# MARS 2025 OBJECTIVE REPORT

Projective Rocket Design and Analysis

***Stellar Booster 401***

METROPOLITAN AEROSPACE ROCKET SOCIETY

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# Abstract

The primary objective of this project is to provide hands-on experience, modeling and manufacturing a single stage model rocket. In a group containing 6 members, the *Stellar Booster 401* team, will construct a functional rocket that will satisfy the list of restrictions showcased later on in the report. Group members will engage in all phases of the engineering design process, from brainstorming conceptual ideas to manufacturing and finalizing designs. This will enhance skills in problem solving, group collaboration and project management skills. A thorough analysis of each component of the rocket as well as its design choice will be implemented and analyzed through conduction of the report.

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# Abbreviations

Throughout the conduction of this report, there will be a series of abbreviations used to exemplify certain aspects of the rocket as well as its manufacture processes, guidelines and regulations. This list is shown below;

Table 1.1 - Abbreviation Table

| Abbreviation | Meaning |
|---|---|
| MARS | Metropolitan Aerospace Rocket Society |
| SB401 | Stellar Booster 401 |
| CAD | Computer Aided Design |
| TMU | Toronto Metropolitan University |
| CG | Center of Gravity |
| CP | Center of Pressure |
| PCB | Printed Circuit Board |
| GPS | Global Positioning System |

## Team Organization

Across the construction and analysis of the rocket, our team, *Stellar Booster 401* consists of 4 members all of which are students moving on to their third year of Aerospace Engineering at TMU. As a team, we've decided on naming our team *Stellar Booster 401* because of its unique authenticity. The term "Stellar" is in correlation to the stars, 'Booster' comes from the ignition of the engine and '401' is known as 'unauthorized' (401 error) showcasing how rebellious our rocket will be in competition. The members of our team and workload structure is shown below;

| Name | Role |
| --- | --- |
| Alec Tabachnik | - Bulk heads sliding mechanism<br>- Created OpenRocket iteration<br>- Fin analysis on openrocket<br>- Contributed to the group presentation / slideshow<br>- Manufacturing |
| Joshua Bisambar | - Briefly designed initial steps in Avionics Bay<br>- Created an iteration in OpenRocket<br>- Created Slideshow and prepared Slides on Aerodynamics and its theoretical results<br>- Manufacture/poxy; fins, tube engine ring<br>- Paint |
| Mohd Talha Talal | - Designed model in OpenRocket<br>- Conducted OpenRocket analysis on model rocket nose cone and fins<br>- Contributed to Group presentation<br>- Manufacturing |
| Adam Gale | - Fully designed Avionics Bay<br>- Fully modified an iteration<br>- Fully designed Onshape model |

The image below is a photo from after launching our rocket


**Figure 1: Team photo**

## Rocket Conceptualization (PDR data)

For this section of the report, there will be 3 designated iterations showing 3 different perspectives on the single stage rocket design. Each iteration will compose an open rocket display with highlighted key features, its open rocket simulation data as well as its ONshape design visualization. A short analysis explaining the design process of the iteration will be provided for each one.

### **<u>Iteration 1</u>**

For the first iteration a construction of a projected rocket plan will showcase a single stage rocket with an "Ogive" nose cone, body tube length of 22 inches, 4 free foam fins of length of 7.65 inches and transition tube of 7.85 inches. The fore diameter used for each component is 3.27 inches as well as the inner diameter of 3 inches. These brief design modifications are shown below in the following Open Rocket display:

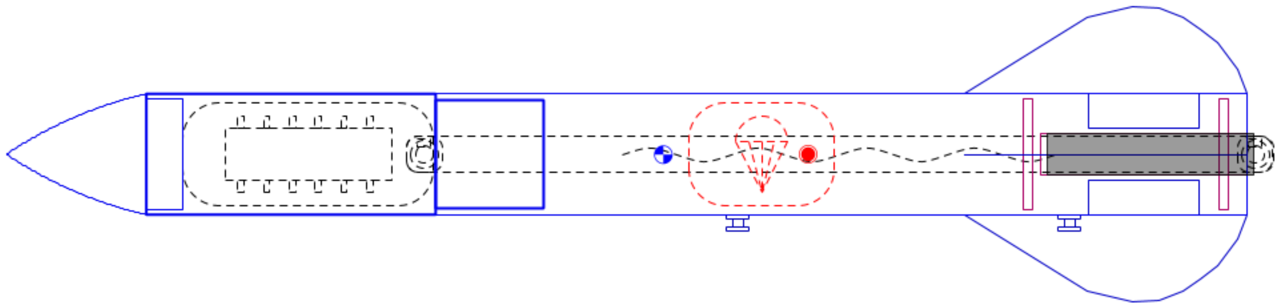

**Figure 2: Open Rocket Design for Iteration 1**

With this given Open Rocket design the following data is yielded as well as its Simulation data provided by the program;

**Table 1 - Specification Table for Iteration 1**

| | |
|---|---|
| Center of Gravity (CG) | 17.827 inches |
| Center of Pressure (CP) | 21.755 inches |
| Apogee | 656 ft |
| Max Velocity | 207 ft/s |
| Max Acceleration | 7.21G (70.73ft/s²) |
| Stability | 1.2 |

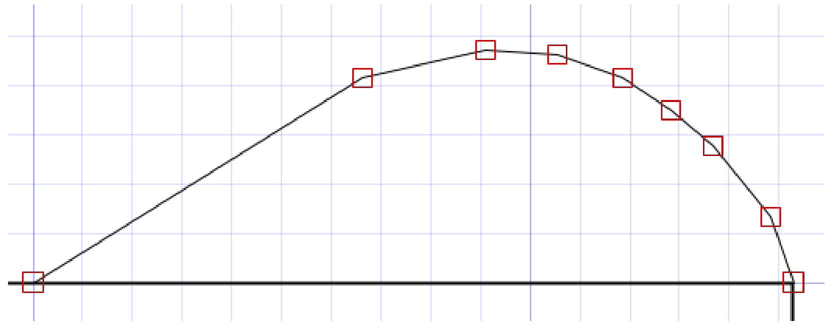

**Figure 3: Fin Iteration 1**

The fins are coordinated in a way to boost stability in its flight progression while still maintaining Apogee. As stated earlier, there will be 4 fins on the rocket and as shown in the picture there will be 9 vertices used to adjust the fins shape. The fin starts with a smoothing shape to pierce through the boundary layer of the air, then transforms to an 'ellipse' shape to have a laminar transition . For this iteration smooth curves were preferred to avoid turbulence. Furthermore, the length of the fins are 7.65 inches with a max height 2.351 inches vertically.

