Hoo-Rizon 1: Subscale Sounding Rocket

A Technical Report submitted to the Department of Mechanical and Aerospace Engineering

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1 Executive Summary

The purpose of this capstone project was to design, build, and fly a single-stage, subscale sounding rocket. The goal was to reach a maximum altitude of 3,000 ft, recover the launch vehicle, and acquire atmospheric data. Throughout the year, various design reviews were conducted to demonstrate the progress to external reviewers. Requirements were based on the Tripoli Rocketry Association restrictions and the team's aspirations. The rocket was launched on April 5th. Despite having a recovery failure, team members were able to develop critical skills in problem solving, structural analysis, and control systems, setting the groundwork for consecutive capstones and future job opportunities.

2 Timeline and Course Assignments

This capstone project ran from Fall 2024 through Spring 2025. Course assignments in the fall included a project pitch, a conceptual design review, and a preliminary design review. The spring course assignments included a critical design review, a post-flight assessment review, and a thesis technical report. Furthermore, students completed peer and self-evaluation surveys to give feedback on team dynamics. A Gantt chart was utilized in the early stages to keep a schedule and break down tasks.

3 Introduction

In 2022, the Under Secretary of Defense R&E department defined "Space Technology" as a Critical Technology Area as part of their National Defense Strategy, highlighting the need for expansion in the commercial sector to maintain the United States' technological advantage (USD R&E, 2022). In turn, there is a growing trend among university aerospace engineering programs to expand student interest in space design. A lack of space-related engineering courses in the aerospace curriculum could cause a shortfall in engineers who can meet the growing national demand within the field.

There is a lack of precedence in both UVA curriculum and projects based on space exploration. The class of 2025 Rocket Capstone Team looks to design, build, and fly a sub-scale sounding rocket to approximately 3,000 ft and develop technical and system design process skills. All to enhance future career opportunities and build the groundwork for consecutive capstone teams.

3.1 Functional Requirements

- F1: Safely launch at Tripoli launch site to apogee of 3,000 ft (Modified to 2,500 ft)
  - Verified through testing
- F2: Sound atmospheric conditions with <5% error
  - Verified through testing
- F3: Safely recover rocket
  - Verified through ground test
- F4: Maintain stability during flight
  - Analysis, OpenRocket, and calculations
- F5: Maintain structural integrity
  - Analysis and calculations

3.2 Operational Requirements

- O1: Parachute deployment within 1 s of apogee
  - Verification through OpenRocket
- O2: Redundant parachute deployment and sounding systems
  - Verified through testing
- O3: All components compatible with 4.02 in diameter body tube and 53.54 in rocket height
  - Verified through Solidworks
- O4: Mass 6.5 - 11 lb
  - Verified through OpenRocket
- O5: Select COTS J-class motor with impulse of 750-900 Ns
  - Verified through OpenRocket and analysis from online comparisons
- O6: GPS Tracking system with range ≥ 3 mi
  - Verified through physical testing
- O7: Incorporate sensors capable of sounding altitude, pressure, temperature, humidity, UV radiation, imagery ± 5%
  - Verified through KiCad
- O8: Power management system
  - Verified through analysis and forums
- O9: Data logging systems
  - Verified through testing

3.3 System Level Constraints

- C1: Altitude limit of 4,000 ft for first flight at Tripoli launch site
- C2: Suitable launch conditions
- C3: Must buy COTS propulsion system that can fit and be attached to aerobody at launch site
- C4: Strict timeline: Launch scheduled for Spring & commercial products have prolonged shipping→ limited design/build time
- C5: Availability of manufacturing techniques and commercial products
- C6: $3,000 Budget

4 Design

The team used a combination of system-level and subsystem-level methods to fulfill the mission goals and objectives. The team has adopted (1) NASA's life-cycle management structure, (2) a systems-oriented iterative design process, and (3) numerous risk, cost, and schedule management practices (NASA, 2023). Through NASA's project life-cycle management structure, the progress was presented in three deliverables: a project pitch, conceptual design review, and a preliminary design review to formulate and implement the design thoroughly. Given the two-semester time constraint, an iterative design process is utilized to create a closed-form solution that meets the mission goals and objectives through simulations and calculations. Finally, project management tools like Gantt Charts, risk matrices, Google Drive, and Discord helped facilitate team logistics.

4.1 Aerobody

4.1.1 Subsystem Requirements

To meet the project's system requirements, the team established the following aerobody subsystem-level requirements presented in Table I. These requirements were informed by primary and secondary system-level objectives and verified using calculations, materials testing, and OpenRocket simulations.

Table I
Aerobody Subsystem Requirements and Verification Methods

Subsystem Requirement	Verification Method
Stability margin of 1.5 to 2.5 caliber	OpenRocket
Able to withstand vibrational, inertial, and aerodynamic loads of the mission	Spring, mass, damper hand calculations, tensile and bend testing
Deploy a parachute to slow descent to less than 31 ft/s	OpenRocket
Use a 4" diameter and 48" long body tube	N/A

4.1.2 Subsystem Components/Analysis

4.1.2.1 Nose Cone

The final design of the nose cone section of the aerobody structure was a parabolic shape. The 2024-25 group (last year's group) researched parabolic, elliptical, and ogive shapes for the nose cone, including computational fluid dynamics (CFD) studies run on these shapes at three different fineness ratios with a velocity of 620 ft/s (their expected maximum velocity). However, their target altitude was higher than this year's (4,000 ft vs. 3,000 ft). At the early stages in the design process, this year's group expected to have a much lower maximum velocity. When the design was finalized, OpenRocket simulations estimated the maximum velocity to be 404 ft/s.

The nose cone shape was based on research, instead of running simulations. Crowell, a resource that the previous year's group used for nose cone research, shows the effectiveness of various nose cone shapes at reducing drag at Mach numbers around 0.8 to 2.1. A graph of this effectiveness is shown in Figure 1.

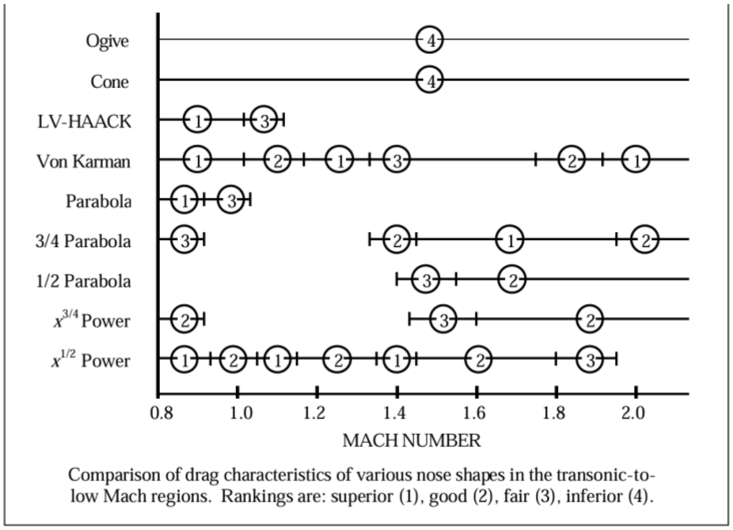


Figure 1. Comparison by Crowell on the effectiveness of nose cone shapes from Mach 0.8 to 2.1 (Crowell, 1996).

Within this Mach number range, the ogive shape is an "inferior" design. This year's rocket did not reach a Mach number of 0.8 – OpenRocket simulations estimated its maximum Mach number to be 0.362. As a reference, last year's rocket was expected to reach Mach 0.5, so Crowell was more helpful for the creation of possible nose cones rather than determining the effectiveness of them for this rocket. However, from Figure 2, it can be seen that within the Mach 0.0 to 0.5 range, most nose cone shapes do not greatly affect the wave drag coefficient. After this research and discussion regarding ease of manufacturing, a parabolic nose cone was selected.

