UK CanSat Competition

*CramSat*

*Wilson's School*

*Critical Design Review*

*Date: February 2023*

# 1 Introduction

## 1.1 Team Organisation and Roles

- Electronics lead
    - Connecting the microcontroller to the sensors and writing code for the microcontroller and sensors.
- Mechanical design lead
    - In charge of designing the stabilisation mechanism and landing legs
- Logistics management
    - In charge of managing logistics and finding the best components to carry out the functions the CanSat requires whilst ensuring it is still cost effective
- Outreach and ground equipment lead
    - Outreach lead and in charge of all ground equipment, making sure it works and carries out its purpose
- Engineering and design lead
    - In charge of designing the parachute

## 1.2 Mission Overview

### *1.2.1 Mission Objectives*

To design a CanSat that is easily mass producible and acts as a deployable weather probe.

**Primary Mission**

- Record and transmit the air temperature and pressure once per second after release.

**To Fulfil the Primary Mission:**

- Ensure that the CanSat:
    - can withstand acceleration of 20g to survive launch
    - has mass between 300g and 350g
    - has a battery
    - has an easily accessible master power switch
- Use a ground station to receive transmissions from the CanSat.
- Transmit air temperature and air pressure once every second to ground station.
- Deploy a parachute that can withstand 500N of force.
- Descends above $10ms^{-1}$.

**Secondary Mission:**

- Land and secure itself to the ground, then begin regular transmissions of air temperature, pressure and airspeed (and other weather information).

There are areas which are hard to reach by ground due to isolation from human inhabited areas. In those cases, it is difficult to gather ground weather data. Weather satellites in space can be used but they are high cost. A collection of small, low-cost and reproducible CanSats with weather sensors may be deployed to the isolated area. There, they may transmit ground weather data at regular intervals which could be collected by regular flights.

**To Fulfil the Secondary Mission:**

- Use legs to secure the CanSat into the ground.
- Record data from sensors and transmit it.

### *1.2.2 What will you measure, why and how?*

| **Measurement** | **Reason** | **Sensor** |
|---|---|---|
| Air Temperature | REQUIREMENT | BMP280 Breakout |
| Air Pressure | REQUIREMENT | BMP280 Breakout |
| Altitude | The BMP280 Breakout is also able to find the altitude, so this data can also be collected. | BMP280 Breakout |
| Humidity | To provide information pertaining to secondary mission | Adafruit DHT20 |
| Location | To find the CanSat after landing | Looking for suitable GPS module |

**Analysis:**

- In-flight temperature and in-flight pressure can be checked against an atmospheric model like the international standard atmosphere to calculate a predicted altitude. This can then be compared with the altitude sensor's readings to verify the accuracy of the atmospheric model at low altitudes.
- After landing:
    - The temperature, pressure and humidity averaged over relatively short time periods (e.g., 5 minutes. They are then transmitted and stored at the ground station. These can be associated with the time received to create a weather-time dataset. This could be used to find the average temperature at a specific time of day over a week, or observe patterns in humidity over a day, or other such analyses.

# 2 PROJECT PLANNING

## 2.1 Time schedule

Delays have prevented integration being done as per the previous schedule. Therefore, testing has had to be significantly reduced.

**Electronics:**

- Create Gerber file for PCB to be fabricated (3/4 hours)

- Assemble components

**Mech design:**

- Assemble parts into can (2 hours)

Following the full assembly, we will test the can.

## 2.2 Team and External Support

In general, our skillset is skewed towards physics and computer science. Therefore, we expect that little assistance will be needed with software development.

The electronics lead is familiar with soldering and using microcontrollers for small projects involving sensors. No-one in the team is familiar with projects using multiple sensors and transmitting data with a radio. However, these have done by other people, so there are lots of resources online to learn how to do this.

The mechanical design and engineering leads are familiar with engineering and materials, however the specifics of the CanSat require that the materials be tougher than simpler materials that have been worked with before. We plan to speak to former CanSat teams about the particulars of suitable materials.

We will also make use of weekly CanSat workshops. These will provide the technical knowledge and resources to assemble the CanSat, as well as allowing us to speak with experts.

## 2.3 Risk Analysis

**Landing:**

The Secondary Mission is conducted on the ground using sensors that detect properties in the air. Therefore, the CanSat needs to be able to secure itself on the ground such that the sensors can access the air. The CanSat may not position itself on the ground such that there is airflow.