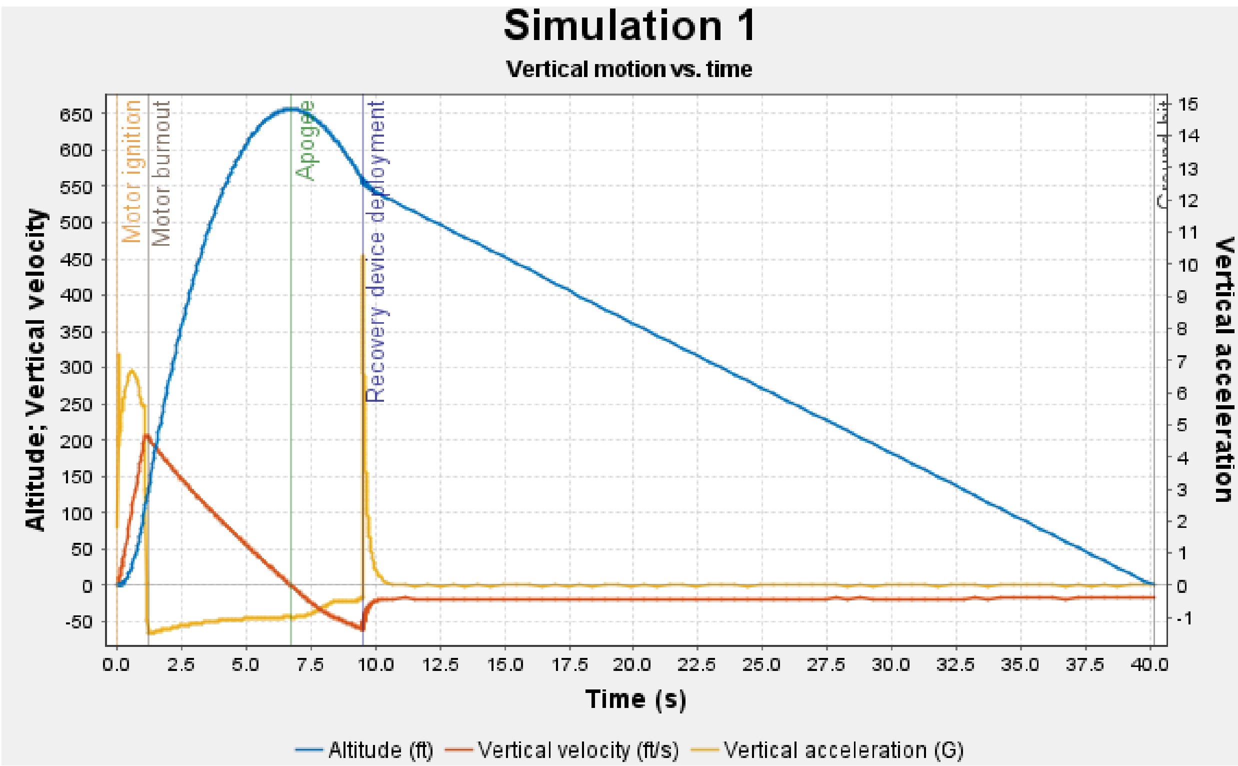


**Figure 4: Plot Simulation for Iteration 1**

The following graph shown in Figure # depicts the flight simulation with respect to the time. The rocket's motor burnout occurs from 0 to 1.25 seconds causing the rocket to incline in altitude drastically as well as reaching its max vertical velocity of 207 ft/s. During that time, it also reaches its maximum acceleration of approximately 70.73ft/s². Furthermore, After about 7 seconds, the rocket reaches it Apogee of 656 feet, transitioning the rocket direction facing towards the ground. After about 10 seconds its parachute is launched at a height of 650 feet.

Having the parachute be deployed immediately spikes in acceleration and goes back down to zero. At this point, the rocket has met its terminal velocity and experiences zero acceleration while having a steady rate of climb back to the ground. Overall this rocket depicts a safe and decent flight with accurate corresponding values and yielded data.

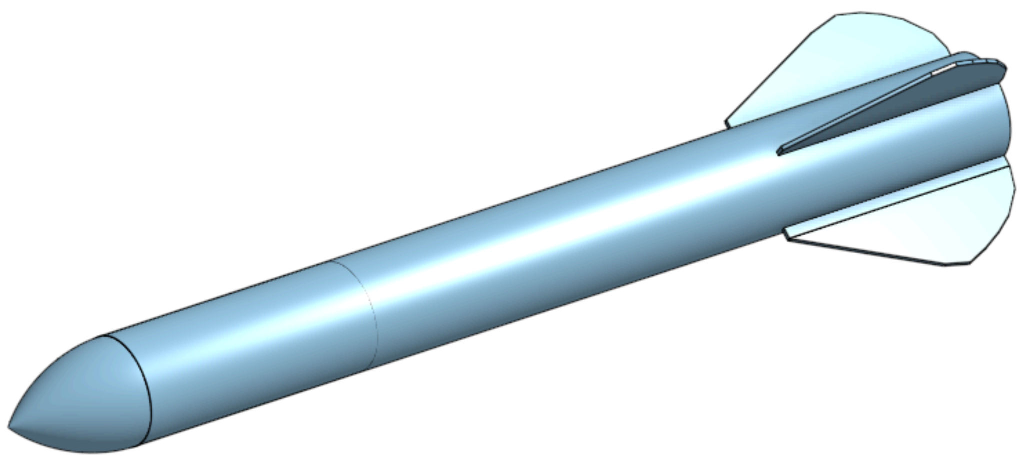

**Figure 5: Open Rocket CAD for Iteration 1**

The following image shown above showcases the ONshape CAD of the first rocket iteration. Each component has been designed with the respective nose cone, fins, transition tube, tube all corresponding to the measurements provided in the open rocket. This visualization provides an accurate depiction of what the actual 3D rocket would look like when manufacturing it for competition.

**Iteration 2**

The second iteration features a 26.5 inch body tube, ellipsoid nose cone with a length of 2.9 inches, and a 7.85 inch long transition tube. The fore diameter is 3.124 inches, matching the aft diameter. The nose shoulder protrudes 2 inches into the transition bay, while the transition shoulder protrudes 2.929 inches into the body tube. This rocket has a total of 3 free form fins which have a maximum length of 4.167 inches. The changes to the rocket were a result of various trial and error runs while changing certain aspects of the tutorial rocket given, arriving at the final version of this iteration, as seen in figure # below;

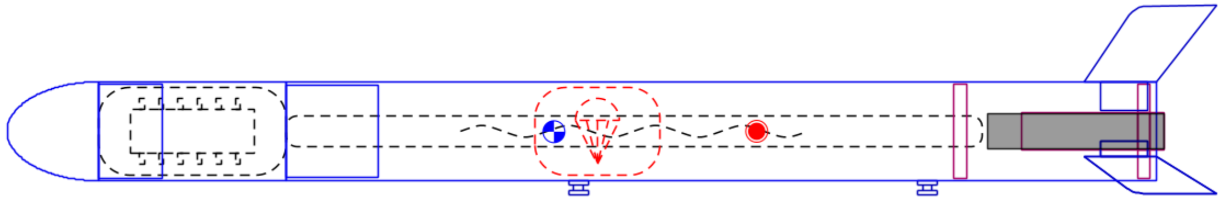

**Figure 6: Openrocket of iteration 2**

The information given by openrocket for this iteration is as follows;

**Table 2: Specification Table for Iteration 2**

| | |
|---|---|
| Center of Gravity (CG) | 17.276 inches |
| Center of Pressure (CP) | 23.683 inches |
| Apogee | 609 ft |
| Max Velocity | 252 ft/s |
| Max Acceleration | 8.7 G (85.347 ft/s²) |
| Stability | 2.05 |

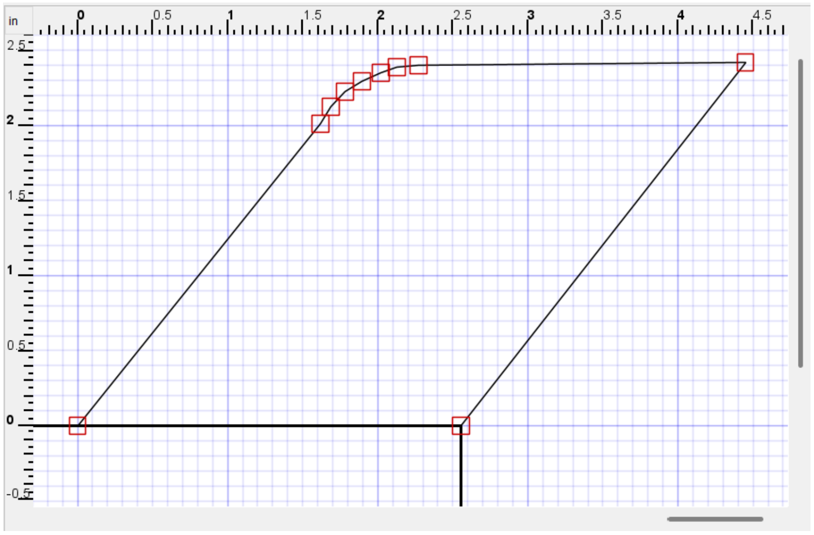


**Figure 7: Fin of Iteration 2**

The rounded corner on the leading edge is inspired from a bird's wings, which are proven to be effectively aerodynamic by evolution. The total number of fins settled on was 3 to avoid overstability. Once settling on the number of fins and the overall shape, a series of trial and error adjustments were made to optimize apogee and stability, leading to the final version of the second iteration. The adjustments included changings lengths, curve angle, etc.

