Metropolitan Aerospace Rocket Society

Post Flight Report (PFR)

ERNIE

Version History

Version	Date	Responsible	Responsible Description
1.1	12/28/2024	Veronica, Shane, Vidyuth	Completed Abstract, Abbreviations, and Team Structure.
1.2	12/30/2024	Shane	Completed PDR Data, and Avionics Analysis
1.3	01/02/2024	Veronica, Shane	Completed Rocket Manufacturing Work Session, and Competition Day
1.4	01/03/2024	Shane, Veronica	Completed Telemetry Data Analysis
1.5	01/04/2024	Veronica, Vidyuth	Completed Conclusion, References, Appendix, and Acknowledgements. Uploaded images and organized report
1.6	1/10/2024	Veronica, Shane, Vidyuth	Finalization

Acknowledgements

The success of this project would not have been possible without the unwavering support and guidance of the *MARS* team.We sincerely appreciate Newt's exceptional leadership and dedication to the project as the team lead, ensuring that every aspect of the project progressed smoothly. A special thanks to Eve, who conducted the critical safety checks with precision and thoroughness, enabling a safe and successful launch.

We are extremely grateful to Anthony and Nathan for their invaluable expertise in avionics, providing insightful assistance and taking full control with the implementation of the rocket’s electronics. We also acknowledge Nikolai, whose oversight and mentorship were key in maintaining high standards across all phases of the project.

Additionally, we thank the entire *MARS* team for their collective effort and continuous support. From providing all of the essential resources to sharing their expertise, overseeing the creation of the rocket and providing valuable feedback. Their contributions played a significant role in shaping the success of this project. The commitment of all members fostered a collaborative and educational environment, which has been both inspiring and deeply appreciated.

1.0 Abstract

Team ERNIE is composed of six second-year engineering students who collaboratively designed, built, and launched a successful rocket on December 19, 2024. Team members: Ernest Choi, Shane Itwarie, Rayyan Mollah, Veronica Chan, Vidyuth Suresh, and Pragith Thyagarajan divided responsibilities across many fronts including rocket design, avionics, and manufacturing.

With the preliminary designs built using *OpenRocket*, which later evolved through research and testing to address stability, structural, and aerodynamic considerations. This was later transitioned into detailed *SolidWorks* models to finalize the rocket's assembly. Key challenges, including time constraints when fabricating custom parts, scheduling conflicts among other challenges, required flexible and swift adjustments to meet the launch deadline.

Manufacturing sessions focused on assembly of the chassis and epoxy work, while the rocket's aesthetic was created and painted using a *Spiderman* theme. The launch highlighted successful collaboration and problem solving. Despite last minute design modifications on launch day, the team's approach demonstrated adaptability which led to achieving a smooth and stable launch.

2.0 Abbreviations

PDR	Preliminary Design Review
PFR	Post Flight Report
MARS	Metropolitan Aerospace Rocket Society
CAD	Computer Aided Design
GPS	Global Positioning System
PCB	Printed Circuit Board
CG	Center of Gravity
CP	Center of Pressure

3.0 Team Structure

Our team, ERNIE, consisted of six second-year engineering students; Ernest Choi, Shane Itwarie, Rayyan Mollah, Veronica Chan, Vidyuth Suresh, and Pragith Thyagarajan. Each member contributed to the design and manufacturing of our rocket in many different ways which ultimately led to our successful launch on December 19th, 2024.

***Figure 1**: Team ERNIE on December 19th, 2024. Pictured from left to right: Ernest Choi, Rayyan Mollah, Pragith Thyagarajan, Shane Itwarie, Veronica Chan, Vidyuth Suresh, and Newt (Team Lead)*

Due to scheduling conflicts and other responsibilities, not every member was able to attend every tutorial. To ensure the success of our team, at least two members were present for at least one tutorial each week. The responsibility was divided amongst the group. Two team members, Ernest and Vidyuth, attended the avionics tutorials and kept up with that aspect of the rocket build for the team. Shane, Veronica, Rayyan, and Pragith kept up with the *OpenRocket* and *OnShape* tutorial sessions.

Shane was the primary designer of the rocket, worked on the *OpenRocket* version of our design, and created the *SolidWorks* CAD. He regularly consulted the rest of the group to ensure that the design was consistent with everyone's vision and the overall criteria that the rocket must follow. The avionics bay was primarily his design, and Shane updated the CAD to meet all expectations whenever necessary. Throughout the manufacturing process, he was an active member and even 3D printed some of the remaining parts needed to complete the rocket for launch day on time. Alongside Veronica, he designed the team's logo and created the PDR presentation with the rest of the team.

Veronica helped Shane with particular aspects of the design, including specific design choices (such as the number of fins and nose cone shape). She actively attended the weekly tutorials with any other available members. Veronica supervised the completion of the PDR presentation, ensuring that all criteria were met. During the manufacturing process, she sewed the shock chords and helped with the epoxying of the rocket.

As mentioned, Ernest and Vidyuth attended regular avionics sessions and were responsible for that aspect of the rocket. Ernest was also present during the rocket manufacturing work session and PDR presentation as a presenter of the CP, CG and stability margin.

Rayyan and Pragith attended tutorials and aided with the manufacturing of the rocket during the work session before the launch.

