Project Technical Report for the 2020 UKSEDS National Rocketry Championship

Design of Solid Fuelled Rocket “SunrIde Jr.”

Student Team Members:
Abdelrahman Al-Omari, Dana Arabiyat, Iulius-Vladimir Seniuc, Zefy Pissaki, Tom Aveyard, Joshua Brown, Mohammed Taha, Piotr Gołaś, Croydon Busse, Rasin Gonenc, Marwan Badreldin, Malik Fernando.

Academic Supervisor: Dr. Viktor Fedun.

1. Introduction

This report consists of the design of SunrIde's team rocket; SunrIde Jr., the participant in UKSEDS National Rocketry Championship. SunrIde Jr. is an amateur mid-power rocket with a 2 grain solid motor, with an expected altitude of 1400 m. The rocket is carrying a camera and a MEMS sensor array, part of an Arduino Nano 33 BLE controller. This system will attempt to record as many measurements as allowed by the hardware (incl. acceleration, altitude, sound, etc.), and estimate the speed of the rocket by means of the Doppler Effect. The report validates the design, performance, and safety requirements outlined by the UKSEDS technical guidelines.

2. Design

2.1 Modelling

2.1.1 OpenRocket

The rocket and its flight behaviour was modelled using the OpenRocket Simulator. The main objective was to design a rocket with a static stability margin between 1.5-2.5 calibers that would reach an apogee greater than 900m. In addition to this, the rocket should be able to carry a payload of around 100g. The final OpenRocket design can be seen in **Figure.2.1** [1].

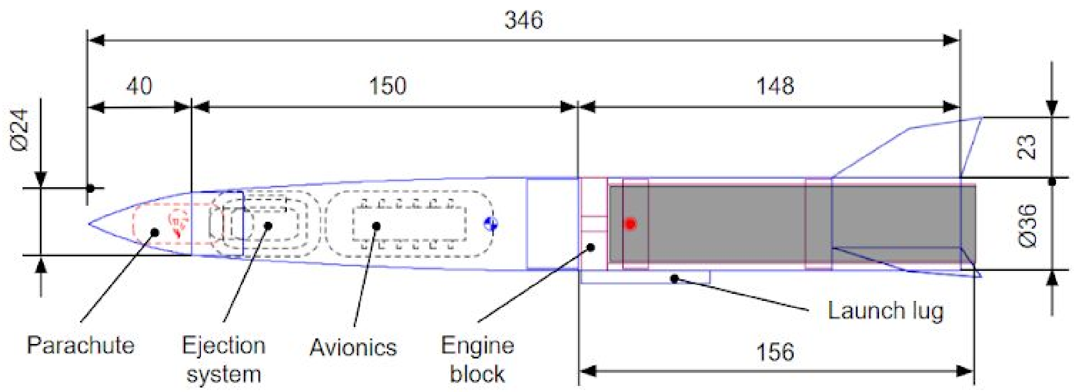

***Figure.2.1 OpenRocket model**, dimensions in mm*

Nose cone:

After experimenting with numerous nose cone shapes, it was determined that the parabolic series and ogive shapes were among the most effective at minimising aerodynamic drag. The team opted for a parabolic series cone with a shape parameter of 0.7, as it allowed the modelled rocket to reach a higher projected apogee than the alternative, without sacrificing stability. The nose cone measures 40 mm in length, with a maximum diameter of 24mm. The interior volume allowed the packed parachute to be fit inside, which also works in favour of the rocket's stability.

Body tubes:

The body tube consists of two sections with a wall thickness of 1.2mm. Instead of the cylindrical tubes commonly used in model rocketry, the team took advantage of the available 3D-printing capabilities to optimize the upper airframe into a tube transition. This follows the parabolic shape trend of the nose cone, with an overall reduction ratio of 0.66.

The 150 mm long upper tube houses the avionics, the parachute ejection system, payloads, and dedicated stability mass. The overall weight inside the upper tube was distributed towards the top, so as to maintain an acceptable static stability margin. A small static pressure hole in the airframe allows the avionics to sample the correct ambient pressure, and release any stray pressure pockets inside.

The lower tube is 148mm long, and 36mm in diameter. This is a crucial and complex component, as it incorporates the engine block, internal motor tube, launch lug, and fins, all 3D-printed as a single unit. The engine is tightly secured to the 10mm thick engine block through a bolt, allowing thrust loads to be passed onto the rest of the rocket's structure.

Fins:

Upon experimenting with different fin designs in OpenRocket, the team opted for a 3mm thick, airfoil cross-section, swept-tapered shape fin. Thanks to the seamless 3D-printing process, the three equidistant fins achieve perfect alignment relative to the rocket's longitudinal axis.

Launch system:

Prior to launching, the rocket will be installed on a G-class compatible, low-cost, portable launch pad. The platform has a 900 mm footprint and is equipped with an adjustable 88 mm stainless steel launch rod, 3.2 mm in diameter [2]. The 50mm launch lug embedded in the rocket's fuselage will provide enough guidance at liftoff to set the rocket on the desired course.

Motor choice:

The choice of motors is regulated by UKSEDS guidelines, with Cesaroni 29mm G-class motors accepted as the upper limit. Browsing through OpenRocket's motor database and considering availability, the team opted for one of the more powerful Cesaroni motors in that range: the G126-WT, expected to deliver a total impulse of 116Ns. Motor specifications shown in **Figure 2.2.**

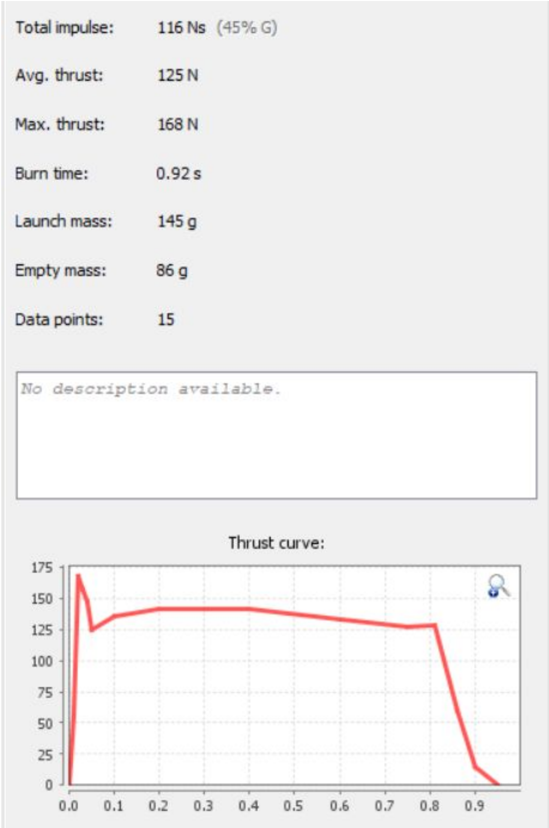

Figure 2.2: Motor Details; G126-WT configuration

Stages	1
Mass at launch	468 g
Mass at burnout	412 g
Static stability	1.5 Cal
Centre of Gravity	156 mm
Centre of Pressure	211 mm
Apogee	1395 m
Flight time	135 s
Time to Burnout	0.95
Time to Apogee	15.3 s
Velocity off rod	22.4 m/s
Max velocity	243 m/s
Max acceleration	372 m/s^2
Ground Hit Velocity	11.2 m/s