The size of the fins was changed continuously to offset the changes to the centre of gravity (to keep a favourable stability). By increasing the overall area of the fin the centre of pressure would move closer to the end of the rocket, and vice versa.

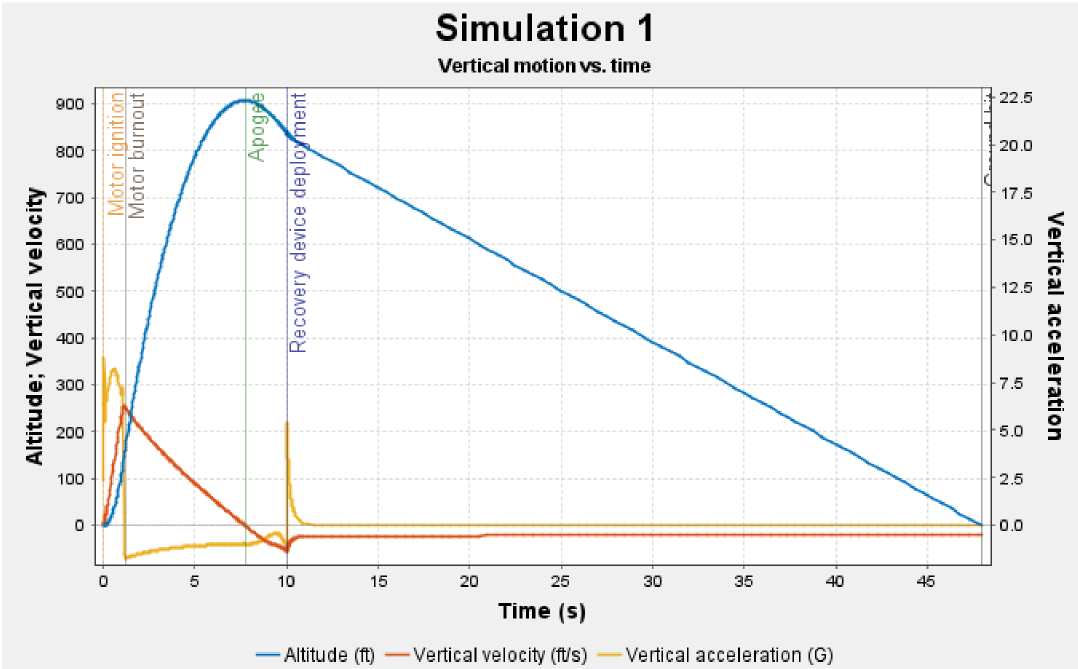


***Figure 8:*** **Plot for simulation of Iteration 2**

In figure # it is noted that the motor burnout occurs around 1.25 seconds after launch resulting in a maximum velocity of 253 ft/s. The launch in this simulation gave the rocket enough power to reach 900 ft, which is well over the openrocket estimated apogee of 609 ft. As the parachute is launched an instant upward acceleration of ~215 ft/$s^2$ or 6.68 G, slowing down the rocket's fall. Due to the uncertainty between the estimated and simulated apogees, as well as the vertical accelerations, this iteration was taken out of contention to be one of the chosen ones.

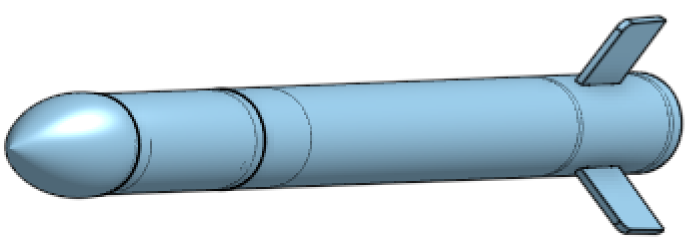

**Figure 9: Cad of iteration 2**

A CAD model of this iteration was made taking into account all of the respective lengths of each component. This model helps illustrate the elegant design of the rocket, showing what it would look like post manufacturing (if painted light blue).

**Final Design**

Through this section of the report, a more thorough analysis of each component and design selection would be implemented on the final design. Based on all 3 design iterations and group decision was made to develop a lead design on a single chosen design. To develop this design, selected ideas and concepts were adopted from previous iterations and were implemented in the final design.

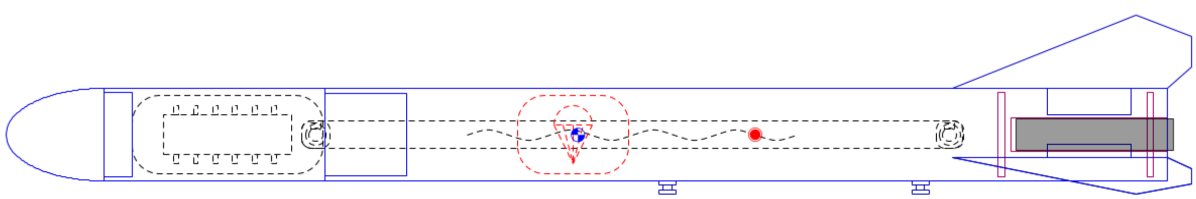

**Figure 10: Open Rocket Design for Final Design**

The following OpenRocket showcases the final design which would be used for competition. As you see based on this image, the nose cone shape from iteration 2 was used as it provided more stability, as well as the corresponding tube length. For this final design concept, the main change was conducted on the fins. The fins were decided to be free form however there was a sense of change only involving 5 vertices for shape deformation. Furthermore with this design, the nose cone was developed to have a length of 3.5 inches with a base diameter of 3.27 inches and a wall thickness of 0.124 inches. The transition tube has a length of 7.85 inches and a fore diameter of 3.27 inches. Lastly, the body tube has a length of 30 inches and an outer diameter of 3.27 inches. Compared to the other previous design concepts, this final design has a longer overall length as well as a more calibrated stability factor. The following rocket specifications and data are shown below in the following table;

**Table 3 - Specification Table for Final Design**

| | |
|---|---|
| Center of Gravity (CG) | 20.362 inches |
| Center of Pressure (CP) | 26.67 inches |
| Apogee | 574 ft |
| Max Velocity | 187 ft/s |
| Max Acceleration | 6.51G (70.73ft/s²) |
| Stability | 1.93 |

Based on the following specification table, it showed that the stability has increased however Apogee has decreased. The increased stability will make the rocket less reluctant to tip over while in flight projection which is crucial for competition standards. One of the major changes is the increased length in the body tube. This change had drastically modified the CG and CP values. However the important note is that the CG is always higher than CP and is roughly the same relative distance apart from the previous iteration. This is important to provide stability and to avoid potential stall rates in flight.

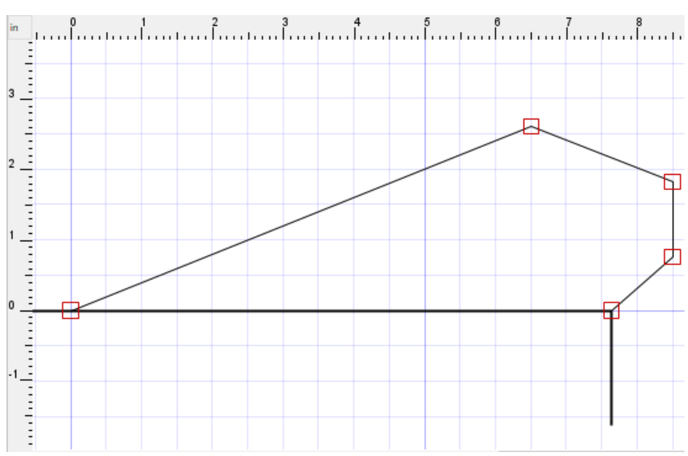

**Figure 11:** Open Rocket Fin Design for Final Design

The image depicted in the above image showcases the fin design. For this rocket, there were only 3 fins utilized for design optimization. Having more than 3 fins would result in an overstable rocket which would cause the rocket to lean and will yield less altitude and speed. The fins shown here have a max height of around 2.6 inches with a length of 7.645 inches. These fins have been optimized with proper accuracy to acquire as much lift and less turbulent drag as possible. The image to the right showcases the fin dimensions.

