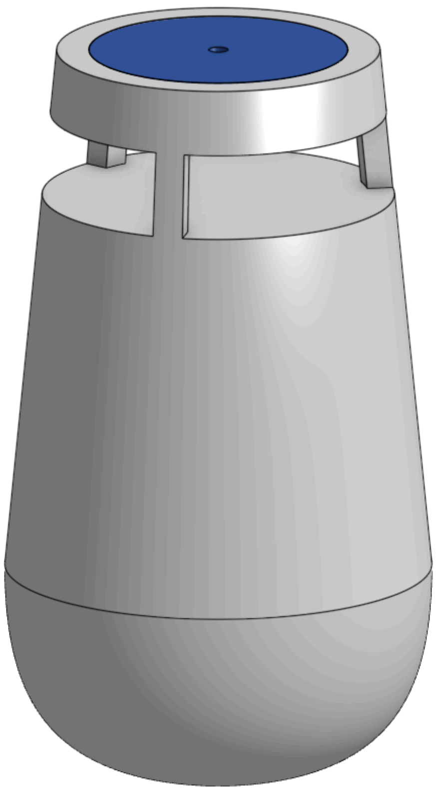
Sketches and Diagrams



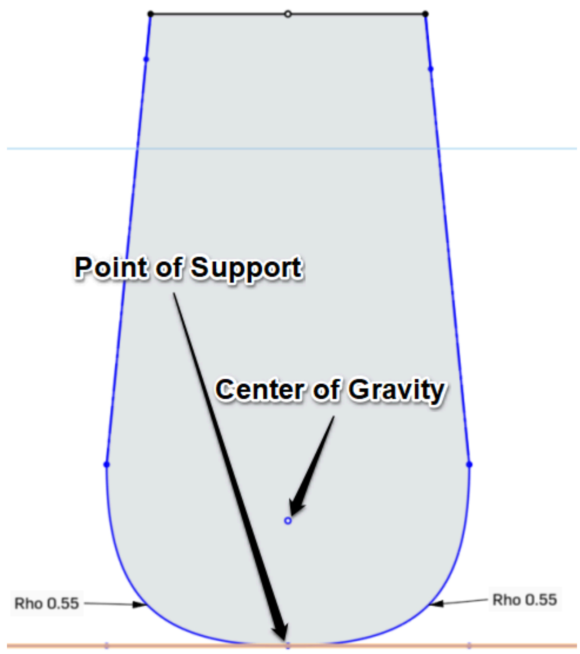


All the measurements are in mm

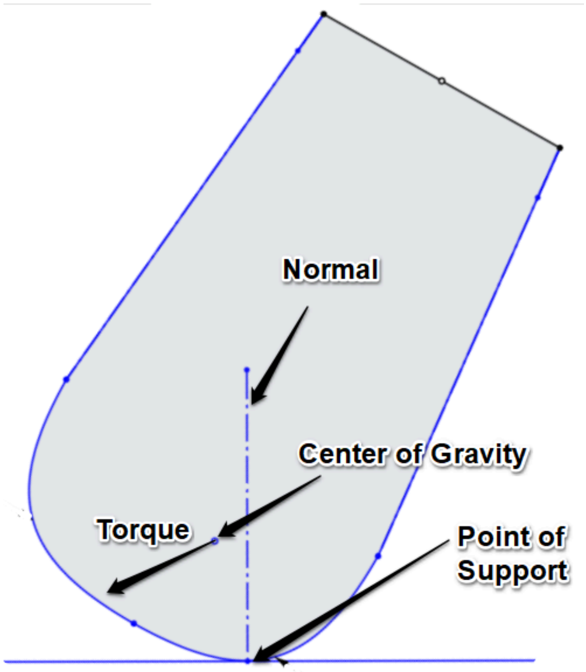
The hemisphere (not exactly a hemisphere) has a radius of 3.3 and the top half is a cone with the top part cut off. The exact flatness of the hemisphere will be decided from testing. By having the space at the top, we will be able to place our parachute in there. However the radius of the top section could and most likely will change as we will have to physically find out the volume the Parachute and its mechanisms take up. Near the top part of the top section, we will have an anemometer placed just under the parachute mechanisms. This means there will be gaps around this area and we can see the 3D model below. We have not figured out the exact dimensions of where the gaps will be and how high up the anemometer, this will be finalised after testing.



Our full CanSat CAD Model



A sketch of what happens when the CanSat is vertical



A sketch of what happens when the CanSat is tilted

Materials

For the exterior of our CanSat, we have decided to use impact resistant PLA. This is because it is an easy material to 3D print due to its melting point being low and lying in the range of 150 - 180 degrees celsius and starters to soften at 60 degrees. It also has great strength and stiffness compared to the alternative we were considering, ABS, which is vital to our mission as if the CanSat changes shape on impact, it may not upright itself correctly. However, PLA has some disadvantages like it has poor heat and chemical resistance, which we will have to consider in the later stages of our project. Impact resistant PLA is also slightly more expensive than the regular PLA so if our budget becomes an issue, we will make our internal support structures out of ABS due to impact resistance being higher than regular PLA (albeit lower than IR PLA).

As a cover for the bottom hemisphere, we might use TPU which will go over the impact resistant PLA. This is due to the fact that TPA is flexible and conforming which makes it a good shock absorber which is useful because as mentioned before if the CanSat hits the ground fully upright the base hemisphere will take a lot of pressure.

