UNIVERSITY OF SOUTH FLORIDA

NASA STUDENT LAUNCH

CRITICAL DESIGN REVIEW

JANUARY 8TH, 2025

4202 EAST FOWLER AVENUE, MSC BOX#197

TAMPA, FL 33620

USF SOCIETY OF AERONAUTICS AND ROCKETRY

THE SKY IS NOT THE LIMIT.

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1 Summary of CDR Report

1.1 Team Summary

Table 1. Team Information

Team Summary				
Team Name	Society of Aeronautics and Rocketry at University of South Florida	Hours Spent on CDR	120
Mailing Address	4202 East Fowler Avenue, MSC Box #197		
Mentor	Enrique Hernandez - enriqueh@usf.edu TRA number: 22521 - Level 2 Certification		

1.2 Launch Vehicle Summary

Table 2. Parachute Information

	Diameter (in)	Cd	Area (m^2)	F Velocity (m,s)	F Velocity (ft,s)
Main	96	2.20	4.67	5.04	16.53
Drogue	18	1.55	0.16	32.02	105.05

Table 3. Vehicle Specifications

Criteria	Value
Target Altitude (ft.)	4075
Motor Selection	Cessaroni Technologies inc. L995
Dry mass without Ballast (lb)	29.4
Dry mass with Ballast (lb)	32.4
Rail Size	1515
Burnout/ Landing Mass (lb)	35.91
Wet Mass (lb)	40.35
Outer Diameter (in.)	6

Table 4. Vehicle Section Specifications

Criteria	Upper Section	Mid Section	Booster Section	Total
Mass (lb)	12.95	11.31	16.1	40.35
Length (in.)	47	30	20.7	97.7

1.3 Payload Summary

The main scoring payload is the Ground Observation Signal Transmitter (G.O.S.T). It consists of doors that will open in the payload coupler to allow the collection of atmospheric data while staying inside the rocket. An APRS system is used to transmit the data to a NASA transceiver upon landing.

2 Changes made since PDR

2.1 Changes made to Vehicle Criteria

Since the Preliminary Design Review, the vehicle went through significant changes. Given that the team was unable to secure the primary motor choice due to supply shortages, a decision was made to utilize a different non-listed motor choice: the Cesaroni L995. This design significantly impacts the design of the vehicle, as the new motor experiences a much lower total impulse. This forces the team to make the rocket as light as possible while still being within the allowable apogee margins. For instance, the camera system, bolted fins assembly, and boat tail were removed from the vehicle design. Other systems like the payload, Airbrakes, and total length of sections were modified to reduce total weight. These changes allowed the team to decrease the projected vehicle mass by 15 lbs.

2.2 Changes made to Payload

The Payload was updated to reflect motor choice, the refinement of the stringer system, and Servo-Door actuation system. The change of materials from Aluminum to Carbon-Fiber Nylon in actuation parts such as hinges to save weight while keeping strength. The length of the system was reduced by one inch and decreased in diameter to fit within a coupler.

2.3 Changes made to Airbrakes

The airbrake details have changed since the last milestone. However, the core design of the system remains the same. The system was modified to keep it below 5 lb. Parts were optimized to be lightweight when possible by removing unnecessary material. Moreover, the length of the system was reduced, limiting the maximum amount of weight on the stringers. The design of the sleds was refined and concluded.

2.4 Changes made to Project Plan

The project plan has been updated to reflect a timeline shift and the introduction of more focused milestones and tasks. These changes were prompted by the delayed Subscale Demonstration Flight, initially planned for November but completed in December, which caused a cascade effect on the overall timeline. The first full-scale flight and vehicle demonstration flight are now scheduled for February 8th, reducing the number of full-scale launches to two. This limitation emphasizes the importance of effective testing within the compressed schedule while managing an increased volume of tasks. The revised milestones prioritize manufacturing final parts and testing systems intended for the actual flight, representing a shift from experimental tasks to systems that will actually fly. These milestones include key phases such as manufacturing, assembly, hardware integration, and system demonstrations. More details about these milestones and the updated tasks are provided in Section 7.4. This approach ensures the readiness and reliability of systems, aligning with the project's transition into its final stages and the rigorous requirements of the NASA Student Launch competition.

3 Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

3.1.1 Mission Statement and Success Criteria

The mission of the launch vehicle system is to guarantee a safe launch from ground to apogee to the payload system. Therefore, the team has to closely collaborate with the payload team to understand their needs and ensure that the payload requirements are feasible and obtainable. The team follows the NASA-given requirements to design and construct the launch vehicle.

The success of the launch vehicle will be measured with the following success criteria.