| X / in | Y / in |
|---|---|
| 0 | 0 |
| 6.5 | 2.6 |
| 8.5 | 1.82 |
| 8.5 | 0.75 |
| 7.645 | 0 |

**Figure #:** Fin Dimensioning

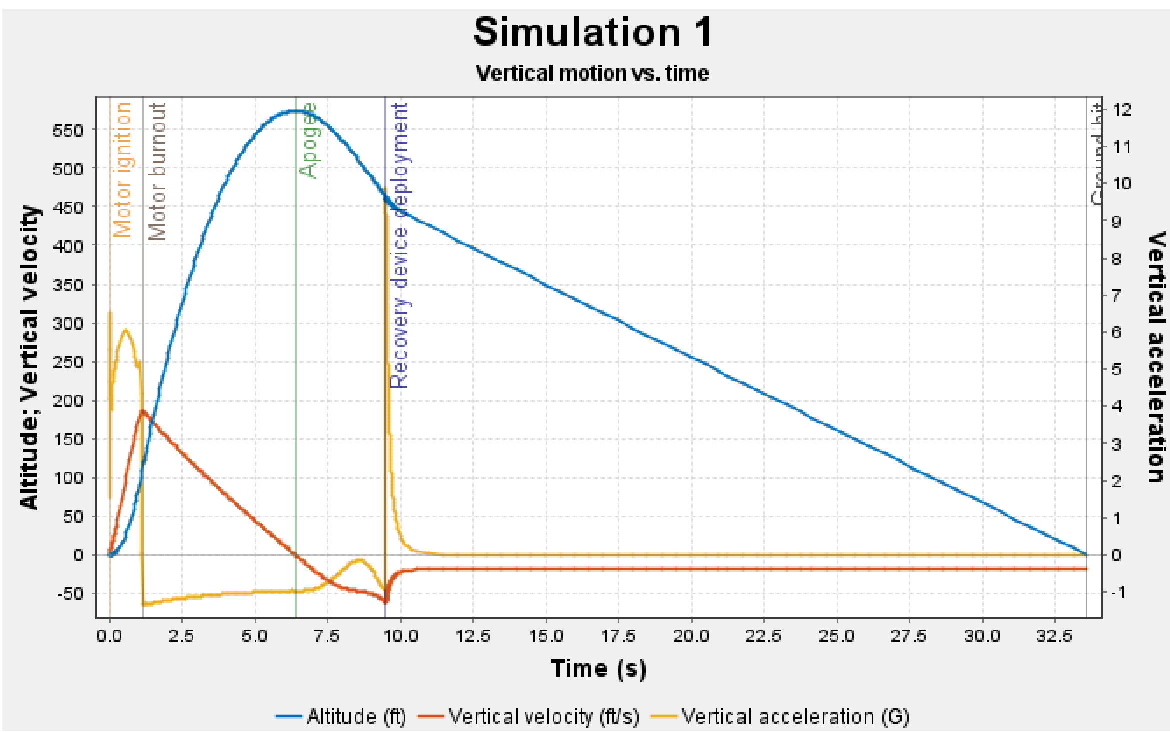


***Figure 12:*** **Plot for simulation of Final Design**

With the following measurements and tabulated data, the corresponding flight simulations can be provided to give accurate flight predictions of our final rocket design. As shown in figure #, our rocket's motor burnout would last for approximately 0 to 1.25 seconds. During this time the entire motor will be used and max velocity would be given. This occurs around 1.25 seconds with a predicted max velocity of 187 ft/s. After reaching max velocity, the rocket will continue to travel in vertical height for a total of approximately 6.5 seconds to where Apogee is reached. This is where the maximum height of the rocket is obtained and the rocket then changes direction facing towards the ground. Furthermore, at around 10 seconds into flight, the parachute is deployed causing a maximum total deceleration on the rocket, causing a decrease in velocity. The velocity continues to reach terminal velocity with the deployed parachute resulting in a steady rate of descent, having the rocket reach the ground with a low velocity. Overall the results predicted in the openrocket display intended results that our team hopes to achieve on launch day.

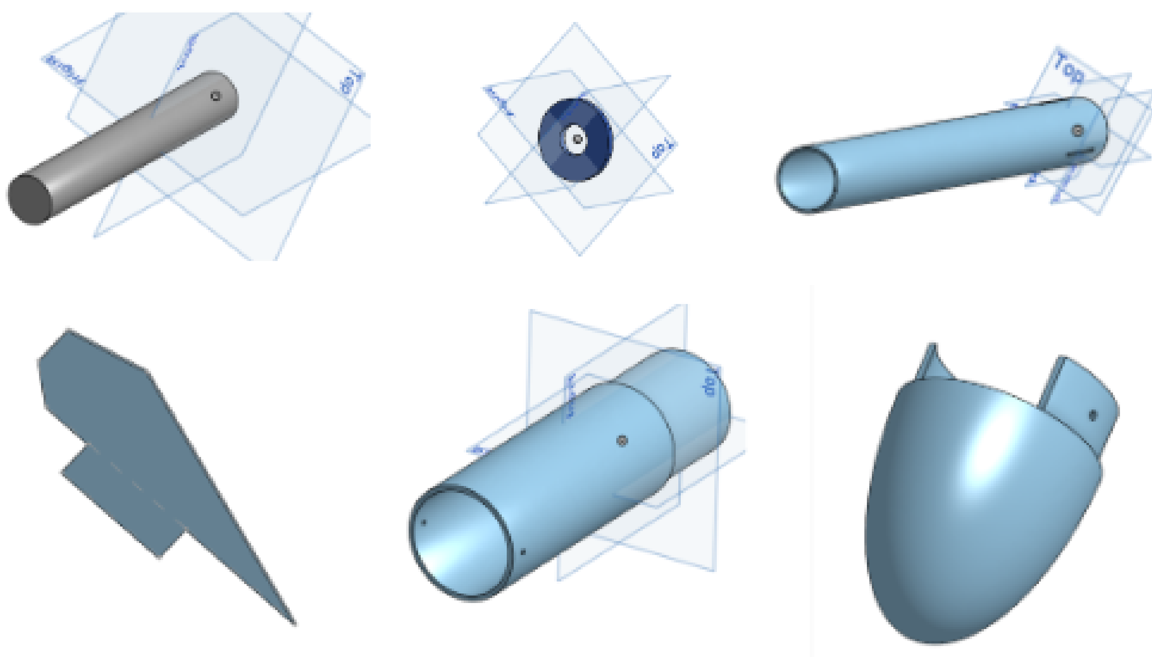

**Figure 13: ONshape CAD for Final Design (each component)**

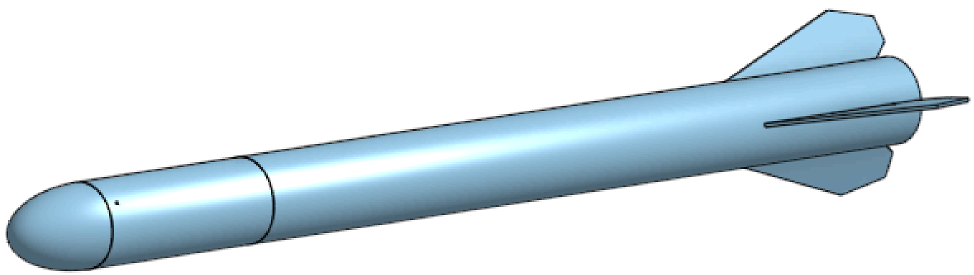

**Figure 14: ONshape CAD for Final Design (Assembly)**

The following image showcases the final design iteration used to create our final model for the competition. Each image shown above shows the accurate dimension and shapes used to construct the rocket with their corresponding measurements in relation to OpenRocket. By calibrating each CAD component from Open Rocket to Onshape will ensure the most accurate flight predictions. Furthermore, there were not too many changes made to the design, roughly the same idea was kept consistent throughout; only main changes that were made were the fins and nose cone. Those changes have improved the rocket's design and predicted results.

