UKSEDS National Rocket Championships 2021-22

Design and Build Report

Team: Unspecific Impulse v2

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1.Introduction

1.1 Mission statement

Following on from our success last year, the University of Birmingham Space Society has been designing a new rocket which fixes flaws and improves many aspects of our rocket design. We've also had an influx of brand-new members this year who have quickly integrated with the team and have provided useful contributions to the project.

1.2 Objectives

- Rocket shall reach a minimum of 1200m above the launch point.
- Rocket shall not explode on pad or during parachute deployment.
- Rocket parachutes shall successfully deploy.
- Data from flight shall successfully be recovered from SD card on telemetry computer.
- Rocket shall land in a reusable state.
- Camera shall record a video of the entire flight.

1.3 Requirements

Requirement	**Reasoning**	**Verification**
Our rocket will reach a minimum altitude of 1000m.	We wish for our rocket to be in competition with the altitude record from last year's competition.	We will use OpenRocket to simulate our rocket design and maximize its performance.
Our team will follow and comply with all UKSEDS guidance design rules as well as UKRA rules when designing the rocket.	Our team wants to safety build and launch a rocket to prevent any team member from being injured.	Our team will discuss the guidelines and any safety concerns with our team members before the start of the project.
Our team will improve upon the electronics payload designed last year.	UKSEDS indicated that they were very impressed with our custom-designed flight computer last year so we wish to continue with this aspect and make it even better.	Improve reliability, performance and features of the flight computer as well as the ground control computer program.
Our team will meet all key UKSEDS competition deadlines.	Required for our team to participate in this competition.	Our team will maintain an internal timeline for designing, manufacturing and testing components that will be used in the rocket.

1.4 Team Roles

Name	**Team Role**
Dimitar Ferdinandov	Team Project Lead
Liam Mackenzie	Electronics Lead
Adrian Jaskolski	Chassis Lead
Haider Ali	President of Society
James Ibbs	Camera Payload
Joseph Ward	Camera Payload
Jack Jones	Chassis & Modeling
Jack Griffiths	Aerodynamic Surfaces
Dmitry Sorokhin	Aerodynamic Surfaces
Chang Wei	Aerodynamic Surfaces

2. Design Concept

2.1 Rocket

2.1.1 Motor Selection

We have opted to use a ‘Classic’ Pro 29 2 Grain motor. We chose this as the longer burn time reduces the maximum thrust, and thus the structural loads on our rocket. The performance of our selection are displayed in Table 1. [1]

Total Impulse	107.80 Ns
Maximum Thrust	85.40 N
Burn Time	1.89s
Loaded Weight	146.00 g
Burnout Weight	87.00 g

Table 1. Performance Metrics of 'White Thunder' Rocket Motor

The team used the simulation software OpenRocket [2] to simulate the flight of Unspecific Impulse v2. The flight profile of the finished rocket is displayed in Graph 1, and key events are summarised in Table 2.

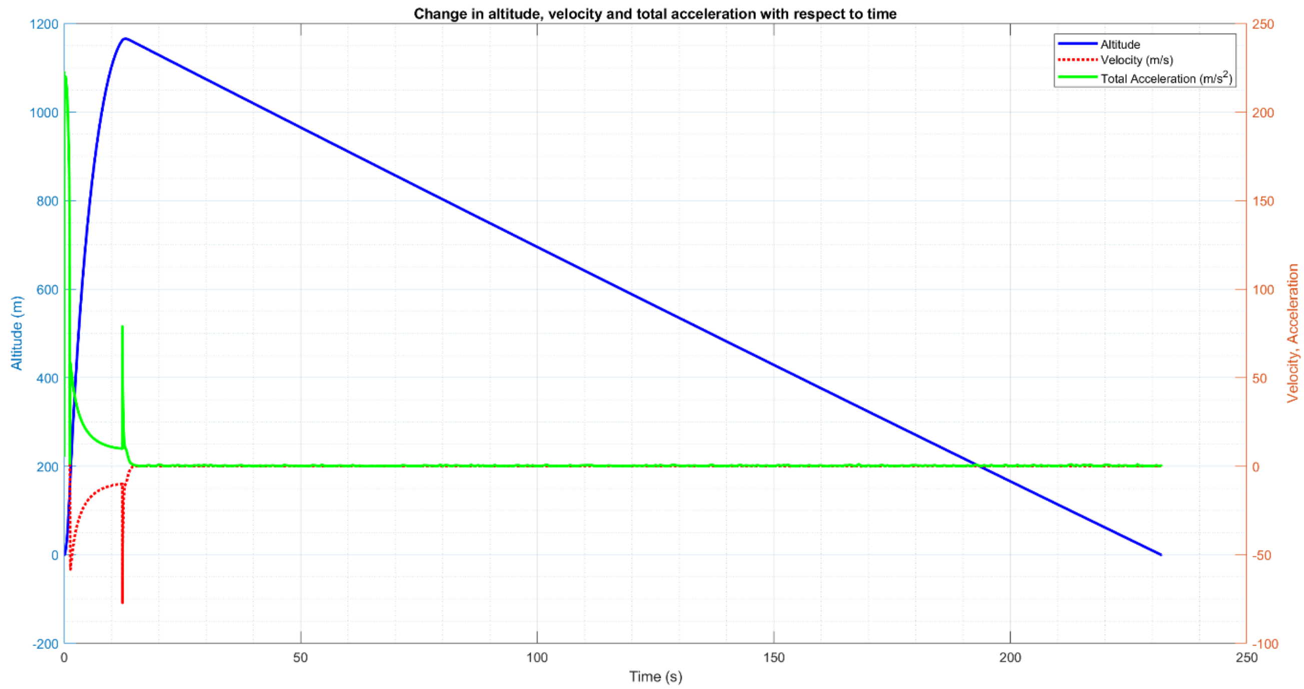


Figure 1. Flight Profile of Unspecific Impulse v2

Apogee	1166 m
Maximum Velocity	231 ms^{-1}
Maximum Acceleration	222 ms^{-2}
Velocity off Launch Support Rod	20.6 ms^{-1}
Velocity at Landing	5.21 ms^{-1}

Table 2. Key Data Points of Flight

Some key points to note are that the rocket leaves the launch pad with a speed greater than 20 ms^{-1}, thus will not stall aerodynamically. Its maximum velocity is 259 ms^{-1} which is below the speed of sound, and it lands with a safe velocity of 5.25 ms^{-1} under the help of the main parachute. Unspecific Impulse v2 has a static stability of 2.34 calibre.

The simulation presented above represents 'ideal conditions' – where we have made the assumptions of an average windspeed of 2ms^{-1}. We have used the International Standard Atmosphere of a 15°C temperature and 101 kPa pressure. We also assumed the rocket launches straight up from the ground.

2.1.2 Components

2.1.2-A - Body Tube

The body tube is the central piece of the rocket chassis. This year, with our increased focus on reaching the maximum altitude, we have gone for the thinnest body tube diameter possible. With the motor diameter of 29mm, we have selected a body tube with an inner diameter of 29mm and an outer diameter of 32mm.

We selected a cardboard body tube last year as it had the necessary structural and mechanical properties for the rocket. Cardboard would also be suitable again this year but due to supply constraints we have selected a phenolic resin tube instead. This has increased strength over carboard but also a higher density therefore there is a slight weight penalty. In OpenRocket this weight penalty led to a decrease of about 20m in the altitude expected compared to a cardboard tube of the same dimensions

One of the limiting factors in the body tube diameter last year was the size of the flight computer. Due to improvements in the design, we have managed to significantly reduce the size of the flight computer so that it is no longer the limiting factor in body tube diameter.

The body tube has a total length of 51cm, consisting of a 25cm upper section and 26cm lower section.

Rather than using tubular launch lugs like last year, we have selected launch rail buttons as they have a lower profile and thus reduces the effect on our rocket's drag.

The team tested the validity of the design using OpenRocket (). Initial approximations of the internal components such as electronics and mountings were added. This allowed for the next components to be designed.

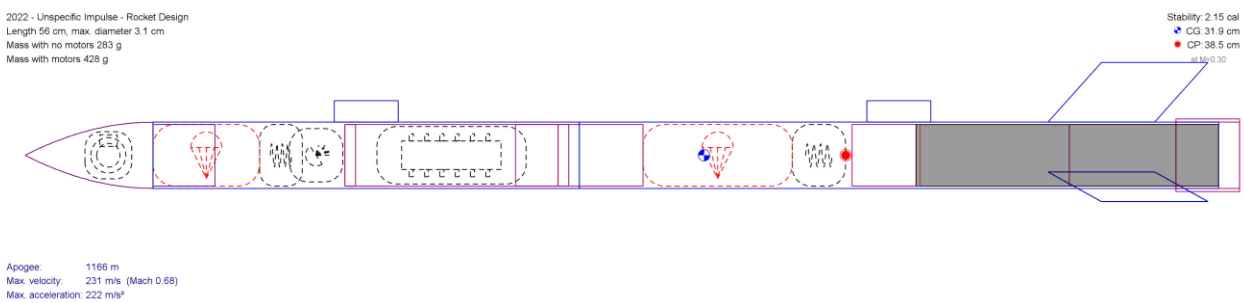


Figure 2. Final OpenRocket Simulation of Rocket

2.1.2-B - Fins

The fin design this year was a major departure compared last year's design. Last year the team 3D printed 3 individual elliptical fins to be attached to the body tube. We encountered issues ensuring the fins were lined up at the right angles, as well as issues with the strength of the connection from the fin to the body tube. This year we printed the fins all as one piece, with an integrated sleeve so that the finished component could easily be slid onto the body tube. Due to the orientation of the print elliptical fins (which were used last year due to their optimal aerodynamics) were not possible due to the overhang angle. Instead we used 3 trapezoidal fins. The design can be seen in *Figure 3* with the print orientation in *Figure 4* and final printed design in *Figure 5* [3].