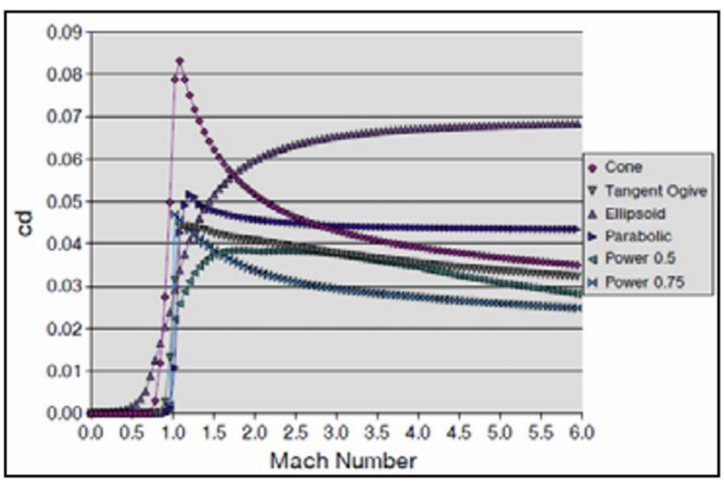


Figure 2. Comparison by Apogee Components of wave drag coefficient of nose cone shapes from Mach 0.0 to 6.0 (Apogee Components, 2014).

From further research, it was found that the fineness ratio of the nose cone should be 4:1 – any lower would increase drag, and any higher would not provide a significant benefit. Last year's group chose to create a carbon fiber nose cone, but to reduce costs, this year's nose cone was 3D-printed. Due to the size of the 3D printer used, the nose cone was split into upper and lower parts, which are seen in Figure 3. The bottom of each part has a built-in coupler that allows it to slide into the part below it.

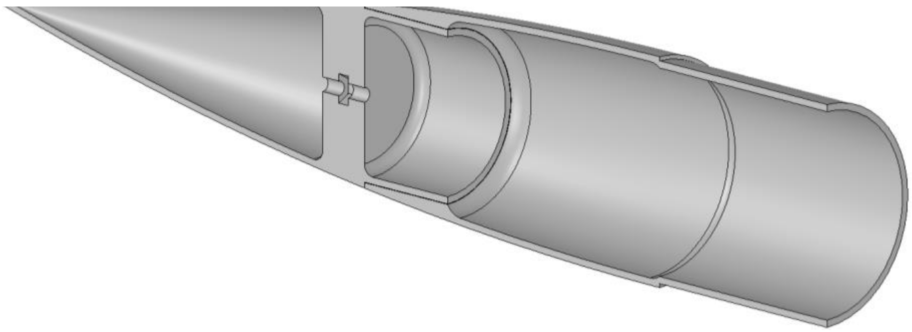


Figure 3. Assembly of the upper and lower nose cone with built-in couplers.

4.1.2.2 Recovery

The recovery system of the rocket was composed of eyebolts, an eye nut, steel quick link carabiners, a Kevlar shock cord, and a Jolly Logic parachute deployment device. All of the components met the required specifications. These specifications were set through a preliminary analysis of the shock by considering the upper body as a spring mass damper system. Analyzing the system with an initial velocity of 22 ft/s as such yielded an estimated force of shock of ~330 lbs as seen in Figure 4.

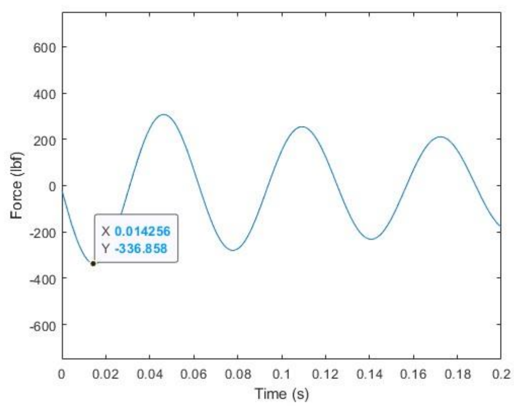


Figure 4. Force imparted on the shock cord plotted against time.

This estimate was likely an overestimate, as the force imparted on the bulkhead was significantly less. This was because the pressurization of the rocket was less than ideal due to the significant number of access ports cut into the rocket. Calculations did not involve drag, as the amount of energy dissipated from including drag was minimal. For a more accurate estimate, the mass of the avionics bay (including the rod) and the mass of the nose cone could be treated as separate spring mass damper systems in series.

The performance of the parachute was verified through a combination of OpenRocket simulation and hand calculations. The drift of the parachute was estimated using the gpsdriftcast.com website. However, the use of the Jolly Logic deployment system would have allowed the parachute to deploy at a set and much lower altitude and as a result decrease the drift.

4.1.2.3 Body

For the rocket's body, a four-inch diameter and 48" long Blue Tube from Always Ready Rocketry (ARR) was used (Always Ready Rocketry, 2023). Purchasing a COTS body tube was determined to be less expensive and more convenient than manufacturing a body tube from composite materials. Blue Tube is reliable, light, strong, and easily compatible with other COTS products. Furthermore, Always Ready Rocketry offers a custom CNC service on their Blue Tube material. Three radially symmetric 0.4 x 4.02" slots were cut into the body tube for the fins, as shown in Figure 5. When the Blue Tube was delivered, its exact diameter and thickness were measured and used to update the dimensions of other components like the nose cone and centering rings to set appropriate tolerances. A combination of the bandsaw and Dremel were used to machine and modify the Blue Tube. Sandpaper was not effective for expanding the fin slots.

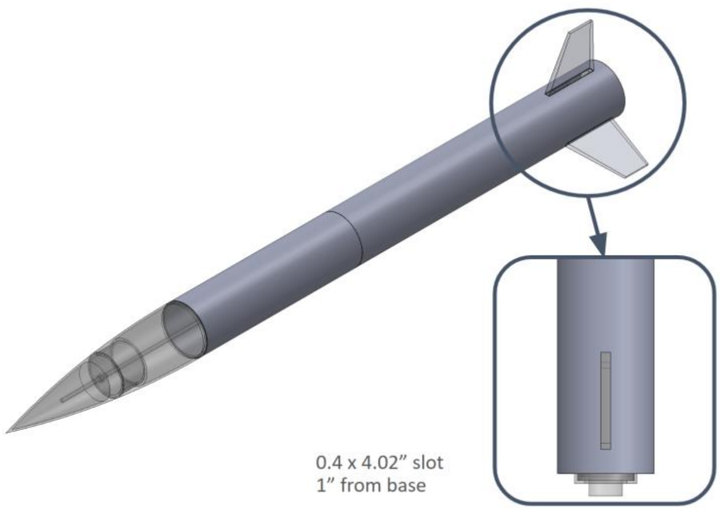


Figure 5. Body tube and CNC fin slots.

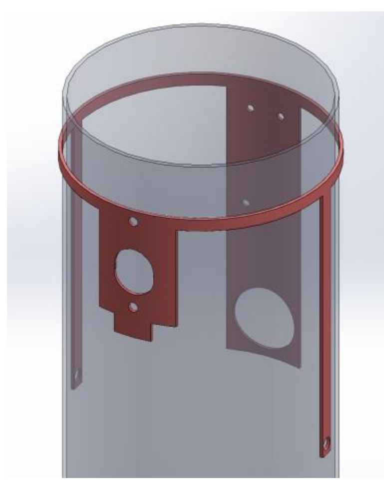


Figure 6. 3D printed guide for cutting holes into the body tube.

To cut holes for sensors, screw switches, and the camera, a 3D printed guide (shown in Figure 6), and Forstner drill bits were used.

The body tube was split into a lower and upper section. The lower section was glued to half of an eight-inch-long standard coupler from ARR. The other half of the coupler was connected to the upper body section. Three holes, radially spaced by 120 degrees were cut through the upper body tube and the coupler, and three nylon M2 screws were inserted into the holes. These "shear pins" keep the two sections of the body connected, and they shear once the ejection charge deploys at apogee. That system is illustrated in Figure 7.

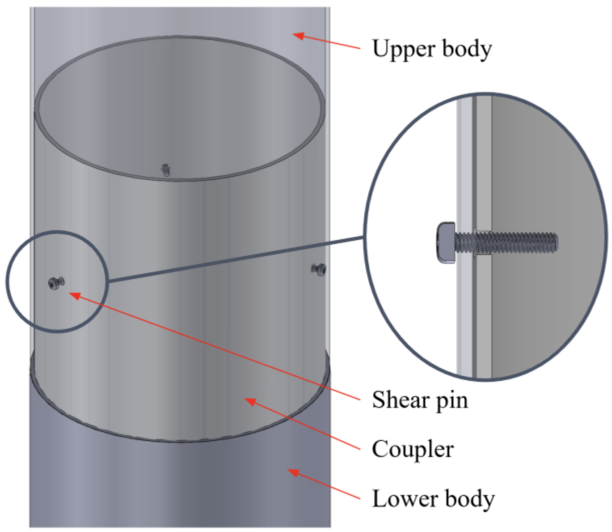


Figure 7. Connection between the lower body, the upper body, and the coupler using shear pins and glue.