- The vehicle shall maintain structural integrity throughout the entire flight.
- The vehicle shall remain undamaged after landing.
- The static stability shall be greater than 2 cal.
- The off-the-rail velocity shall be greater than 52 ft/s.
- The vehicle shall not interfere with any of the payload's actions.
- The projected altitude shall be 200 ft greater than the target altitude for airbrake correction.

3.1.2 PDR Design Alternatives

The payload system drives the design of the entire rocket. Therefore, the rockets were built around different payload ideas. However, the team was made aware of the great lack of availability of the motor choice, calling for a fourth design configuration. In the following sections, each rocket design will be detailed and a leading configuration will be chosen.

3.1.2.1 Fixed Payload Design

In the previous report, this idea was reported as the leading one. As the name suggests, it consists of a rocket that is designed around a payload that is fixed around the launch vehicle. The vehicle design consists of 3 independent sections.

The Upper Section is the first independent section from the tip of the rocket. It contains the ballast and payload system. It has 2 couplers of which 1 is at a separation point. This exposed coupler has an anchor point that connects the Upper Section to the Main Parachute and the rest of the tethered rocket.

The Mid Section is the second independent section. This section, before apogee, contains all the recovery systems within. The parachutes, shock cords, and avionics are contained within this section. The core of this section is the avionics bay, which shares space with the Airbrakes system. The location of the energetics is at both ends of the avionics bay. The Mid Section contains 2 points of separation at both ends of the airframe. No coupler is present in the second independent section.

The Booster Section is the third independent body. It is the heaviest and most structurally complex section. The Booster Section is the heaviest and most structurally complex section. The motor is placed at the end of this section through a custom-built motor retention system that will also connect the fins to the airframe. The Booster Section will also integrate a camera bay, whose exposed coupler will have an anchor point that will connect the Booster Section to the drogue parachute and the rest of the tethered rocket.

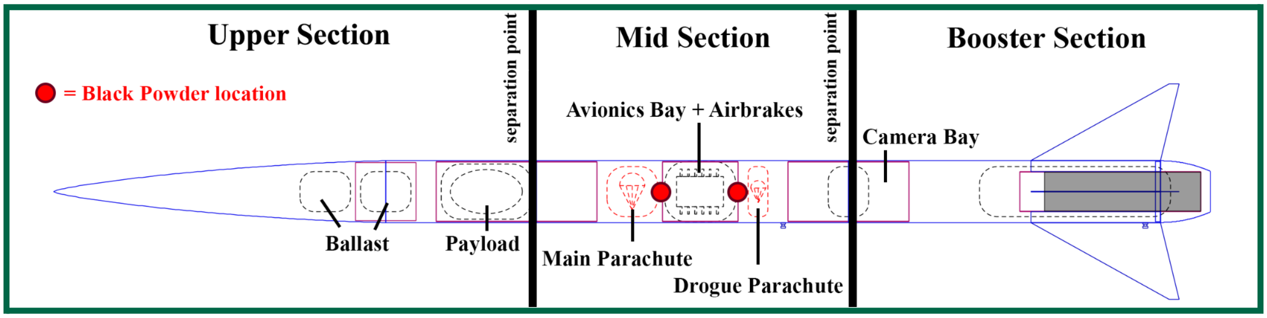


Figure 1. **Fixed Payload Design OpenRocket Model (L3150 Motor)**

3.1.2.2 Nosecone Drone Payload Design

The second vehicle configuration, as the name suggests, contains a jettisoning payload. A very important design feature that drastically changes the vehicle design is the way the payload is deployed. The falling payload would be part of the nosecone, allowing for an easy deployment during descent, when the nosecone is facing downwards. This implies a non-traditional nosecone that would allow for clearance during descent and safe landing. In comparison to the previous vehicle configuration, this section consists of 4 independent sections: Falling Payload, Upper Section, Mid Section, and Booster Section. Only the last 3 sections are tethered together.

The Upper Section will house the payload and ballast system until the target payload deployment altitude is reached. Until then, the system is secured to the airframe of the rocket, serving as the main structural component. The anchor points of this section would be at the end of the payload coupler, which is connected to the main parachute and the rest of the tethered vehicle.

The Mid Section houses all the recovery systems. The avionics bay, main, and drogue parachutes are located in this section. However, given that a deployable payload is being designed, this rocket configuration will not have an active airbrake system.

The Booster Section is not quite different from the other configuration. The fins of this launch vehicle design were modified to accommodate the short nosecone. As a result, the center of pressure was kept at a distance that stays within the requirements.