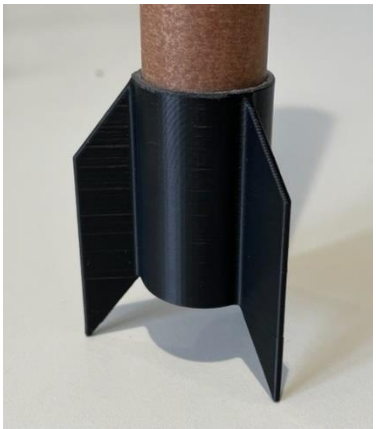


Figure 5. Fin Design Printed

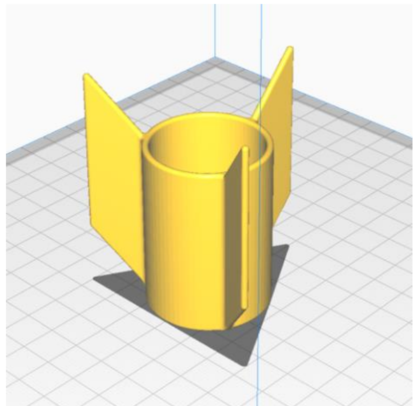


Figure 4. Fin Design Print Orientation

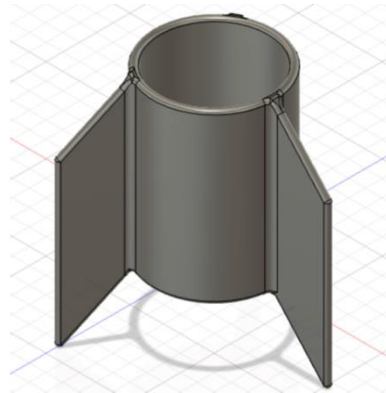


Figure 3. Fin Design Fusion 360

2.1.2-C - Nosecone

Following a similar design process to the fins, various sizes shapes of the and nosecone were tested in OpenRocket leading us to select a spherically blunted tangent ogive shaped nosecone. The nosecone will house the camera payload whilst also connected to the main parachute shock cord. In order to allow the camera to record the flight a section of the nose cone hole to accommodate the camera's FOV. This however can increase drag of the rocket as there would be a pressure change thus a sticky transparent foil will be stuck onto the nosecone to smooth eliminate the hole. The total length of Unspecific Impulse when the nosecone is attached is ~600mm.

Figure 6. Nose cone isometric view (- left), without hat (- middle), hat only (- right)

2.1.2-D - Engine Mounting

The engine block component has been designed to not only to transfer the thrust into the body tube structure, but to also function as a mounting point (in the form of a lifting eye nut) between the upper and lower body sections for the shock cord between these body part segments.

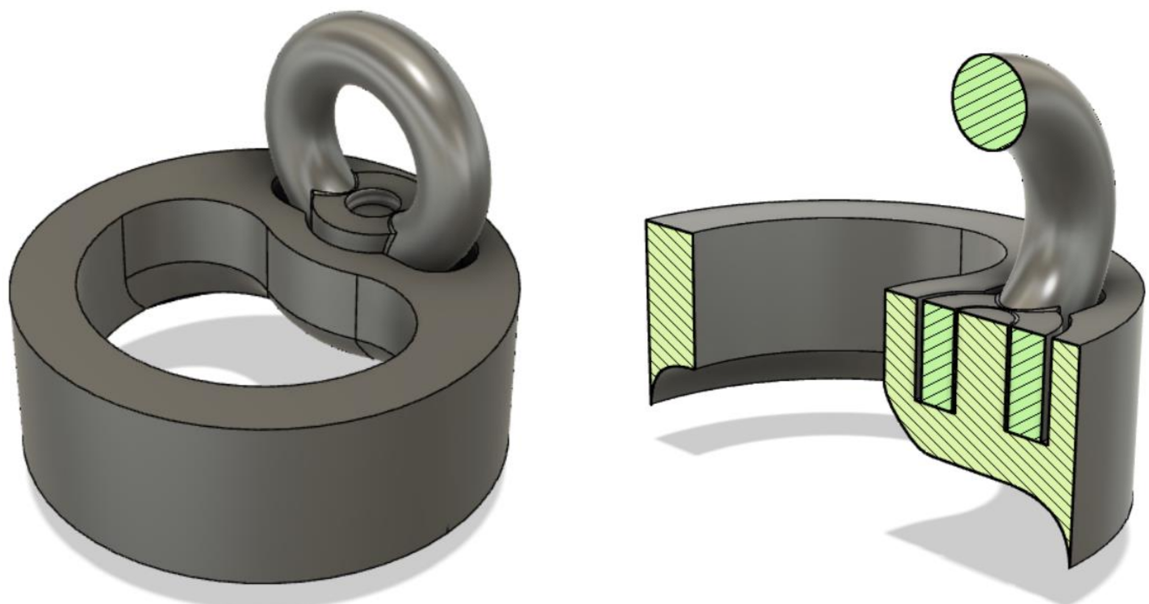


Figure 7. Engine Block (isometric view (left) vs Sectioned view (right))

2.1.2-E - Engine Case Retainer

The motor retainer consists of two individual 3D printed components. The files were designed, optimized, exported and sliced ready for the printing. PLA was chosen material for printing for the following reasons: accurate printing of threads, no stringing, lower cost and lightweight. PLA starts to warp at 60’c but this is not a major concern for the rocket as the heat transferred from the case through the tube to the retainer is marginal and should not affect its performance. The thread is set to 35mm at a 1.5mm pitch rate following ISO standards which prints very finely and fits snug. To ensure the threads weren’t over tight, during the creation of the threads on the software the inner threads were recessed slightly to allow for greater tolerances between the two in order to successfully print.

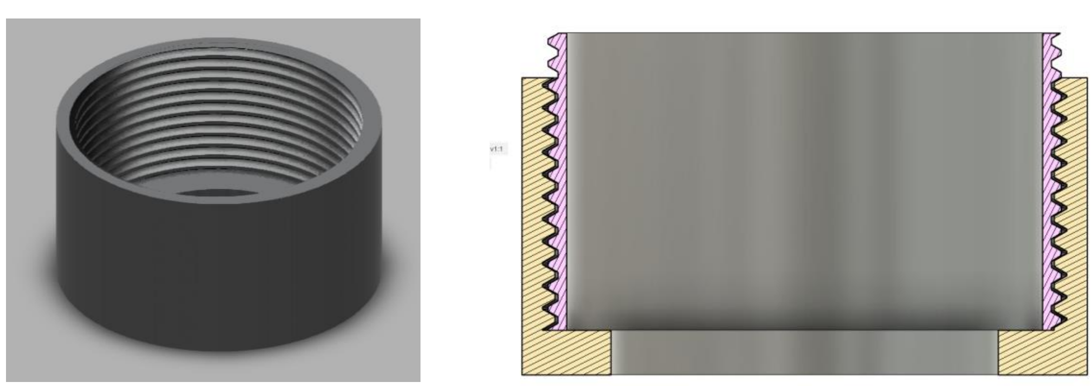


Figure 8. Motor Retainer (Isometric View (left) vs Sectioned View (right))

2.2 Recovery System

Our recovery system consists of a drogue parachute deployed at apogee to aid an initial stable descent and ensure the rocket does not drift far from the launch site. This is followed by a main parachute deployed at 150 m (during descent) to slow the rocket down sufficiently for landing.

The size of the parachute is critical as the parachute must slow the descent rate so that the rocket safely lands in a reusable state. The requirements state that the "descent rate must not exceed 15ms^{-1}". [4] In addition, the parachute should not be too large so that it is unable to fit into the body of the rocket. Fig.9 was used for determining the parachute diameter sizes. The dry mass of the rocket is ~400 g, therefore with the help of Fig.9 we decided to use a 21" main parachute and a much smaller size for the drogue parachute (9" in diameter). To prevent the parachutes and shock cords from burning due to the ejection charge exhaust, recovery components will be wrapped in a fire retarded material (Nomex) [5]. This Nomex material will be attached through the shock cord not to lose the retarded material during parachute deployment because not to litter and reused it for future flights.

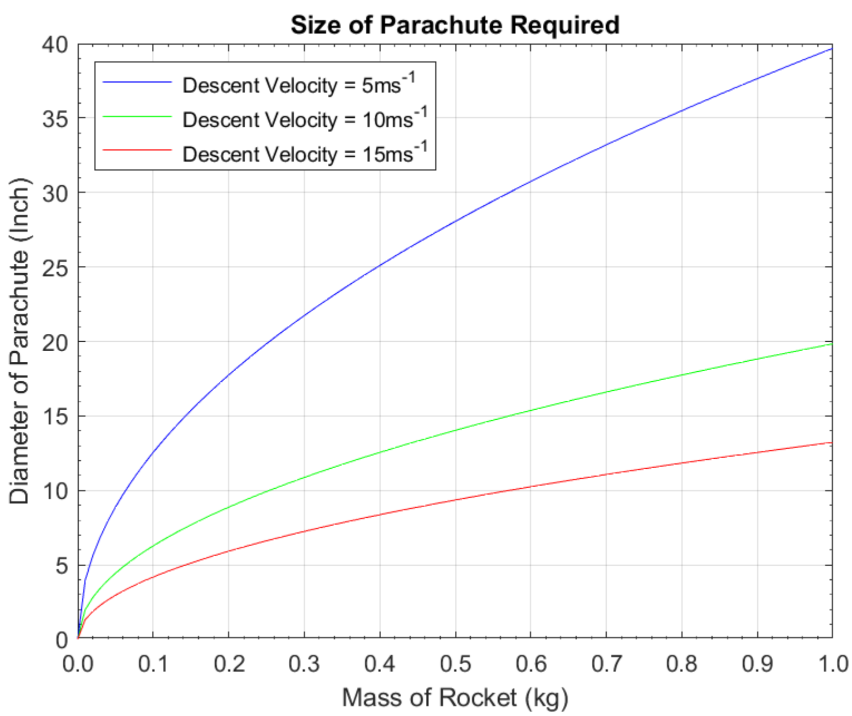


Figure 9. Size of parachute vs (dry) mass of rocket

Image 1. Drogue parachute unfolded (left) and folded (right)