Table 2.1: OpenRocket result

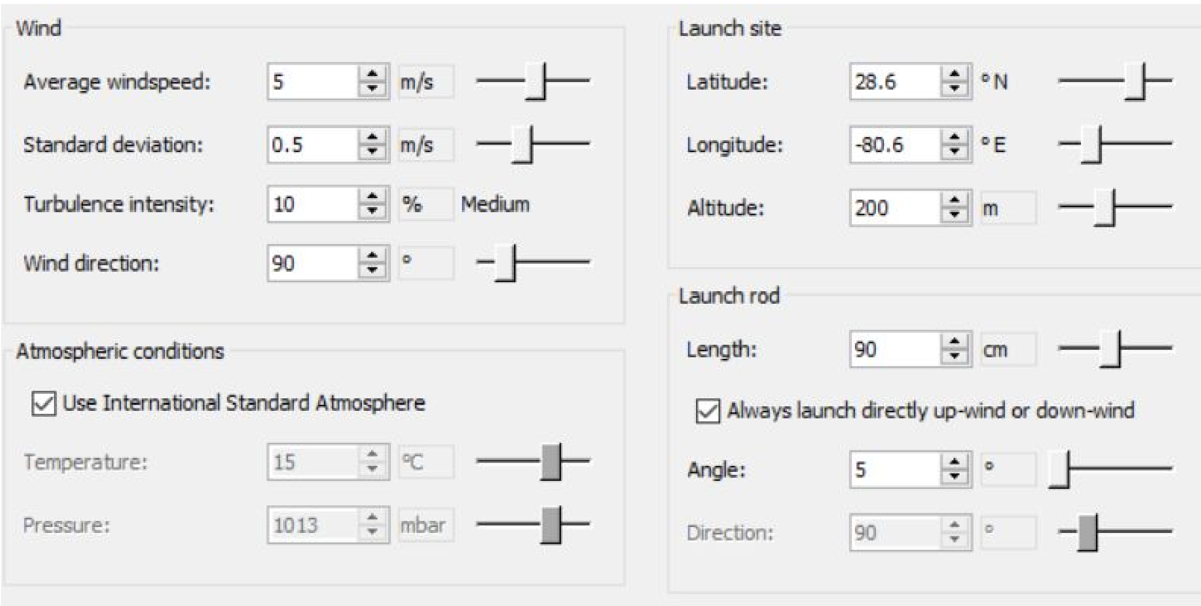

Figure 2.3: OpenRocket launch parameters; suboptimal conditions

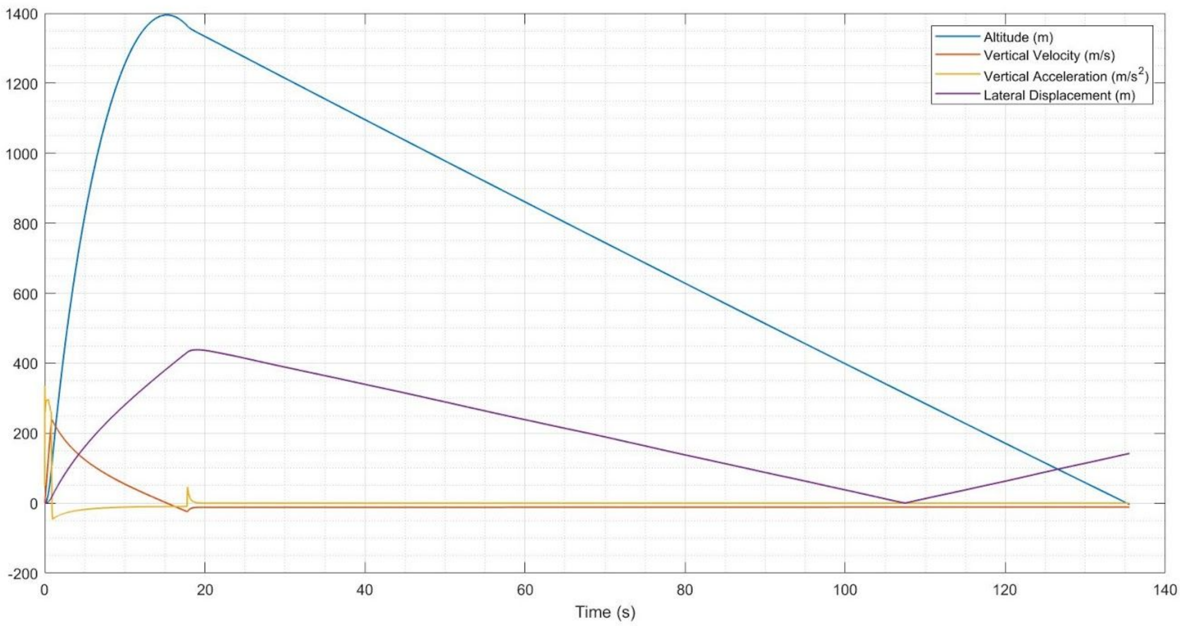

Figure.2.4: OpenRocket simulated flight behaviour; *full prediction, G126-WT configuration*

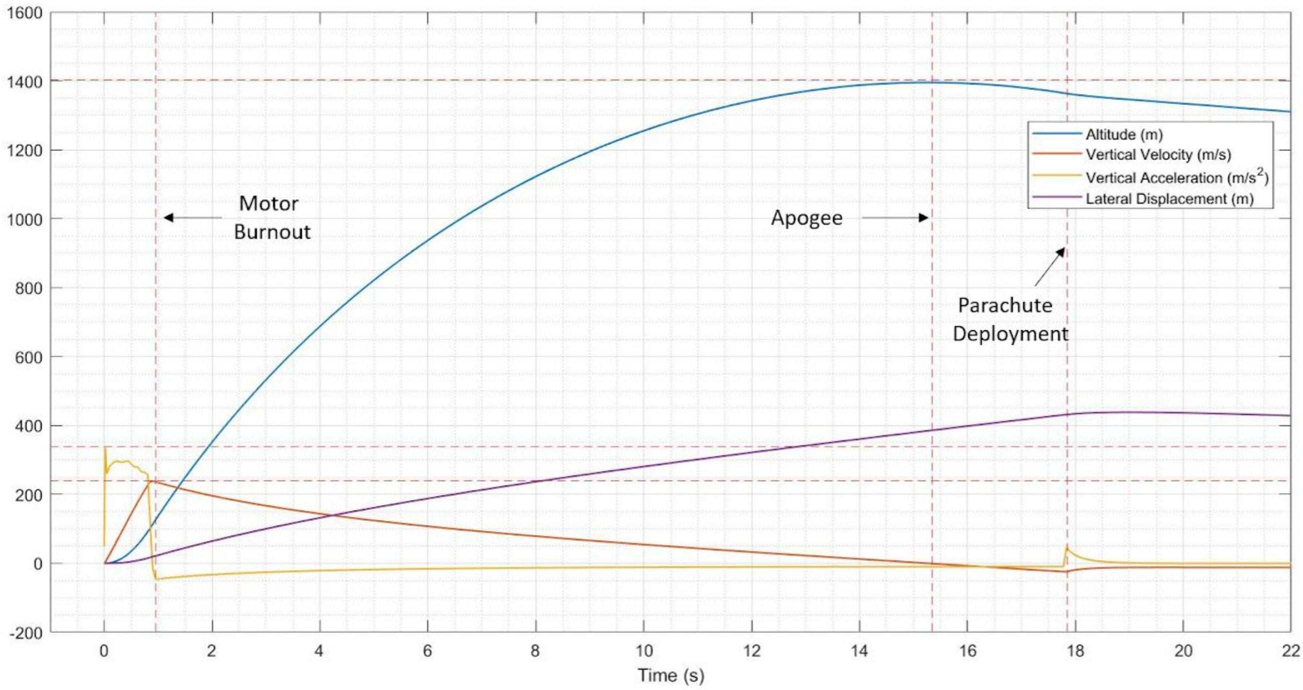

Figure.2.5: OpenRocket simulated flight behaviour; *detail, G126-WT configuration*

Launch conditions:

The simulated flight behaviour is highly dependent on the launch conditions. The goal is to reach the highest possible altitude under suboptimal atmospheric conditions, accounting for a maximum lateral drift distance of 1km. The team plans to launch the rocket in the summer of 2020, from an area around Sheffield, at a geopotential altitude of ~200m. During that period, the wind is expected to blow predominantly from the West, at an average speed of 9.7 mph [3], rounded to 5 m/s, for simulation purposes. The International Standard Atmosphere conditions were taken as reference. Given these estimated wind conditions (**Figure 2.3**), the rocket is predicted to launch up-wind, at an angle of 5°. This will be refined on location, shortly before launch, to increase the confidence margin.