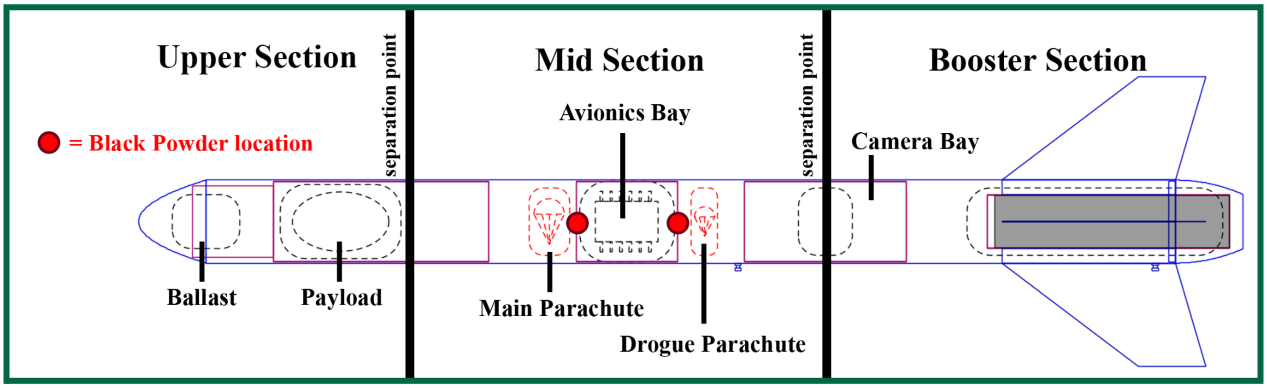


Figure 2. Nosecone Drone Payload OpenRocket Model

3.1.2.3 Airbags Payload Design

The last vehicle design configuration consists of a modified version of a jettisoned payload. In this scenario, the nosecone would be dropped as an independent section, allowing for a free path for the payload to be deployed. This section will contain 4 independent sections, of which only 2 are tethered: Mid and Booster Sections.

The Upper Section will contain the deployable nosecone, ballast system, and deployable payload. During descent, the nosecone will be deployed under a small parachute. This will allow for an easy and straightforward payload jettisoning, which will happen shortly after the nosecone deployment.

The Middle Section will house the recovery system. The Avionics Bay and parachutes will be housed in this department. Like the second vehicle configuration, the Airbrakes were removed from this rocket, being compliant with the new maximum payload number requirement.

The Booster Section will house the motor retention, passive stabilization, and camera system. The vehicle experimented with a 3-fin bolted design configuration.

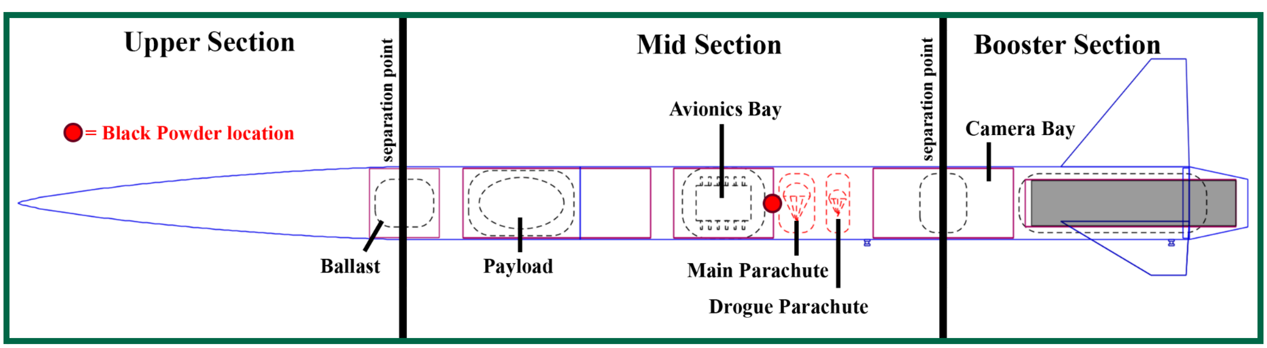


Figure 3. Airbags payload design OpenRocket model

3.1.2.4 Fixed Payload Design - Lightweight Version

Modifications were quickly produced to support the principal designs of the rocket once it was clear that acquiring the primary motor choice was not feasible. This was following the team's decision to move forward with a motor which was already available: the Cesaroni L995. The team is aware of the effects that would result from choosing a different motor than the declared motor choice in the PDR, and is willing to move forward with this option.