Furthermore, the landing legs may break under the force of impact.

**Team:**

The team lacks technical experience with electronics. However, those running workshops are experienced enough to help us resolve issues.

**Time constraints:**

Since A levels and mock exams are during the spring term, time may be lost then. However, as long as we follow the schedule, placing an emphasis on more work being done earlier, this should not be an issue.

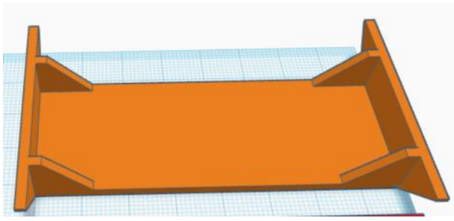
**Equipment:**

The current design uses technical Lego. It is unclear if this can withstand launch forces. This will be resolved with testing.

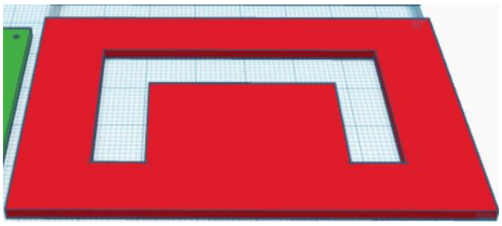
# 3 CANSAT DESIGN

## 3.1 Mechanical design

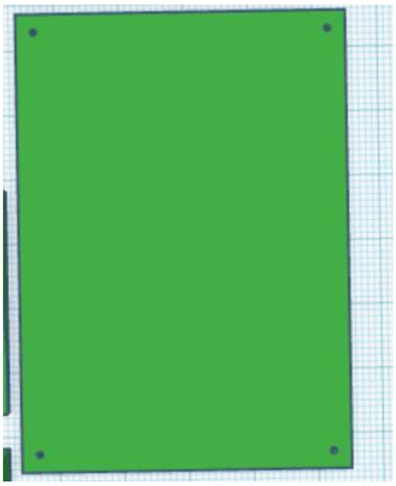
For our CanSat project, we had to design a frame for all the components and the legs to be placed on. This was designed on a 3D software, which I had learnt to use for this project.



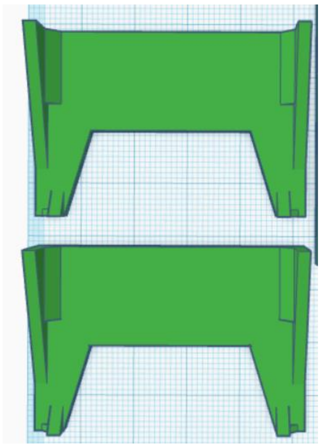
This part is designed to fit on the bottom of the can, and was meant to be some extra space for components, though other parts were large enough to do that instead, so this was used as a place to hold the battery. The next part would be attached on top of it using epoxy.



This part was designed to hold the legs, with the hole in it meant for the gears to fit in, since they needed some room to turn. The motor that will power the legs will also go on this piece.



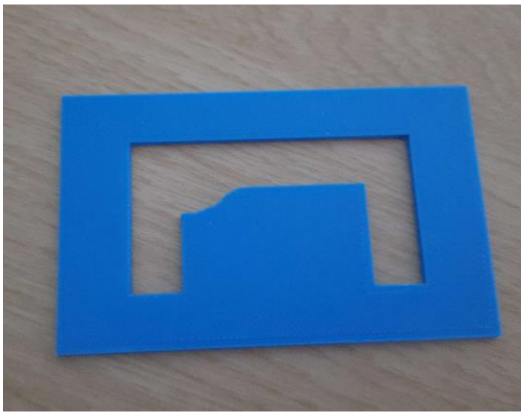
The piece on the left is designed to go at the top and is meant to hold all the electrical components on it. The holes in the corners are to let screws in.



The two pieces on the right are designed to hold the piece with the components on above the piece the legs are going to go on. The gaps are meant to give space for the gears in the leg mechanism to rotate.

There were also 2 circular pieces that are designed to hold everything together, though this may not be used.