## Avionics Bay

In order to properly manufacture a single staged rocket, an electrical component needed to be incorporated in the rocket's system to track its location and record accurate data. This will be done through use of the avionic bay which is implemented within the transition tube located on the diagram shown to the right;

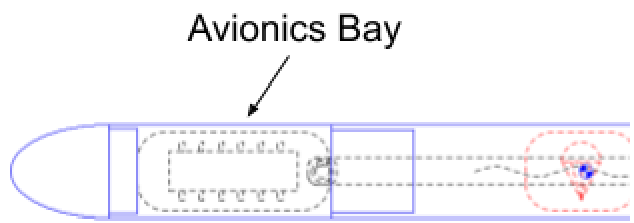


**Figure 15: Avionics Bay Location**

Although an Onshape depiction of the Avionic Bay shows a brief iteration to the design, it does not actually specify any direct insight towards the module that would be used within our rocket. For this term, an *AmongUs* themed PCB would be used to record the GPS location of the rocket as well as flight data that will further be explained in the *Telemetry Data Analysis* section of the report. Furthermore for our group, we've decided to use a custom avionics bay design iteration which we've developed and 3D printiend to suit our rocket. Designing the avionics bay from scratch did impose challenges with tolerance and the CAD of certain components and fillets. Components that were CADed in this design were the top plate, bottom plate, the board and the battery cover. The *AmongUs* PCB and the GPS locator were imported and assembled accordingly. The image shown the the left showcases the final assembly of the avionics bay;

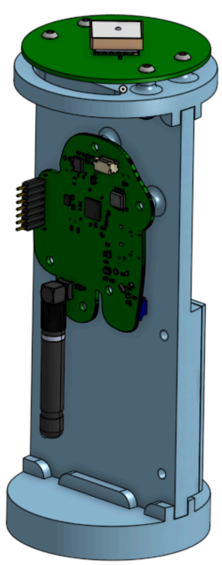

**Figure 16: ONshape Avionics Bay**

The most enduring challenge when creating the avionic's bay was making sure the Open rocket design specifications for the transition tube aligned with the Onshape CAD of the avionics bay. The avionic bay functions mainly through use of the PCB and GPS locator as stated before. Since there isn't a direct power source in flight, a Lithium-Ion battery would be used to generate power to the PCB and GPS locator while the rocket is in flight. The PCB works through a transistor (The black cylinder that's pointed down) that transmits data to a computer of the flight data. For the mission objective for this launch, the altitude, acceleration and velocity were primarily recorded. The PCB is coded in a way that those values can be derived and recorded the data for the launch. Below are some more pictures of the Avionics Bay as well as its measurements.

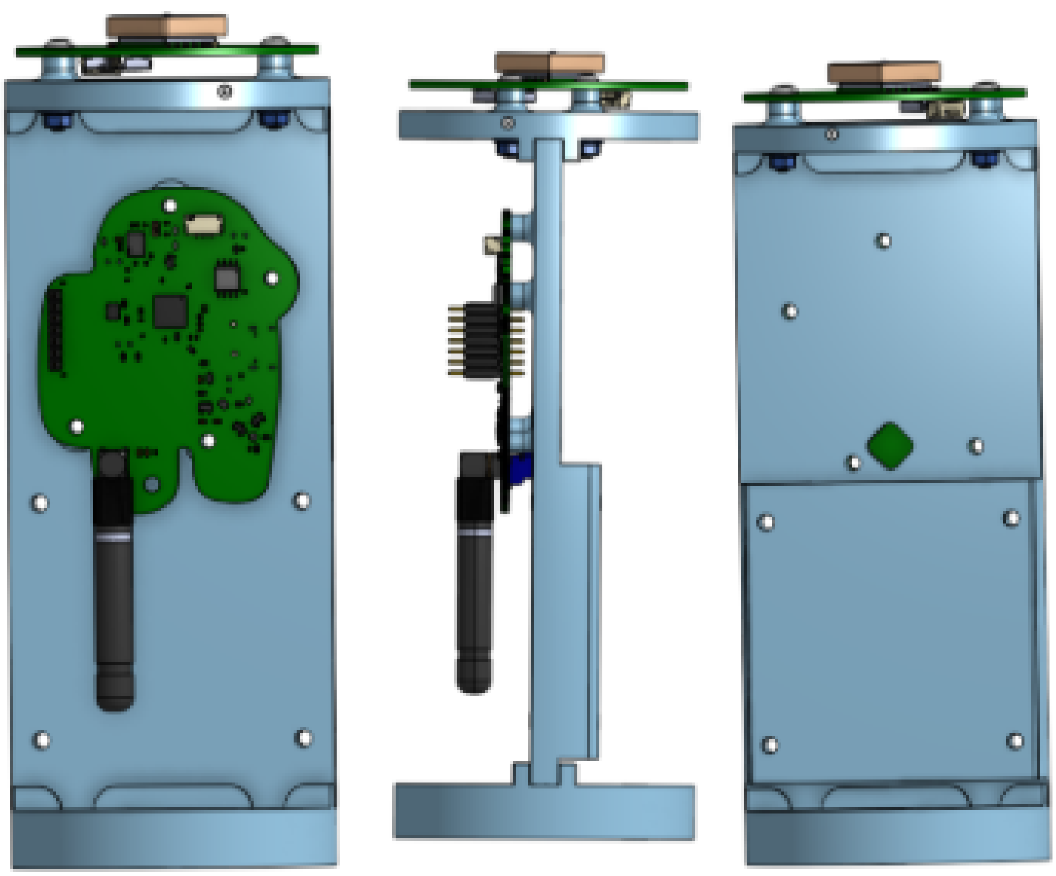

**Figure 17:** Avionics Bay Views

# Manufacturing

A final version of the avionics bay (including bulkheads) and nose cone were 3D printed, while fins and centering rings were laser cut prior to the chosen manufacturing day. Aside from these parts, the rocket is composed of a 37.5 inch kraft phenolic body tube, nylon parachute, tubular shock cord, 2 eyebolts, epoxy, 2 rail buttons and a 93G80-14 motor.