Finally, to paint the body tube, a layer of spray sand sealer was applied, followed by blue spray paint. A die cutter was used to create a paper stencil, which, along with white spray paint, created the "HOO-RIZON 1" text.

4.1.2.4 Fins

The research and design of the fins began with an initial concept exploration phase, where various fin designs were analyzed and compiled from multiple published sources and articles. This initial research study helped formalize top systems-level requirements, such as stability calibre and max load forces, and iterate into more detailed performance requirements. These requirements were then initially conceptualized and consist of the following: planform geometry, cross-sectional geometry, quantity, replaceable vs permanent fins, form of attachment, and active vs passive fins.

For the geometry, a clipped delta with a rectangular cross section was chosen (shown in Figure 8). Clipped delta was found to be the most aerodynamically efficient shape for operating in the subsonic to transonic velocities the rocket traveled in, and having the cross section be rectangular simplified the manufacturing process. The quantity of fins was chosen to be three instead of four as it reduced the overall drag profile, and it was also determined that a desired caliber ranging between 1.5 and 2.5 could still be achieved with three. Permanent fins, as in fins permanently glued into the rocket, were chosen over replaceable fins, as in fins that can be taken out for maintenance/damage, as it simplified the design by reducing the number of moving parts, which also reduced the total weight of the rocket. Thus, the form of attachment was chosen to be a glue attachment via epoxy resin. Lastly, passive fins were chosen over active fins for reasons similar to choosing permanent fins over replaceable fins. Active fins are referring to a system of springs attached to the fins to correct potential deflections that may occur on the fins mid-flight, while passive fins are reliant purely on the strength of the attachment to prevent deflection.

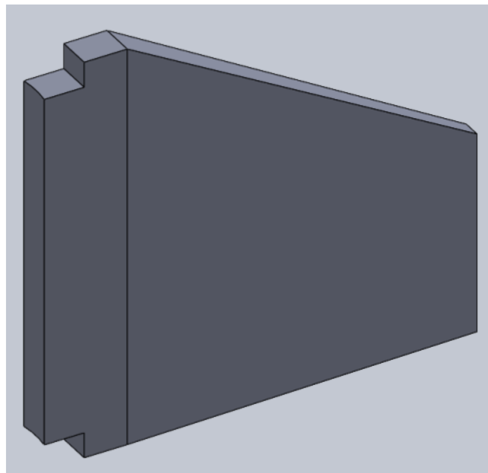


Figure 8. Final Clipped Delta Fin Design.

Several different tests/simulations were conducted to verify the fin performance. Firstly, the fin was tested using the low speed wind tunnel to test both for flutter and resistance to loading forces; however, the results of the testing were found to be mostly unhelpful due to the wind tunnel being unable to achieve the max theoretical velocity of the rocket, which was determined to be around Mach 0.5. Secondly, bending tests were performed on the 3D printed test pieces used for the fins at four infill percentages (30%, 40%, 50%, 60%) to test the strength of the PLA material being used for the fins and retrieve the shear modulus, G, for fin flutter calculations. While these tests proved somewhat fruitful, the actual results were dubious as the anisotropic structure of the prints meant the strength observed was not necessarily uniform in all directions. Lastly, an Excel-based fin flutter calculator was used to verify that the fin structure was strong enough to withstand flutter, given the rocket's theoretical max velocity and atmospheric conditions.

4.2 Avionics

The avionics system includes the electronics surrounding the flight computers and CO_2 ejection system, sensor data collection, live telemetry, and GPS tracking. The avionics subteam was also tasked with designing the avionics bay that houses all respective components. After the team's first launch attempt on March 23rd, a new avionics bay and PCB were designed.

4.2.1 Subsystem Requirements

The avionics subsystem requirements drove the design and provided goals for the final launch. These were broken up into functional and operational requirements. One of the main functional requirements was parachute deployment, and this was tested on the ground by simulating apogee conditions. Another functional requirement was the recording of inertial measurements (IMU), and this capability was also tested on the ground by testing the IMU sensor. To sound data, four functional requirements to measure ambient humidity, ambient temperature, atmospheric pressure, and Ultraviolet (UV) rays were included. These were all tested by verifying sensor outputs against ground values. Although not implemented, real-time data transmission was another subsystem requirement. A final functional requirement was to visually document flight conditions via a camera, and this was tested on the ground with a monitor. In addition to these, there were three main operational requirements surrounding the power management, data logging, and avionics bay systems.

4.2.2 Subsystem Components/Analysis

4.2.2.1 Bay Configuration

The avionics system was housed in the Avionics Bay (AvBay). The first iteration consisted of a single sled in between two bulkheads as seen in **Figure 9a**. The AvBay contained sensors, a PCB, two altimeters, a CO_2 ejection charge, and switches. Due to time constraints, components were rearranged throughout the assembly process, resulting in the real AvBay to look slightly different as seen in **Figure 9b**.

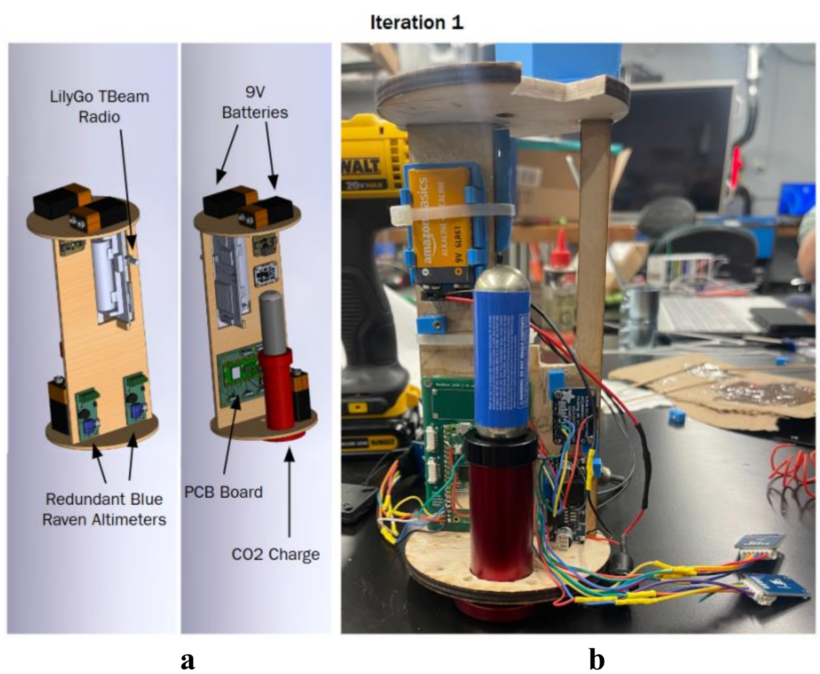
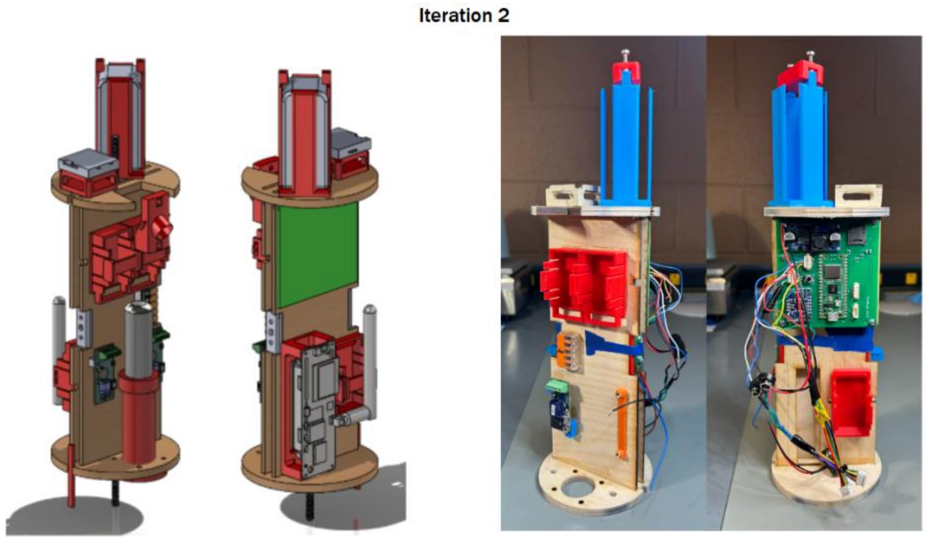


Figure 9. First Iteration of Avionics Bay CAD (a) and Real Bay (b).



a b

Figure 10. Second Iteration of Avionics Bay CAD (a) and Real Bay (b).