4.0 Preliminary Design Review Data

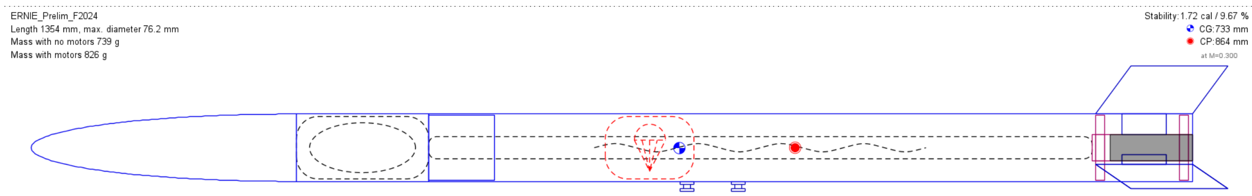

Figure 2: *First OpenRocket design*

This design was mainly used for us to get an understanding of the *OpenRocket* software, this is shown in the fact that there are many errors and missing components. This includes the lack of eyebolts, the discrepancies in the motor, the diameter, and length of the actual materials being used, and the distance between the rail buttons.

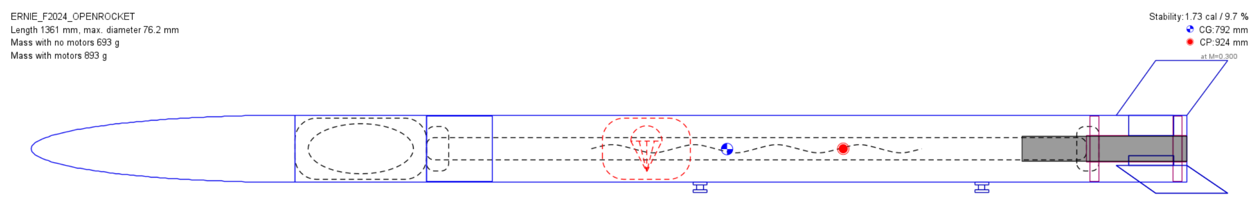

Figure 3*: Second OpenRocket design*

The main change in this iteration was the addition of eye bolts and the customization of our fins. The length was increased as we conducted research into what type of fins are optimal for this kind of rocket. This would be the final design that our team had made on its own.

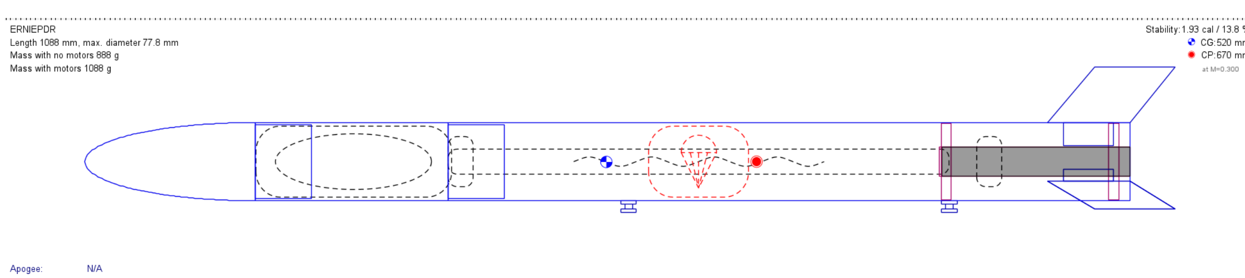

Figure 4*: Final OpenRocket design*

Although we had our original *OpenRocket* design and avionics bay completed, unfortunately, we were unable to print our CAD transition and avionics bay due to time constraints. This meant that our team had to use the standard parts provided by the *MARS* team. Taking into account the exact measurements and weight of the standard parts it changed our stability quite a bit. This meant we had to redesign our nose cone to fix this issue as we had already made our fins. The main changes of this iteration were the shortening of the fuselage and the shortening of the nose cone. The changes made on this OpenRocket were crucial to our team having a smooth and successful launch.

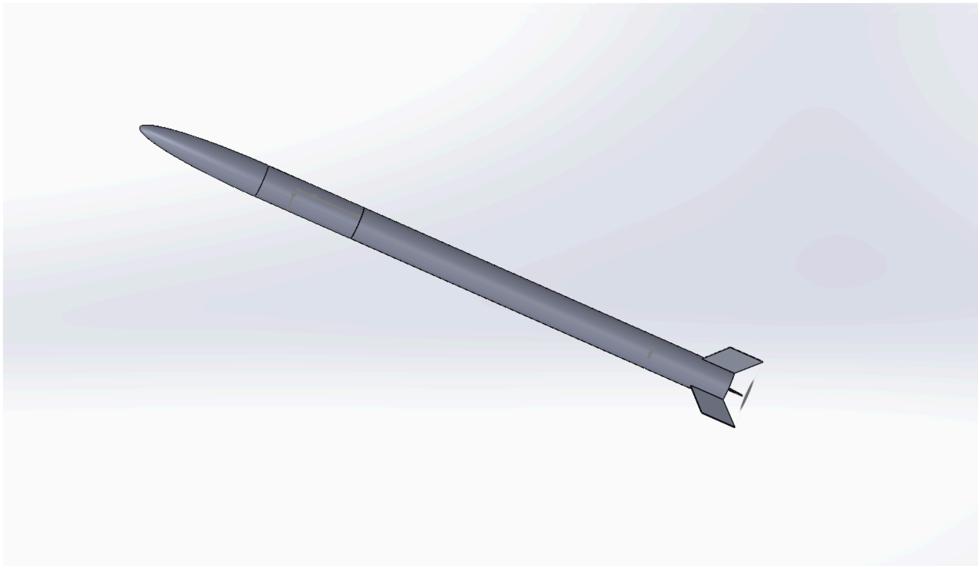

***Figure 5**: SolidWorks assembly of our rocket*

A full mock-up of our rocket including all parts we designed based on our second iteration on *OpenRocket*.