Flight behaviour:

Considering the launch conditions above, once the motor is ignited, the rocket is projected to reach apogee at around $1400\,[m]$, after 15 seconds (**Figure 2.4**). The maximum velocity of ~$242\,[m/s]$ (Mach 0.71) is experienced at motor burnout, at an altitude of roughly $126\,[m]$. The maximum acceleration of ~$350\,[m/s^2]$ is expected to occur at parachute deployment, programmed 2.5 seconds past apogee, and is comparable to that recorded at liftoff (**Figure 2.5**). After deployment, the rocket is expected to descend at a constant rate of ~$11.2\,[m/s]$ before hitting ground.

2.1.2 Fusion 360

The design process inside Autodesk Fusion 360 implied a transfer of the OpenRocket design into a manufacture-ready CAD model. The same parabolic formulas were used in order to generate a set of coordinates in Microsoft Excel and imported into Fusion to draw the required profile. The part design and assembly process executed in Fusion as shown in **figure 2.6** was key to integrating the avionics and recovery systems in the airframe design.

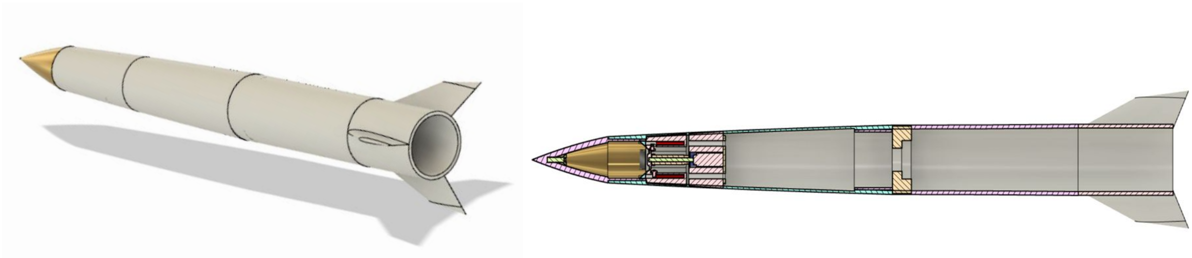

Figure 2.6: Fusion 360 model; *isometric / cross section view*

FEA (Finite Element Analysis)

Lateral fin loading:

The UKSEDS technical guidelines state that displacement from a normal load at the edge of a fin must be less than 10 degrees when loaded with the launch weight of 466g. A Finite Element Analysis (FEA) simulation was performed using Fusion 360 to ensure compliance (see **Figure 2.7**). The results show maximum displacement is significantly less than the critical value of 4.06mm. The calculation has been expressed in **Figure 2.8,** with the fin geometry in **Figure 2.9** for reference.

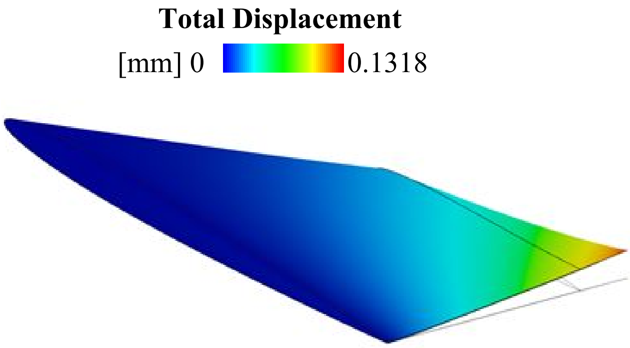

Figure 2.7: Fin lateral loading; displacement study

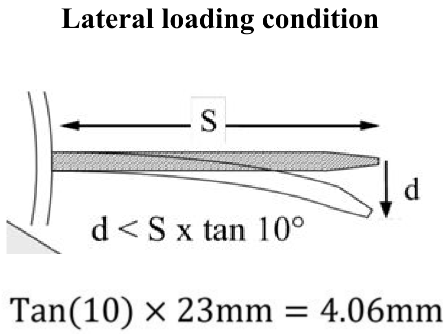

Figure 2.8: Fin lateral loading; UKSEDS

Fin longitudinal loading:

In addition, the guidelines state the fins must withstand twice the inertial force generated by their own mass at maximum acceleration. The mass of a single fin was estimated to be 1.902g from Fusion. Therefore, this critical force is calculated by multiplying the maximum acceleration predicted by OpenRocket ($338[m/s^2]$) by 2, yielding $1.28[N]$. After running a static stress study using this value, it can be seen in **Figure 2.10** that the safety factor is reliable. One potential reason for concern in **Figure 2.11** would be a stress concentration at the root trailing edge. Further mechanical testing will conclude if this issue needs to be addressed through reinforcing.

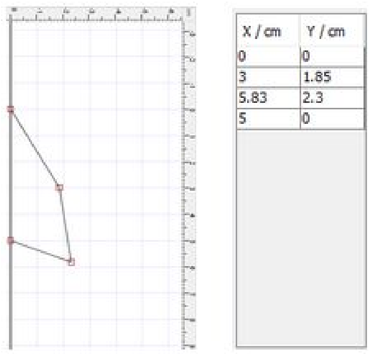

Figure 2.9: Fin dimensions

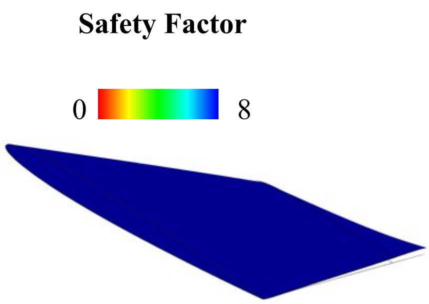

Figure 2.10 Fin longitudinal loading; safety analysis

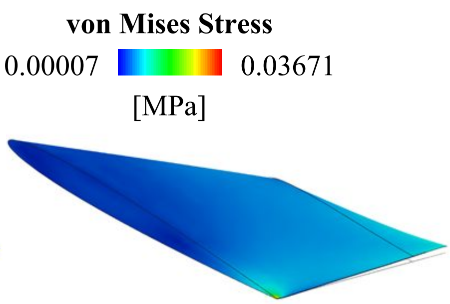

Figure 2.11 Fin longitudinal loading; stress analysis

Inertial static strength:

Another strength requirement in the UKSEDS guideline states that all structural parts, in the present case the entire airframe, must be able to withstand twice the maximum inertial load. From OpenRocket, this value is $168\,[N]$. This force would be applied directly to the engine block. **Figure 2.12** shows this load in a simulated environment. From this study, the minimum safety factor is 2.8, meaning the airframe is well capable of withstanding over twice the force loads expected under nominal flight conditions.