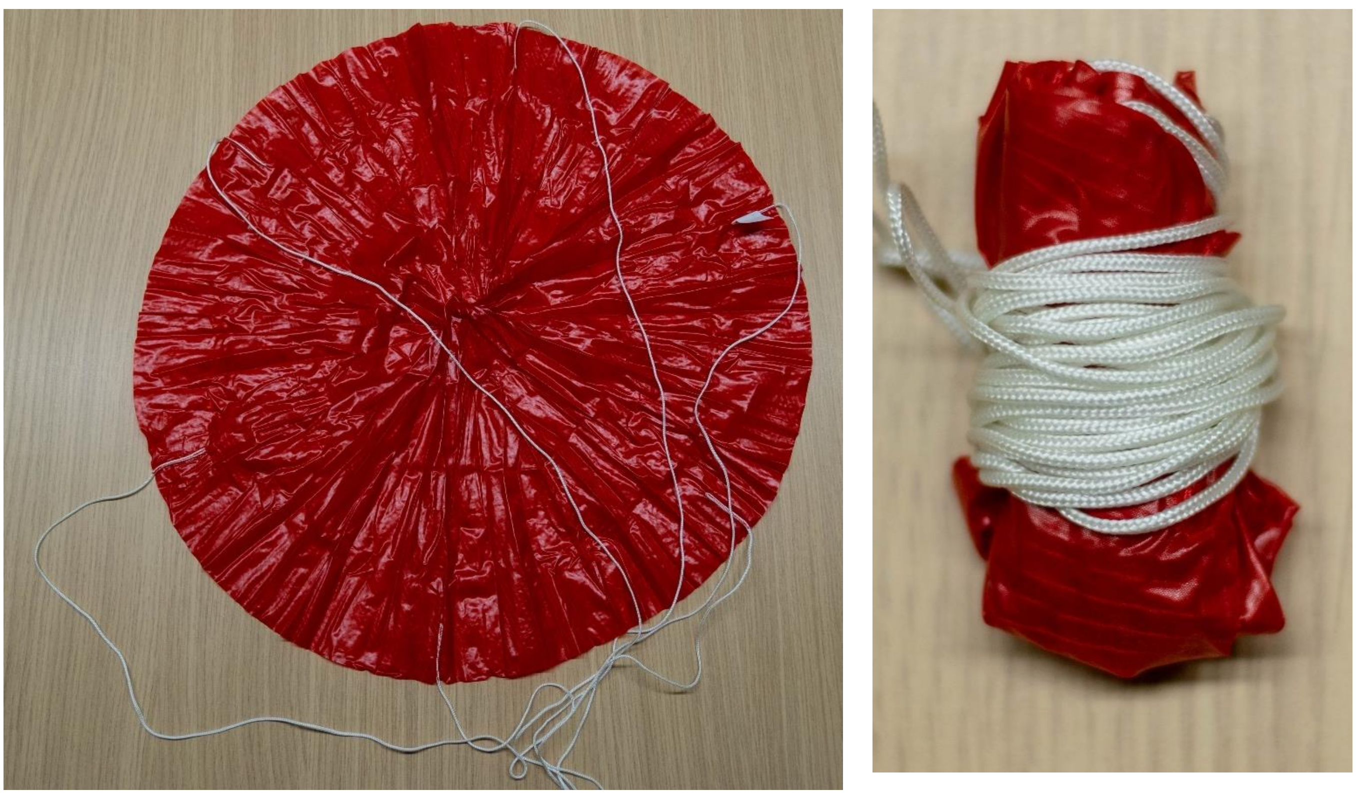


Image 2. Main Parachute unfolded (left) and folded (right)

Image 3. Cut Nomex for parachute protection

Ejection of the drogue parachute is executed at apogee with the help of an ejection charge. The telemetry computer (see Section 2.3.1) calculates altitude using a barometer (as rocket gains altitude, atmospheric pressure decreases and vice versa), and will then ignite the ejection charge as close as possible to the apogee point using the battery current and N-channel MOSFET. Deploying at apogee (when the velocity is at minimum) will prevent large shock loads from developing in the parachute lines as well as in the shock cord, which could lead to failure.

A shock cord of x2-3 the rocket length has been used to prevent body tube zipping [6]. A longer shock cord length would further decrease shock loads acting on the parachute as well as the body tube.

The single use ejection charges (shown in Image 4) are filled with 2 g of gunpowder. These will be housed inside an “ejection bay” (see section 4.5). The leads from the ejection charges connect to terminal blocks on the telemetry computer. The ejection charges can only be fired by the telemetry computer under certain conditions for safety reasons:

- Safety pin must be pulled on the rocket before launch.
- Parachutes can only be deployed after launch has been confirmed by telemetry computer (using both altitude and commands sent by the ground station).
- The drogue parachute can only eject after the motor has burnt out.
- The main parachute deploys only after the drogue parachute has been deployed.

Two backup systems exist for ejection of both parachutes. If the barometer fails, the parachutes will be deployed on a timer system using predicted apogee and descent times. Secondly the parachutes can also be deployed with a remote command from our ground control station (see Section 2.3.1).

A tri-color LED on the telemetry computer is used to indicate the status of the ejection system: red indicates it is currently armed, green indicates it is safe. This status is also indicated on the ground control program. The telemetry computer will automatically disarm the recovery circuit after touchdown, or it can be disarmed by either reinserting the safety pin or sending a disarm command from the ground station.

Image 4. Single-use Black Powder Ejection Chares

To ensure the rocket is visible during descent, the parachutes are orange/red (bright) coloured to contrast with the sky and ground. Another potential solution could be the use of reflective streamers on the shock cords. However, we decided that the bright orange/red parachutes provide sufficient visibility during the daytime and contrast with greenery environment.

2.3 Payload:

2.3.1 Description

The telemetry computer the team designed last year was commented on as one of the most unique parts of our design. We decided this year we would like to make it even better.

The telemetry computer sends the recorded telemetry back to a "ground control" computer on the ground in real time, which then displays the telemetry in our custom-built control program (Image 5. Ground Control ProgramImage 5). Graphs display the telemetry data and buttons can be used to send commands to the rocket.

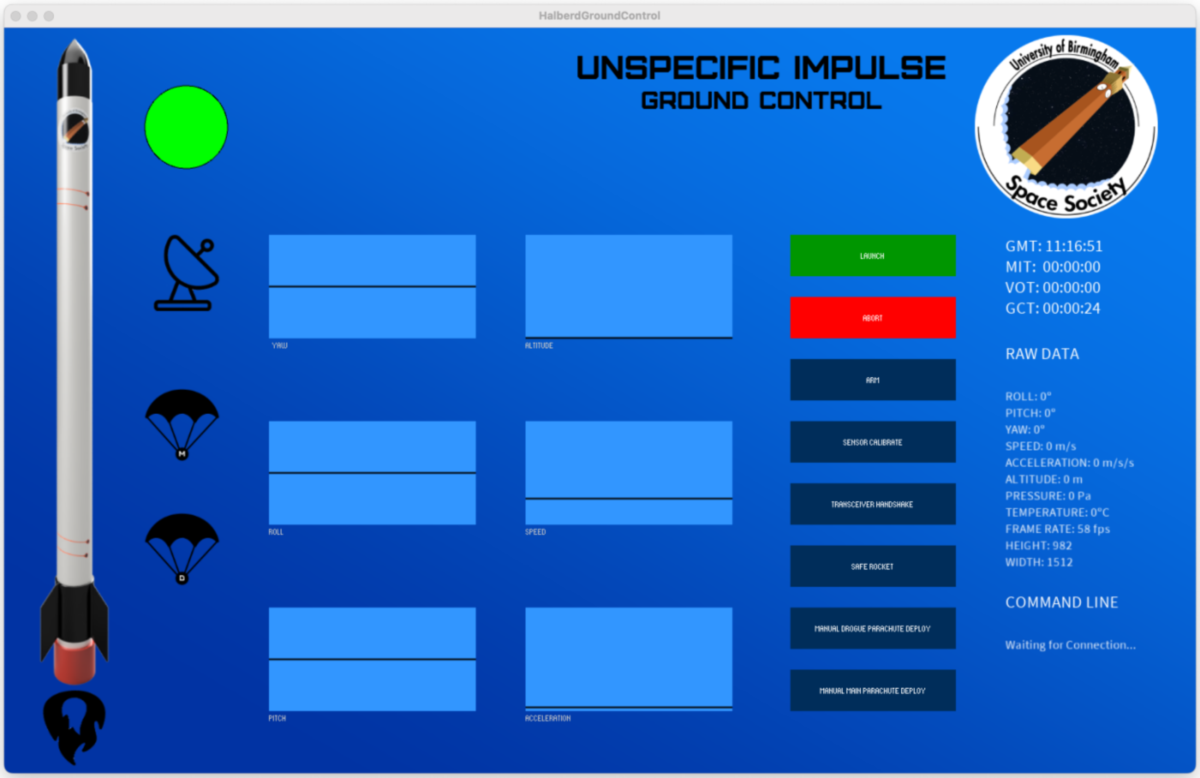


Image 5. Ground Control Program

2.3.2 Motivation

The telemetry data collected by our electronics will allow us to make improvements to our rocket designs in the future. For example, if we notice a deviation in orientation during flight as measured by the IMU, it may indicate an issue with our vehicle aerodynamics which could be improved. Designing our own electronics has also allowed members of the team to learn complex new skills such as programming, soldering and PCB design.

The design last year was centered around an Arduino Nano and used breakout boards for additional sensors. This included a barometer to measure altitude and calculate speed, an IMU to measure orientation, an SD reader/writer to record data, a GPS module for position data, a transceiver to send and receive live data, and pyro channels for parachute ejections. This design proved well, the schematics can be seen in and the telemetry computer itself in Image 6.

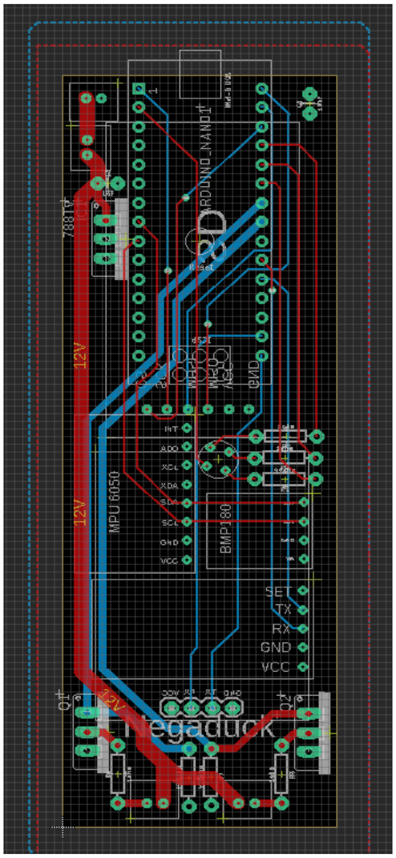


Image 7. Telemetry Computer Board Schematics

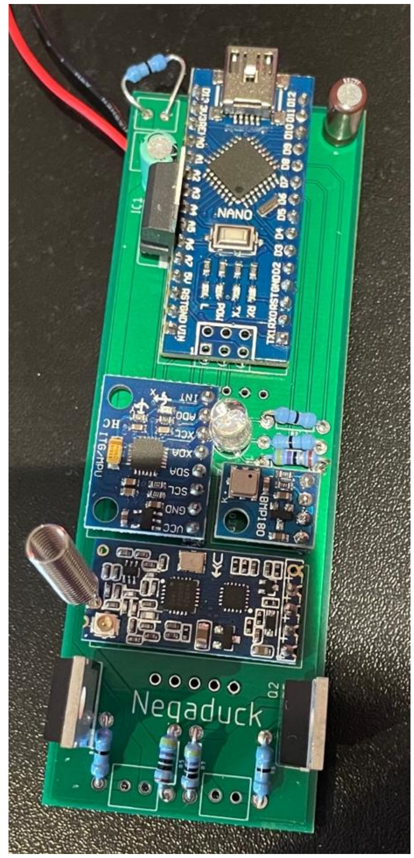


Image 6. Telemetry Computer Board

2.3.3 Design and Schematics

For this year's design the decision was made to take all the chips and sensors and mount them all to the same custom designed board, rather than using the Arduino and breakoutboards like last year. This allows for a significantly smaller and lighter design that should also hopefully be more reliable due to having less total parts and connections. The reduction is weight has left us under the required weight for the payload therefore we have also added a camera.