After the unsuccessful launch attempt on March 23rd, the Avionics subteam decided to remake the avionics bay with a cleaner layout that would be easier to assemble at the launch site. The second iteration of the avionics subsystem (Figure 10a) included two sleds, as opposed to one, sandwiching the rod to prevent it from getting caught on any wires during rocket assembly. One side contained all sensors and PCB systems, while the other contained mission-critical components like the altimeters and ejection charge. All components were fastened onto the AvBay using custom 3d printed mounts. This new design allowed for easier wire management and cleaner attachment methods. The second iteration of the AvBay is seen in Figure 10b.

4.2.2.2 Manufacturing

There were multiple manufacturing methods used within the AvBay. For the sleds and bulkheads, a combination of ¼” and ⅛” Baltic birch wood was used. This was cut into shape using a laser cutter and assembled with fast-set epoxy. A Printed Circuit Board (PCB) was designed and used as a foundation to mount electrical components, as seen in Figure 11, neatly. The PCB was outsourced for printing by JLCPCB. Finally, 3D printed mounts were developed to allow components like altimeters and sensors to be elevated and removable on the AvBay. Other components were 3D printed, like the LiPo, 9V battery, and transmitter mounts.

4.2.2.3 Camera

The camera system used was the Walksnail Avatar HD Pro VTX and VRX. The system selected had issues regarding maintaining functional temperatures and reception. This was in part because the heat sink for the final design was ultimately scrapped to save on weight. However, designing and testing a heat sink and mounting the antenna externally would be a worthwhile endeavor. Besides those faults, the camera and capture card system both worked sufficiently well to provide high-quality recording and streaming capabilities.

4.2.2.4 Sensors & Wiring

In the first iteration, rocker switches were used to turn on both altimeter systems. On March 23rd, after placing the AvBay within the rocket, it was proven to be difficult to turn on.

To flip the switch, a lot of force was required. Given that there was a small hole in the upper body tube for the team to access the switch, the second iteration changed these components. In the second AvBay design, screw switches were supplied by a team advisor which was much easier to access through a small port on the side of the aerobody tube. This allowed for fast and easy access to turn the altimeters on.

4.2.2.5 PCB

The sounding sensors monitoring humidity, temperature, pressure, and the UV index in addition to the IMU, were powered and interfaced with the Raspberry Pi Pico W using a PCB. The PCB was 2 layers, with one being ground. There were SMD Pico blade connectors to wire to the externally mounted sensors and an SD card reader with its required circuitry. The schematic in Appendix C outlines each of the connections and the nets they fall into. The layout seen in **Figure 11** shows the routing between all of the components. Continuity tests were performed both before and after soldering on all components. For the second iteration, a DC-DC buck converter was mounted on the PCB to step down the 9V battery supply to the acceptable 5V that powered the RP Pico. Also, the SD card was added onto the PCB for the second time to minimize loose wire connections.

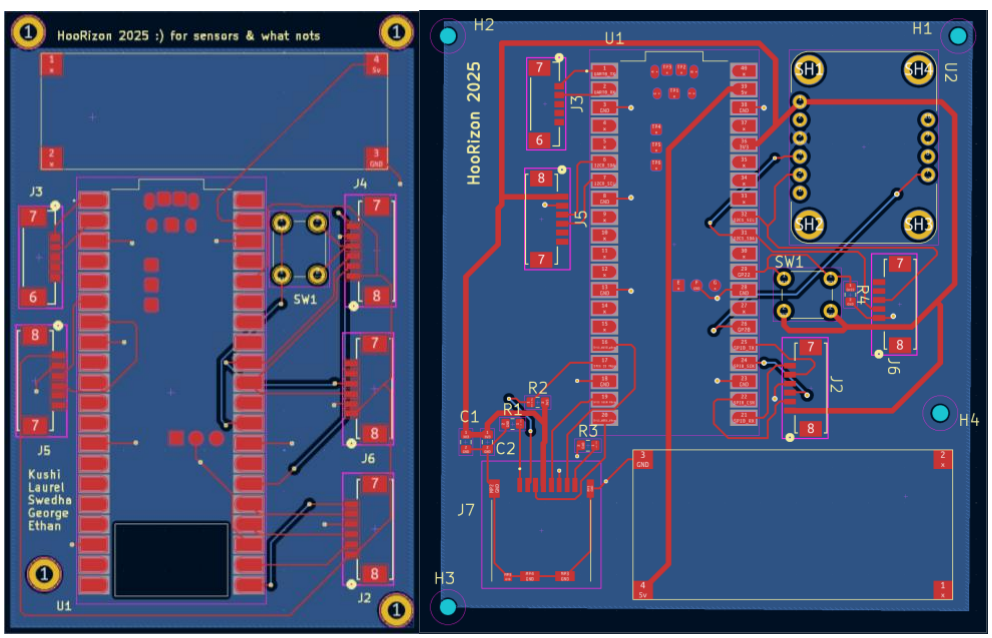


Figure 11. PCB Layout of First Iteration (Left) and PCB Layout of Second Iteration (Right).

4.2.2.6 Programming

The Raspberry Pi Pico W (RP Pico) was used to interface with the sensors through SPI and I2C protocols. To program the RP Pico, the Raspberry Pi C/C++ SDK was utilized. The BNO055 and LTR390 used I2C protocols, while the BME280 and SD card breakout board used SPI. For debugging, the sensors were individually programmed to communicate with the RP Pico. Once validated, the code for sensors was integrated into a main program that utilized the no-OS-FatFS-SD-SPI-RPi-Pico library from GitHub. This library allowed the sensor data to be logged into a microSD card.

4.2.2.7 Altimetry

The Blue Raven altimeter was a necessary component within the AvBay that tracks the altitude of the rocket and sends a current spike at a specific height that separates the rocket at the coupler. This is the most important component of the rocket since the parachute will not deploy and the rocket will not safely land without it. Figure 12 shows the wiring for the AvBay. This component is also user-friendly as it incorporates a smartphone application, Featherweight UI, that actively updates all measurements it takes. To test the altimeter, both ground and drone tests were performed. The smartphone application has a capability for a ground test for any of the four channels, and this was first performed to test the validity of the ejection channels. To test flight data, the altimeter was flown up via a personal drone and brought back down. During the drone test, the 9V battery supplying voltage to the altimeter did not have enough power to enable Bluetooth mode.

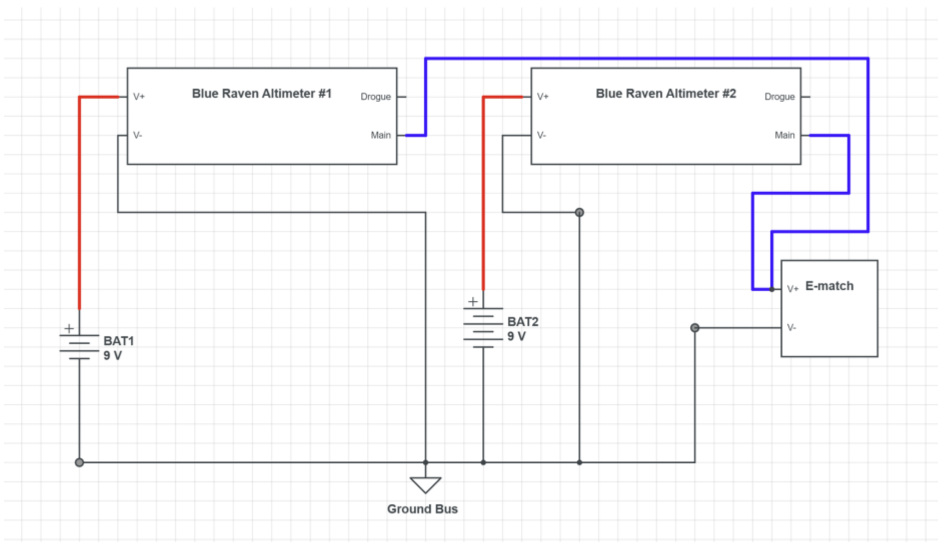


Figure 12. Original Altimetry Wiring Diagram.

4.2.2.8 Ejection System

This rocket used Tinder Rocketry's Eagle CO_2 ejection system with a 16 g cartridge, similar to the system shown in Figure 13. It works by the altimeter sending a current surge that sets off an e-charge. The e-charge then triggers a needle to puncture the CO_2 cartridge, creating an impulse strong enough to break the shear pins.