As a result of this drastic change, the team had to greatly modify the rocket in one main aspect: weight. The Cesaroni L995 has significantly less total impulse than the projected Cesaroni L3150. As a result, the team had to shave 15 lb from the design, removing many extra features while still keeping the core design. More lightweight options were chosen, a better mass distribution was obtained, and a more mass-focused design was followed. Similar to the previous fixed payload vehicle design, this fourth vehicle configuration consists of 3 independent sections: the Upper Section, Mid Section, and Booster Section.

The Upper Section is the first independent section from the tip of the rocket. The design of this section was not fundamentally affected by the design configurations and stayed quite the same. Length of this section was reduced.

The Mid Section has most of the recovery components of the vehicle. The laundry, avionics bay and Airbrakes are located in this section. The length of this section was reduced.

The booster section was greatly affected by the mass reduction changes. The motor retention method was changed from a bolted approach to the traditional epoxied method. The vehicle will use centering rings to fix the motor tube and fins in place. The length of this section was greatly reduced.

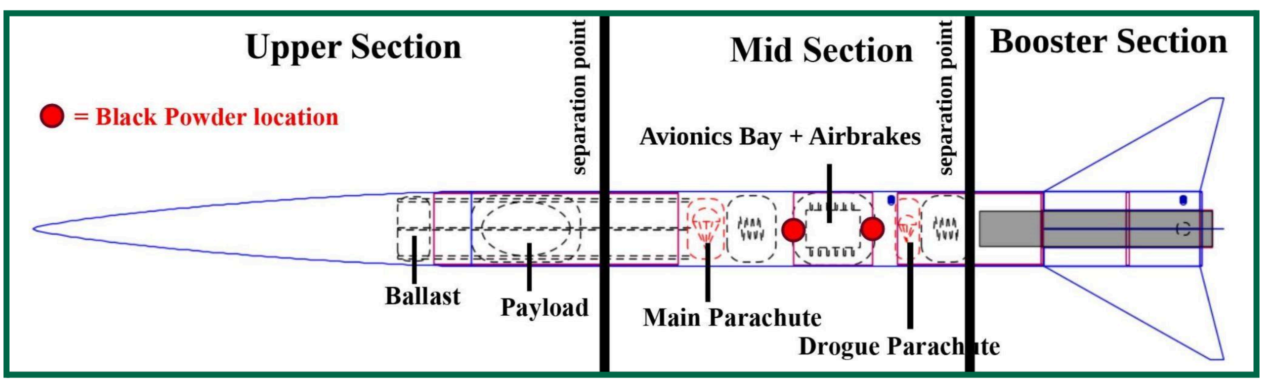


Figure 4. Fixed Payload Design OpenRocket Model (L995 Motor)

3.1.3 Vehicle Design Details

3.1.3.1 Vehicle Complete Assembly

3.1.3.1.1 Dimensions

The rocket has a total vehicle length of 97.77 inches, with distinct sections for the booster (20.50 inches), mid-section (30.00 inches), and upper section (47.00 inches). The design features an outer diameter of 6.17 inches and a wing span of 21.57 inches.