5.0 Avionics Analysis

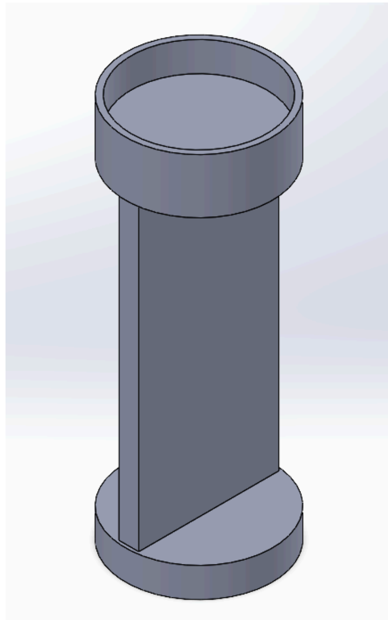

Figure 6: *First iteration of avionics bay design on OpenRocket*

Original Design Analysis and Improvements

The initial design was developed as a starting point to integrate the GPS board, a battery, and the "Among Us" PCB. The GPS board was positioned on the top, while the battery and PCB were placed on opposite sides. However, feedback from the project leads highlighted several design flaws:

1. **Lack of Mounting Holes for PCB**
   The absence of dedicated mounting holes for securing the PCB was a significant oversight. This not only compromised the structural stability but also increased the risk of accidental displacement during operation.
2. **Potential Damage to the Battery**
   The proximity of the PCB screws to the battery posed a serious safety risk. There was concern that improper screw placement or over-tightening could puncture or damage the battery, leading to potential electrical or thermal hazards.

Proposed Improvements

To address these issues and enhance the design:

1. **Incorporate Dedicated Mounting Holes**
   Add strategically placed mounting holes for the PCB. Ensure these are compatible with standard screw sizes and include countersinks or recessed areas to prevent the screws from protruding.
2. **Introduce Protective Layers or Shields**
   Place a protective barrier or insulating layer between the battery and PCB screws. This

could be achieved using:
  - A thin sheet of non-conductive material (e.g., plastic or rubber).
  - A dedicated battery enclosure that physically separates it from the screws.
3. **Optimize Component Placement**
   Redesign the layout to minimize interference between components. For instance:
   - Shift the battery slightly to provide a safe clearance from the PCB mounting screws.
   - Use a modular approach where each component has a distinct and isolated mounting space.
4. **Enhance Structural Support**
   Integrate additional supports or brackets to reinforce the overall structure. For example:
   - Add side rails or standoffs to secure the GPS board.
   - Use snap-fit or screw-fit components to ensure tight assembly.
5. **Material Considerations**
   Use lightweight yet durable materials (e.g., ABS or polycarbonate) for the enclosure to ensure robustness while maintaining portability.

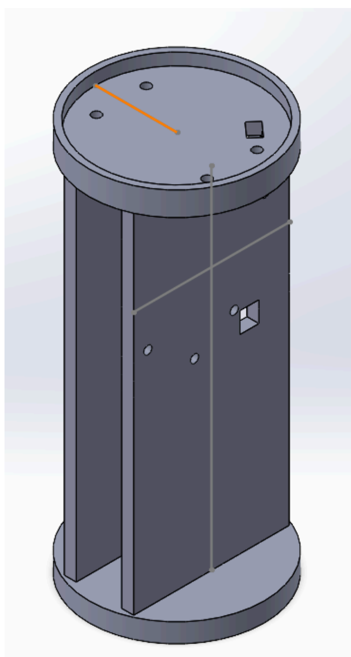

FIgure 7: *Second iteration of avionics bay design*

Updated Design and Feedback

The second iteration addressed the primary concerns from the initial design. Key improvements included:

1. **Incorporation of Mounting Holes**
   Holes were added for all boards, allowing secure attachment and preventing displacement

during operation.

2. **Increased Separation Between PCB and Battery**
   Space was introduced between the PCB mounting area and the battery compartment, effectively mitigating the risk of screws making contact with the battery.

However, during the review process, additional concerns were highlighted:

Issues Identified

1. **Thickness of the Two Extrusions**
   The extrusions were noted to have insufficient thickness, potentially compromising structural integrity. Thin extrusions may lead to deformation, especially under load or during assembly.
2. **Thickness of the Lower Bulkhead**
   Similar concerns were raised regarding the thickness of the lower bulkhead. A thinner bulkhead may not adequately support the components, leading to potential failure or instability.