The design is still a work in progress and has taken longer than expected due to component shortages. The design is centred around a ATMEGA4809 processor – the same that is found on an Arduino Nano Every. Other main components are listed in along with their use.

Component	Use
ATMEGA4809	Microprocessor
ICM-20689	IMU
BMP390	Barometer
UBLOX ZOE M8Q	Transceiver

Table 3. Telemetry Board Components

The current state of the schematics can be seen in Image 8. Lots of development work is still required followed by manufacturing, testing and qualification of the flight computer.

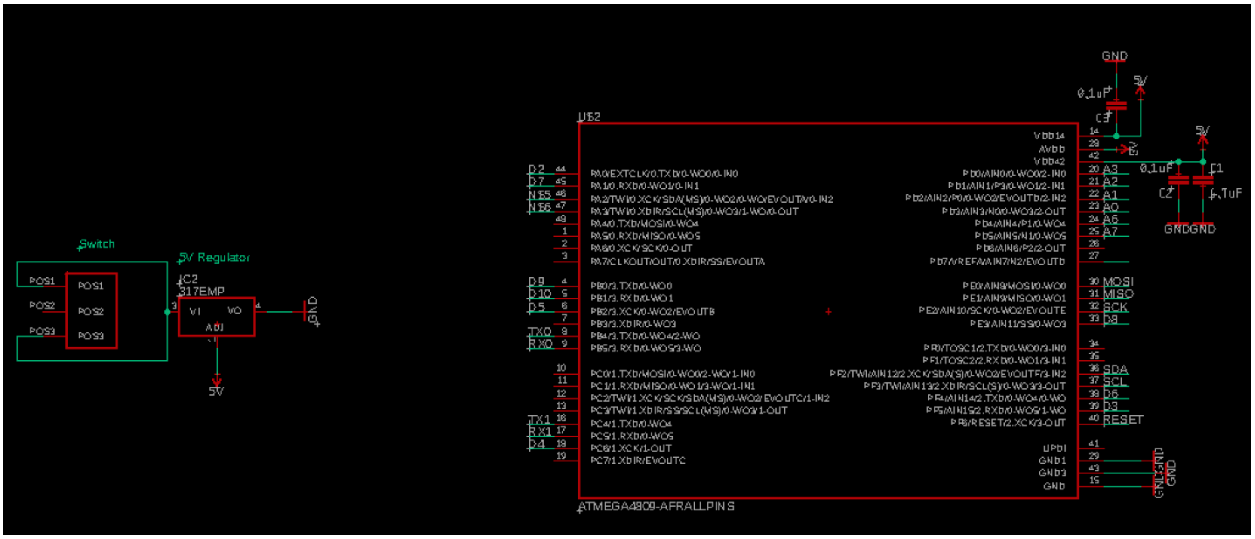


Image 8. Computer Electronics Schematics

2.3.4 System Integration

The control of the telemetry computer is integrated within our ground control software. Commands and data are sent and received through transceivers. However, to prevent in-flight failure in the case of a loss of signal, all critical functions are performed by the onboard telemetry computer, where telemetry data is also saved locally onto the microSD card.

Calibration of all sensors are performed when the computer is powered on, and the measurement and transmission of telemetry begins when a 'STARTUP' command is sent. The launch countdown begins when the 'LAUNCH' command is sent, at which point the telemetry computer takes over the countdown. However, this can be cancelled at any time by sending an 'ABORT' command.

2.3.5 Camera

A camera module (Image.10) was added on board the rocket to record a video of the flight. This involved a nose cone redesign to house the camera (once the camera was disassembled from its main casing), which allows for a much lower camera angle relative to the vertical axis when compared to mounting it inside the body tube.

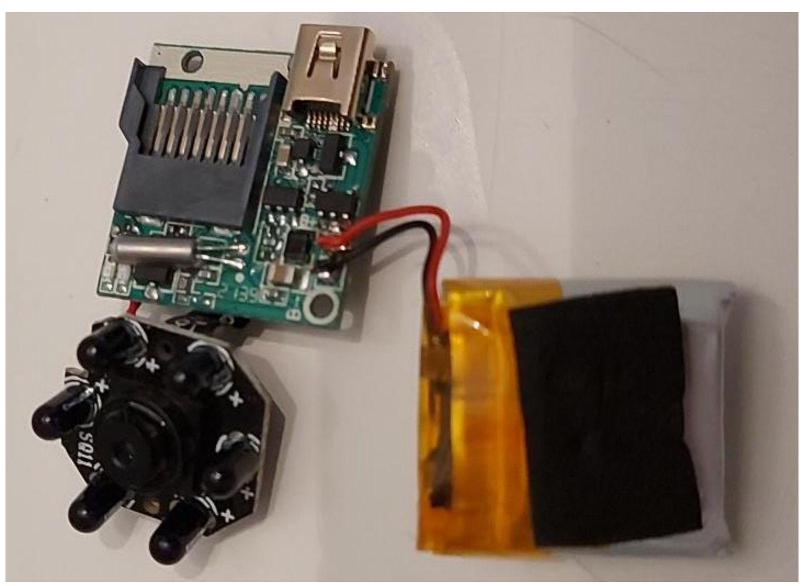
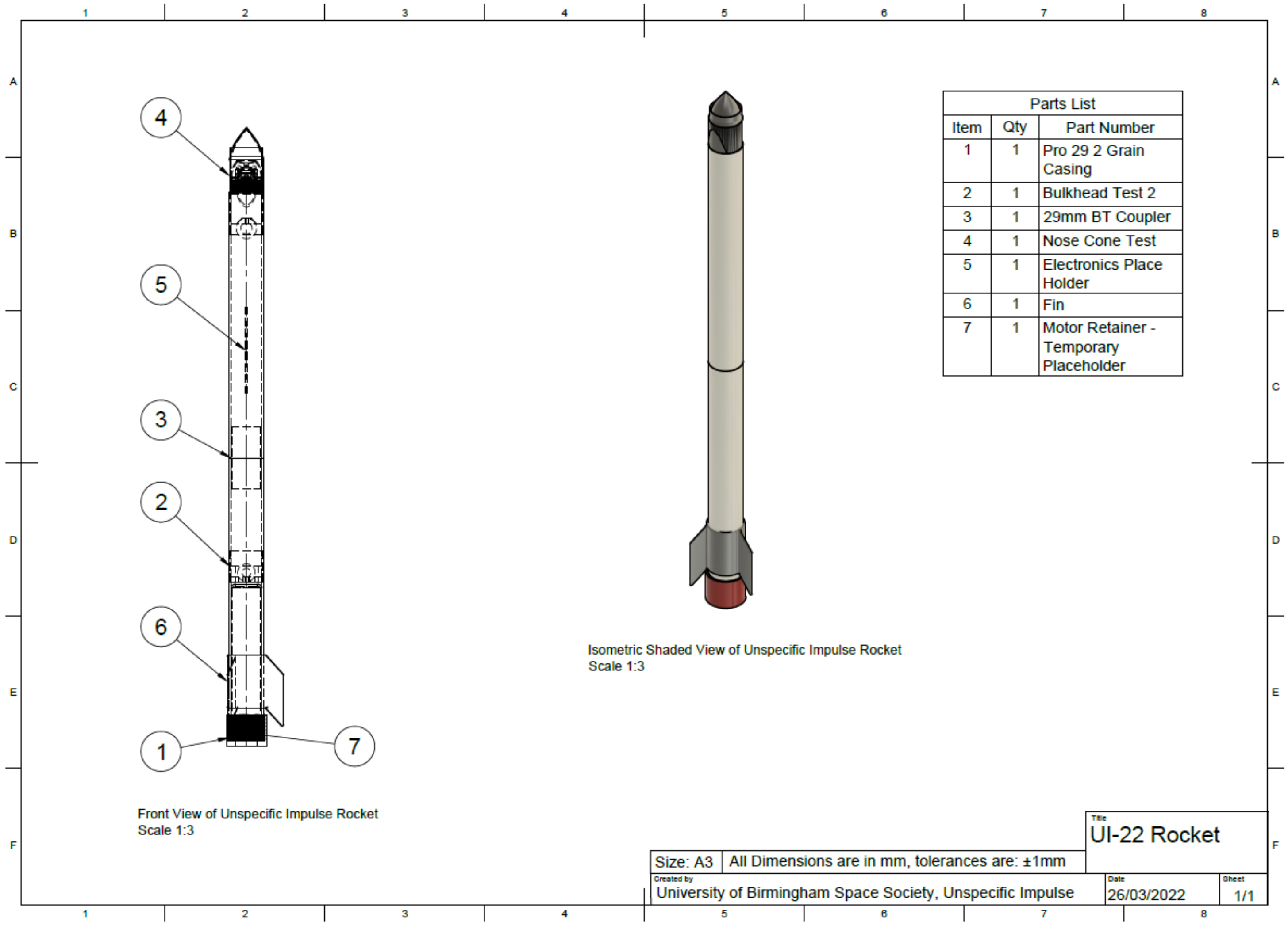


Image 9. Camera Module

3. Design Drawings/Models

3.1 Design Drawings:



Parts List

Item	Qty	Part Number
1	1	Pro 29 2 Grain Casing
2	1	Bulkhead Test 2
3	1	29mm BT Coupler
4	1	Nose Cone Test
5	1	Electronics Place Holder
6	1	Fin
7	1	Motor Retainer - Temporary Placeholder