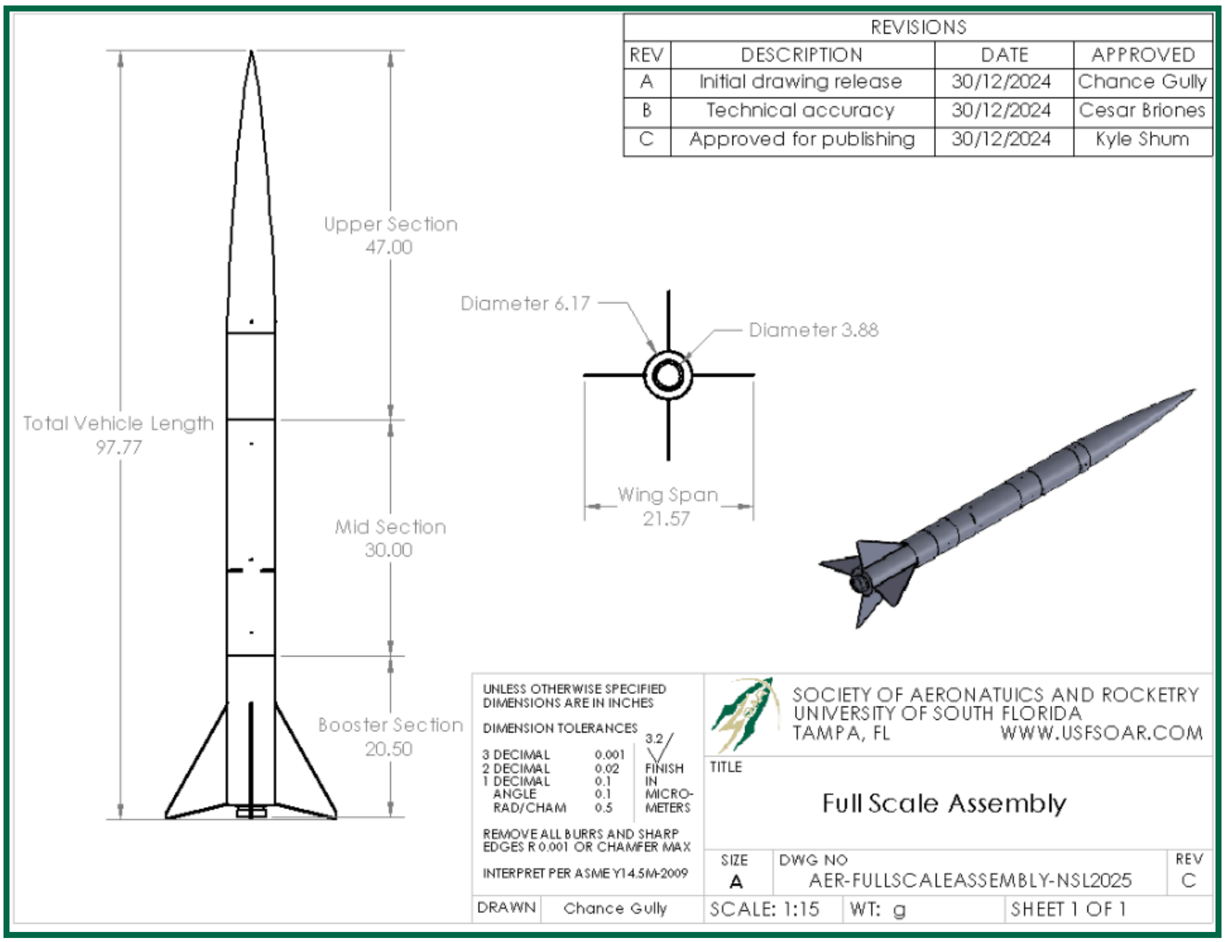


Figure 5. Fullscale Assembly Engineering Drawing

3.1.3.1.2 Mass

The fully assembled rocket has a total mass of 40.35 pounds. Starting with the section with the greatest mass, the booster makes up nearly half of the weight of the rocket, primarily from the motor due to the many complex mechanical and electronic components that are used during its fabrication and assembly. The coupler, airframe, retaining rings, motor tube, and fins all have low to medium impact on the mass as they are made from G10 fiberglass, which provides a high strength-to-weight ratio. The second greatest mass comes from the upper section, containing approximately one third of the total. The largest contributor for this section is the payload, once again due to its various electronic and mechanical components it contains. The ballast comes in a close second, with its construction being primarily of stainless steel. The coupler, nose cone, and airframe are again all made from G10 fiberglass, providing only a low-medium impact. The section containing the least mass for the rocket is the midsection, with its largest contributor being the Airbrakes and avionics bay. The avionics bay contains crucial electronic components and PLA encased in aluminum 6061 to protect them. The Airbrakes are made from a rigid material as well to allow for quick stopping without fear of structural or mechanical failure. The main parachute, main shock cord, drogue parachute, and drogue shock cord are all small contributors in the midsection. However, the airframe itself is a medium-high impact due to its greater size as compared to the upper and booster sections.

Table 5. Wet Mass Vehicle Section Components

Section	Mass (lb)	MASS %
UPPER SECTION	**12.95**	**32.08%**
Nosecone	2.49	6.17%
Ballast	3.00	7.43%
Airframe	1.05	2.59%
Coupler	2.41	5.97%
Payload	4.00	9.91%
MID SECTION	**11.31**	**28.03%**
Airframe	2.85	7.06%
Main	0.43	1.07%
Main Shock Cord	1.50	3.72%
Airbrakes + Av Bay	5.00	12.39%
Drogue	0.03	0.07%
Drogue Shock Cord	1.50	3.72%
BOOSTER SECTION	**16.10**	**39.89%**
Coupler	1.45	3.59%
Airframe	1.80	4.46%
Fins	3.14	7.78%
Motor	7.92	19.63%
Retaining Rings	0.85	2.10%
Epoxy	0.35	0.87%
Motor Tube	0.59	1.46%
TOTAL	**40.35**	**100.00%**

3.1.3.2 External Structures

3.1.3.2.1 Nosecone

The nosecone is made from fiberglass with a length-to-diameter ratio of 6:1. Compared to the PDR submission, there has not been a major change in the profile chosen.