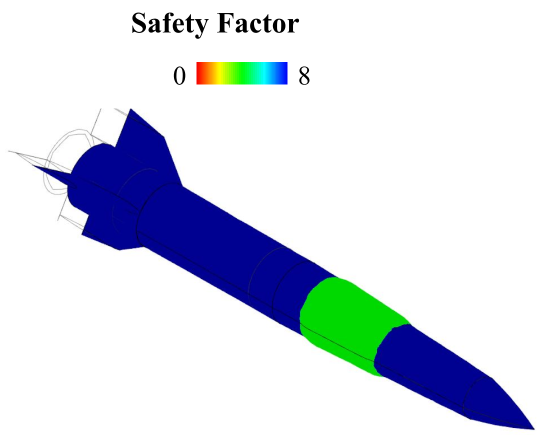

Figure 2.12 Inertial static strength; safety analysis

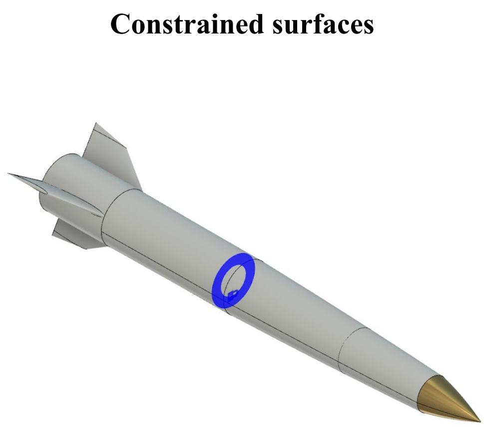

Figure 2.13 Inertial static strength; constrained

Aerodynamic static strength:

The next requirement imposes that the rocket needs to be able to withstand twice its aerodynamic load. OpenRocket can be used again, this time to determine the maximum drag force. Doubling it yields 30N. **Figure 2.13** shows this applied load across the profile of the rocket. The resulting safety factor outputted by the Fusion study was 15, meaning that there should be no issues with the rocket withstanding the aerodynamic load.

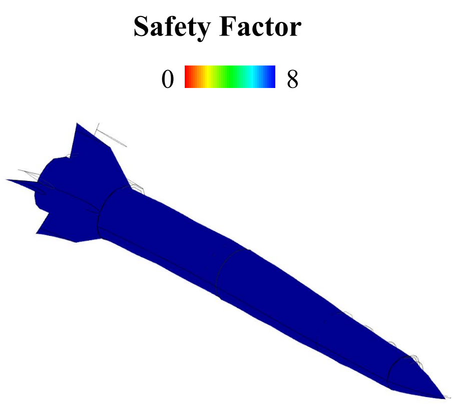

Figure 2.14 Aerodynamic static strength; safety analysis

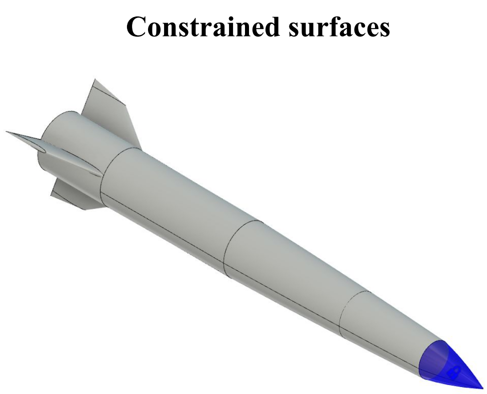

Figure 2.15 Aerodynamic static strength; constrained

Fuselage stiffness

Since the rocket is allowed to deflect by no more than 0.01 radians (10mm) under its own weight, around its centre of mass, an equivalent study would involve applying twice its weight across the full length, as shown in **Figure 2.17.**

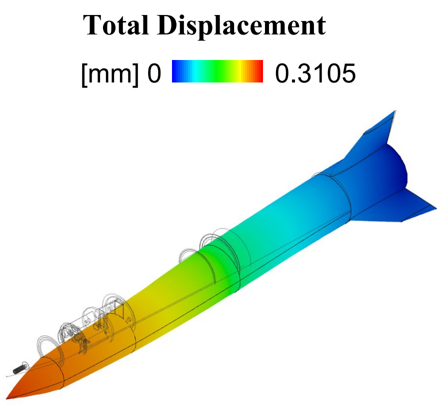

Figure 2.16 Fuselage stiffness; displacement study

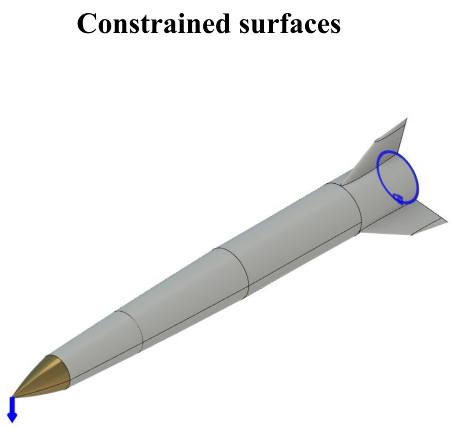

Figure 2.17 Fuselage stiffness; constraints

Name	Minimum	Maximum
Safety Factor		
Safety Factor (Per Body)	1.221	15

2.2 Material Selection

The material choice for the body tubes was primarily linked to mass and manufacturing constraints. ABS (Acrylonitrile Butadiene Styrene) is a lightweight (1.07g/cm^3), low-cost, and common thermoplastic polymer. This makes it suitable for 3D-printing the complex surface topology required by the airframe, relatively quickly (for prototyping and replacement purposes). Its mechanical properties are also satisfactory with regard to thrust and aerodynamic forces, as shown in the Fusion report. The maximum continuous working temperature of ABS is in the range of 80-95°C [5]. Despite the high exhaust temperatures, the motor casing inside the inner body tube is not expected to exceed this threshold for a sustained period, so it's extremely unlikely for thermal deformations to occur.
Due to design considerations, the nose cone needed to be manufactured from a denser material, namely brass (1.2g/cm^3), lathed separately.

The surface finish of the airframe, especially for its scale, is a determinant factor in flight performance. Therefore, all aerodynamic surfaces need to exhibit a uniform and smooth finish, for minimal friction drag. Primer/spray-paint application is to be avoided, as it produces inconsistent results and adds weight to an already light structure [6]. The 3D-printed tubes will be polished using an acetone vapour bath instead, while the nose cone will be polished using increasingly lower-grit sandpaper.

2.3 Avionics

The rocket avionics system serves three purposes: Motor Ignition, Recording and Storing in-flight data, and triggering the Recovery System.