Weight/Surface Area Calculations

We can calculate the surface area of our CanSat by considering the hemisphere (our bottom isn't an exact hemisphere but we can approximate it to be one) and cone separately. For the hemisphere, we can use the calculations below:

$$\text{Area of a Sphere} = 4\pi r^2 \Rightarrow \text{Area of a hemisphere} = 2\pi r^2 = 2\pi(3.3)^2 \approx 68.4cm$$

For the part at the top, we calculate the area of a full cone and minus the top cone

We can calculate the height of the large cone:

$$tan(\theta) = \frac{Opposite}{Adjacent} \Rightarrow Opposite = tan(\theta)*Adjacent = tan(84.428)*3.3 \approx 33.8cm$$

Then we can calculate the slant using Pythagoras' theorem:

$Slant^2 = 3.3^2 + 33.8^2 \Rightarrow Slant = 34.0cm$

Now we can calculate the surface area of the full cone:

$\text{Surface area of a cone} = \pi rl = \pi(3.3)(34) \approx 352cm^2$

Now we can calculate the area of the small cone in a similar manner.

First calculate the height:

$$\text{Small Cone Height} = \text{Big Cone Height} - \text{Bottom Height} \approx 34 - 8.2 = 25.8cm$$

We calculate the slant like before and get:

$\text{Slant} = 25.9cm$

Now we can calculate the surface area of the smaller cone:

$\pi(2.5)(25.9) = 203cm^2$

Then we can subtract the two surface areas and get the surface area of our top half:

$352 - 203 = 149cm^2$

Our thickness will be 0.175cm so the volume is:

$0.175 * 149 = 26.1cm^3$

We can calculate the mass by using the Density of PLA:

$\text{Density of PLA} = 1.25g/cm^3 \Rightarrow Mass = 1.25 * 26.1 = 32.6g$

This is plenty less than our limit which gives us room to work with.

We can similarly work out the weight of the bottom hemisphere and get that it weighs:

$15.0g$

This is a lot under what we need so this confirms that we need a mass in this part.

3.2 Electrical Design

Microcontroller

We are planning to use the Pimoroni Pico LiPo as our microcontroller. This is for a few reasons. It is small and light weight which is crucial in a space and weight limited mission like this. The size also gives more room to play around with when deciding where internals go for the correct centre of gravity. For its size, it also has a lot of pins which is necessary as we will be using a lot of sensors. We are using this instead of the regular Pico as it has a 8x greater flash memory which will allow us to store plenty more readings. It also allows for the use of a LiPo battery without a separate battery charging circuit, which would take up valuable space.

Components

Below is a list of the components we are planning to use for our CanSat.

Component	Type	Use	Dimensions (mm)	Included?	Price
Pico LiPo (16MB)	Microcontroller	Controls everything, variant of Raspberry Pi Pico with more flash + built-in LiPo controller	51 x 21 x 8	No	£13.50
Adafruit BME680	Sensor	Will be used for sensing pressure and VOCs	3.0 x 3.0 x 1.00	No	£18.90
1200mAh 3.7V LiPo Battery	Battery	Powers everything	62 x 35 x 5	No	£8.00
Adafruit PA1616D	Sensor	GPS sensor to allow us to locate the CanSat and track its trajectory	25 x 35 x 6.5	No	£29.80
RFM96W LoRa 433MHz (Transceiver)	Radio Transmitter	Transmits signals back	29 x 25 x 4	Yes	£19.50
RFM96W LoRa 433MHz (Transceiver)	Radio Receiver	Same as previous, but this time will be used to receive signals	29 x 25 x 4	No	£19.50
E24 Series Resistor Kit	Resistor	To create a voltage divider in series with the Light Dependent Resistor	-	No	£6.00
Heat Shrink Pack	Other	We will need heat shrink to insulate the soldered connections and prevent short-circuits.	-	No	£4.30
DHT-20	Sensor	Measures the temperature and humidity (higher accuracy than BME680)	5.8 x 12.5 x 16	No	£4.50
MPU-6050	Sensor	Accelerometer/Gyroscope	15 x 21	No	£12.80
Light dependent resistor	Sensor	Used for measuring light intensity	-	No	£2.00
TOTAL	£119.30	**Remaining Budget**	£230.70		

Reasons for Using The Sensors:

BME680:

We had a choice between this sensor and BMP280 as they both measure pressure. Initially we were going to choose the BMP280 as it was already included in the pack however the BME60 also measures VOCs which opens a lot of doors for analysis in the Primary Mission. This swap also doesn't lose any accuracy, both measure pressure with ±1 hPa, and the dimensions are almost identical so it doesn't affect our arrangement.

Adafruit PA1616D GPS Sensor:

There were many options for the GPS sensor but we chose the PA1616D for multiple reasons. Firstly it has a coin cell battery slot which eliminates "cold starts" which saves us roughly 30 seconds every time we start the GPS. This also has a very high max velocity, 515m/s, and has 3V logic level making it compatible with the Pico (3.3V). Its accuracy is quite high with it being accurate to ± 3m. However this one of the most energy demanding sensors we use but this is a feature in all GPS sensors and this has one of the lowest current draws with it being only 30mA.

DHT-20:
Even though we already have a temperature and humidity sensor (the BME680 also senses humidity and temperature) this is more accurate so given that we have the budget we decided the extra space it takes is worth it. However, the sensor itself is quite large so if we find out the internals don't fit, the DHT-20 will be the first electrical device we cut.

MPU-6050:
The main reason we chose this for our accelerometer\gyrometer was that our Electrical designer had already used it many times and was familiar with how it works. It is also very small, accurate and can measure up to 16g which is plenty for the mission.

Light Dependent Resistor:
It was between this or a photodiode and we chose the LDR because it was cheaper, lighter and smaller. However this comes at the cost of speed (photodiodes take mere nanoseconds to adapt to change in light intensity) which isn't that significant as the measurements will be taken slowly on ground.