In rocketry, the two most common ejection systems are CO_2 and black powder. Despite CO_2 being less common, it was picked over black powder. Black powder uses hot gases that can damage and dirty other components, while CO_2 uses cold, pressurized air, making it safer and cleaner.

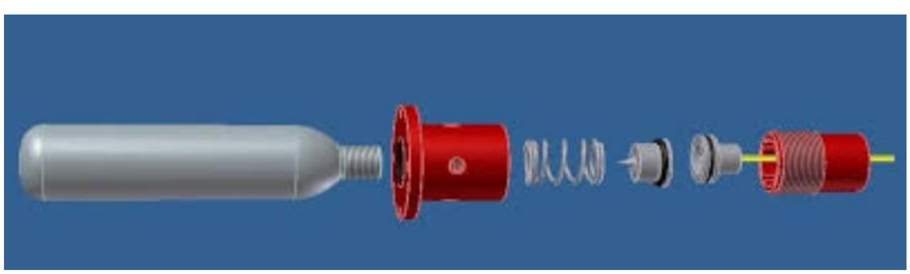


Figure 13. Model of CO_2 Ejection System.

4.3 Propulsion

The propulsion system includes the motor, motor casing, adapter components, aft end enclosures, and centering rings. The subteam is specifically tasked with selecting motor components to provide the propulsive force to aid in the rocket's apogee and stability objectives.

4.3.1 Subsystem Requirements

Within the overarching system objectives, propulsion was tasked with finding an engine appropriate for the mission, and aiding in the withstanding of flight loads/stability maintenance. To achieve those objectives, the requirements were to select a motor and motor mount tube that could help the rocket reach an apogee between 3,000 - 4,000 ft, and fit within the body tube. These requirements were to be verified with OpenRocket and SolidWorks simulations, respectively. Finding an engine appropriate for the mission required consistent feedback regarding the weight and structure of the rocket to maintain needed stability and apogee requirements. As the team streamlined motor selection, additional constraints and requirement details were determined, which are described below.

4.3.2 Preface: COTS Constraint

It is important to note firsthand that the motor was constrained, given that the first launch for Tripoli Certification had to have all Commercial Off The Shelf (COTS) components. The team focused on simulating and testing motor components for optimal performance and designing/testing the centering rings. Fortunately, many of the characteristics of the COTS motor components (diameter, class, etc.) were standardized, which greatly reduced the complexity of motor component selection.

4.3.3 Motor Selection

A primary goal was set to reach a minimum altitude of 3,000 ft. To accomplish this, and given a set mass range, it was determined that a level 2 motor was needed. In particular, of the available letter designations, K, L, and J-class motors were the most likely to fit the mission needs. J-class motors have an impulse range between 640.01 to 1,280 Newton-seconds, which was enough to carry the rocket to the height limit. When deciding on a motor, a height range was taken into account. The team defined the height range as the distance between the minimum altitude, 3,000 ft, and the height restriction, 4,000 ft. To make this range more consistent in terms of narrowing motor selection, it was constricted between 3,400 ft and 3,600 ft. It should be noted that the primary altitude goal was not changed to 3,400 ft. This range was set in place to narrow motor selection and provide a safety net. The safety net accounted for any added mass after motor selection to ensure that the rocket would reach its minimum altitude. It also ensured that the rocket would not fly beyond the field height restriction.

After constraints were set, the propulsion team began running simulations on motors for selection. To conduct simulations, OpenRocket software was used to model the rocket. Using the rocket blueprint specifications (design, size, weight, etc.), motors from Cesaroni and Aerotech (whose data was already included in the Open rocket software) were tested relative to the rocket. The data that was taken into account was altitude, burn time, specific impulse, product availability (determined through distributor websites), size(radius), and ejection charge fuse. All data was compiled and then narrowed down to three motors to choose from: Cesaroni J430, Cesaroni J380, and Aerotech 180T. The motor selected of the three was the J 430, boasting the most optimal delivery time, price ($146.72), altitude within the height range (3,465 ft), and casing price ($104.12).

Due to complications with level two motor certification, time constraints, provider availability, shipping and handling procedure, the team was unable to acquire this motor, or any other selected/modeled motors. A partner/advisor to the project provided us with a spare level 2 motor. The motor used was the Cesaroni J 350W. Simulated calculations predicted an altitude of 2,736 ft.

4.3.4 Motor Adapter Components

The motor selected had a 38 mm diameter. To align with the propulsion system that was originally designed for a 54 mm motor, a motor adapter was used. This aluminum adapter allows the 38 mm diameter engine to be integrated into the motor mounting system without any faults. The adapter shown in orange below played an important role in allowing for an easy integration for either size motor, without compromising the weight considerations.

4.3.5 Centering Rings

Our centering rings served multiple functions in ensuring the structural integrity of the rocket. First and foremost, they secured the motor mounting tube, which contains the rocket engine, within the body tube. This arrangement maintains proper alignment and allows thrust forces to be transferred from the engine to the body. Secondly, during the recovery stage, the rings help absorb the dynamic loads created when the parachute deploys. A third function of the centering rings is to support the fins by providing an internal mounting point for fin tabs, which experience significant aerodynamic loading in flight. With these roles defined, the final design includes three centering rings, each made by laminating two ¼-inch birch layers (for a total thickness of 0.5 inches). As shown in Figure 14, the lower two rings have notches for fin support, and the upper ring features two ¼-inch holes for eye bolts that attach to the parachute.

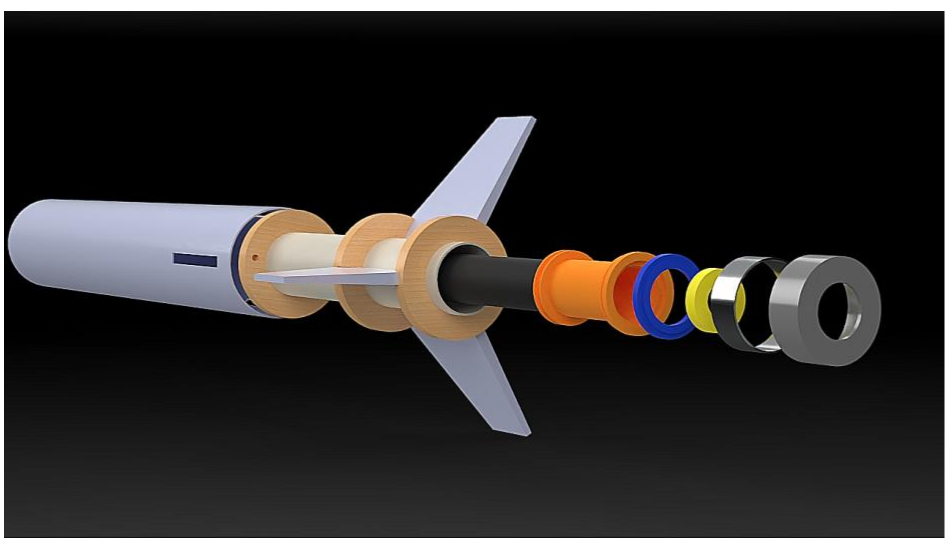


Figure 14. Exploded Engine Assembly.

In developing this design, there were three key priorities: ensuring adequate strength, simplifying manufacturing and assembly, and minimizing both cost and mass. Given these constraints, birch wood was selected for the material because of its excellent strength-to-weight ratio and ease of bonding with common adhesives like epoxy. Alternative materials such as aluminum or composite plates could offer even greater strength, but would come with higher costs and fabrication complexity, which did not yield a net benefit for the project requirements.

To create the centering rings, SolidWorks and the laser cutter in Lacy Hall were used. Through that process, a tight tolerance of 0.2 mm was achieved around both the body tube and motor tube interfaces and for the fin tab cutouts. Such a clearance allows epoxy/wood glue to fill any gaps evenly and create a strong bond. While waterjet cutting was considered, concerns about waterlogging and weakening the wood led us to dismiss that option. After cutting, we reinforced each ring by laminating two ¼-inch birch layers to achieve the necessary 0.5-inch total thickness. This additional thickness helps prevent deformation under thrust and parachute deployment loads.