We had initially planned to 3D print these parts at a 3D print shop using TPU, a plastic that is soft and can absorb impacts well, which would be useful for this. However, this was quite expensive, and it would take some time, so instead, we decided to print it out using our school's 3D printer, which was much quicker and cheaper. The material used was PLA, which would be quite useful since it is very cheap to print compared to TPU, and it is biodegradable.



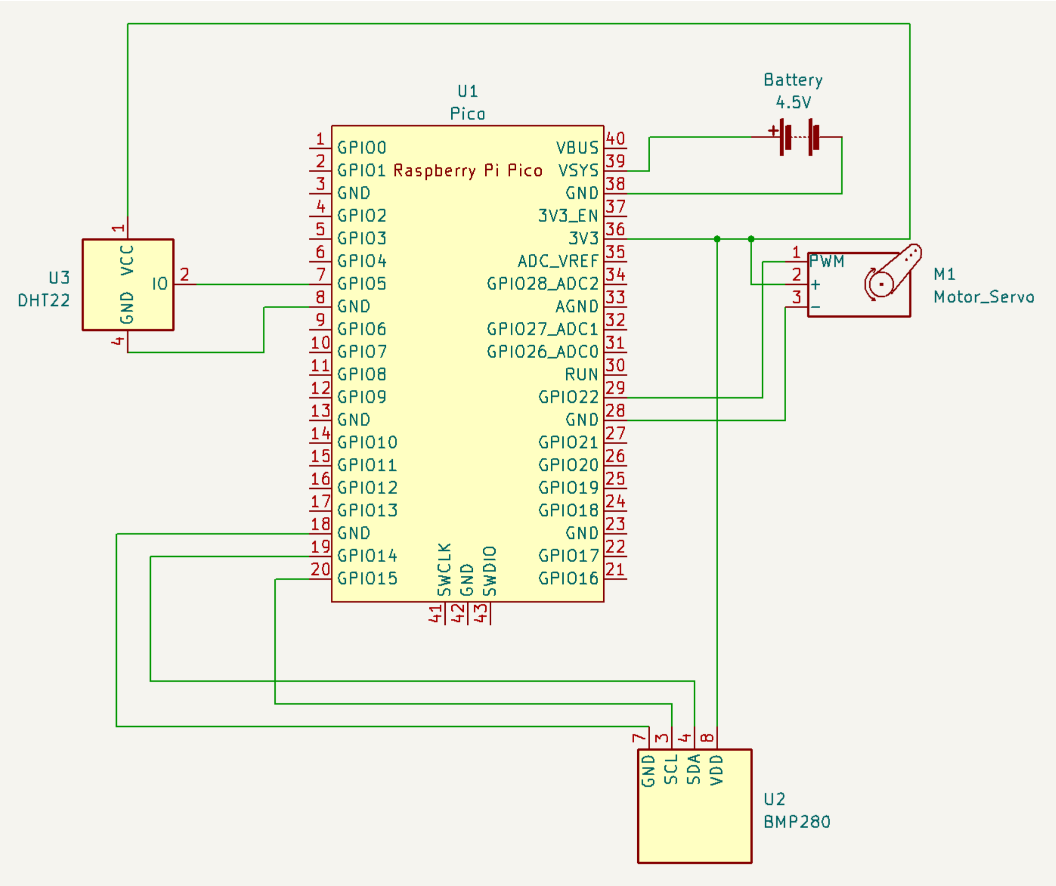
The part that was meant for the legs has to be cut down slightly in order for the gear that connects the leg mechanism to the motor to be able to rotate, shown right.

## 3.2 Electrical design

We are using the RP2040 microcontroller on a Raspberry Pi Pico board. Firstly, it is good for our project because it can use MicroPython, which allows code for embedded systems to be written in Python. This simplifies the software process as code doesn't need to be written in C or C++. It is also very cheap so if one is damaged then it can be easily replaced. Furthermore, it can be easily scaled as per the reasoning of the Secondary Mission. It has 38 GPIO pins, and can use I2C, UART and SPI, so many sensors can be connected.

The BMP280 Breakout sensor has been chosen because it can measure both temperature and pressure (fulfilling the primary mission). It also is compatible with the Pico and therefore can be managed with MicroPython. It is especially good as it has a dedicated MicroPython library that vastly simplifies the process of managing the data.