Suggested Improvements

1. **Increase Extrusion Thickness**
   - **Recommendation:** Analyze the load and stress requirements for the extrusions and increase their thickness to ensure durability. Use tools like finite element analysis (FEA) to simulate stress distributions and optimize the design.
   - **Material:** If weight is a concern, consider using lightweight yet strong materials such as aluminum alloys or reinforced plastics.
2. **Reinforce the Lower Bulkhead**
   - **Recommendation:** Increase the bulkhead's thickness based on stress analysis. For added strength, integrate ribs or gussets to distribute loads more effectively.
3. **Standardize Wall Thickness**
   - **Recommendation:** Ensure uniform wall thickness throughout the design, where possible, to simplify manufacturing and improve strength without creating weak points.
4. **Review Component Alignment**
   - **Recommendation:** Revisit the alignment and spacing of all components to ensure adequate clearance and uniform load distribution.

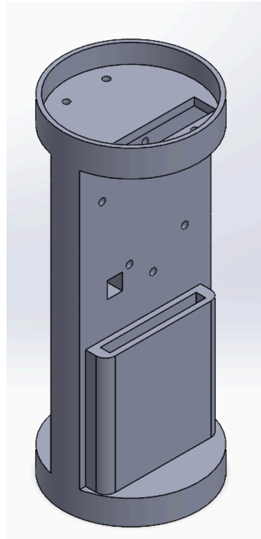

Figure 8: *Third iteration*

Updates in This Iteration

The design was modified to improve structural stability and address previous concerns. Key changes included:

1. **Incorporation of a Battery Sleeve**
   A dedicated sleeve was introduced to securely house the battery, enhancing safety and organization within the design.
2. **Addition of a Single Middle Extrusion**
   A central extrusion was added to reinforce the structure, ensuring greater durability and reducing potential flexing or deformation.

Feedback from Avionics Leads

After presenting the revised design, the avionics leads provided the following recommendations:

1. **Revert to the Original Design**
   The leads highlighted that the original design was more suitable for avionics requirements and advised returning to it.
2. **Battery Placement**
   It was emphasized that the battery must be positioned away from the antenna to prevent interference that could compromise signal accuracy.

Next Steps

1. **Re-Adopt the Original Design**
   Implement the original configuration while incorporating additional features only where necessary.
2. **Optimize Battery Placement**

Ensure the battery is positioned at a sufficient distance from the antenna to eliminate interference risks.

By aligning design changes with expert feedback, the final configuration will better meet the project's technical and functional goals.

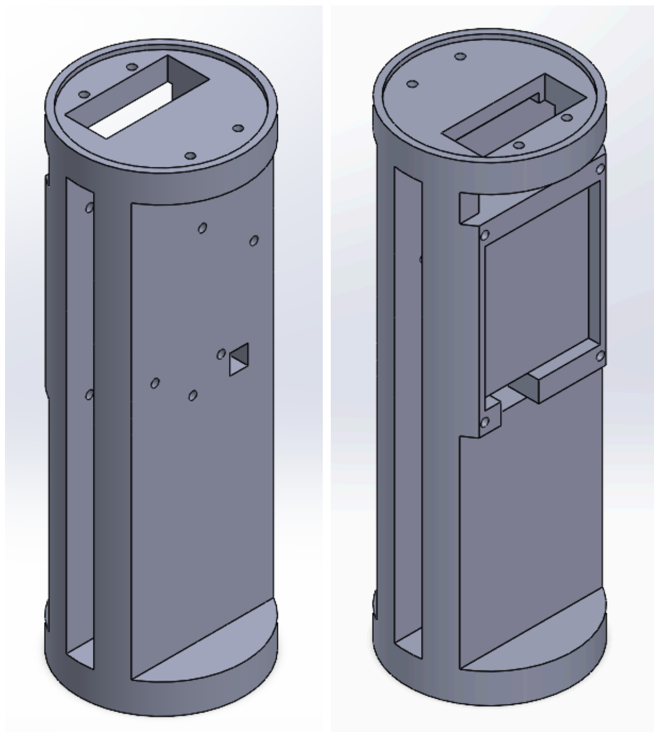

Figure 9: *Final iteration*

Key Features of the Final Design

The final design reflects a comprehensive approach, addressing previous concerns and integrating stakeholder feedback. Key features include:

1. **Battery Slot with Cover**
   - A dedicated slot for the battery was introduced, along with a secure cover to hold it firmly in place.
   - The placement ensures the battery is positioned away from the antenna, preventing interference and maintaining the accuracy of signal readings.
2. **Reversion to Original Two-Middle-Extrusion Format**
   - The design returns to the two-middle-extrusion configuration from the original iteration, providing enhanced structural support and maintaining simplicity in assembly.
   - This format was chosen based on its proven reliability in earlier reviews.
3. **Improved Accessibility and Safety**

- The new configuration not only secures the components effectively but also facilitates ease of access for maintenance and inspection.
- Additional considerations for material and slot alignment ensure durability and reduce the risk of damage during operation.

Feedback Incorporated

This iteration directly responds to the avionics leads' recommendations, specifically:

- **Battery Placement:** Ensuring the battery does not interfere with the antenna.
- **Structural Design:** Re-adopting the proven two-middle-extrusion layout for stability and functionality.