Anemometer: To detect wind speed, we will need an anemometer. However, there are none which are small enough for our CanSat. This is why we are going to 3D print out our own. It will be a scaled down version of a regular anemometer with cups at the end and will be connected to a DC motor which outputs different voltages based on the speed it is spinning. This will be used to get a rough estimate of wind speed. Currently we are planning to place this custom made anemometer a bit below the parachute platform. There will be holes in the wall around to get the wind. However as a consistent amount of air will be blocked, our speed will most likely be off by a constant ratio so we will have to account for that.

Location of Anemometer is shown in Appendix 3

Power Source: We will have two power sources. Our main power source is 1200mAh 3.7V LiPo Battery. The hourly power consumption of our CanSat will be roughly 120mA so the battery will last for 10 hours which is plenty of time and meets the requirement of at least 3 hours. However the battery is quite big and it is a tight fit in our CanSat but if size becomes an issue, we will downgrade to a 720mAh battery and we only lose £8 so the budget isn't affected greatly. Our secondary power source will be solar foil. This will be wrapped around the outside of the CanSat and we have it because hypothetically the CanSat will be stationed at another planet for a long time so it needs a source of energy after the battery runs out. As of right now, we haven't decided what solar foil we'll use but the price will not affect our budget and the weight is negligible so this won't affect our future plans.

Compatibility Check
We completed the following checks for compatibility:
- Checked that I^2C (a bus network used for communicating with the sensors) addresses do not clash. This ensures each device has a unique address.
- Checked the GPS sensor uses a compatible UART baud rate of 9600, which ensures data can be transmitted between the CanSat components and the antenna.
- Checked that the Pico has 3 analog pins, which means we can use analog sensors such as the light sensor. The pico has a 12-bit ADC (analog to digital converter), which means it can measure 4096 unique light values—definitely enough for our mission.

3.3 Software Design

For our language, we had two options: C++ or Micropython. In the end we decided to choose C++ for a few reasons. Firstly it runs at a higher speed which is useful when taking real time measurements as our CanSat can't afford long delays due to its speed. Secondly, C++ is a compiled language compared to Micropython being interpreted. This means that nearly all errors in C++ will be caught at runtime; this is vital in a mission where we won't have access to the device for a long time and can't afford a breakdown mid-descent. Due to being constrained to a microcontroller, memory is an issue with us only having access to 256 KB of RAM and 16 MB of flash memory. This is where again C++ comes ahead of Micropython as it is memory efficient since it gives control over the memory to the user with the use of things like raw pointers. Finally, due to the need of taking measurements at precise intervals, a tool which helps with that will be greatly beneficial. This is where C++ opens the door for us to use FreeRTOS (Real Time Operating System). Real time operating systems are nearly nonexistent in the Micropython ecosystem, therefore we must use C++ to be able to take advantage of such tools. This will allow us to log data at very precise time intervals and also has the added benefit of allowing easier multitasking. Real time operating systems are also used in NASA missions and practically all space missions which speaks to its usefulness.

There is a risk that during data transmission, a signal gets lost or ground loses contact with the CanSat for a while. To help mitigate this risk we will store some data to the Flash Memory of the Pico so once we recover it we can use the data in case we have gaps in ours. However we will need to make smart decisions about which data to store as the memory is limited. Currently, we are leaning towards prioritising the store of the Primary Missions readings as the chance of losing signal is higher during the descent.

Our software will be broken down into 2 parts, the descent part and the grounded part. The main objective of these two parts is to accurately collect data from the CanSat and then send, record and analyse the data.

<u>Descent Part:</u>

- While ascending, acceleration readings will be taken every second and once the readings are less than a value (which will be calculated in the next review), a string saying "CanSat pushed" will be sent to ground
- Once the CanSat is pushed out of the rocket, every second Temperature, Air Pressure and VOC readings will be sent down to the ground in a formatted string
    - The Air Pressure readings will be converted into altitude using the formula below:
    - $$\text{Alt} = \frac{10^{\frac{\log_{10}(\frac{PF}{PS})}{5.2558797}} - 1}{-6.8755856 * 10^{-6}}$$
    - Here, PF is the pressure we take in from the CanSat and PS is the sea level pressure which we will assume to be constant
    - However, this formula gives the altitude from sea level so we will need to subtract the altitude of the landing site from the value from the formula
- After some time (which will be calculated in the next review) the parachute will be deployed
- After some more time (which will be calculated in the next review) accelerometer readings will be take every 2 seconds and the Pico will calculate if the parachute has been deployed (the readings should decrease by roughly a specific amount) and this will be sent down to ground in a formatted string with a boolean variable, the variable being true if the parachute has been deployed successfully

- After some time (which will be calculated in the next review), an accelerometer reading will be taken, the Pico will then see if terminal velocity has been reached (reading = 0) and formatted string will be sent down to ground with a heading called “Terminal Velocity Reached” followed by a boolean, it being true if terminal velocity has been reached
- When the altitude is 0, a string will be sent to ground saying “Descent Over”

<u>Grounded Part:</u>

- Every 10 seconds, a readings will be taken from all sensors and sent back to ground as a formatted string
- This data will be stored at ground and every time new readings are sent, they are averaged and stored
- On Command from ground, the averages will be taken in by the algorithm:
  - It will have pre-determined values of readings from Earth and the ranges these new readings must fall into for the Energy production to work
  - Then the algorithm creates a report which contains:
    - A table of predetermined values compared to live values
    - Reading-Time Graphs
    - Most likely to work sources (a source being likely to work if readings are significantly higher than hard coded values)
- Now we can analyse and come to a conclusions about if the place is suitable for energy production and if so, what type

Flowchart for decent is Appendix 1
Flowchart for grounded is Appendix 2

3.4 Landing and Recovery System

<u>Parachute Design</u>

Since our secondary mission isn’t reliant on the CanSat having a certain descent speed, our parachute does not require any specific features. Nonetheless we still need our CanSat to descend at a rate of 10m/s or greater.