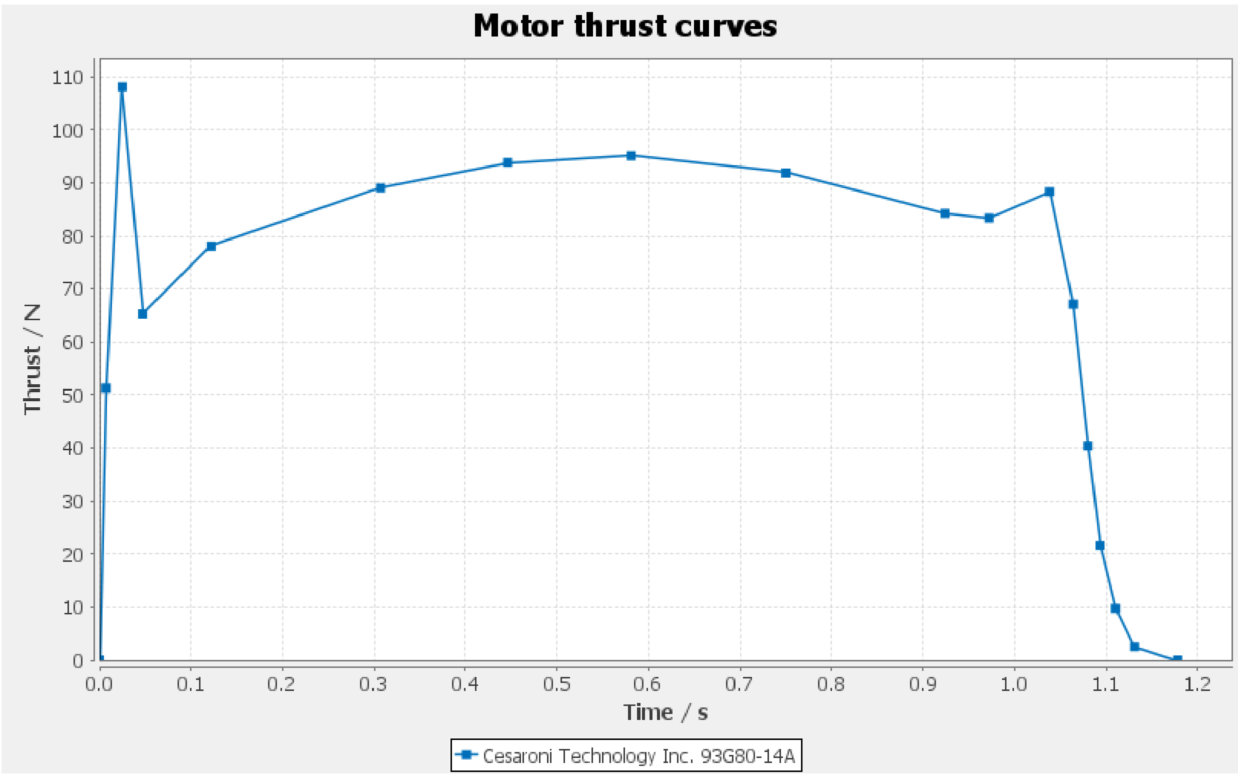


***Figure 18:*** **93G90-14 Motor Thrust Curves**

An issue presented during manufacturing was inaccurate measurement tools. When given the body tube, the lead measured it to be 28.5 inches, which was slightly less than the intended length for our rocket, which was 30 inches. Due to this miscommunication, the tube was not trimmed on the manufacturing day, and this error went unnoticed until launch day. Despite the rocket being 7.5 inches longer than intended, the stability of the rocket did not take too much of a hit, resulting in a successful launch.

Another issue that needed to be addressed on the manufacturing day was 'faulty' 3d printing. Our group's avionics bay featured a slider into the bulkheads, which were barely attached when given to us by our lead. This issue was fixed by using epoxy to secure the slots in place, however the epoxy is the only thing holding it together upon impact, and making sure it fully secures the slots in place was crucial. As noted after landing, the slots remained intact, proving the solution to be effective.

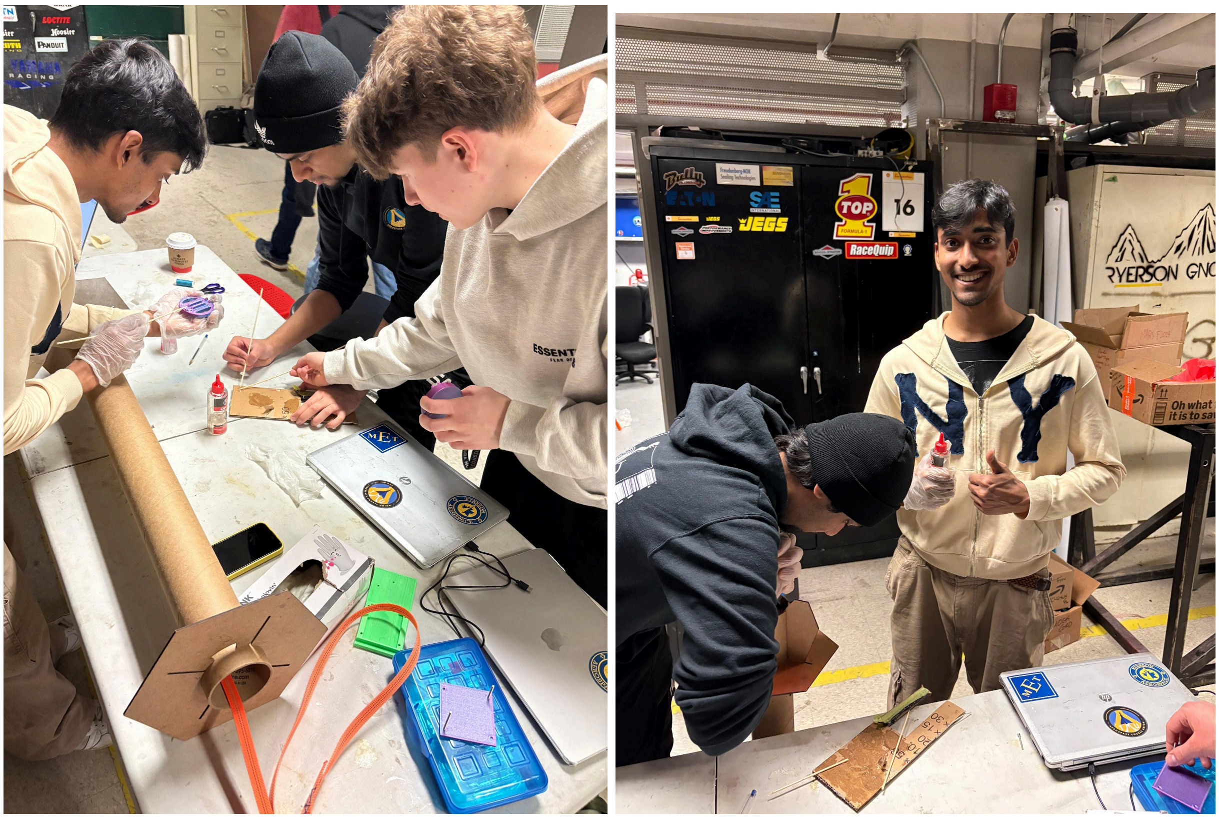


***Figure 19:*** **Manufacturing Day Progress**

**<u>Cosmetics</u>**

The cosmetics featured on the rocket include a cool multicolor paint job of blue as well as a MET sticker and the initials of your team SB401. A following picture of cosmetic design iterations is shown below;

**Figure 20: Collage of cosmetics during manufacturing**

## Competition Day

An issue faced on competition day occurred when the rocket fell over. Despite the rocket already being tilted, and the fall being on grass, both of the 3d printed nose cone ‘brackets’ broke off. This left nothing keeping the nose cone on the rocket, requiring an immediate solution. The ‘brackets’ had to be held at a perfect angle while the epoxy dried, otherwise the nose cone would not fit in the transition bay, or the screws would improperly align. After periodic adjustments, the nose cone was successfully attached to the transition bay.

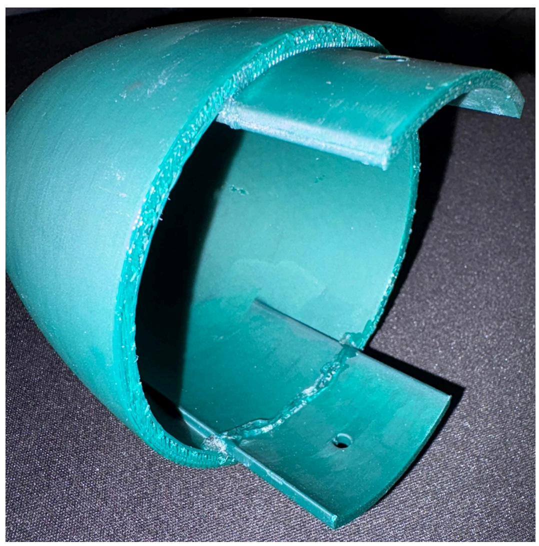

***Figure 21:*** **Fixed Nose Cone Bracket**

Another issue faced was that the transition bay shoulder was a bit too small for the body tube, requiring layers of tape to create more of a friction fit. Each time tape was added, it would successfully hold the transition bay in place 1 time, and after that become loose again. This battle went back and forth for over 10 minutes, finally ending at the following tape structure:

*Figure 22:* **Transition Bay Friction Fit (Tape)**

As mentioned in the manufacturing part of the report, the tube was unexpectedly 37.5 inches, as opposed to the 28.5 inch measurement given by the leads on manufacturing day. This resulted in the stability decreasing dramatically, from around 1.9 to 1.62. This was still in the acceptable range for launch. The rail button locations were very close to where they would have needed to be accounting for a 37.5 inch tube, meaning that no modifications were needed to overcome this problem.