The material was chosen to be fiberglass because of its lightweightedness, combined with heat-resistant characteristics and being durable. Fiberglass is resistant to damage from impacts, heat, and environmental conditions. This makes it ideal for repeated use or for flights, or repeated testing in environments where materials like plastic or wood might fail. Moreover, fiberglass can be molded with high precision into smooth and aerodynamic shapes. This reduces drag and improves flight stability and efficiency, which is essential for achieving predictable flight paths. The smooth surface of a fiberglass nosecone contributes to reduced turbulence and drag. Additionally, it can be painted or coated to enhance its appearance and further improve aerodynamic performance, which was the final decision for past iterations of the rockets designed by the team.

The nose cone design follows the Von Karman profile which is a special case of the Haack series optimized for a given length and maximum radius of the nose cone. The Von Karman profile is applied to minimize the drag on the rocket efficiently.

The profile is defined by the equation:

$$\theta(x) \ = \ arccos(1 - \frac{2x}{L})$$

With the variables being:

x: Distance along the axis from the tip of the nose cone.

L: Total length of the nose cone.

θ: Angular parameter corresponding to the position x along the nose cone.

Simplifying the Von Karman equation to the equation below because the C parameter equals 0 as a special case for the Haack series:

$$y(\theta) \ = \ \frac{R}{\sqrt{\pi}}\sqrt{\theta - \frac{sin(2\theta)}{2}}$$

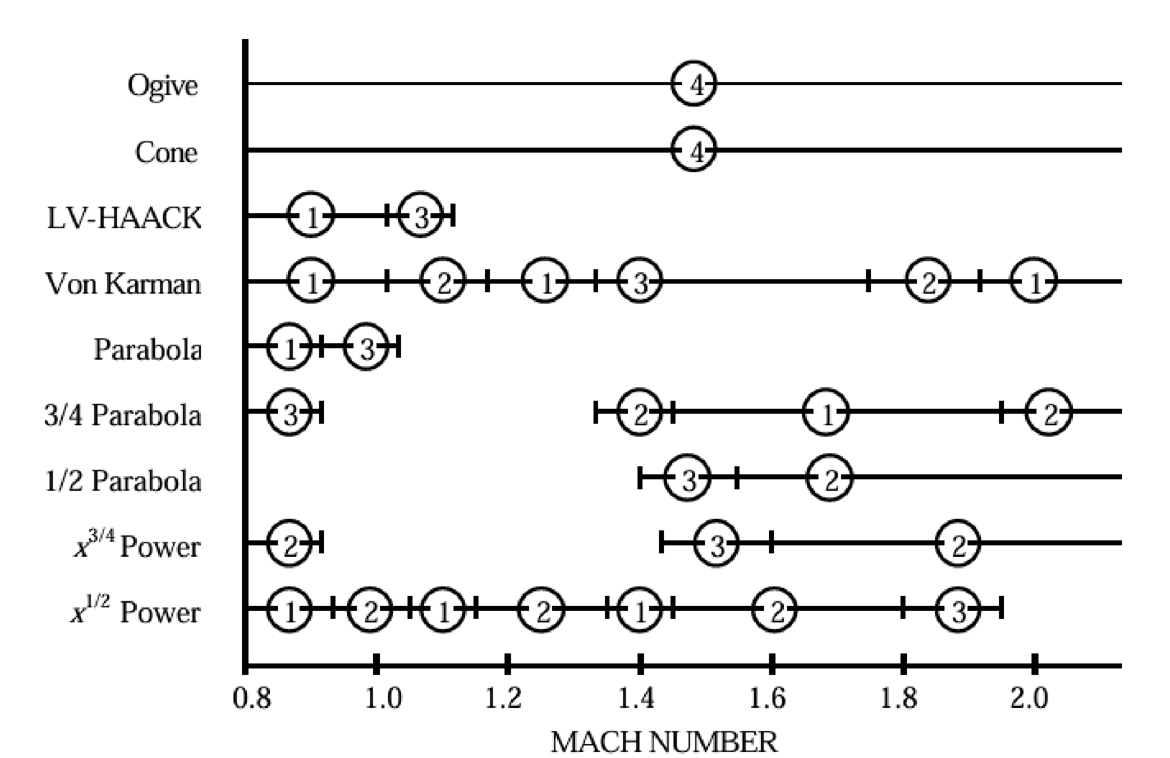
With the variables being:

R: Maximum radius (the base of the nose cone)

θ: Angular parameter calculated from the equation above.

y: Radius at a specific axial position x.