For the design of the parachute, we had to decide between the Flat Hexagonal shape and the Hemispherical shape. In the end we decided to go for the flat hexagonal shape. This is for two reasons. Firstly, the hexagonal shape has a higher drag coefficient which we need to decrease the speed enough to stop possible damage to our CanSat. It also is a lot easier to make which is very useful as now our team can carry out other more impactful tasks instead of spending time making a time consuming hemispherical parachute.

We want our descent rate to be 11m/s as we don’t want too big of a parachute due to weight constraints but we also don't want to cause damage to our CanSat as it could affect the uprighting system or internals. We can use the formula for Force of Gravity on the object and the Force of Drag to calculate the area of our parachute. Terminal velocity is reached when the Force of Gravity is equal to the Force of Drag as they are opposing forces. Assuming the drag coefficient of the parachute is roughly 0.8 and the air density remains constant at 1.225 g/m^3 we can calculate the required area of the parachute.

$$\text{Force of Gravity} = m * g \text{ Force of Drag} = \frac{1}{2}C_d pAv^2$$

$$mg = \frac{1}{2}C_d pAv^2 \Rightarrow 2mg = C_d pAv^2 \Rightarrow A = \frac{2mg}{C_d pv^2}$$

In this equation m is mass, g is the force of gravity on earth, C_d is the drag coefficient, p is the local air density, A is the area and v is the velocity. We can plug in our values and get:

$$A = \frac{2(0.35)(9.8)}{(0.8)(1.225)(11)^2} \approx 0.0579m^2$$

So our parachute area has to be 0.0729m^2 which is small enough to fit in the top of the CanSat.

We can then figure out the dimensions of the parachute using the formula below:

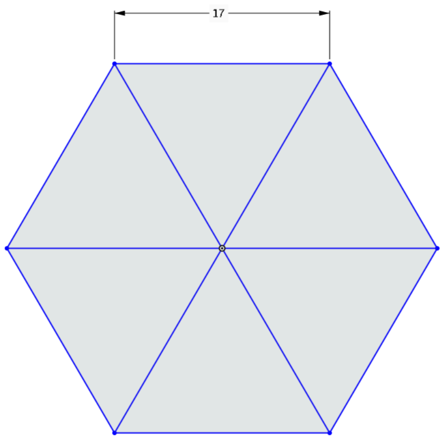
$$\text{Area of a Hexagon} = \frac{3\sqrt{3}}{2} * a^2 \Rightarrow a = \sqrt{\frac{2A}{3\sqrt{3}}}$$

Where A is the area and a is the side length.
We can plug in A as 0.0579 and get:

$$a = \sqrt{\frac{2(0.0579)}{3\sqrt{3}}} \approx 0.14922m \approx 14.92cm$$

The radius will also be the same value as we can break the hexagon down into 6 equilateral triangles and the sides are equal. For a buffer, we can round this up to 15 cm.

Therefore the diagram will look like:



<u>Parachute Materials</u>
For our parachute material, we are thinking of going for Nylon ripstop fabric. This is for a few reasons. Firstly it's easy to obtain and customisable so we can make it into our own design easily. As it is woven with coarse, strong warp and filling yarns the tears don't spread decreasing the chance of failure. The major reason we chose this material is because it is waterproof, tear resistant and has zero porosity which reduces the chance the actual CanSat gets extremely wet. Finally, it also has a high strength to weight ratio which favourable as in this competition every gram matters. We also have terylene, a polyester fabric, as a possible alternative due to it being very strong and heat resistant. However for the time being we will be using Nylon Ripstop due it being easily accessible and is already an established parachute material which makes guides on the internet abundant.

<u>Recovery System</u>
To recover our system we have two features in place to make sure our CanSat is not lost. Firstly, our parachute will be a colour like Magenta or Purple, something which is hard to find in nature. Now, our parachute won't blend in into the surroundings and we can easily track its flight path which is especially useful when we are testing it and want to record the effects of wind. It will also have a GPS, letting us keep track of it all the time.