Once the laminated rings had fully cured, we thoroughly inspected them and performed a test fit on the motor mount tube before installation. Although the fit was slightly looser than anticipated, it did not compromise structural integrity, since the wood glue filled any gaps between the inner rings and the outer motor mount tube. After confirming a secure fit, we applied epoxy to the outer surfaces of the rings and created epoxy fillets along the outer diameters and around the fin tab interfaces, ensuring even stress distribution and reinforcing the overall load path. As shown in Figure 15, the fillets further improve the structural continuity between the fins, centering rings, and body tube. Ultimately, this approach of careful material selection, straightforward fabrication, and easy precision assembly ensured that the centering rings reliably handled both thrust-generated forces and the abrupt impacts associated with recovery.

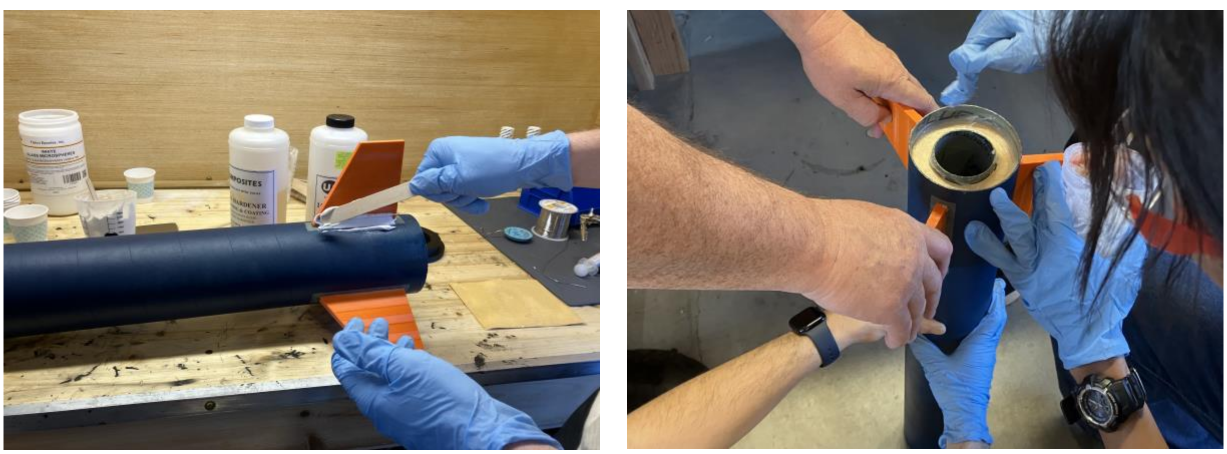


Figure 15. External and Internal Fillets Being Applied.

4.3.6 Subsystem Analysis:

4.3.6.1 Centering Ring Simulation

Simulations were run on the centering rings to confirm their ability to successfully transfer the propulsive force of the motor to the body tube and to withstand the force of the parachute when deployed (Figure 16). If the rings were to fail, the engine could bullet through the body of the rocket, or the parachute could rip the eye bolts out of the rocket. To test these rings, models were made in Solidworks, and their material was defined. Based on the thrust curve, the maximum force applied by the motor would be 614 Newtons. Applying this force to the inside diameter of the centering ring and running the simulation provides a minimum factor of safety of 42. The eyebolt holes were tested with the 350-pound maximum force from the parachute. This simulation yielded a minimum factor of safety of 9.8, proving the centering rings' capabilities for flight.

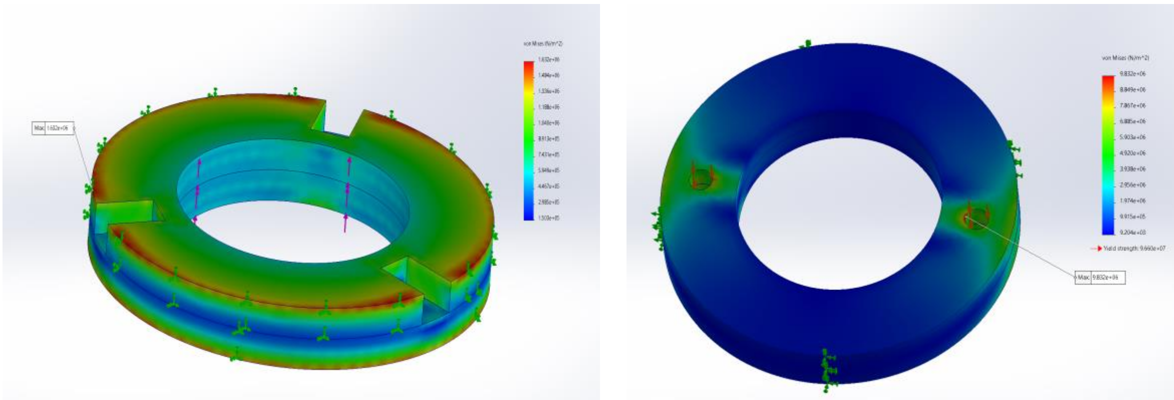


Figure 16. FEA Analysis of Motor and Parachute Forces.

4.3.6.2 OpenRocket Simulation

Using the model created by the aerobody team in OpenRocket, a chosen motor and its thrust profile can be added to run a simulation. Numerous simulations can be created, but the most important simulation that was run predicted the altitude versus time and therefore the apogee. The limiting factor of apogee is the 4,000-foot maximum allowable height at the launch site. The simulation predicted an apogee of 2,750 ft and a flight time of about 100 seconds. While this does not reach the original 3,000-foot goal, it does not exceed the criteria of the launch site. OpenRocket was also used to predict the drift of the rocket due to wind. The simulation predicted that the rocket would land on the launch site (Figure 17).

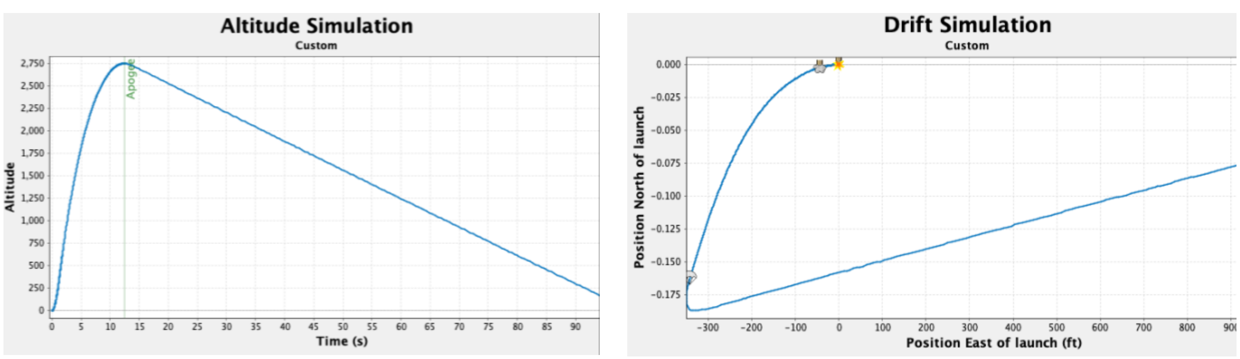


Figure 17. OpenRocket Simulations Showing Altitude and Drift.

5 Launch Day Breakdown

5.1 Pre-Flight

Leading to the launch, we created a pre-flight checklist to prepare the rocket for flight in a defined sequential order. Before the rocket would officially launch, the team had to conduct a ground ejection test to ensure that the rocket would safely separate when the altimeter detected apogee. While prepping and connecting the avionics, the technical advisor, Professor McPherson, started assembling the motor to fit into the rest of the motor assembly. The team prepped the rocket as if it were the actual launch, folding the shock chord, attaching the parachute, sliding the avionics bay into the upper body tube, and then inserting the motor and motor casing into the aft end of the assembly. With the retention ring screwed into place, the avionics were armed, and the rocket was ready for the ejection test.

Three ejection tests occurred: one where the rocket failed to separate, one where the rocket separated but from the nose cone instead of the coupler, and one that was fully successful. There were two altimeters on the avionics bay, one of which was set to work as a backup system. However, one of the altimeters seemed faulty, so the decision was made to fly with just one altimeter. A check-in was conducted with the range safety officer, which included weighing the rocket with the motor inserted, a discussion on flight characteristics (such as expected apogee, motor class, etc.), and confirmation that the ejection test was a success. Then, the team was cleared to launch. A flight card was given, and the rocket was mounted on the third farthest line of launch rails.

5.2 Post-Flight

While the apogee altitude of the rocket was hard to determine, it was estimated to be around 2,500 ft. During the flight, the parachute failed to deploy, and the rocket descended directly south past the launch range and onto an empty field. When it landed, the upper body tube and nose cone crumpled, creating approximately an 8-inch deep crater in the field. The motor assembly was mostly recoverable, except for the uppermost centering ring. Please reference Appendix E for images post-launch.