Image 10. Unspecific Impulse Drawing with BoM

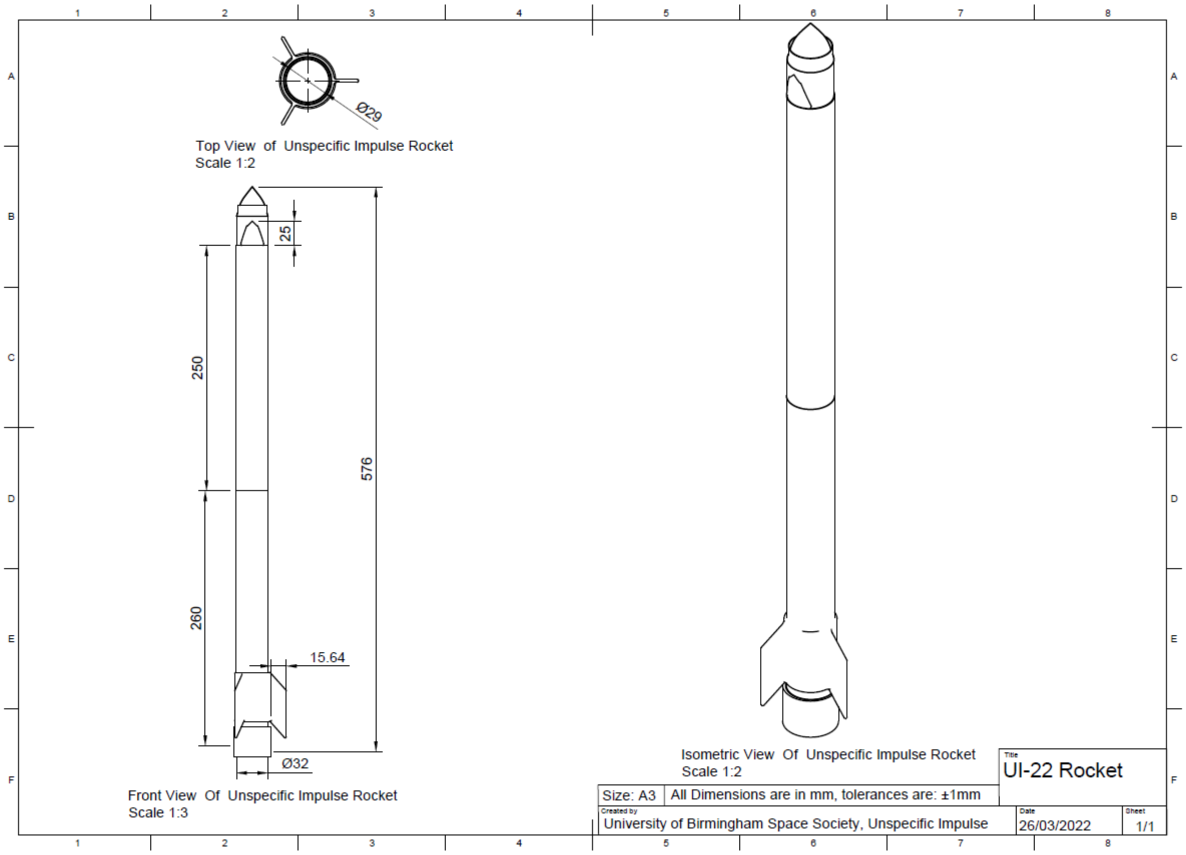


Image 11. Different views and dimensions of the Unspecific Impulse Rocket

3.2 CAD Models

Image 12. Unspecific Impulse v2 Rocket CAD model Rendering

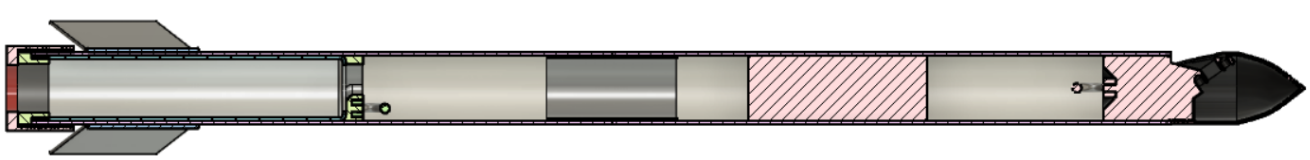


Image 13. Unspecific Impulse v2 Rocket Section View

4. Manufacturing Process

4.1 Body Tube

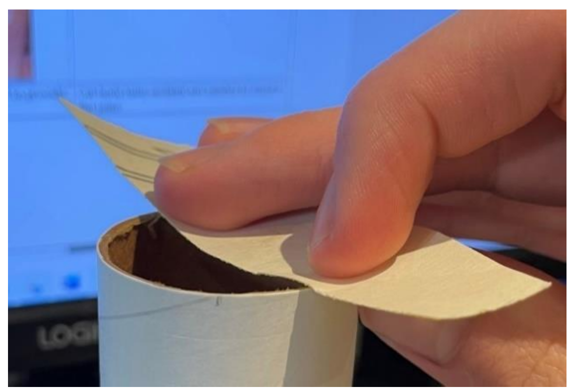
	
Body tube is cut slightly too large, then sanded down to the right size to ensure we had a flat surface.	Ruler is used to mark body tube lengths
	
Tape was used to mark out a straight cut to be made. A rotary tool was used to cut the tube.	Body tube ends were sanded to ensure a flat end, first with a rough grit, then a finer one.

Table 4. Body Tube Manufacturing

4.2 Fins

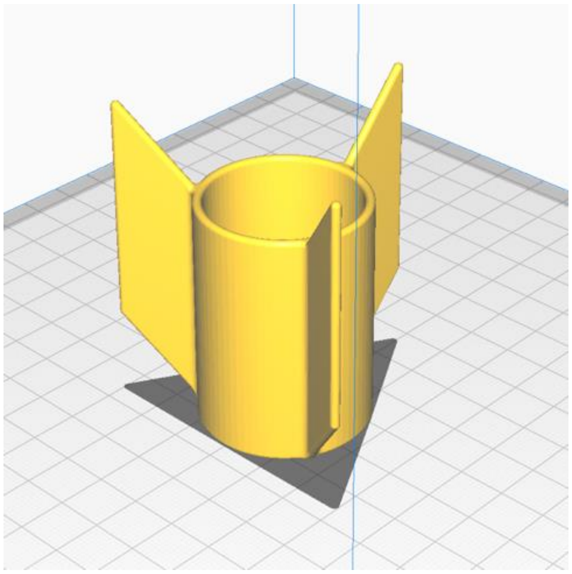
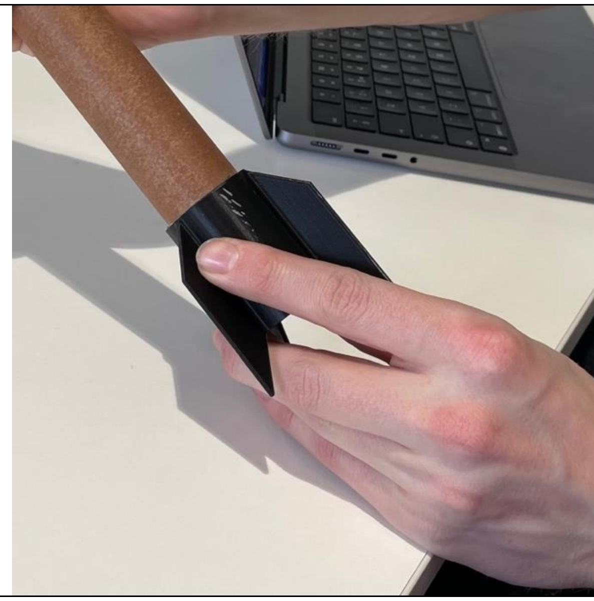
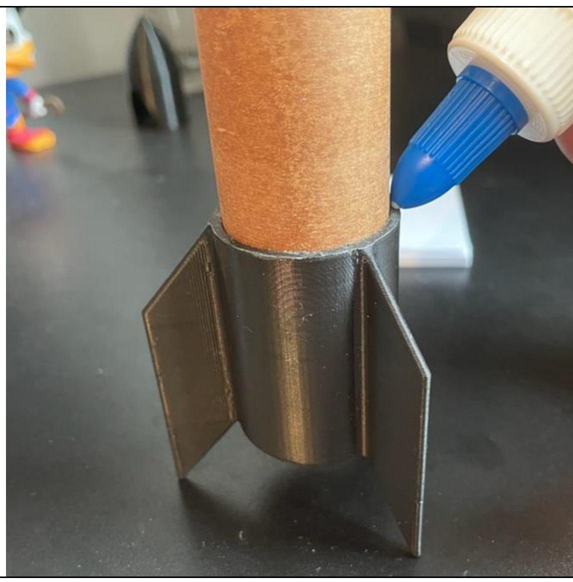
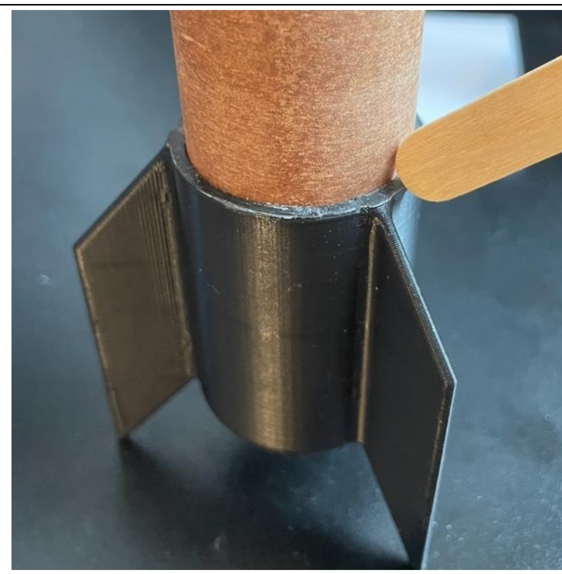
	
The fin assembly is printed as one piece. The overhang angle for each fin is chosen so that supports aren't required as this would worsen the surface finish.	Fin assembly is slid onto the rocket body tube
	
Fin assembly is secured in place using PVA glue	A lollipop stick is used to produce a filleted edge with the glue where the body tube runs into the fin assembly in order to produce a more aerodynamic shape