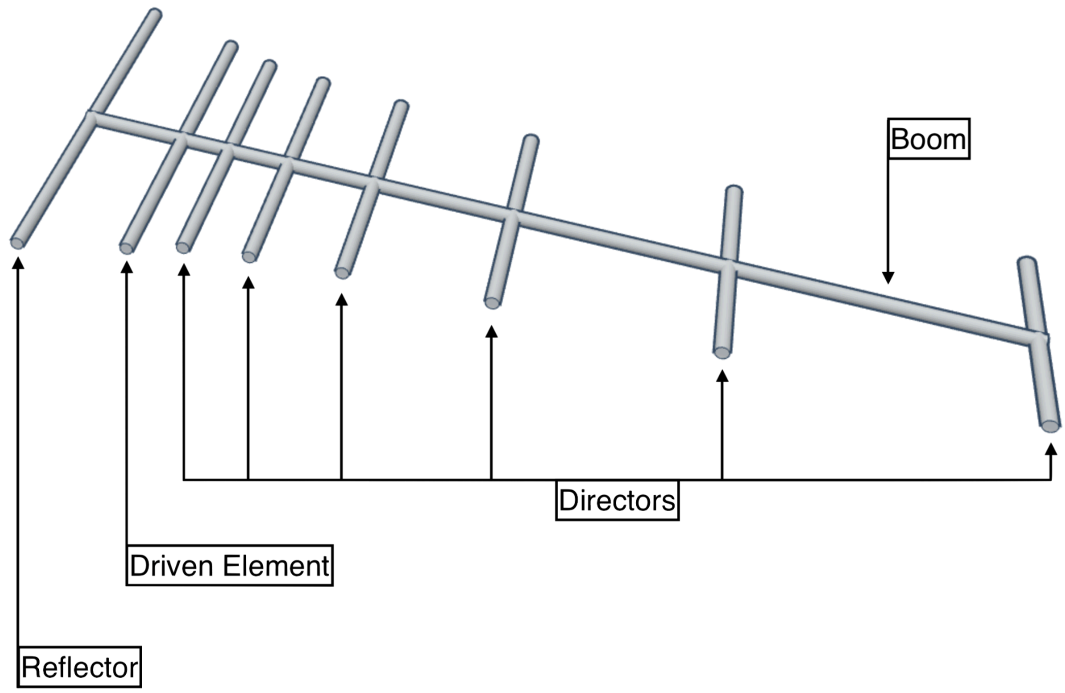
3.5 Ground Support Equipment

Specifications

Our ground support must be able to transmit signals to at least 350 m above ground (will be adjusted for the Final and potentially European Launch), in order to give it buffer height for our missions, and relay data to and from our CanSat. It must also be able to direct the CanSat to land and be able to transmit (insert amount) of data at a time.

Ground Antenna Choice

We will be using a cheap Yagi-Uda antenna for our CanSat Ground Station, because a typical model is designed to transmit signals miles above ground and is used for high quality television and telecommunications.



Above is a simple model of the Yagi Antenna. The driven element is the one that has a current applied, while the reflectors and directors help direct the signal in the right direction, which means this type of antenna works well in precise, targeted signals, and therefore it would be able to send/receive up the signals to/from from our CanSat. There are also models available on the internet that are easy to assemble and under 60 pounds.

Our only challenge regarding the choice of this antenna is that we would need to decide which frequency to use and adjust the antenna for it. Our current proposed frequency matches up with that of our CanSat transceiver (details in Section 3.2), 433MHz, but different ideas are being floated around depending on signal interference. Because wave speed = frequency * wavelength, the smaller our antenna, the higher frequency it would be able to transmit signals in.

CanSat Antenna Choice

For our CanSat Antenna we have singled out two choices: Duck/Rubber-Duck Antenna and the PIFA Antenna. Below is a table listing the comparisons of the antennas.

Antenna	Advantages	Disadvantages
Rubber	• One of the most common	• Electrically short,

Duck	• Often used in walkie-talkies so definitely compatible	poorer performance
PIFA	• Small and mobile, can fit into CanSat easily • Can be engineered into a large broadband range	• Uncertain of the success rate

As of now, our team is inclined to using the rubber-duck antenna, because we are not transmitting a significant amount of data, and it is one of the most common. However, as we do testing of our interior design in January and February, we might change this.
The rubber-duck would have a required length that can be calculated using the formula

$$\text{Length} = \frac{\text{Speed of Light}}{4 * Frequency}$$

Assuming that 433MHz is the frequency we want to work with, below is the calculation to which we can draw a conclusion about how long the antenna should approximately be.

$$\text{Length} = \frac{3 * 10^8}{17.3 * 10^8} \approx= 17.32cm$$

<u>Free Space Path Loss</u>
One thing we need to consider about our CanSat is the fact that radio wave signals weaken over distance. We are using the upper bounds for all our variables in order to calculate the maximum signal loss. We can do that by using the Free Space Loss formula below:

$$\text{FSPL} = 20 * \log_{10} \frac{4\pi df}{c}$$

Where:
d is distance between transmitter and receiver (km)
c is the speed of light
f is the frequency (Hz)
FSPL is the Free Space Path Loss (measured in dB)

Bounds:
Frequency is 433MHz, or $4.33*10^8$ Hz,
Vertical distance (altitude) is 350m (We will adjust this for the National and European Finals)
Horizontal distance is 100m (Again will be adjusted)

We can first use Pythagoras' Theorem to calculate the maximum distance:
$\sqrt{100^2 + 350^2} \approx 364.0055m$
This can be rounded to 365m.

Then, we can plug that value and the frequency into the formula in order to get the result.

$$\text{FSPL} = 20 * \log_{10} \frac{365\pi * (17.32 * 10^8)}{3 * 10^8} \approx 76.417dB$$

This data would help us identify how powerful our antennas should be and the dimensions of them. This is just a rough measurement to identify the antenna as there are many variables such as the transmitter and receiver gains, however for a CanSat this would be precise enough.

Other Equipment
We will also need a laptop in order to send transmissions of the signal.

3.6 Testing

During the process of designing our CanSat, we also came up with a list of things that we would need to test.