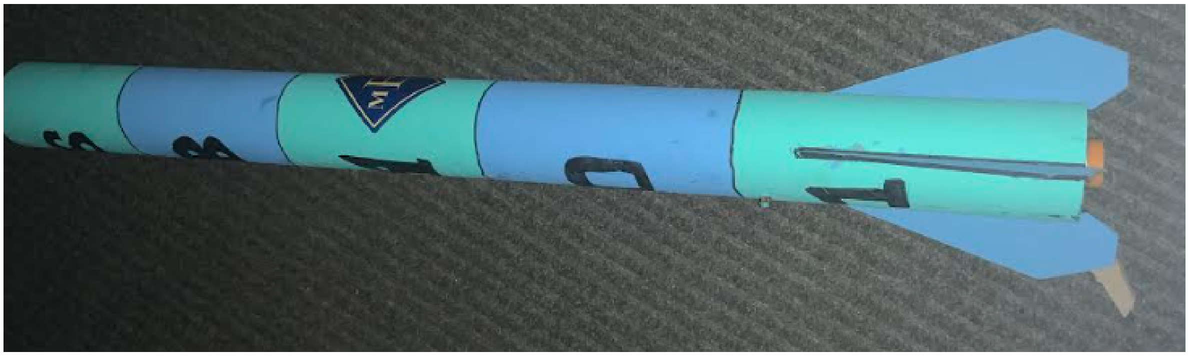

**Figure 23: Body Tube After Launch**

# Telemetry Data Analysis

This section of the report will highlight key aspects of the flight data as well as if the launch data correspond accordingly to the open rocket flight simulation predictions. An analysis of the altitude, velocity and acceleration will be done, as well as a comparison with the OpenRocket simulation.. Additionally, the drag characteristics and maximum dynamic pressure will be examined. The altitude over time can simply be plotted using the data provided from launch day. The maximum altitude was found to be 354 metres.

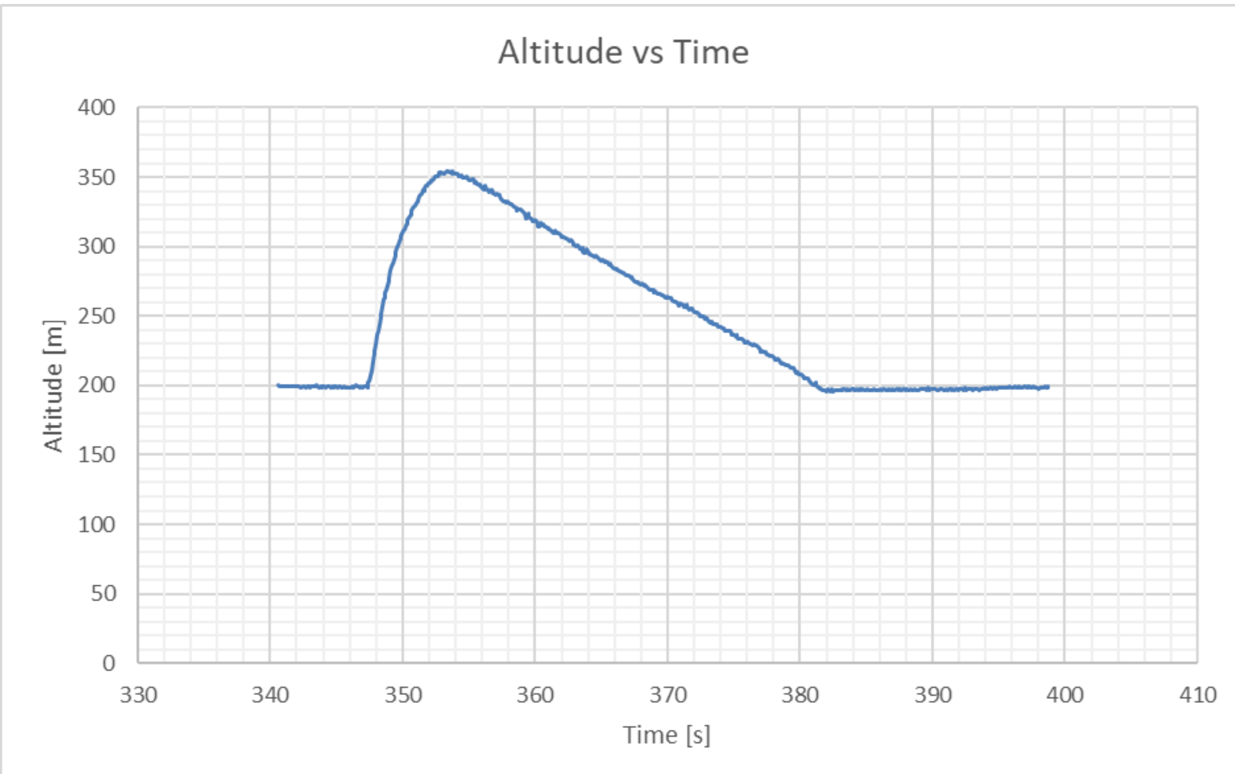


***Figure 24:*** **Altitude vs Time Plot**

To find the velocity of the rocket, the derivative of the altitude vs time plot is taken. Simply using the dx/dt of a derivative, the velocity for any given point is found. An example of the excel calculation is: $V_2 = \frac{X_3 - X_1}{t_3 - t_1}$. This formula finds the velocity at the second given timestamp. Repeating this equation for every timestamp provides the following velocity over time graph. From these calculations the maximum velocity was found to be 77.1 metres per second.

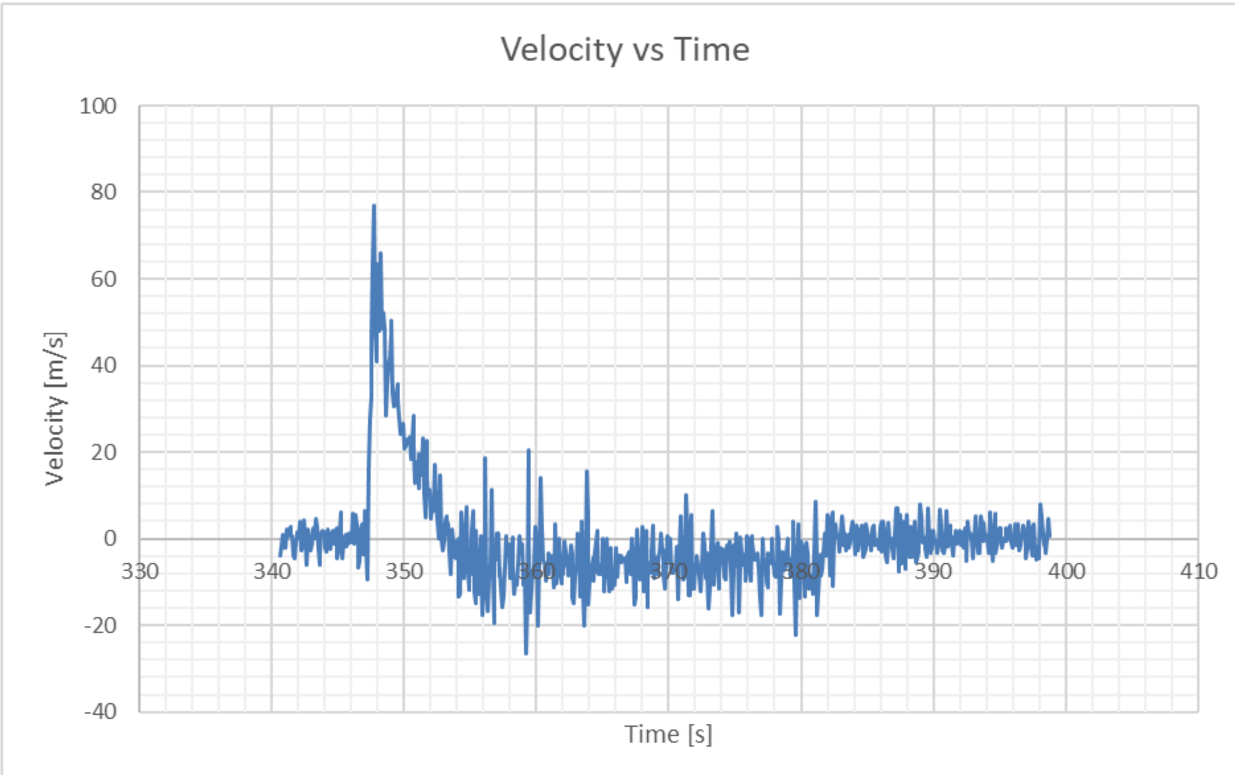


***Figure 25:*** **Velocity vs Time Plot**

Similar to the altitude plot, the acceleration over time graph can be made using the data provided. Plotting the accel_y vs timestamp results in the following plot for acceleration vs time. From the data, the maximum acceleration was found to be 39.21 metres per second per second. As mentioned in the documentation provided, the data from the GPS may not be entirely accurate due to sampling rate. The acceleration data may be affected by this, assuming this data is collected by the GPS. This can be seen by the seemingly instantaneous jumps in acceleration. Alternatively, this could just be the result of the motor ignition and can be ignored.