In terms of aerodynamics, in a paper written in 1996, Gary A. Crowell Sr. has shown that for subsonic flight speed, the Von Karman profile possesses drag characteristics that are superior to the commonly used cone profile. Comparing to the parabola design, the Von Karman nosecone possess more versatility, as it is efficient in both subsonic and supersonic flight. Moreover, it possess superior drag reducing in a greater range when it comes to subsonic flight. This was explicitly justified in the aforementioned work. Attached below is the comparison done by the author in his work.



Comparison of drag characteristics of various nose shapes in the transonic-to-low Mach regions. Rankings are: superior (1), good (2), fair (3), inferior (4).

Figure 6. Drag characteristics of Nose Shapes in Flight

The design for the nosecone was tested in CFD (Computational Fluid Dynamics), from which a good balance between aerodynamic efficiency, structural practicality and stability was considered. Furthermore, the smooth geometry and drag-reducing characteristic in both supersonic and subsonic flight (the latter being the only flight condition in NSL) of the profile make it a reliable and effective choice of design.

Regarding how its mounted the nose cone to the payload coupler, the nose cone has four 0.25-inch holes 90 degrees apart from each other. The nose cone is bolted directly to the payload coupler via the aforementioned holes.

The engineering drawing summarizing the characteristics of the finalized design of the nosecone is attached below.

Mathew, Bilji. (2021). A review on computational drag analysis of rocket nose cone.