What is being tested	How we will test it	What we expect to see	What to improve
Parachute	We will drop an object with the same weight, size and shape as the CanSat from a building in our school at least 3 stories tall	The parachute deploying correctly and slowing down the fall of the pretend CanSat to a speed at which the CanSat will not sustain damage. We will use an accelerometer to get precise readings of its movement.	If the parachute does not slow the CanSat enough we will need to increase the area of the parachute so there is greater air resistance to slow the CanSat down. If the parachute does not deploy properly, then we will change the shape\area of the parachute and the way it is stored inside.
Light Sensor	We will shine different colours of light at different intensities to test our light sensor in most scenarios	We expect to see the light sensor taking in the intensity and brightness of the light shone at it, so we can work out the amount of energy possible solar panels can get from it.	If we find that the sensor is not working properly or not giving the right data, we will have to compensate for it by either buying another one or modifying the data we receive to get more suitable data
Anemometer	We will use a fan to simulate different wind speeds and intervals of wind. We will then use the sensor to find out the wind speed and the wind reliability	We expect to see the sensor giving us accurate information and data about the wind speed. We will then use this data to figure out whether the wind can be used as a renewable resource	If we find that the anemometer is not working properly or not giving the right data, we will have to re-print it with a different size design.
Humidity sensor	We will spray water (a different number of times) into the near proximity of the sensor at different intervals to simulate different humidities	We expect the humidity sensor to give us reliable and accurate results on the humidity in the atmosphere. We can use this information to judge whether the conditions may allow hydroelectric power	If we find that the sensor is not working properly or not giving the right data, we will have to compensate for it by either buying another one or modifying the data we receive to get more suitable data
Durability	We will test the CanSat physically by dropping it from increasing CanSat to see when it starts taking damage and how we can stop that	We expect to see at least a few points that may need fixing or reinforcing. When we drop the prototype, we expect to see some cracks and dents once we start dropping it from around 3m	When we test it physically, if we see any damage to certain areas of the CanSat , we will further reinforce that area, however, we will have to be careful of the size and weight of the CanSat .
Data transfer	We will test whether the data that our CanSat is getting is able to be transmitted to us over long distances. We will do this by steadily increasing the distance between us and the CanSat , whilst it is relaying data to us. This way we can find out its limits.	We expect the CanSat to relay data to us up to a few hundred metres away. This will be needed as the CanSat will be going around 300m up into the sky and we will be needing information from the sensors the whole time.	If the hardware/software is unable to transmit the data that far or fast enough, we may need to swap out some of the equipment for better equipment which meets the needs of our project.

3.7 Overall Testing for Launch

What is being tested	How we will test it	Improvements
Parachute Connection Withstanding Force	We will attach a parachute to an object that weighs 50N in suspension just above ground to test it.	We could change the material of the parachute connection or the mechanism itself
Wind Effect on CanSat	On a windy day, we will do the drop test and deploy the parachute mid-air, and investigate how far the parachute deviates from the initial predicted landing position. We will then calculate the predicted deviating distance for the altitude of launch day	If the deviation distance is too significant, we would possibly consider changing the design of the parachute or add a spill hole to our CanSat.
Descent Rate and Parachute Opening Manoeuvre	We will be dropping the CanSat from a height, where the parachute will be deployed (hopefully with success). We can see how long it takes between dropping and landing in order to calculate the descent rate.	We might look into improving the parachute design to make it more/less air resistant. We will do this by either making the area greater or adding holes.
CanSat Force Withstanding Capacity (20G)	We would attach a string to the CanSat, and receive readings from the accelerometer as we swing the CanSat around, reducing/increasing acceleration when necessary.	Improve durability of inner components and evaluate the possibility of using structural supports.

Part 4: Outreach

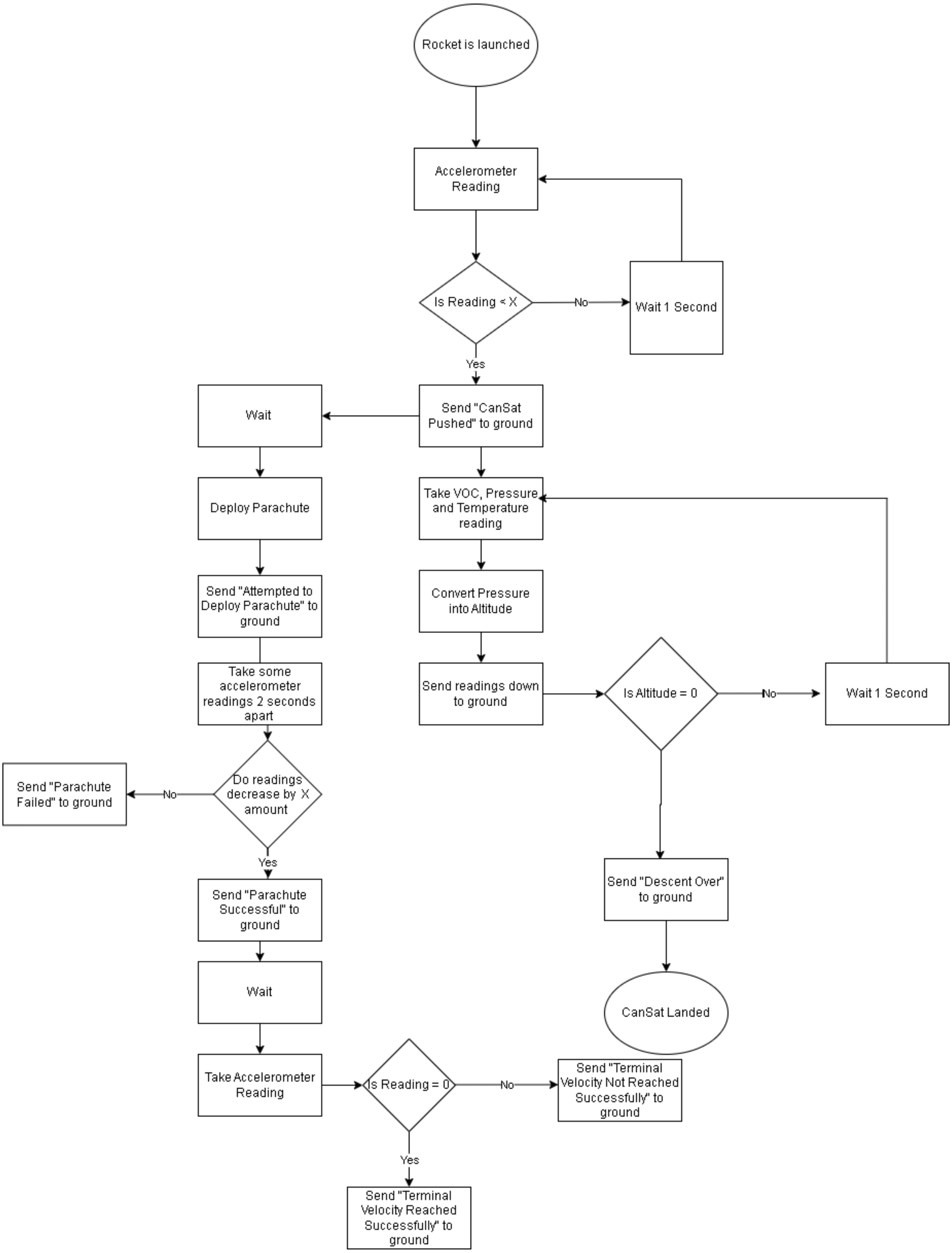
For outreach we will have 2 main streams in which we will raise awareness about our mission. We will use Social Media to raise awareness on a macroscale and then we'll use our school resources to raise awareness locally. The main goal of these 2 streams is to primarily raise interest in the competition and robotics\engineering in general but our secondary goal is to educate people on how it all works and explain some of the core concepts/fundamentals.