Table 5. Fin Manufacturing

4.3 Nosecone

4.3.1 Images

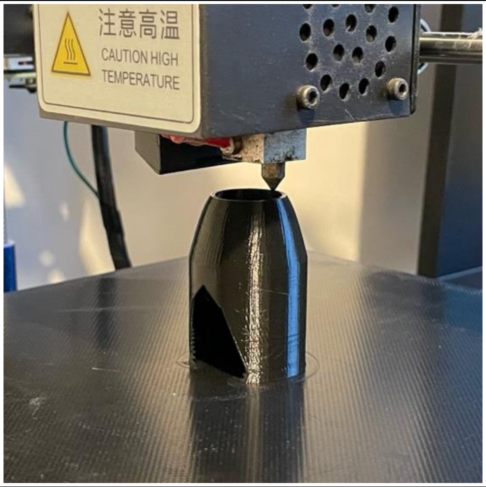
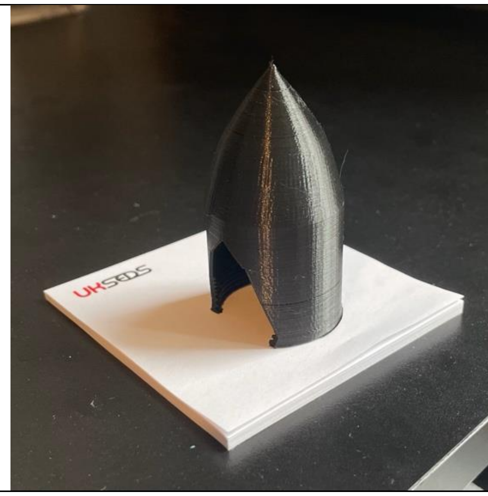
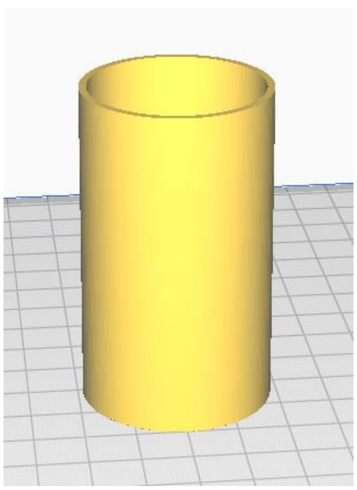
	
Nosecone sections are 3D printed in PLA	3D printed nosecone completed

Table 6. Nosecone Manufacturing

4.4 Engine Block

	
Engine block is 3D printed.	Lifting eye nut is epoxied into position.
	

Engine block is epoxied into the rear section of the body tube, the engine casing is used as an assembly jig to provide correct location.	

Table 7. Engine Block Manufacturing

4.5 Motor Retainer

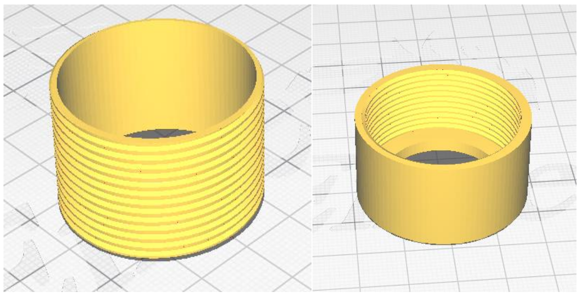
	
The motor retainer is 3D printed in two parts.	Inner retainer piece is glued to body tube surface

Table 8. Motor Retainer Manufacturing

5. Testing

5.1 Test Matrix

Test	Type	Validation
Fin Longitudinal Loading Test	Maximum Load Test	Component will survive the desired loading conditions
Fin Lateral Loading Test	Maximum Load Test	Component will survive the desired loading conditions
Engine Block Loading Test	Maximum Load Test	Component will survive the desired loading conditions
Drogue Parachute Deployment Test	Recovery Test	Ejection charge will fire, and body sections will separate as desired
Main Parachute Deployment Test	Recovery Test	Ejection charge will fire, and body sections will separate as desired

Table 9. Testing Matrix – Tests to be carried out

Engine Block Loading Test

The maximum thrust of the 'Classic motor is 85.40 N, therefore using a safety factor of 2, the minimum axial load in which the thrust structure must support is 170.80 N. Allowing for a misalignment of 5°, the minimum lateral load in which the thrust structure must support is 29.18 N.

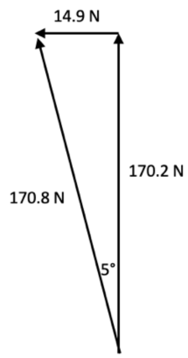


Figure 10. 5° Offset Thrust

Minimum Acceptable Axial Load	170.80 N
Minimum Acceptable Lateral Load	14.90 N

Table 10. Load Summary

5.2 Fin deflection

Longitudinal Loading Test

To ensure the fins are attached to the body with sufficient strength to withstand the forces of flight, they will be tested by subjecting them to a lateral longitudinal loading force equal to 2*fin mass* maximum acceleration.

Lateral Loading Test

To ensure the fins were attached to the body with sufficient strength to withstand the lateral forces caused by the fins producing lift during flight, the fins will be tested by subjecting them to a lateral loading equal to the launch mass of the rocket. The deflection of the fins will then be measured

Weight	4g
Longitudinal Loading Test Requirements	2 x 4g x 222ms^{-2} = 1.8N (181g)
Longitudinal Loading Test Outcome	Still to test
Lateral Loading Test	Still to test

Table 11. Fin Deflection Tests

6. Further Improvements

6.1 Any changes to initial Design

- The nose cone was made larger to accommodate the camera, which was detrimental to the aerodynamics and thus max altitude but was preferable as it allowed for a much better camera angle.

6.2 Improvements or Future Work

- We would like to continue to improve our telemetry computer – the next stage will be forgoing the breakout boards and implementing the chips and sensors directly onto the main board. This will involve a more difficult design phase, but the overall telemetry computer will be lighter and more compact.
- The nosecone needs to be remanufactured. It has a bumpy surface which indicates the PLA filament used has absorbed too much water from the atmosphere, thus, needs to be dried out before further use.
- We would like to upgrade the camera system to include real-time video transmission to the Ground Control and Telemetry computer.

References:

1. Pro38.com. 2009. - || Pro-X || - A better way to fly - - Cesarani Technology Incorporated. [online] Available at: http://www.pro38.com/products/pro29/motor/MotorData.php?prodid=116G126-13A
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Appendices:

Appendix A: OpenRocket Simulation Graph

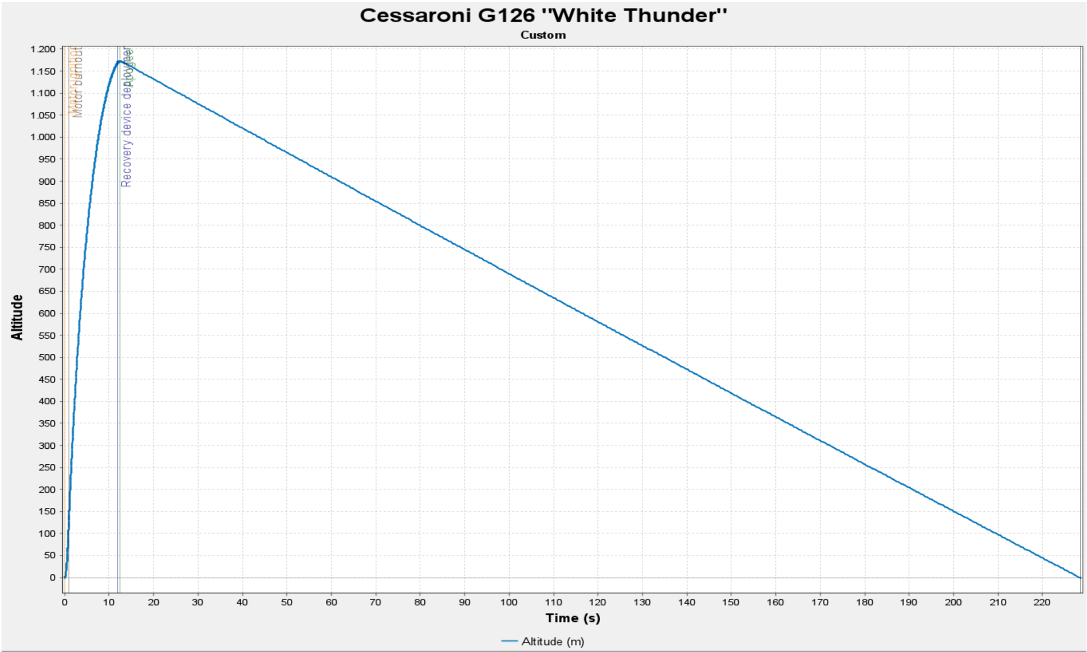

Figure 11. OpenRocket Simulation (Altitude vs Time Graph)

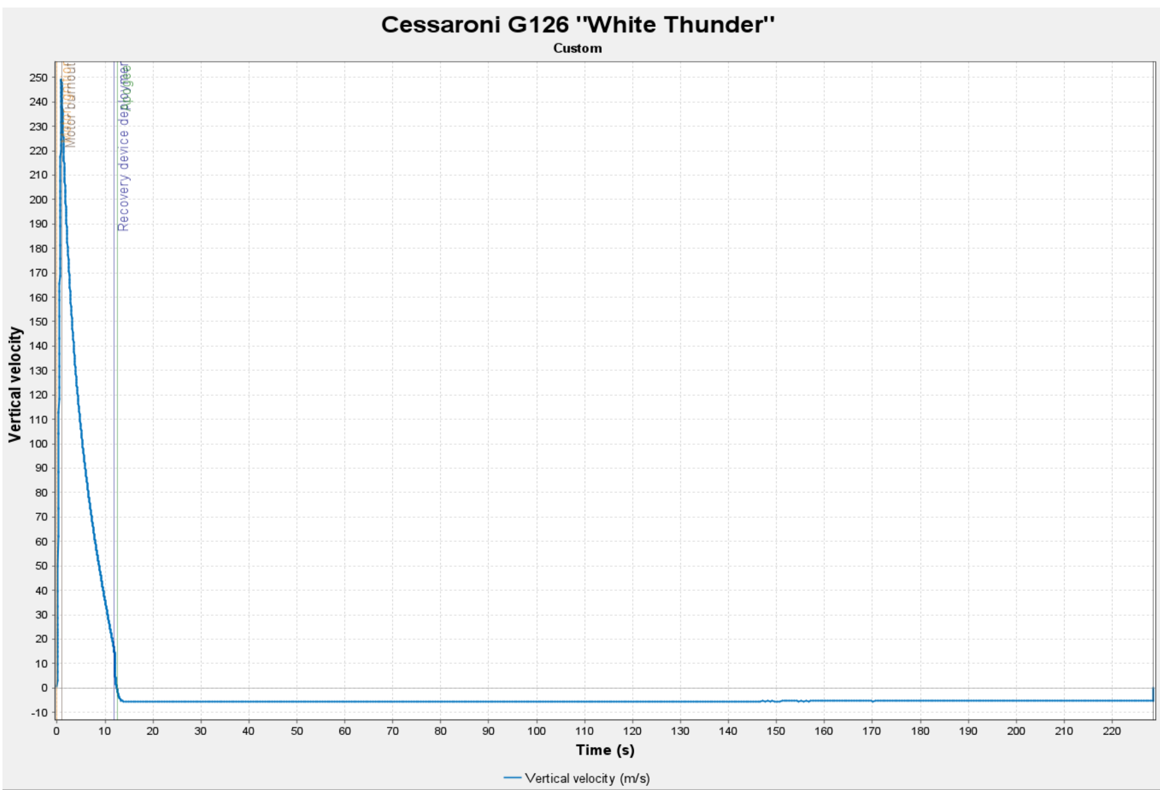

Figure 12. OpenRocket Simulation (Vertical Velocity vs Time Graph)