Figure 2.18: Arduino BLE sense

The programmable microcontroller (MC) used to manage these operations is the Arduino NANO 33 BLE Sense (**Figure 2.18**). It was chosen because it integrates a wide array of sensors dedicated to motion-tracking applications, straight on its main board, replacing the need for external sensor shields, and thus, increasing robustness. Among the sensors used, a 9-axis IMU, a microphone, and a barometer. The MC is responsible for the motor ignition sequence, logging all available sensor measurements during flight, calculating altitude values in real-time, based on barometric and temperature data, and triggering the servo mechanism inside the parachute ejection system. The MC transmits data using both Serial and Wireless communication modules. **(Figure 2.19)**

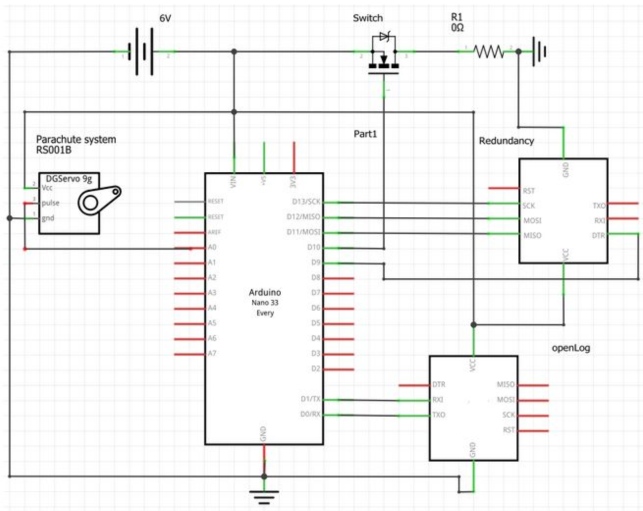

Figure 2.19: Avionics circuit diagram

2.3.1 Energy Management:

The power supply consists of four CR2032 batteries in 2P2S configuration (**Figure 2.20**), adding up to a combined capacity of 480mAh. It is capable of delivering a stable voltage of 6V to the Arduino as well as the higher current impulses required by the ignition system. The MOSFET transistor acts as a switch leading to the igniter cables (shown as a 220Ω resistor on the schematic).

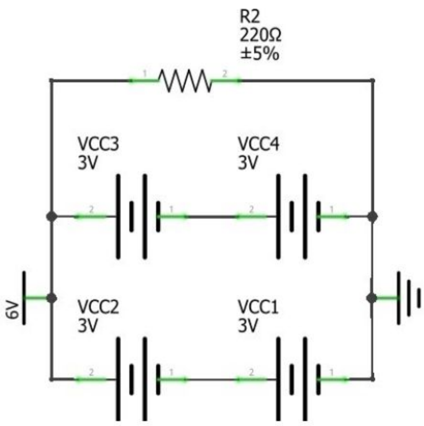

Figure 2.20: CR2032 Power supply

Accommodating the Avionics:

All components will be soldered as a solid structure and insulated by heat shrink, secured in place using friction fit inside the airframe.

2.3.2 Ignition System

Utilizing the Bluetooth module, the team will initiate the launch wirelessly. The signal will activate the D10 pin, triggering the MOSFET transistor from a safe distance of at least 10m. This effectively closes the switch enabling current to flow through the igniter wire initiating ignition.

2.3.3 Data Capture and Storage

The data capture stage makes use of the on-board Arduino sensors, reducing weight and simplifying the system. All telemetry and sensor values are transmitted through the UART ports to the **Sparkfun OpenLog Blackbox** chip for immediate storage into a 16GB SD card shown in **Figure 2.21**.

Figure 2.21: OpenLog

2.3.4 Redundancy

Ensuring that sensor data is stored safely and accurately is critical. So there is a second data logger connected to the Arduino Nano BLE through SPI ports in case the UART ports fail or carry errors (**Figure 2.22**). The two data files will be compared and analysed post landing to check for potential read/write anomalies/corruption.

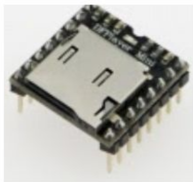

Figure 2.22: Redundancy Log

2.3.1 Recovery System

Using the measurements of the accelerometer and pressure sensor, the code interprets these two parameters as conditions to signal Apogee Detection. In case of an error, the system will automatically register a reattempted deployment after 25 seconds from launch to ensure a safe landing. **Figure 2.23** shows the practical test of the electronics.

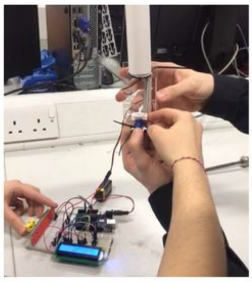

Figure 2.23: Ejection test

2.4 Recovery system

Choosing an appropriate recovery system:

Model rockets are usually equipped with both a drogue and a main parachute, which regulate the descent speed during different flight stages. For the landing to be deemed safe, as per UKSEDS guidelines, the on-board recovery system must:

1. reduce the vertical descent rate of the rocket to less than $15[m/s]$, and
2. account for a lateral drift distance post-apogee of no more than 1km.

Taking into account the relatively low apogee target of $1.4[km]$, as well as the limited volume available inside the rocket, provisions were made to include a single appropriately-sized main parachute.

Preliminary parachute sizing:

The aerodynamic drag D exerted by an open parachute is known to be proportional to the square of its terminal velocity V, reference cross-sectional area S, and half the surrounding air density ρ, as follows: $D = C_d \frac{\rho S V^2}{2}$, where C_d is some proportionality constant or drag coefficient [12]. During the recovery phase, the drag equals to the weight of the rocket mg, where m stands for the rocket's dry mass (post-burnout), and g is Earth's gravitational constant. To retrieve an initial estimate of the minimum surface area required by the parachute to descend safely, the previous equation is solved for $S = \frac{2mg}{\rho C_d V^2} = 39.6 \cdot 10^{-3}[m^2]$, where $m = 0.409[kg]$ is the approximated dry mass of the rocket, $\rho \simeq 1.202[kg/m^3]$ is the air density around the touchdown region, (geopotential altitude dependant, as per the International Standard Atmosphere model), $C_d = 0.75$ is the assumed drag coefficient for typical model rocket parachutes [12], and $V = 15[m/s]$ is the maximum allowed descent rate.

Consequently, the overall dimensions of the final parachute should exceed the theoretical minimum diameter $d_{min} = \sqrt{\frac{8mg}{\pi\rho C_d V^2}} = 0.22[m]$, by a reasonable amount.

Parachute choice:
The next largest standard parachute size that satisfied the minimum diameter condition, was found to be a commercial 12"/30cm hexagonal parachute [14]. By updating the landing velocity V to account for the new diameter ($d_{hex} = 0.3[m]$) and shape ($S_{hex} = 0.866{d_{hex}}^2$ [11]), the rocket is projected to land at $10.7[m/s]$, yielded by $V = \sqrt{\frac{2mg}{0.866{d_{hex}}^2\rho C_d}}$. The slight difference compared to the $11.2[m/s]$ simulated previously, stems from OpenRocket's limitation to define non-round parachutes. A more thorough evaluation of the physical parachute descent speed is planned prior to launch, by timing repeated test drops. This will help refine the OpenRocket model using empirical data.

The preferred parachute material was ripstop nylon, as it's generally lighter and more tear-resistant than plastic alternatives. The bright orange colour of the chosen canopy material (**Figure 2.24)** that will aid tracking efforts upon landing, as advised by UKSEDS**.**

Figure 2.24: The parachute to be used

Shock chords:
The shock chords are thin, flexible and semi-elastic ropes that connect the parachute's shroud lines to the nose cone and ejection system (detailed below). They keep the rocket's sections linked together during the descent portion of the flight. They are also meant to allow the parachute to unfold at a safe distance from the airframe, to avoid tangling, as well as dampen the deployment shock loads. The cord binding the parachute to the airframe's ejection system is 1m long, over three times the length of the combined body tubes, while the nose cone chord is significantly shorter (100mm), to prevent it from puncturing the thin airframe. An extra 10% is reserved for knotting the attachment points.
Even though OpenRocket simulations indicate that the main parachute is likely to deploy at relatively high speed (~30 $[m/s]$), due to the airframe's low inertia, zippering [15] is unlikely to occur.