The team reconvened at the setup area after collecting the remaining pieces of the rocket and did preliminary analysis and discussion on the potential causes of the separation failure. It was hypothesized that the altimeter had failed to send a signal to the CO_2 cartridge to separate the upper and lower body tubes. This was supported by the fact that the e-matches were still intact and the ejection system still contained black powder even though the cartridge was punctured. Most likely, the power wire connected to the altimeter disconnected upon launch. Solid core wires were used to connect the altimeter's screw terminals to power and ground. It is hypothesized that the vibrations and g-forces experienced by the system during launch disconnected this wire, preventing the altimeter from sending a current spike that would ignite the e-matches and trigger ejection.

6 Risk and Reliability

For a first-time launch like Hoo-Rizon 1, careful risk mitigation and reliability planning are essential to ensure mission success and safeguard valuable hardware. Proactively addressing potential failure points allows the team to learn safely, build confidence, and pave the way for future high-powered launches. Figures 18 - 20 show the pre-mitigation and post-mitigation assessments of the various subteams. Tables II - IV highlight the qualitative risk and mitigation strategies.

6.1 Aerobody Risks

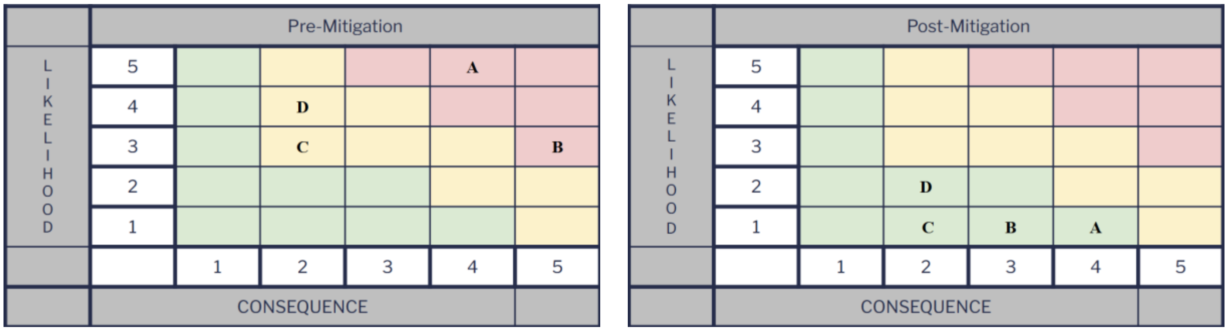


Figure 18. Pre and Post-Mitigation Contrast of the Aerobody Subteam Risks.

Table II
Aerobody Subteam: Pre and Post-Risk Mitigation Strategies

Aerobody Risk Mitigation		
Risk Letter	**Risk**	**Mitigation**
A	Overlook of Tripoli + rocketry regulations	Getting a secondary check with Tripoli safety personnel
B	Failed recovery system deployment	Standard Packing, Tape, Insulation
C	Nose Cone structural failure from ejection	Shock Cord material and length, mass distribution, Tape, Shearing Pins
D	Fin Flutter	Infill increase, Wind tunnel and calculation verification

6.2 Avionics Risks

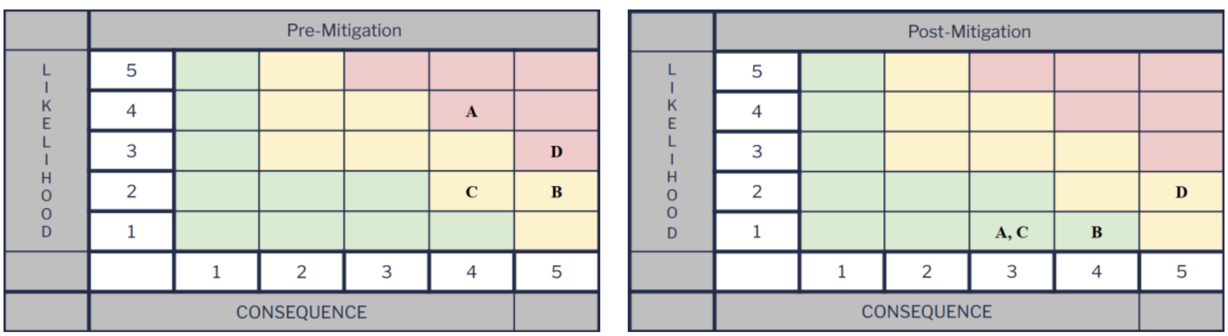


Figure 19. Pre and Post-Mitigation Contrast of the Avionics Subteam Risks.

Table III
Avionics Subteam: Pre and Post-Risk Mitigation Strategies

Avionics Risk Mitigation		
Risk Letter	**Risk**	**Mitigation**
A	Lead time for avionics components	Found alternative components
B	Altimeter fails	Have two altimeters connected to ejection charges
C	Jolly Logic fails	Tested with drone & have Jolly Logic in series in case the first doesn't unhook

D	CO2 ejection failure	Ground test CO_2 ejection system

6.3 Propulsion Risks

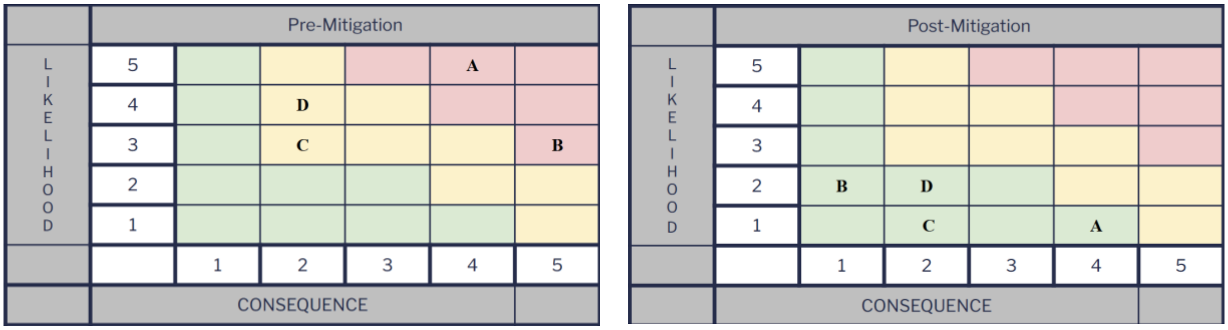


Figure 20. Pre and Post-Mitigation Contrast of the Propulsion Subteam Risks.

Table IV
Pre and Post-Risk Mitigation Strategies of the Propulsion Subteam

Propulsion Risk Mitigation		
Risk Letter	**Risk**	**Mitigation**
A	Overlooking Tripoli + Rocketry regulations	Getting a secondary check with a Tripoli safety personnel
B	Concern over faulty motor (pre-launch manufacturing errors)	Acquisition of a second motor to serve as a backup and/or for a secondary launch
C	Displacement of centering rings due to stress from shock cord	Selection and simulation of a durable material + doubling up of centering rings
D	Uneven horizontal drying of epoxy	Creation of an upright drying apparatus

7 Conclusion

The *Hoo-Rizon 1* Rocket Capstone project successfully achieved its primary objective of designing, building, and launching a subscale, single-stage sounding rocket, despite setbacks during recovery. The team followed a rigorous engineering process guided by system and subsystem-level requirements, iterative design strategies, and continuous validation through simulation and physical testing. Each subsystem contributed to a cohesive, functional launch vehicle. This project not only laid the foundation for continued advancement in rocketry at UVA but also equipped students with skills and experience that will serve them well in aerospace and related fields.

7.1 Future Recommendations

Throughout the process of designing, building, and launching Hoo-Rizon One, the team encountered several challenges that led to valuable lessons. These insights should serve as guidance for future capstone teams to streamline their workflows and avoid common setbacks.

7.1.1 Aerobody Recommendations

For 3D-printed nose cones, consider adding a tip fillet or reinforcing with a stronger material to prevent chipping, especially during handling or ejection tests. Use a 3D-printed jig or sleeve to ensure accurate, repeatable hole placement on the body tube. Also, assess whether composite fabrication is worth the effort—commercially available body tubes are often cost-effective and save significant time.

7.1.2 Avionics Recommendations

Acquire altimeters early and begin ground testing immediately, as they are mission-critical and must be validated to prevent delays. Complete and assemble the avionics system early to allow time for troubleshooting and advisor feedback. Regular check-ins with the capstone advisor (e.g., Prof. McPherson) help ensure safety and performance standards. Do not launch with only one altimeter.