The Adafruit DHT22 is a humidity sensor with appropriate accuracy (2%) for an inexpensive project. It can also measure temperature, which can be used to verify the readings from the BMP280. It is also compatible with CircuitPython, simplifying the programming needed.



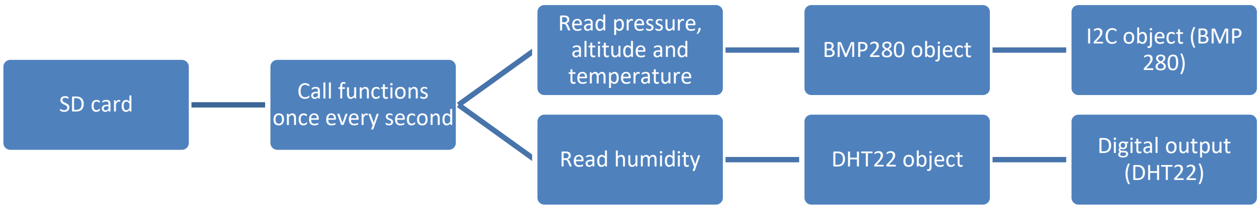

Shown is a partial diagram of the circuit. It includes the servo to drive the landing gear, the battery, the DHT22 sensor and the BMP280 sensor. The BMP280 is connected by I2C, the DHT22 gives digital output and the servo is connected as PWM. If the 3.3V power input is not enough to drive the motor, then the positive terminal of the motor will instead be rewired to connect to the battery (with a resistor.)

Not shown in the diagram is the master power switch between the battery and the VSYS pin, the SD card, or the

## 3.3 Software design

The CanSat primarily uses CircuitPython and CircuitPython libraries as these simplify the programming process. The selected sensors are able to use CircuitPython. We are aware that Python is likely to use up lots of memory on the Pico, however, the Pico was designed with using Python in mind and has lots of memory.

**Overall (right to left)**




**BMP280**

The BMP280 is connected by I2C. An I2C object is instanced in CircuitPython to handle the BMP280. Using the I2C object, and the official BMP280 CircuitPython library, a BMP280 object is instanced. It is provided with the sea level pressure on the day, in the general location. The BMP280 object then has functions to read temperature, pressure and altitude.

**DHT22**

The DHT22 has a simple single pin digital output. Using the official DHT22 CircuitPython library, a DHT22 object is instanced. The object has a property for humidity.

**Loop**

Every second the main loop repeats. It calls every reading and writes the data into a new row in an SD card.

**Transmitters vs SD card**

Due to time constraints, building a ground antenna has proven difficult. Therefore (until one has been built) we will use an SD card.

**Servo**

In the current state, after a fixed amount of time in the air (45 seconds) the servo deploys the landing gear, regardless of external input. There are a few proposed ways of making this more responsive to the environment:

- Using the BMP280, average altitude readings every 5 seconds. If these average altitudes start to show a decrease, then the cansat must be falling, so the landing gear should be deployed.

- Using an accelerometer, the cansat should be able to keep track of its speed and position by dead reckoning. Then, once the cansat has reached its maximum height and begins to fall, the landing gear can be deployed.

## 3.4 Landing and recovery system

**Parachute**

The Formula for the area, A of the parachute, in $m^2$ is as follows.

$$A = \frac{2mg}{C_D \rho v^2}$$

Where:

- m = the mass of the object falling, the CanSat, in kg.
- g = acceleration due to gravity, in $ms^{-2}$
- $C_D$ = the drag coefficient of the parachute, dimensionless
- $\rho$ = the density of the fluid the object is falling through, in $kgm^{-3}$
- v = the terminal velocity of the object falling, in $ms^{-1}$

Taking the mass of the CanSat to be 0.350kg, g to be 9.807$ms^{-2}$, the density of air to be 1.225$kgm^{-3}$, and the upper and lower bounds of terminal velocity to be 10$ms^{-1}$ and 8$ms^{-1}$ respectively, we can calculate the upper and lower bounds of the required area of each of the four parachutes

| | Drag Coefficient | | Area($m^2$) | |
|---|---|---|---|---|
| | upper bound | lower bound | upper bound | lower bound |
| hemisphere | 0.77 | 0.62 | 0.251 | 0.0728 |
| cross | 0.8 | 0.6 | 0.259 | 0.0701 |
| paraglider | 1.1 | 0.75 | 0.208 | 0.0509 |
| hexagon | 0.8 | 0.75 | 0.208 | 0.0701 |

From these values, we can produce diagrams of the parachute, with the CanSat for scale:

*From left to right, Hemisphere, Cross, Hexagon. (The Paraglider design has been omitted as it takes on the shape of a rectangle, with multiple different possible dimensions.)*

These diagrams are to scale with a can, 66mm in diameter. The shapes that have been greyed out are the upper bounds, and the ones that haven't are lower bounds.