Parachute Ejection System

The parachute is ejected out of the rocket using a compound ejection system, detailed in **Figure 2.25**

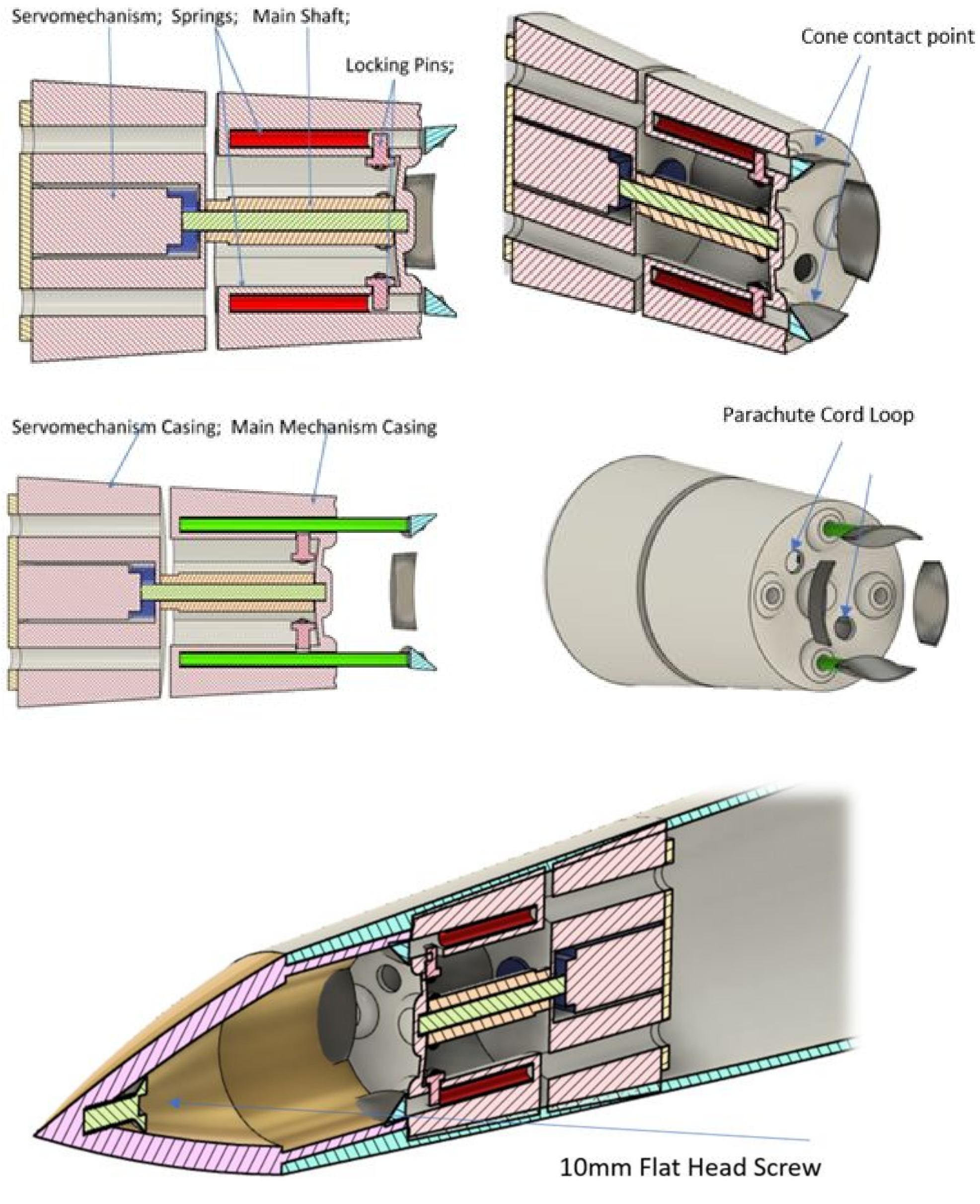

Figure 2.25: Fusion 360 model of the ejection system

This system consists of helical compression springs that are locked in place with a pin each, and are connected to the main central shaft. Once activated, a servomechanism rotates the main shaft via a system of gears, releasing each pin and therefore each spring. This releases the cone coupling, separating the nose cone and allowing the parachute to deploy. The cone is kept tethered to the main body to ensure they stay together for recovery. There are two holes labelled as the parachute cord loop to allow for the parachute to attach to the rocket. This cord will also attach to the nose cone through use of a flat head screw which will be screwed directly into the nose cone in order to wedge the cord in place. The parachute will need to be tightly and carefully packed, to avoid tangling at deployment.

2.5 Payload

There are two different payloads onboard SunrIde Jr. The first payload is a miniature camera, which will record the entire flight in FHD 1080p resolution. The second payload is an Arduino Nano 33 BLE Sense, and the main reason for choosing it is to optimise the CFD simulations that will be made for future rockets.

DOPPLER PAYLOAD

The microphone onboard the Arduino Nano 33 BLE will measure the speed of the rocket using the Doppler Effect, which states that the perceived frequency of a sound produced by a moving object varies depending on its velocity relative to the observer.

Let T be the transmitter that produces the sound of frequency $f[Hz]$, and R the receiver that perceives it with a frequency $f'[Hz]$. Let the velocity of the transmitter be v_T and the velocity of the receiver be v_R. v is the speed of sound.

All these are related by the following equation: $f' = f \cdot \frac{v+v_R}{v+v_T}$

The microphone inside the rocket will measure the frequency of the sound produced by the engine. Another microphone will be placed close to the rocket's take-off spot and will record the sound created by the engine as the rocket rises. With *MATLAB* both the frequency of the sound inside the rocket (f), and the one of the sound recorded on the ground (f') can be extracted. *f is expected* to remain more or less constant, Since the microphone on the ground will not be moving: $v_R = 0$. As f' should vary, we should be able to obtain a graph that would give us the speed of the rocket $v_T[m/s]$ in terms of f' and that will have the following equation: $v_T = \frac{fv}{f'}$. **Figure 2.26** shows an earlier similar experiment done by our team when launching rocket Helen [16].

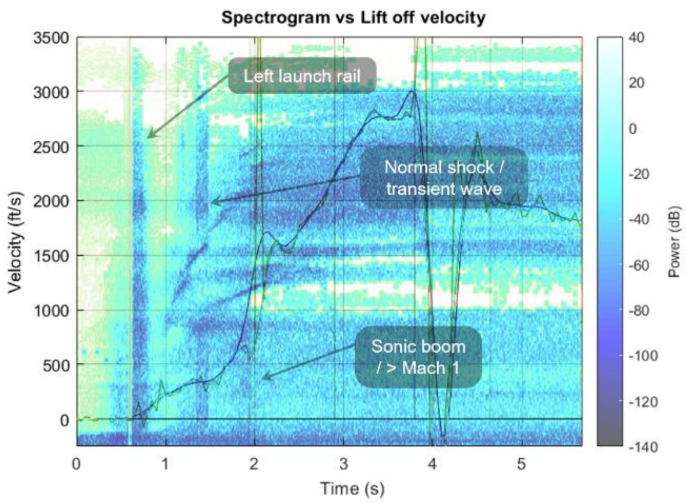

Figure 2.26: Expected results example; example from a single source of sound from earlier launches

3. CFD Aerodynamic Analysis

A 3D, third-body CFD simulation was performed on the airframe using Ansys Fluent to analyse the aerodynamic performance through a range of Mach numbers. A poly-hexcore mesh was generated using Fluent meshing, and progressively refined to establish mesh independency.
A pressure-based solver was used to perform the analysis. The k-ω SST turbulence model was used due to its suitability for external aerodynamic applications. A $y+ \approx 1$ was achieved for all simulations, fulfilling the required near-wall resolution required for an accurate solution with this turbulence model. The analysis was performed from Mach 0.01 to Mach 0.7 (**Figure 3.1**).