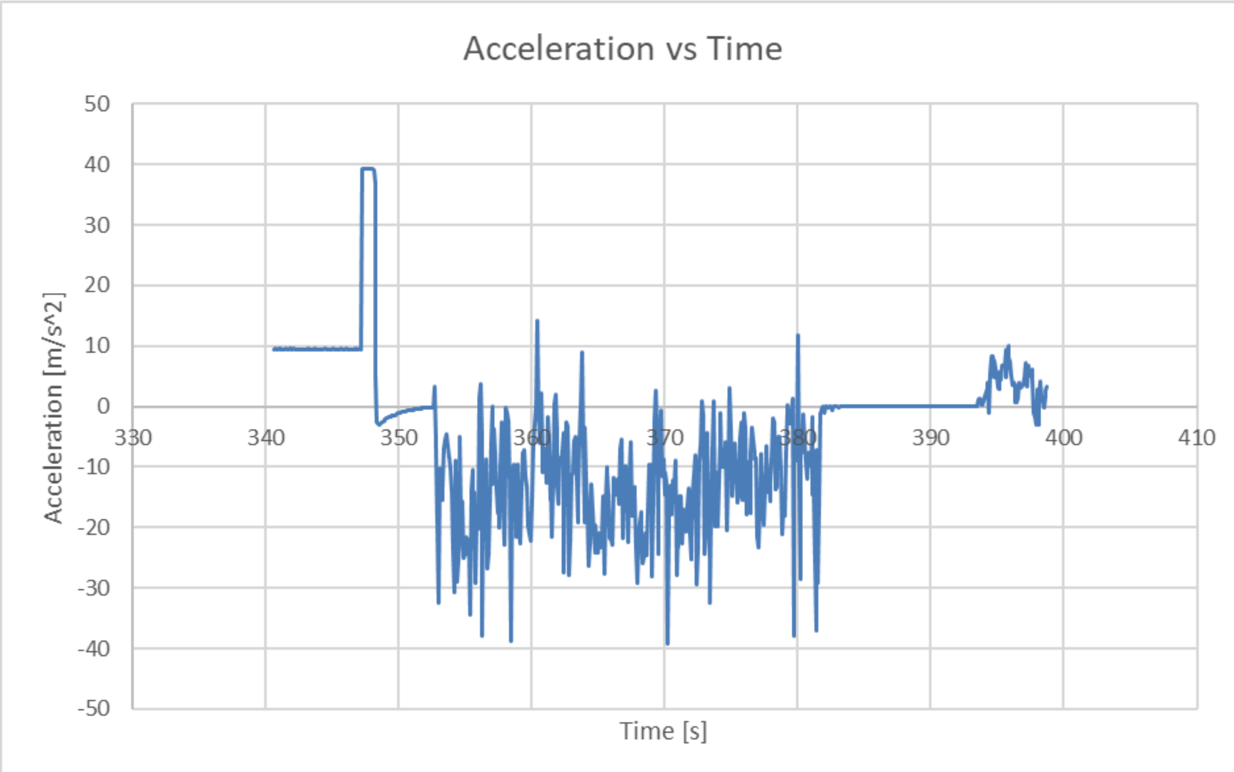


***Figure 26:*** **Acceleration vs Time Plot**

The maximum dynamic pressure can be found using the equation $q = \frac{1}{2}\rho v^2$. The density can be found using the ideal gas law, with an R value of 287 and assuming constant temperature of 290 kelvin. The maximum dynamic pressure is found to be 3731 pascals using these calculations. The impact velocity is difficult to determine from the velocity plot, but it appears to be about 7 to 10 metres per second. This high velocity can be seen in the real world by the damage done to the rocket during landing.

When comparing the plots from launch day and those from OpenRocket, it is clear that they follow the same patterns. The OpenRocket simulation can be seen in the design section of this report. The altitude plot is the same shape, however it appears that the rocket performed better than the simulation predicted. Additionally, the time of apogee seems to match on both plots. As for velocity, it is difficult to make any fine analysis due to the quality of the velocity data. However, the plots maintain similar shapes overall. The maximum velocity from launch day also appears to surpass the prediction of the simulation. Finally, the acceleration graphs can be examined. These graphs do not have many similarities. But, the launch and recovery deployment times can clearly be seen on both plots (346 and 352 seconds respectively on the launch day acceleration plot). As previously mentioned, the acceleration data may not be entirely accurate, which could affect this comparison. This can also be expanded to all of the data from the launch. The instruments and data collection may not be entirely accurate or high quality, giving a lot of 'noise' in the data. Any other discrepancies between the real world and simulation data can be explained by a number of reasons. Primarily, the launch day conditions do not exactly match the simulation, neither would the exact model of the rocket. This would have greatly affected all three plots, and the overall performance of the rocket.

To calculate the drag coefficient an understanding of the lift induced on the rocket, the span of the rocket, the deployment velocity and the air density needs to be calculated. This can be done by assuming lift is twice the weight, which can be calculated by taking the mass and multiplying it by gravity. Once the weight is calculated, the fluid properties of which the parachute is deployed needs to be considered when calculating the drag coefficient. For this scenario, air at the altitude the parachute is launched from needs to be found using standard atmosphere tables. Below is a table or properties as well as the calculations for both the coefficient of drag on the rocket and parachute;

**Table 4: Assumed Properties**

| | |
|---|---|
| $Density = 1.1901\ kg/m^3$ | $Platform\ Area\ of\ parachute = 0.6567m^2$ |
| $Deployment\ velocity = 26m/s$ | $Platform\ Area\ of\ Rocket = 0.08017m^2$ |
| $Rocket\ Mass = 1.383kg$ | $Rocket\ weight = 13.57N$ |
| $Parachute\ Mass = 0.0576kg$ | $Parachute\ weight = 0.56507N$ |

Rocket

$$S = \frac{2W}{\rho V^2 C_d} \rightarrow C_d = \frac{2W}{\rho V^2 S} = \frac{2(13.57)}{(1.1901)(27)^2(5.42\times10^{-3})} = 0.3902$$

Parachute

$$S = \frac{2W}{\rho V^2 C_d} \rightarrow C_d = \frac{2W}{\rho V^2 S} = \frac{2(0.5284)}{(1.1901)(1)^2(0.6567)} = 1.35$$

Therefore as shown in the calculations above, it can be determined that the coefficient of drag for the rocket is 0.3902 and the coefficient of drag on the parachute is 0.00185. Although the rocket is traveling downwards at velocity of roughly 27 m/s, the parachute itself is relative to the rocket, however the parachute isn't moving therefore the assumption can be made that its velocity is low (1m/s). In terms of calculations, the coefficient of drag for the parachute should have a higher value compared to the rocket, as the parachute will experience more resistance when deployed.

## Conclusion

Our team, Stellar Booster 401, successfully designed, constructed and launched a single stage model rocket, providing valuable hands-on experience. Despite issues with the nose cone and transition bay during manufacturing and launch day, the rocket performed better than expected. Reaching a maximum altitude of 354 metres, the rocket surpassed predictions from the OpenRocket simulations. The telemetry data analysis shows that the data collected on launch data correlates with the OpenRocket simulations, with some discrepancies due to real world conditions and imperfect data collection. A higher than ideal ground hit velocity caused minor damage to one of the rocket's fins, with no other issues after launch. The calculated drag coefficients for the rocket and parachute, 0.3902 and 1.35 respectively, validate the aerodynamic efficiency of the team's design. This project not only enhanced the team's skills in CAD, engineering design, and manufacturing but also helped to develop problem solving and project management skills, laying a better foundation for future aerospace projects.