For the school resource stream, we will be focusing mainly on the primary goal as it is hard to explain concepts using physical means. Our three sub-goals in raising awareness are: To inform students about the Competition itself, to inform students how they can do things like this and to show what they can gain through activities like this. To achieve this we will use 3 different resources. Posters, Articles and Assemblies. Using the posters, we will primarily achieve the first sub-goal. The posters will contain crucial information about this competition like what you do, entry requirements, how to enter and what skills you need to learn. The posters will also mention our team and will encourage the students to talk with us if they are interested in CanSat. The posters will be flashy and eye-catching and they will be themed about space. Using the Articles, we will document our progress\any achievements we get. This will achieve the third sub-goal. Our school has a school-wide magazine called The Hoot where our major achievements will be posted. There is also a Physics magazine where we are planning to write about the science behind our mechanisms and electronics. Finally, we also have a Geography magazine where we are planning to write about renewable energy sources and how missions are tied into them. Using assemblies, we will show students how they can take part in competitions like these. This will achieve the second sub-goal. In these assemblies, we will show them websites which they can use for up and coming events, give a sneak-peek behind the scenes and explain what work they'll have to do if they take part. These assemblies will give students who may have the passion for competitions like this practical guidance. The main target audience with these three resources are students in KS3 as many of them have the interest but not the knowledge.

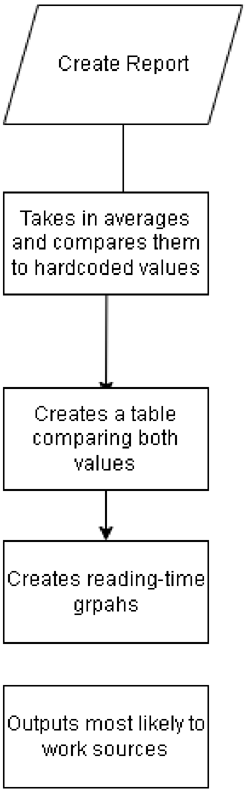
For social media, we will have a heavier emphasis on the secondary goal but there will also be information on the primary goal. We have decided to use YouTube, Instagram, Reddit, Snapchat, TikTok and Facebook. We decided not to use X due to our team being against the owner's views. Each member has been put in charge of each account and we all have a shared password, username and logo (our cover image). All accounts will be posting the same content but each manager will be individually responding to community feedback. Video editing and creating will be handled by our Social Media Manager. Our videos will be in two forms, short and long. Primarily the short form will be used to show snippets of what we are doing and will act as mini progress updates. For example we can make videos displaying our uprighting system working, make unboxing videos of our sensors, participate in viral trends with our members (such as the “I’m passing the phone to somebody who ___” trend) and show us carrying out tests (we will mainly show tests like the durability and drop test as they will garner more views). The short form content is mainly to garner interest and develop a following. For longer videos we will be focusing on more detailed explanations on the science behind the system. For example we will make a video explaining roly-poly physics, another explaining what our sensors do and how the electronics work and another video on parachute physics. These videos will be based on channels like ElectroBoom, this channel makes primarily electronic based videos and we believe his video formats will be great for our purpose. This is because they are very educational yet they have a comedic aspect through his failures which leads to him getting electrocuted. Obviously we won’t purposely get hurt but we will plan our long-form videos with this mix of content in mind. Our main attraction in both forms will be a 3D printing timelapse, where we will put some carefully chosen music over the printing. We will be using OctoPrint to get the video and we plan to post a timelapse of everything we print to drive engagement. We plan to post a short form video every two weeks (excluding the timelapses) and we will try to get a longform video out once a month. For the text content, we will focus on community interactions and carry out things like polls, Ask Me Anythings and possibly share science related content. This content is mainly aimed at people our age (13-18). The short form content is aimed at all people falling in that age range as we are mainly using the short form content just to get interest and a following. The long term content will be focused on people in that range who have an interest in robotics/physics and want to follow along with the journey. To gain an initial interest, these accounts will be shared with family and friends and further connections of those family members and friends.