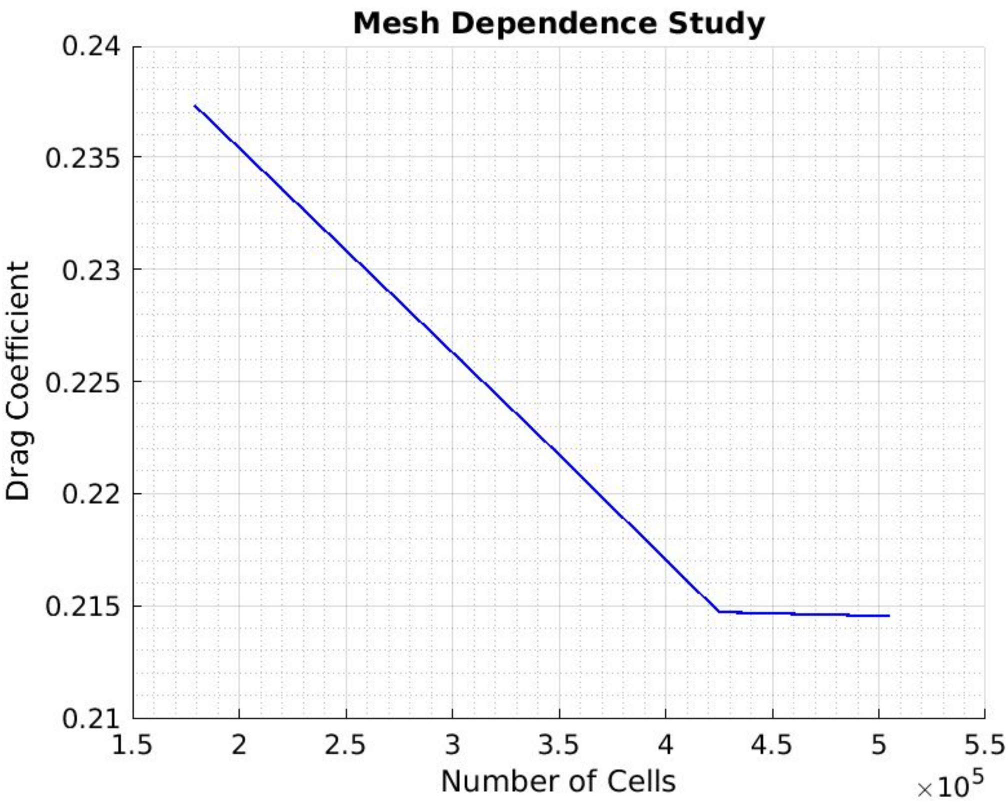

Figure 3.1: Mesh dependence plot

Figure 3.2 and 3.3 are the contours of velocity and total pressure shown on a plane through each fin:

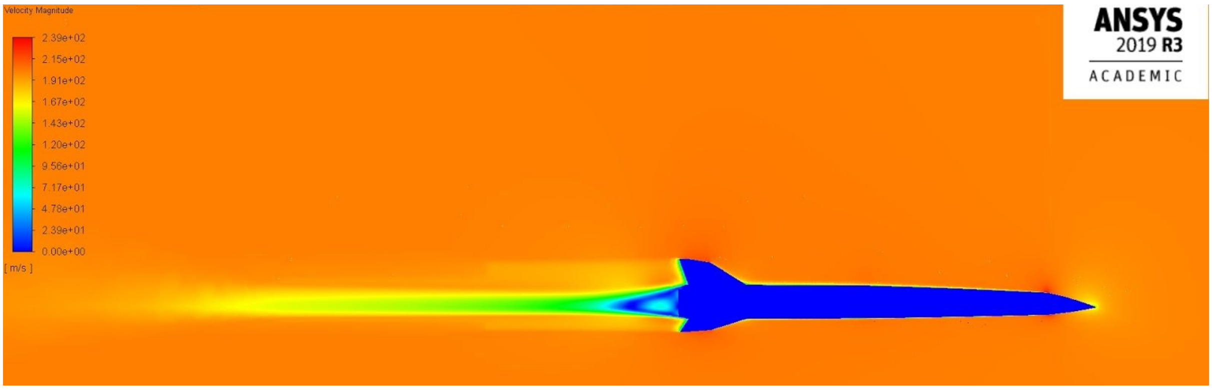

Figure 3.2: Contours of velocity

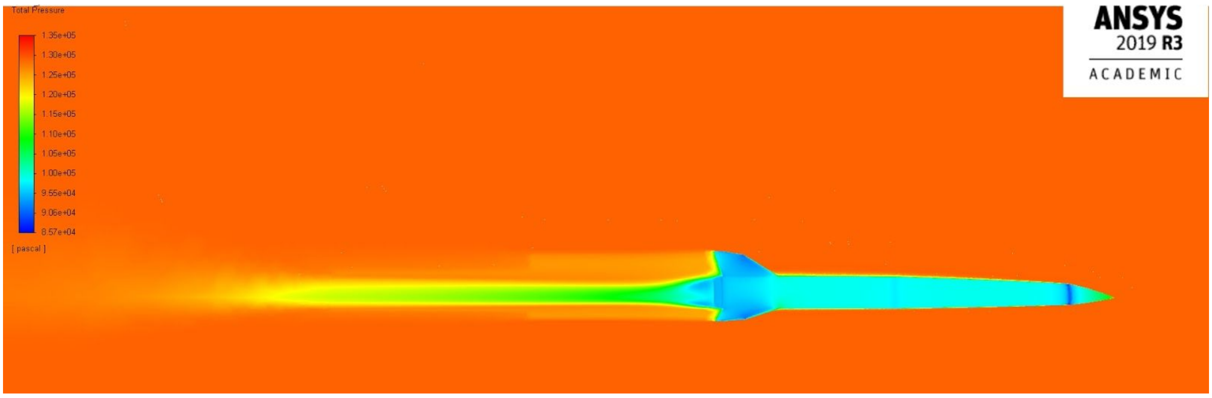

Figure 3.3: Contours of pressure

Figure 3.4 and **Table 3.1** show the variation of drag coefficient predicted by CFD in comparison to the OpenRocket predictions. As can be seen, OpenRocket has overestimated the C_D, which in turn suggests the apogee predicted by OpenRocket may be underestimated.

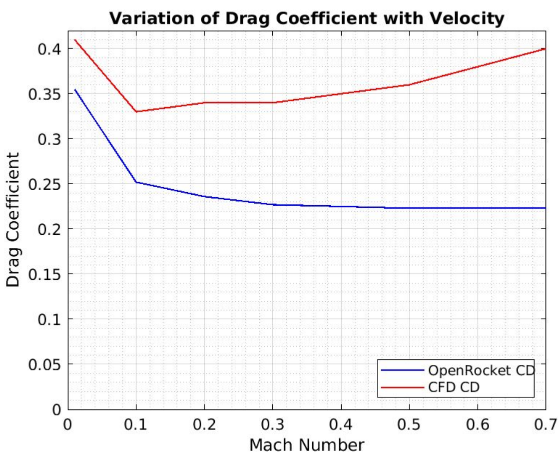

Figure 3.4: Variation of drag coefficient predicted by CFD in comparison to the OpenRocket predictions.