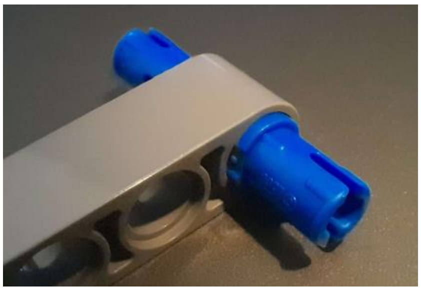
We have opted to use the Hexagon shaped design for our parachute as, while the Paraglider design is controllable and manoeuvrable, it is also exponentially more complicated to make than the other three designs, all while still being susceptible to oscillations brought about by the way the paraglider allows air to escape out from the top of it. After discarding the Paraglider, out of the remaining three, the Hexagon has the lowest upper bound for area, meaning it will take up the least space before it is deployed, making it the most efficient.

It will be made of 6 equilateral triangles of material, each with a side length of 31.1cm, sewn together in the shape of an equilateral hexagon.

**Legs**

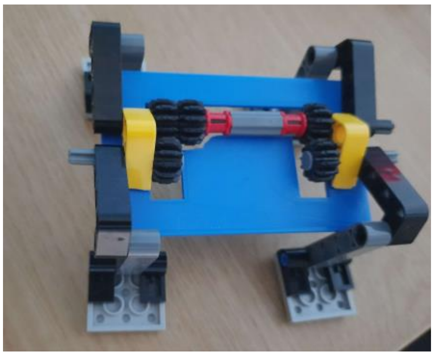
The leg mechanism will work by having a motor connected to the gear near the middle, which will rotate the side connected to it. The gear that it is connected to will then rotate the other leg in the opposite direction. Holes in the side of the can will guide the leg to go in the correct direction, and the pads on the bottom will be against the ground and will keep the can steady.

The leg mechanism was designed to be made using Lego, which are easy to put together and did not require too much designing. However, certain parts did have to be modified slightly, such as the part that held the 2 legs on each side (the yellow piece in the left and right images), since they were too long, so they were cut down with a saw and sanded to the right size. The left image was before, right was after



The pins connecting the main leg to the main central mechanism (shown left, the black piece) and the pins connecting the legs to the pads (shown right, the blue piece) had to be cut down slightly, since they were not smooth enough and needed too much force for them to rotate.

After this was put together and cut down to the right size, it was attached onto the part of the frame that was meant to hold the legs using 2-part epoxy glue, which is quite strong and good for attaching plastic parts together. The final leg mechanism is shown below, after it had been put together.



## 3.5 Ground support equipment

- RF Transceiver Module RFM96W - Used because it was provided by organiser and therefore easy access and low cost

- Laptop to monitor this data received from the CanSat's transceiver

- Considering: Yagi antenna, coaxial wire and power supply - relatively cheap and easy to make and therefore cost effective for our CanSat but it may not be sensitive enough to collect all information.

## 3.6 Testing

**Performed**

BMP280:

- BMP280 tested outside. Expected conditions of 6°C, 1029hPa at an elevation of 120m.
- Readings of 6.4°C, 1007hPa with a calculated elevation of 171m.
- Hence while the temperature and pressure readings are fairly accurate, the altitude readings are unlikely to have any reasonable precision, except at higher altitudes.