Advantages of the Final Design

- **Signal Integrity:** By eliminating interference between the battery and the antenna, the design ensures reliable avionics performance.
- **Structural Robustness:** The return to the original extrusion layout improves stability under operational stresses.
- **Ease of Assembly:** The inclusion of a battery cover and optimized slots simplifies the assembly and maintenance process.

6.0 Rocket Manufacturing Work Session

Our rocket manufacturing work session took place on December 15th, 2024. Throughout the session, we epoxied the fins onto the main body tube, attached the rail buttons and centering rings, and added the sock chord. Unfortunately, not all of the parts were 3D printed for the work session, so our group found it necessary to complete the rocket on our own time. Thanks to our lead, the manufacturing session ran very smoothly. There were no issues with the epoxying, and all the parts fit perfectly together. The most challenging aspect of the manufacturing was epoxying the centering ring at the bottom of the rocket, as we needed to use a long rod to stick through the body tube. Initially, there was a little nub at the end of the rod, but we found it challenging to pick up the epoxy. To solve this issue, we taped one of the popsicle sticks to the bottom, which made the task much more manageable.

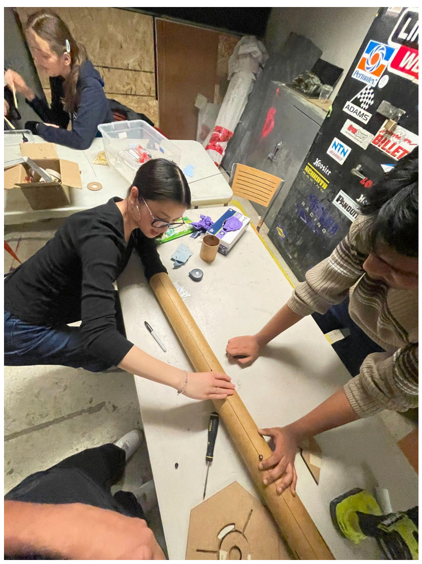

Figure 10: *Attaching the rail buttons.* ***Figure 11:*** *Attaching the shock chord.*

Figure 12: *Epoxying the centering ring from the inside.*

After the session, Shane took the rocket home and completed the decorations. The main theme of the rocket was *Spiderman*. He spray painted the entire rocket red and then painted the webs in black. Unfortunately, the rocket could not be completed because we were missing the transition and nose cone until launch day. This is also why the nose cone and transition did not match the final rocket during the launch.

Figure 13: *Rocket waiting for the epoxy to dry.*

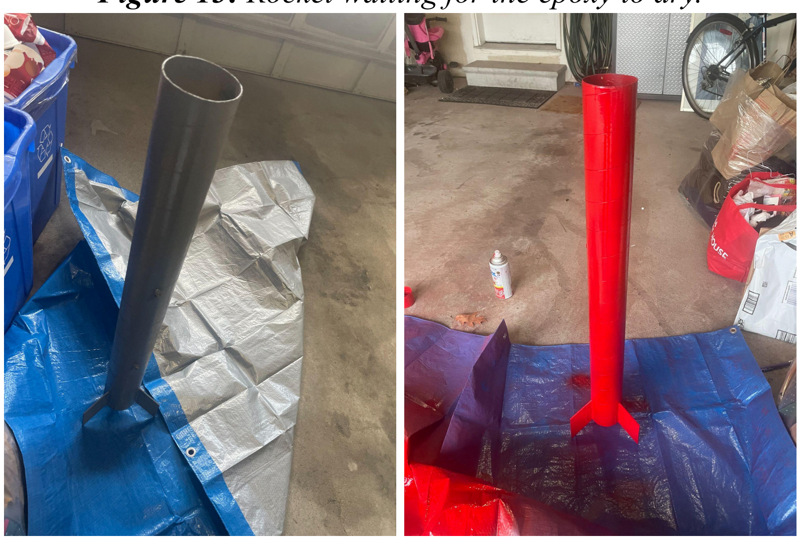

Figure 14 & 15: *Spray painting process.*

Because of the updates and changes to the rocket, the *OpenRocket* needed to be updated and therefore the stability became out of range. To resolve this issue, we shortened the body tube and this readjusted the stability margin to be between the necessary range. Unexpectedly, this became an issue during the launch day.

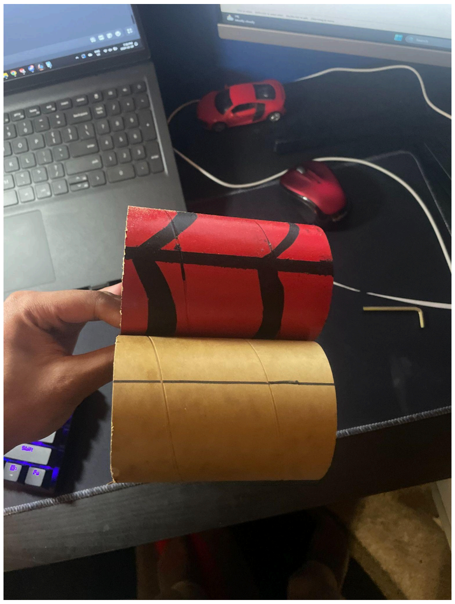 

FIgure 16: *Portion cut off of the rocket.* ***Figure 17:*** *3D printed portion completed by Shane.*