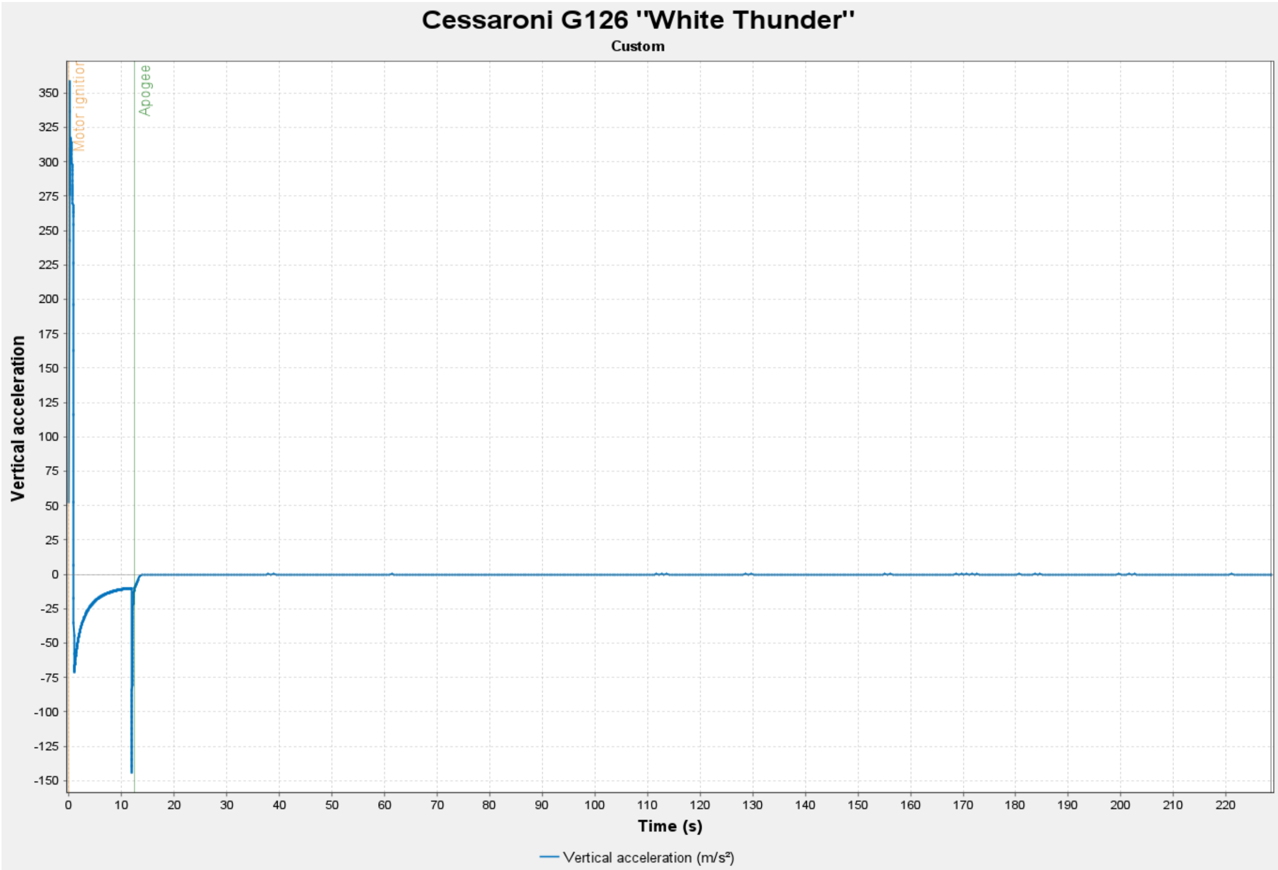

Figure 13. OpenRocket Simulation (Vertical Acceleration vs Time Graph)

Appendix B: Additional Drawing(s)

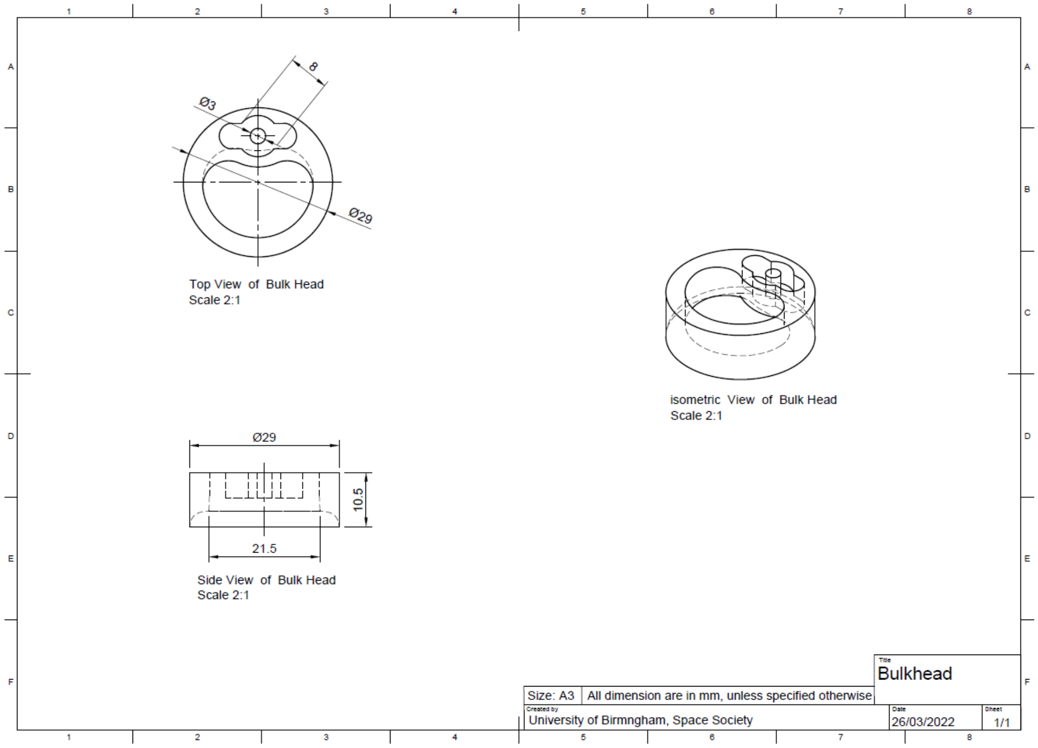

Image 14. Bulkhead Drawing

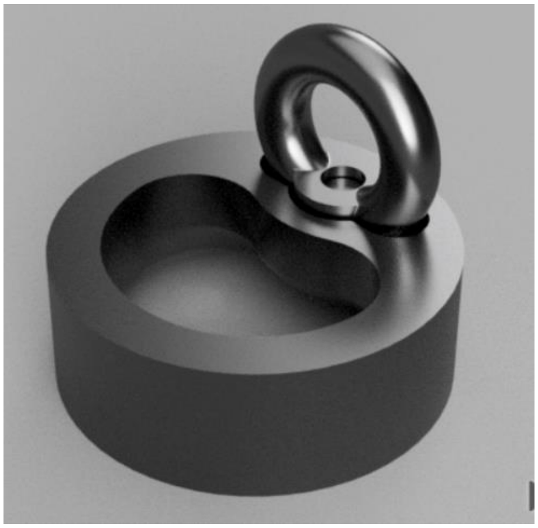

Image 15. Bulkhead Render

Appendix C: Parachute Drag Theory

The parachute will allow the rocket to descend softly onto the ground, without damaging the rocket and any critical parts inside. This will allow certain parts to be reused in later flights such as the parachute, electronics, and payload. The parachute must be large enough to dimmish the speed of the descending rocket, to a speed lower than $15ms^{-1}$ at stated in the guidelines. [4]

We know that when the rocket is falling (after reaching its apogee) it will hit terminal velocity, and therefore, the forces of weight and drag will be equal. The frictional skin forces generated from the rocket tube body, will be negligible compared to the parachute drag, thus not included in the calculations. The force produced by weight (Eqn.1) will be equal to the drag force created by the parachute (Eqn.2).

$$F_{Weight} = mg \quad \dots \quad Eqn.1$$

$$F_{Drag} = \frac{1}{2} C_d \rho A U^2 \quad \dots \quad Eqn.2$$

$$Area = \frac{\pi d^2}{4} = \pi r^2 \quad \dots \quad Eqn.3$$

$$Diameter = \sqrt{\frac{8mg}{\pi \rho C_D v^2}} \quad \dots \quad Eqn.4$$

Hence, we see that the only dependent variables will be mass and velocity, as the other variables will stay constant when calculating a suitable size parachute. The constant variables include:

- g (gravitational acceleration = $9.80665 m/s^2$)
- C_d (Drag coefficient = 0.8) [2,8]
- π (Pi = 3.131593)
- ρ (density of air = $1.225 kg/m^3$)

We wanted to find the density of air during a given month for our calculations, and therefore, we decided to calculate the average air density during a given month. We assumed that we would launch our rocket on the average temperature during a given month. We therefore took the average temperature in Birmingham from a weather reporting website called World Weather Online. [9] The average temperatures of each month are shown in Fig.C1~C2. This figure shows the mean temperatures for April, May, June and July between the years 2009 and 2019. From the average temperatures, we used a density calculator for air [10] to calculate the estimated air density in each given month (shown in Fig.C3).