**Planned**

- Running Temperature
  - Test running all the electrical components in a suitable circuit, for a minimum of 3 hours, to check for overheating issues, which could also affect the accuracy of the temperature sensor readings.
  - Testing to ensure that there is sufficient thermal insulation of each of the electrical components (i.e., insulation provided by the casing of the component itself or by the CanSat can) – will low temperatures during launch or extreme weather conditions like snow affect the running of the electricals, and can we achieve the minimum temperature required for the components to run efficiently and give accurate readings?
- Waterproof-ability
  - Water test – does any water leak onto components when they are packed into the CanSat can – locating the potential areas for water leaks as this would be very relevant if we land our CanSat in a moist environment, or if there is rain, hail etc.
  - Waterproofing the entire CanSat apparatus, and then testing the waterproof-ability.
  - Ensuring, using online information, that the electrical components are at least water resistant, in the case that we still get minor water leaks.
- General Weather Resistance

        - Testing that factor such as data transmission work effectively, even in extreme weather conditions like strong winds or storms, or in different environments.
    - Material
        - Testing durability and resistance of primary materials used in the construction of the CanSat (i.e., the material the can is made of) – can it withstand the forces of the landing, and does it rust etc. in certain environments.
        - How well does it withstand tension, compression, and other forces that it could experience during launch, suspension, or landing?
    - Centre of Mass
        - Testing the physical design and layout of the CanSat to ensure it is fairly balanced (i.e., the centre of mass is as close to the middle of the can as possible) – an off-centre centre of mass could result in the CanSat falling at an angle that doesn't enable the landing mechanism to work properly and could result in damage to the CanSat.
    - Overall Mass
        - Checking regularly that we are within the weight limit, and cutting down on components and design elements where necessary
    - Landing Mechanism
        - Timing how long the motors take to extend the legs of the landing mechanism, so that we know when to turn the motor on launch day.
        - Where the desired falling angle is achieved, does the landing mechanism ensure a smooth landing, regardless of falling speed – is the mechanism weak, flimsy, or prone to electrical failure/damage?
        - Does the landing mechanism work effectively on all surfaces/environments? – particularly, does it have enough padding even if it lands on a hard surface?
        - Carrying out drop tests on the CanSat, to fine tune the size of the parachute required, as well as other aspects, such as the exact design of the parachute, and when it needs to be deployed.
    - Quality of Construction
        - Testing for any general air leaks (affecting aerodynamics), flimsiness in joints, durability etc.

## 3.7 Overall testing for launch

We will go to a park/open greenspace to launch (launch mechanism TBD) the CanSat into the air, communicate with it, and ensure it lands securely. We will use the relevant ground support equipment in 3.5 and check if it works.

Before this, we will be conducting separate tests for each function of the CanSat (see relevant section)

Goals:

- Ensuring that there are no technical issues when combining all parts of the CanSat
- Ensuring the transceiver can function from a high altitude
- Ensuring the CanSat parachute and landing mechanisms are effective

# 4 OUTREACH PROGRAMME

For our Outreach campaign, we have started a TikTok account to promote interesting facts about space and engineering with entertainment to target a younger audience. We have also started a Facebook account and joined many Science groups, promoting CanSat as Facebook is one of the largest science discussion forums and also caters to a different audience than those on TikTok as people on Facebook are more likely to be older thereby increasing our reach and total engagement.


The types of videos made on TikTok are not only detailing the CanSat process but also videos like “2 truths and 1 lie” where viewers would have to find out which statements are true and which is false from 3 space / engineering statements. The first video of this concept was a resounding success with 400 views which shows these types of videos will engage more people and will have a larger audience as it isn’t catering to a specific niche such as STEM but is much more accessible and entertaining for non-STEM inclined people. An example is shown above.

On a more regional scale, we have gone to some clubs that would have students that would be interested in the CanSat project such as Aviation Society and Astronomy Club and promoted CanSat and our CanSat team which allows us to promote CanSat actively to fellow students in our school.

In addition to this we have also started a website for our CanSat team and on that website, we have started a blog which will go through our whole process for the CanSat and hopefully promote the testing and launch of the CanSat as well as the building of the CanSat itself. This will cater to another audience that are perhaps less inclined to more popular websites like TikTok and Facebook and would rather read about our efforts. However, our website was much less popular than our TikTok account as we only had around 5 visitors to our website.

In addition to all of this, we have also made an official YouTube channel for the group which is mainly going to be used when we launch the CanSat and during testing.

Although most of our Outreach campaign is focused on social media and at a large external audience, we are hoping to promote it more at school via the STEM magazine which is still publishing its most recent issue and so we can’t promote our CanSat in an article yet, but we are hoping that the new issue will be available before the FDR comes around. In addition, we would like to take a more active role in our YouTube Channel.