7.0 Competition Day

Our launch was scheduled for 8:30 AM on December 19th, 2024. Due to unforeseen circumstances, our launch was delayed to 3:00 PM. One of our first obstacles was our missing nose cone and transition. Unfortunately, since we had to wait we weren't able to launch at our specified time. There were also challenges with the avionics bay that we were supposed to use in our rocket which caused even more delays. When we were finally able to go through our safety check, the center of gravity and center of pressure were too close. For some reason the rocket had the correct weight before the addition of the engine, but as the engine was attached, the weight was thrown off. In order to fix this issue, we had to add rocks to the nose cone of the rocket in order to offset the weight and adjust the center of gravity to ensure that the stability margin was in a safe range to launch.

The red team consisted of Shane and Veronica as they were those who were the most familiar with the design of the rocket. They were the two assigned to be at the launch pad. Mission control (the blue team) was initially going to be assigned to Vidyuth as he had spent the most time with the avionics. Unfortunately, due to all of the delays he was unable to be there during the launch. Instead, Ernest was assigned to be at mission control. Our green team, or recovery team, consisted of Pragith and Rayyan.

After the rocks had been added to the nose cone, the rocket was safe for launch. Our team was able to answer all of the questions for the safety procedure with the LCO Miguel, and were given the "OK" to proceed with the launch.

Eve, Miguel, Baron and Ivan, explained the procedures for the parachutes and the engines before we left the tent and headed towards the launch pad. While there, the rocket was set up onto the launch rail and the ignition cables were attached, with the help of Miguel.

Figure 18: *Miguel, Eve and Baron attach the ignition cables onto the rocket.* ***Figure 19:*** *Veronica and Shane on the launch pad, setting up for launch.*

Figure 20: *Miguel (LCO) explains the ignition cables and how to launch.*

The launch went smoothly and there was no damage to any portion of the rocket. Recovery was very easy as the rocket had not veered very far from its path.

Figure 21: *Rocket launch.*

Figure 22 & 23: *Successful recovery of rocket.*

8.0 Telemetry Data Analysis

Key Results

Parameter	**Value**
Maximum Altitude (m)	134.112 m
Maximum Velocity (m/s)	12.8 m/s
Maximum Acceleration (m/s²)	2.45 m/s^2

Graphical Analysis

The **Altitude vs. Time** graph illustrates the rocket's ascent and descent phases. The altitude steadily increases during the powered phase until it reaches the maximum altitude, after which the descent begins.

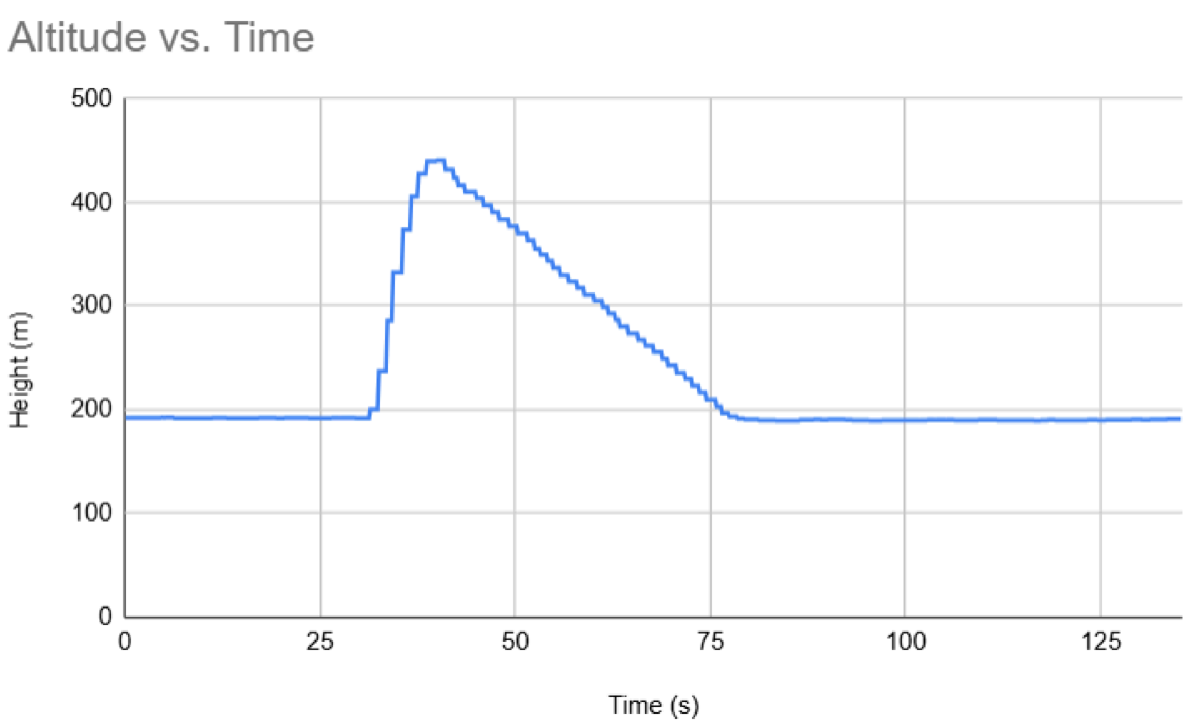

Figure 24: *Altitude vs. Time graph*

The **Pressure vs. Time** graph illustrates the variations in atmospheric pressure experienced by the rocket throughout its flight. During the ascent phase, the pressure steadily decreases as the rocket gains altitude and moves into thinner layers of the atmosphere. The minimum pressure is reached at the rocket's peak altitude. During descent, as the rocket returns to lower altitudes, the pressure increases again due to the denser atmosphere near the ground. This trend provides a clear indication of the rocket's altitude profile over time, closely tied to its vertical motion.