7.1.3 Propulsion Recommendations

Careful planning of the assembly sequence is essential. Make sure all components, like eye bolts, are in place and centering rings are aligned before applying epoxy, as adjustments aren't possible after curing. Establish both primary and backup motor options early, since availability can vary seasonally. When choosing propulsion hardware, consider that Aerotech is more commonly used in amateur rocketry, while both Aerotech and Cesaroni offer reliable, well-documented systems. Apogee Rocketry is a helpful resource for motor selection, compatibility, and ordering.

7.1.4 Team Organization

We recommend assigning one lead per subteam—propulsion, avionics, and aerobody—with a project manager overseeing the entire effort. This structure improves coordination and oversight. Given its heavy workload, the avionics team should be split into two groups: one for sensor systems and one for the physical hardware, and should include more total members. To ensure continuity, we suggest establishing a formal outreach process to attract new members early and maintaining a persistent Discord channel as a knowledge-sharing hub for current and future teams.

8 Acknowledgements

The team would like to express their sincere gratitude to the team advisors, Dr. Haibo Dong, Dr. Chen Cui, and Jiacheng Guo, along with Prof. McPherson and Dr. Goyne, for their invaluable guidance, support, and encouragement throughout the course of this project. Their insights and expertise greatly enhanced the quality of this work and helped the team achieve its goals.

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Appendices

Appendix A: Budgets

Monetary Budget

The estimated budget for the capstone splits the original budget ($2,800) into four categories. These included the aerobody, avionics, and propulsion subteams and a buffer category. The breakdown of the estimates is in **Table V.**

Table V

Original Estimated Budget

Category	Budget
Aerobody	$500
Avionics	$1,000
Propulsion	$700
Miscellaneous	$600
Total	$2,800

After gaining a new member in the spring semester, the budget increased to $3,000. Furthermore, the budget shifted as new design considerations were made with the avionics subteam. All categories were under the original estimated budget, as seen in Table VI. A rough estimate of the final budget's total is about $1,600.

Table VI

Final Budget

Category	Budget
Aerobody	$295.63
Avionics	$874.43
Propulsion	$131.99
Miscellaneous	$281.43
Total	$1,583.48

Note: This total does not reflect items that were purchased as a result of replacing borrowed components.

Power Budget

The power budget breaks down the various components on board the AvBay. As seen in Table VII, each component has its voltage, maximum current, power usage, active time, and energy consumption listed.

Table VII

Power Budget

Component	Voltage (V)	Current (A)	Power (W)	Active Time (s)	Energy (J)
Blue Raven	9	0.002	0.018	120	2.16
RP Pico	3.3	0.7	2.31	120	277.2
BME280	3.7	0.014	0.0518	120	6.216
IMU	5.0	0.015	0.075	120	9
UV Rays	3.3	0.02	0.066	48	3.168

Weight Budget

The weight budget values in Table VIII were found through OpenRocket simulations, while the total was based on the measured weight at Tripoli.

Table VIII

Weight Budget

Subteam	Weight (lbs)
Aerobody	4.1
Avionics	1.5
Propulsion	2.5
Miscellaneous*	2.1
Total	10.2

*Items not accounted for in modeling, such as epoxy, wood glue, and wiring. Miscellaneous weight was determined using the total weight measured before launch.

Appendix B: PCB Schematic

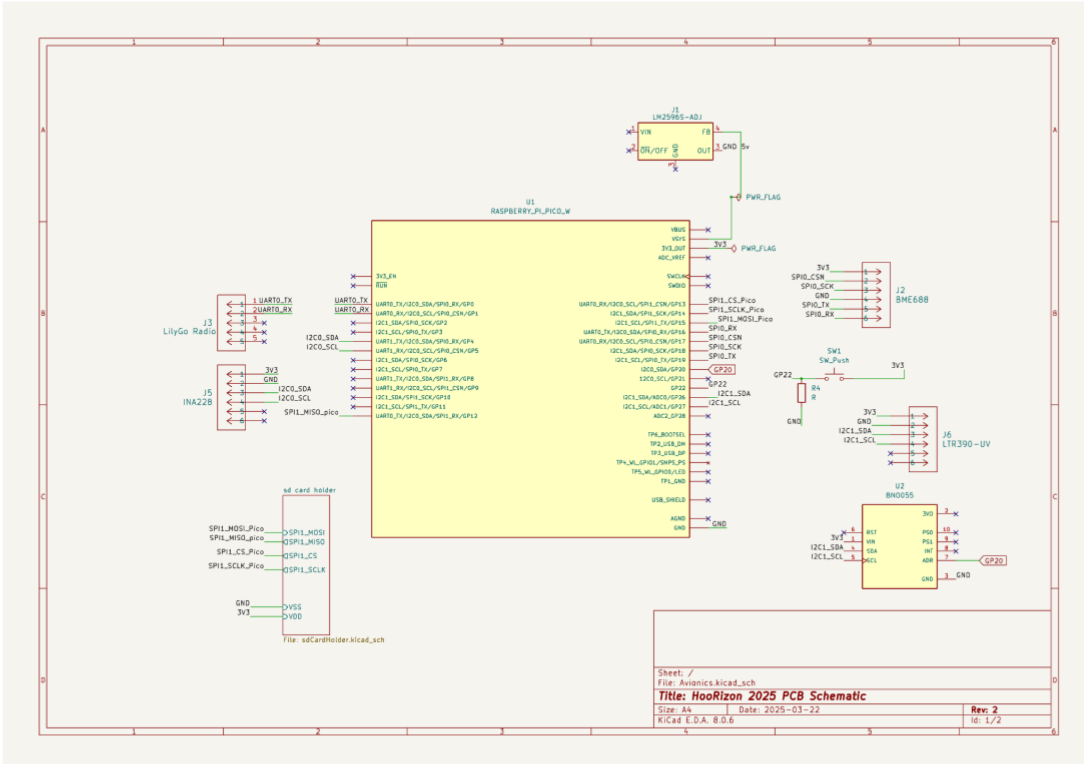

Figure 22. Top level PCB schematic for sounding sensors and on board computer

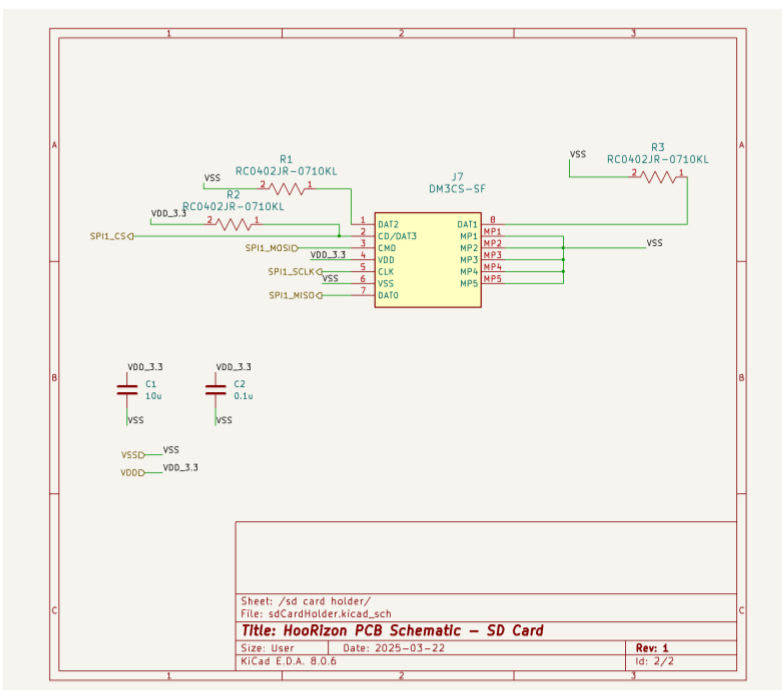

Figure 23. PCB Schematic of the MicroSD Card

Appendix C: Codes and Standards

Table IX
Codes and standards governing Hoo-Rizon One launch

Code/Regulation	What it Covers
FAA Order JO 7400.2 Chapter 31 Section 2	Amateur Rockets
14 CFR 101.22 (b)	Class II Rocket Regulations
14 CFR 101.25	Operating limitations for Class 2-High Power Rockets
NFPA Code 1127	Code for High Powered Rocketry (Requires purchasing)
NAR	High Power Rocketry Safety Code

Appendix D: Post-Launch Rocket Images