Table 3.1: variation of drag coefficient in CFD and OR

Mach No.	OpenRocket CD	CFD CD	CFD Drag (N)
0.01	0.41	0.355	0.00107
0.1	0.33	0.252	0.076
0.2	0.34	0.236	0.285
0.3	0.34	0.227	0.619
0.4	0.35	0.225	1.088
0.5	0.36	0.223	1.686
0.6	0.38	0.223	2.426
0.7	0.4	0.223	3.306

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5. Appendices

6.1 Appendix A: Nomenclature

ϱ	= Air density (kg/m^3)
μ	= Dynamic viscosity of fluid
γ	= Ratio of Specific Heats
M	= Mach Number
T	= Static Temperature (K)
R	= Specific Ideal Gas Constant
Cd	= drag coefficient of a round parachute
F	= Force needed to eject the compartment (N)
g	= The gravitational acceleration = 9.81 m/s^2
S	= Parachute area
v	= Velocity of fluid
H_P	= Altitude
T_0	= Temperature at sea level = 228.15K
L	= Troposphere lapse rate = 6.5×10^{-3} °C/m
P_S	= Static pressure
P_{S0}	= Pressure at sea level = 101.325 kPa
R_a	= Gas constant for unit mass of dry air = 287.0529 J/K kg

6.2 Appendix B: Hazard Analysis Appendix/Risk Assessment

Activity being assessed:	SunrIde Jr. Manufacturing and Launch		
Location:	Sheffield	Assessment date:	14/07/2020

Significant Hazards What could cause harm?	What harm might occur, and to whom? Remember to consider all affected groups	Existing control measures	Risk Rating (with current controls)		
			L	S	RR
Filing the rocket	Scrapping or cutting hand/finger	Making sure rocket is being held from a spot far from the one being filed	3	1	3
Falling Parts	Pieces falling on someone leading to head injury	Staying far enough from launching point, closing area to the public	2	3	6
Mid-air explosion	Enflamed pieces falling on someone, potential fire if one of those pieces falls on a flammable spot	Staying far enough from launching point, closing area to the public, making sure to have access to a fire extinguisher	2	4	8
Explosion at ignition	Pieces (potentially enflamed) flying off and hitting someone at high speed, blinding if eye is hit, could start a fire	Staying far enough from launching point, closing area to the public, making sure to have access to a fire extinguisher	2	5	10
Recovery system failure	The whole rocket falling on someone, causing serious head injury	Staying far enough from launching point, closing area to the public	1	4	4

Likelihood	Guide Description
5	Very likely/imminent – certain to happen
4	Probable – a strong possibility of it happening
3	Possible – it may have happened before
2	Unlikely - could happen but unusual
1	Rare – highly unlikely to occur

Severity	Guide Description
5	Catastrophic - fatality, catastrophic damage
4	Major – significant injury or property damage, hospitalisation
3	Moderate - injury requiring further treatment, lost time
2	Minor - first aid injury, no lost time
1	Very minor – insignificant injury

L = likelihood, S = severity, RR = risk rating

Likelihood (L) \ Severity (S)	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Risk Rating (RR)	Action
High Risk	Stop the task/activity until controls can be put into place to reduce the risk to an acceptable level
Medium Risk	Determine if further safety precautions are required to reduce risk to as low as is reasonably practicable
Low Risk	No further action, keep under review

[ref]: hs.shef.ac.uk. (n.d.). Health & Safety Training - Documents. [online] Available at: https://hs.shef.ac.uk/documents?utf8=%E2%9C%93&q%5Bsearch_by_keyword%5D=blank+risk+assessment&q%5Bcategories_id_eq%5D=&q%5Bdocument_category_id_eq%5D=&bookmarked_only= [Accessed 20 Jul. 2020].

6.3 Appendix C: System Behaviour

Altitude Calculation

In order to calculate altitude measurements, the ambient pressure will be sampled through the static pressure port drilled in the upper body tube, using the on-board LPS22HB barometer of the Arduino BLE. It also acts as a digital output barometer. The library for this is the ArduinoLPS22HB library.(#include <Arduino_LPS22HB.h>)

The altitude is then calculated using the formula below:

$$H_P = \frac{T_0}{L}\left(1 - \left(\frac{P_S}{P_{S0}}\right)^{\left(\frac{LR_g}{g0}\right)}\right)$$

Gyroscope and Accelerometer

Gyroscopic and Vibration data will provide a more detailed picture of the orientation and vibrations of the rocket during flight. This IMU sensor, uses the Arduino library LSM9DS3 (#include <Arduino_LSM9DS1.h>)

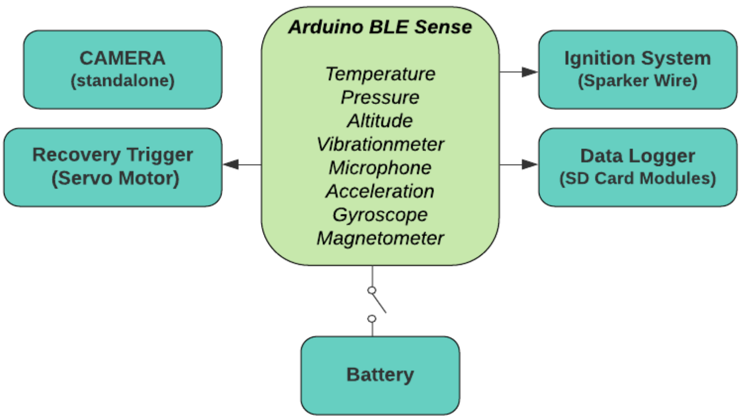
Microphone

The onboard digital microphone MP34DT08 will be part of the Doppler Experiment (refer to Payload Report) using the PDM library (#include <PDM.h>)

Other Measurements

During the flight, a series of further measurements will be obtained to help analyse the flight progress and improve the development of the next project. This will be Temperature, Humidity, and Gyroscope and Vibration data, which will be stored in the Sparkfun Data Logger OpenLog, to be analysed post landing.

The avionics system is summarised in the block diagram below:



6.4 Appendix D: MATLAB script for parachute sizing

```
%% Parachute calculator for SunrIde Jr., single-stage rocket
% The University of Sheffield, 20/07/2020
% UKSEDS Rocketry Competition 2020
% Requirements*:
% - 1 main stage
% - main @ apogee + 2.5s; descent @ <15m/s
% *based on UKSEDS 2020 guidelines; check notes
% Reference: [pag. 13] https://ukseds.org/wp-content/uploads/2014/09/UKSEDS-NRC-2015- ↙
technical-guidelines1.pdf
%% Reset workspace
close all; clearvars; clc
%% Input parameters
g = 9.807; % [m/s^2]; earth's gravitational constant
vd = 15; % [m/s]; maximum descent velocity allowed; main
md = .409; % [kg]; dry rocket mass; w/o fuel
cd = .75; % []; drag coefficient of typical model rocket parachute
%% Calculate air density
[~,~,~,rho] = atmosisa(200); % [kg/m^3]; air density at ground level (launch site ↙
altitude estimate)
%% Parachute diameter
Dp = sqrt(4/pi*2*md*g/cd/rho/vd^2); % [m] minimum theoretical diameter
%% New descent rate (for 30cm hexagon parachute*)
Dh = .3; % diameter of commercial hexagon parachute
Sh = 0.866*Dh^2; % area of octagon - https://www.apogeerockets. ↙
com/education/downloads/Newsletter449.pdf
cde = cd; % measured drag coefficient; physical parachute; assumed theoretical until ↙
proper testing
mde = md; % measured dry mass; physical rocket; assumed theoretical until proper ↙
testing
vde = sqrt(2*g*md/rho/Sh/cde); % revised descent speed
%% Display results
disp(['Teoretical main diameter: ',num2str(round(Dp,2)),' m'])
disp(['Experimental descent speed: ',num2str(round(vde,2)),'m/s'])
%% Notes
% - parachute behaviour requires iterative validation using OpenRocket
```