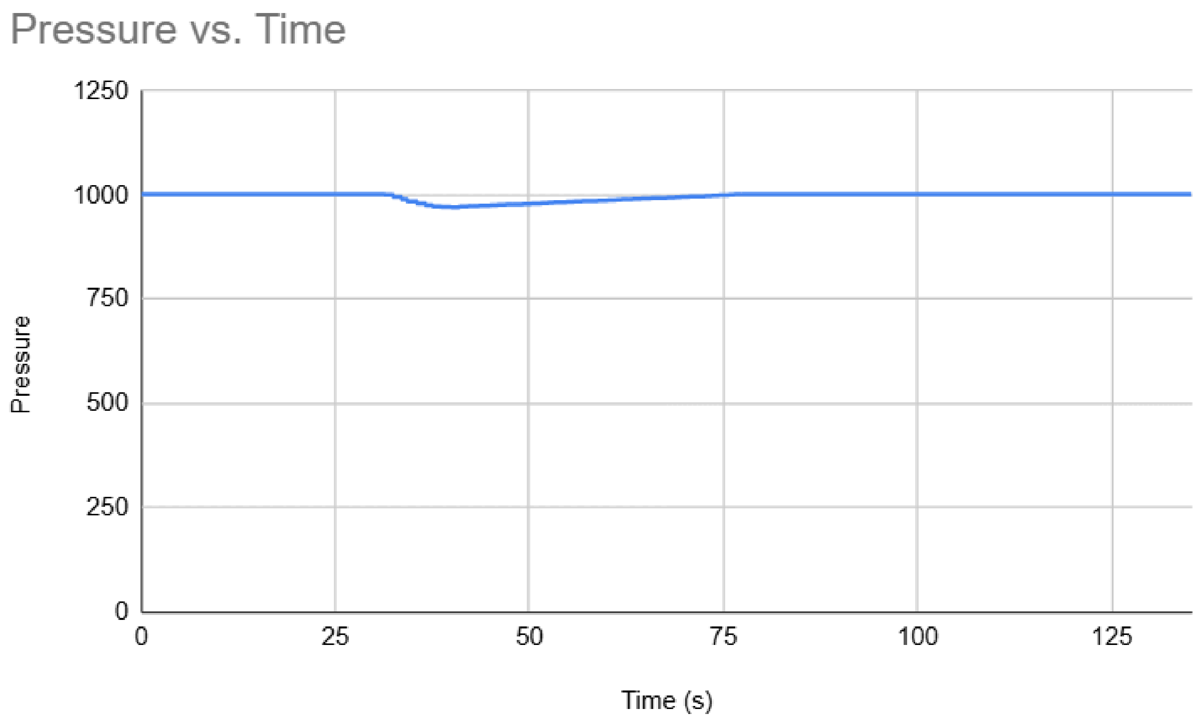

Figure 25: *Pressure vs. Time graph*

Observations and Differences

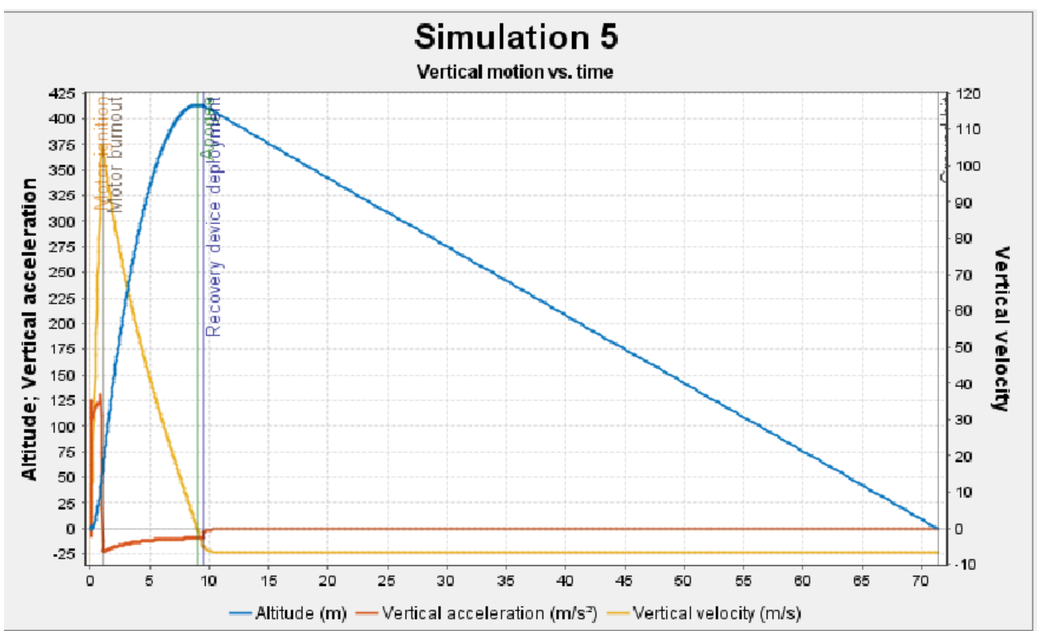

Figure 26: *OpenRocket simulation.*

1. **Maximum Altitude**
   - **CSV Data:** The maximum altitude recorded is approximately **201.5 m**.
   - **Simulation Graph:** The graph shows a maximum altitude of approximately **425 m**.
   - **Difference:** The simulation predicts a significantly higher altitude, possibly due to idealized assumptions (e.g., no wind resistance, perfect thrust, and drag parameters) compared to real-world conditions.
2. **Maximum Velocity**
   - **CSV Data:** The maximum velocity calculated is **12.8 m/s**.
   - **Simulation Graph:** The graph indicates a much higher peak velocity of around **90 m/s** during ascent.
   - **Difference:** The CSV data suggests slower acceleration and overall velocity, likely due to underperformance of the motor, environmental factors (e.g., drag or wind), or measurement inaccuracies in the physical test.
3. **Maximum Acceleration**
   - **CSV Data:** The maximum acceleration is **2.45 m/s²**.
   - **Simulation Graph:** The graph shows a peak acceleration exceeding **150 m/s²** during the initial thrust phase.
   - **Difference:** This discrepancy highlights possible limitations in thrust delivery, errors in sensor data, or differences in the mass and drag coefficients used in the simulation versus real-world conditions.
4. **Descent Phase**
   - **CSV Data:** Descent shows a gradual decrease in altitude and relatively consistent velocity.
   - **Simulation Graph:** The descent includes the deployment of a recovery device (parachute), sharply reducing velocity.
   - **Difference:** If a recovery device was used in the physical test, it may not have deployed as effectively as simulated. Alternatively, the simulation's drag coefficient for the parachute may be too optimistic.
5. **Dynamic Behavior**
   - The simulation shows distinct transitions: motor burnout, coasting phase, and recovery device deployment.
   - The CSV data does not reflect these transitions as sharply, possibly due to limitations in data granularity or inconsistencies in actual flight conditions.

Potential Sources of Error

1. **Drag Coefficient Assumptions**
   The simulation may use an idealized drag coefficient, while real-world drag is affected by weather, manufacturing imperfections, and surface roughness.
2. **Thrust Variation**
   Differences in motor performance, including thrust duration and magnitude, could result in lower altitude and velocity in the actual test.
3. **Sensor Accuracy**
   The sensors collecting the CSV data may introduce errors due to noise, calibration issues, or delayed response times.

4. **Environmental Factors**
   The simulation likely assumes no wind or external disturbances, which do not align with real-world conditions.