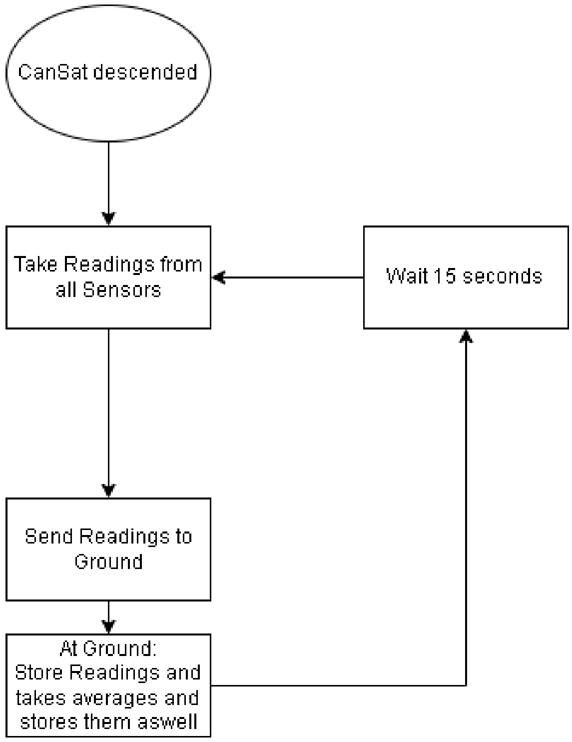
END OF PDR - Appendices on next page

Appendix 1:

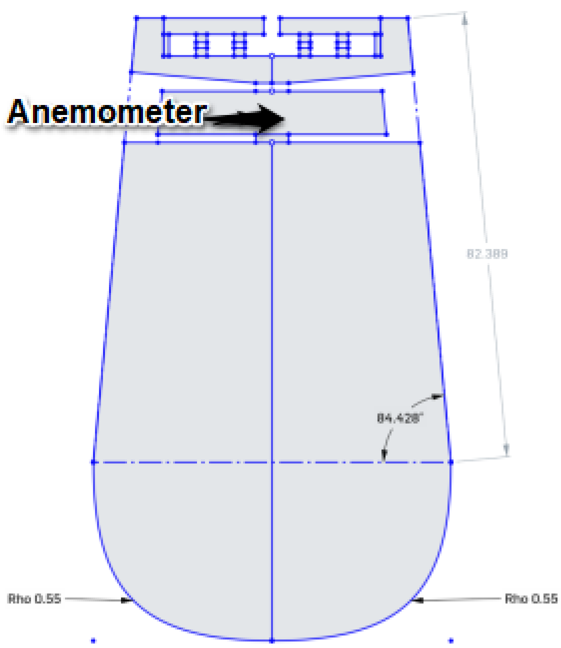

Rocket is launched
Accelerometer Reading
Is Reading < X
No
Wait 1 Second
Yes
Send "CanSat Pushed" to ground
Wait
Deploy Parachute
Send "Attempted to Deploy Parachute" to ground
Take some accelerometer readings 2 seconds apart
Do readings decrease by X amount
No
Send "Parachute Failed" to ground
Yes
Send "Parachute Successful" to ground
Wait
Take Accelerometer Reading
Is Reading = 0
No
Send "Terminal Velocity Not Reached Successfully" to ground
Yes
Send "Terminal Velocity Reached Successfully" to ground
Take VOC, Pressure and Temperature reading
Convert Pressure into Altitude
Send readings down to ground
Is Altitude = 0
No
Wait 1 Second
Send "Descent Over" to ground
CanSat Landed

Appendix 2:





Appendix 3:



Appendix 4:

TASK NAME																		
Week 1	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Work on PDR with RFand TJ																		
Find which parts to use for the Raspberry Pi.																		
Look into design aspects of PDR.																		
Continue on the risk assessment course of work																		
Introduction and Missions(Section 1) of PDR																		
Learn the topics required for the parachute system																		
Week 2																		
Research materials of potential use to CanSat.																		
Work on Landing Mechanics																		
Begin Logo Design																		
Work on Outreach, Onshape or Fusion 360 developing																		
Outreach - SnapChat and Instagram																		
Uprighting System																		
Week 3																		
Fix Gantt Chart and format the PDR																		
Mechanics of parachute and size equations																		
Develop Outreach Program																		
Expand Outreach, Penultimate PDR read-through																		
Finalise material research into the material and the landing mechanics																		

Appendix 5:

TASK NAME	START DATE	DAY OF MONTH *	END DATE	DURATION* (WORK DAYS)	TEAM MEMBER	PERCENT COMPLETE
First Week						
Work on PDR with RF and TJ	8	8-12	12	1	AH	100%
Find which parts to use for the Raspberry Pi Pico.	10	8-12	11	1	NP	100%
Look into design aspects of PDR.	8	8-12	12	4	AEC	100%
Continue on the risk assessment course of work	9	8-12	10	1	RF	100%
Introduction and Missions (Section 1) of PDR	8	8-12	12	5	TJ	100%
Learn the topics required for the parachute system	8	8-12	10	2	AC	100%
Second Week						
Research materials of potential use to CanSat.	14	13-17	17	3	AH	100%
Work On Mechanics Of Landing	13	13-17	15	2	NP	100%
Begin Logo Design	14	13-17	15	1	AC	100%
Work on Outreach, CAD Model Development	13	13-17	17	3	AEC	100%
Focus on Outreach - Instagram and Snap	13	13-17	13	3	RF	100%
Uprighting System Plans	13	13-17	17	4	TJ	100%
Third Week						
Fix Gantt Chart and format the PDR	23	18-25	25	2	RF	100%
Mechanics of parachute and size equations	18	18-25	20	2	AEC	100%
Develop Outreach Program	21	18-25	23	2	AC	100%
Develop Outreach, Penultimate PDR read-through	24	18-25	25	1	NP	100%
Finalise Material Research and Landing Mechanics	19	18-25	20	1	TJ	100%
Check compatibility and finalise sensors	19	18-25	20	1	AH	100%