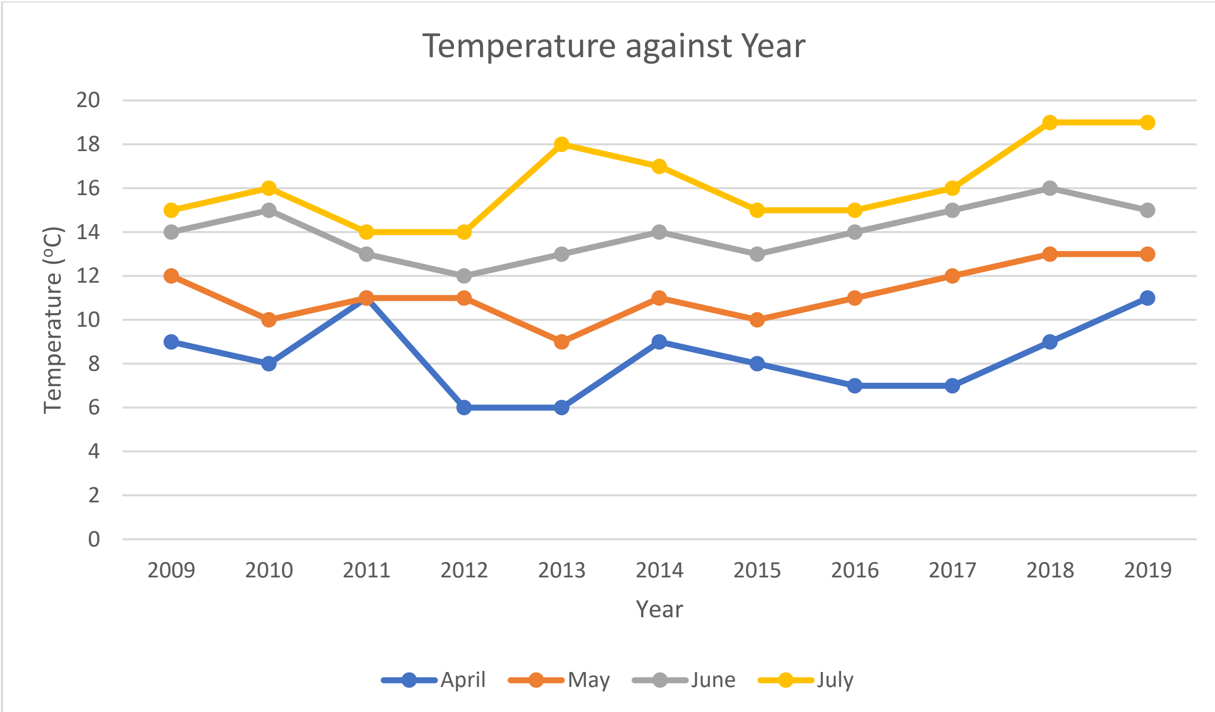

Figure C 1: Average temperature per month for a given year

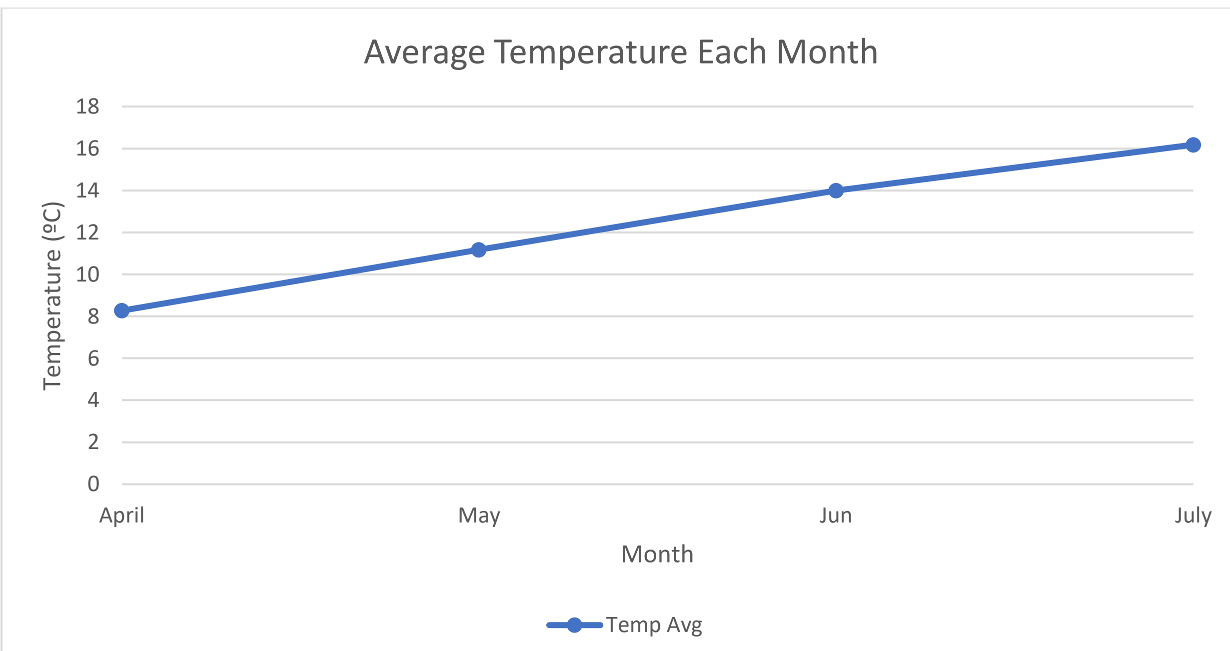

Figure C 2: Average temperature against a given month

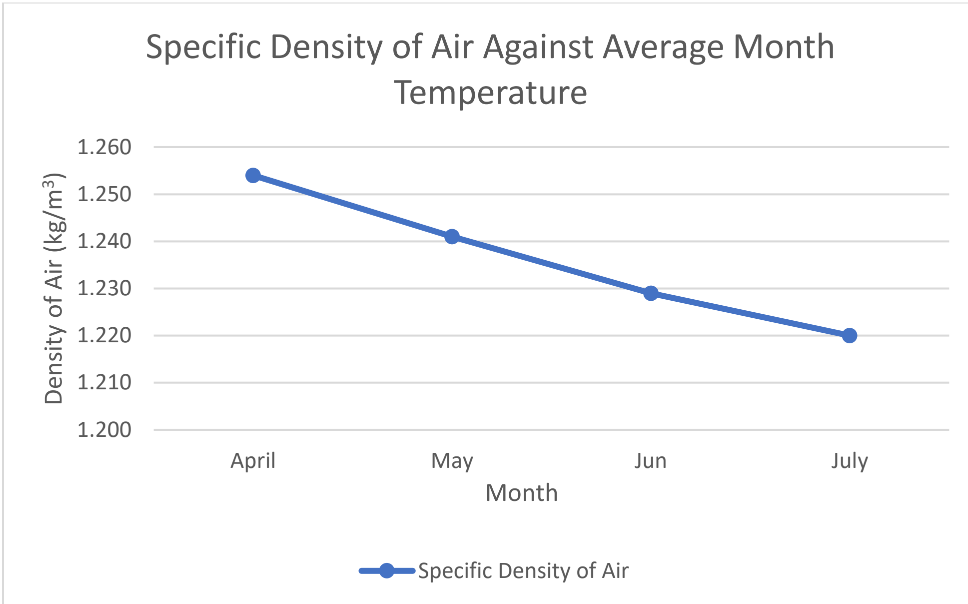

Figure C 3: Specific Air Density against each month

From this data, we decided to use 1.225kg/m^3 as the air density in each calculation. This value was kept fixed since the density did not vary significantly with each month. We also compared the air density using NASA's website, which indicated an air density value of 1.229kg/m^3. [8] The small change in the density obtained using weather reporting website compared to the value found from NASA, showed a negligible difference for determining the size of the parachute needed to land at a given velocity of 5ms^{-1}, as shown in Fig.C4.

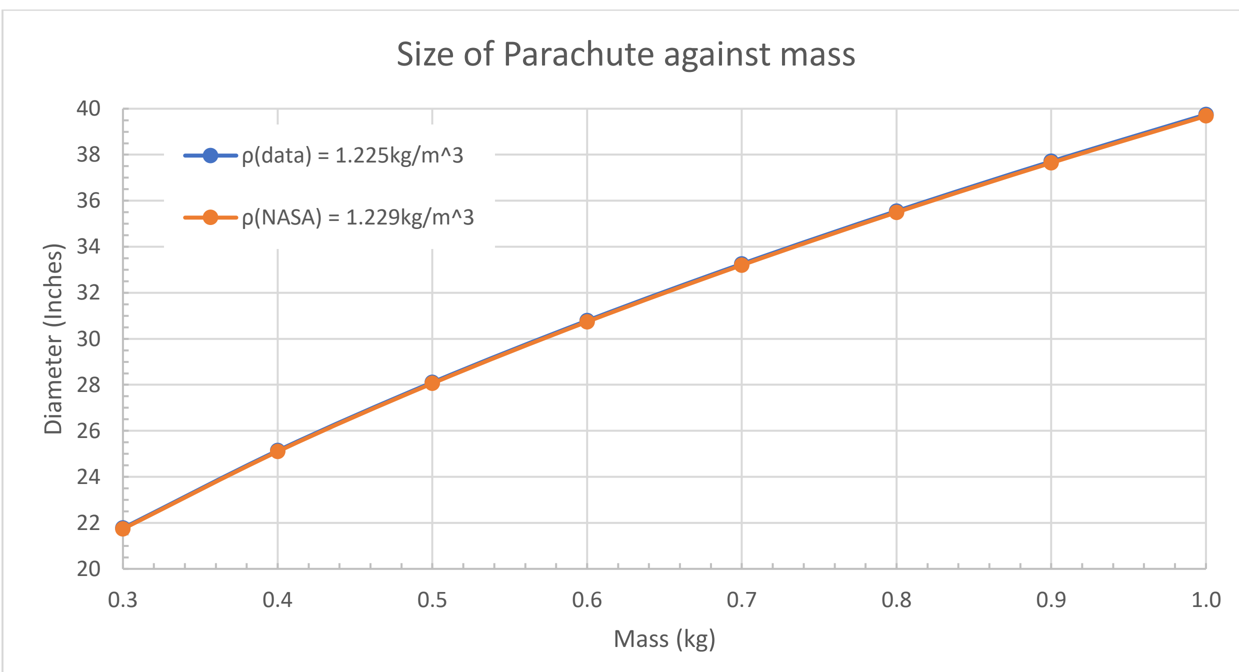

Figure C 4: Size of Parachute against (dry) mass of rocket descending at 5m/s

From all our variables, we found the given (diameter) size of parachute needed to land the rocket at 5 ms^{-1}, 10 ms^{-1}, 15 ms^{-1} depending on the rockets' (dry) mass. These values are presented through a graph shown in Section 2.2.