5. **Parachute Deployment**
   Differences in the effectiveness of the recovery device between the test and simulation could explain variations in descent behavior.

9.0 Conclusion

The successful completion and launch of the rocket highlights the dedication, creativity, and adaptability of the team. Throughout the process, members faced and overcame numerous challenges, including tight deadlines, scheduling conflicts, and technical setbacks. These obstacles tested not only engineering capabilities but also the ability to collaborate effectively under pressure.

The design phase marked the beginning of a rigorous process to create a stable, functional, and aerodynamic rocket. Initial concepts in *OpenRocket* evolved through multiple iterations as the group refined fin configurations, nose cone geometry, and avionics integration. *SolidWorks* models further finalized the design, ensuring the assembly met the required specifications. Each refinement, whether addressing stability margins or material constraints, contributed significantly to the eventual success of the flight. Manufacturing sessions provided their own set of challenges, particularly during epoxy work and the assembly of custom components. Despite missing 3D printed parts, the team adapted quickly, completing essential tasks efficiently. The *Spiderman* inspired paint scheme was a creative highlight, reflecting attention to detail and adding a personal touch to the finished rocket.

On launch day, the group demonstrated exceptional adaptability and resourcefulness. Delays and unexpected stability issues required immediate problem-solving, including the addition of ballast to the nose cone to adjust the center of gravity. Despite these setbacks, the rocket met all safety criteria, passed inspection, and launched successfully. The seamless recovery, with the rocket sustaining no damage and landing close to its launch site, was a display of the quality of work. Telemetry data from the flight confirmed a peak altitude of 201.50 meters, a maximum velocity of 12.80 m/s, and an impact velocity of 6.10 m/s. While minor deviations were noted between simulated and observed results, these differences were likely due to environmental variables, drag coefficient variations, or sensor noise. These findings provided valuable insights into the interplay between design assumptions and real-world performance.

This project served as an invaluable learning experience, fostering skills in iterative design, manufacturing precision, and dynamic problem-solving. Beyond technical accomplishments, the collaboration and teamwork displayed throughout the project were crucial to its success. The knowledge and experience gained from this project will serve as a strong foundation for the future, maybe even for a second launch with an improved rocket.