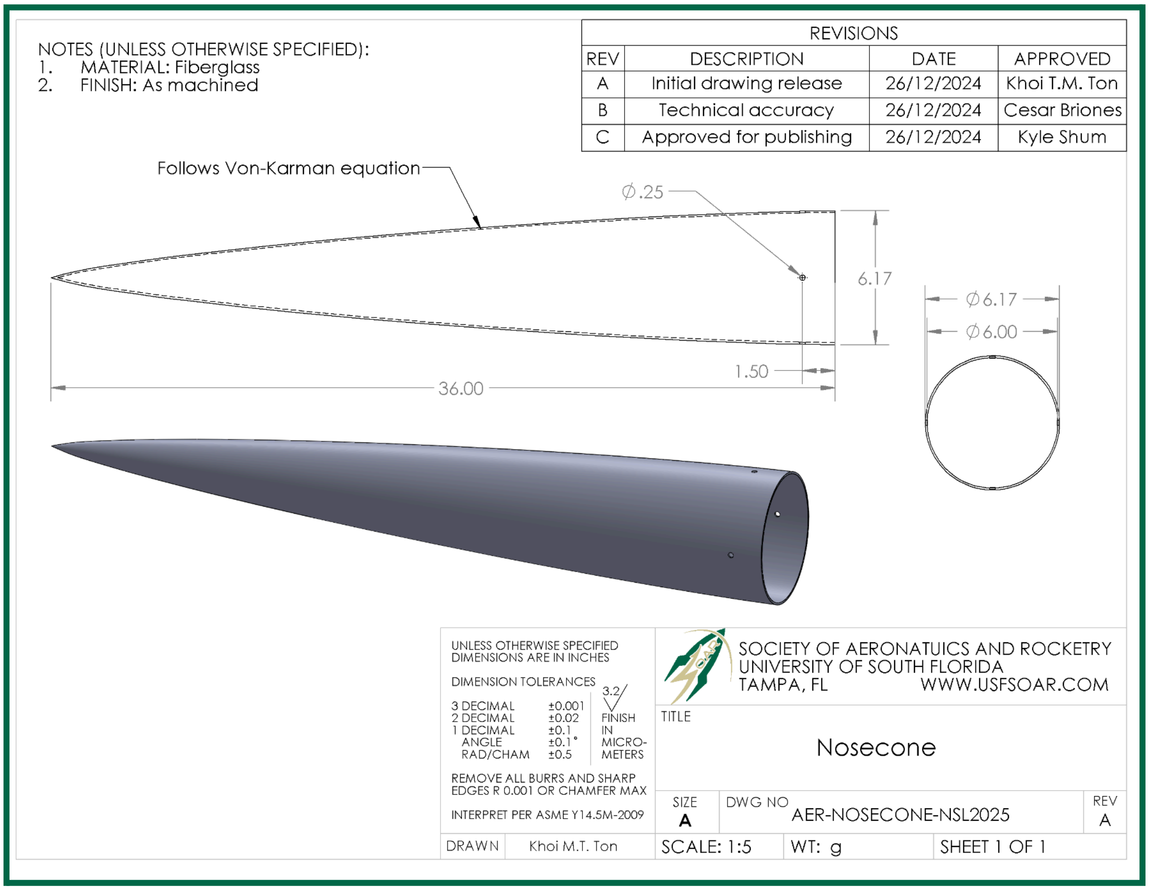


Figure 7. Nosecone Engineering Drawing

3.1.3.2.2 Airframe

The airframe of the rocket is constructed entirely of carbon fiber tube to provide high strength with a low relative weight, allowing the material to support internal components and withstand external forces placed upon each section. Moreover, the booster section of the airframe incorporates the fins' notches directly into the design, ensuring a more secure fit compared to using epoxy or other fastening methods. Lastly, each airframe section contains holes that align with their subsequent couplers, allowing for the seamless attachment of each part.

First, the upper section airframe is the first airframe from the tip of the nosecone. This small component houses the payload system, ballast, and telemetry system within. It connects to the payload coupler, which connects to the nosecone and midsection. The airframe has many cutout sections, which is done for the payload mission. Given that removing a great cross-sectional area of the airframe greatly diminishes the structural integrity of the rocket, the team has integrated aluminum bars that go along the airframe. This provides extra strength where needed.

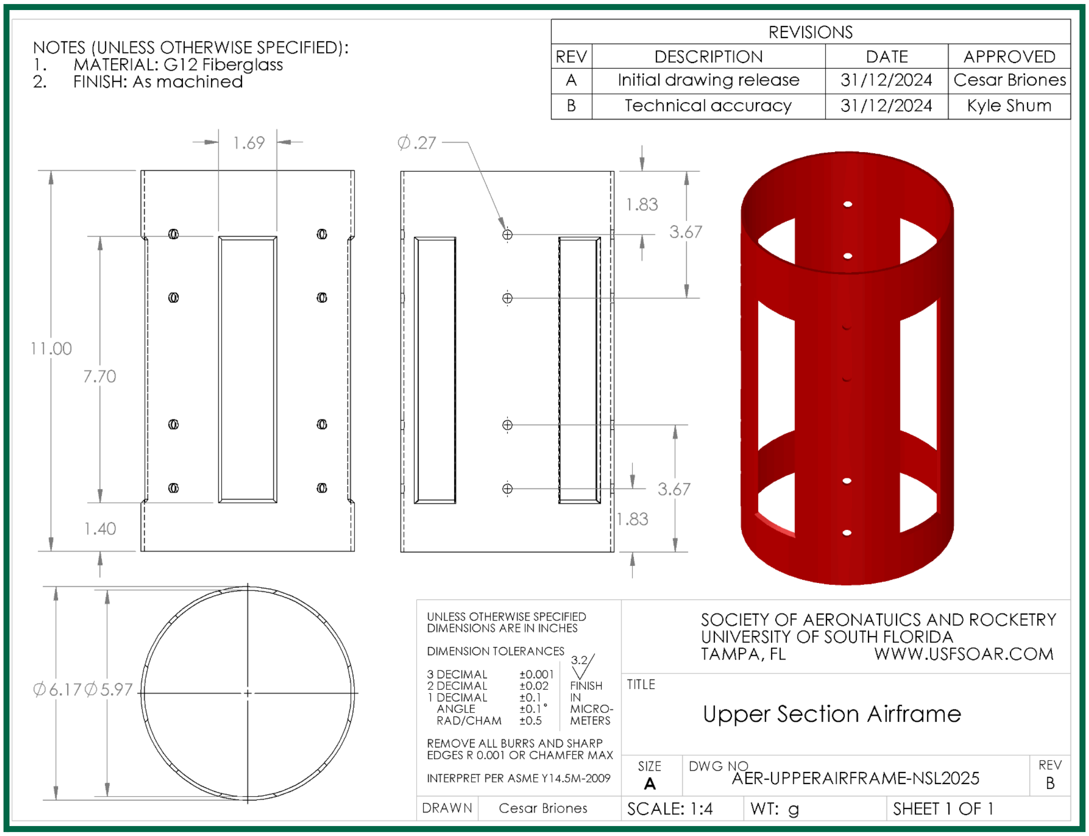


Figure 8. Upper Section Airframe Engineering Drawing

The Mid Section airframe follows a traditional design. It has 4 shear pins at each end of the section, 3 inches from both ends. These holes represent a point of separation and are in connection with a mating coupler from the Upper and Mid Section respectively. An important design feature is the slot for the Airbrakes. They are 10.95 from the bottom of the tube and reduce the local cross-sectional area by 50%. This sudden loss of strength around the slots calls for the reinforcement of the airframe. Thus, the stringers for the Airbrakes were created.

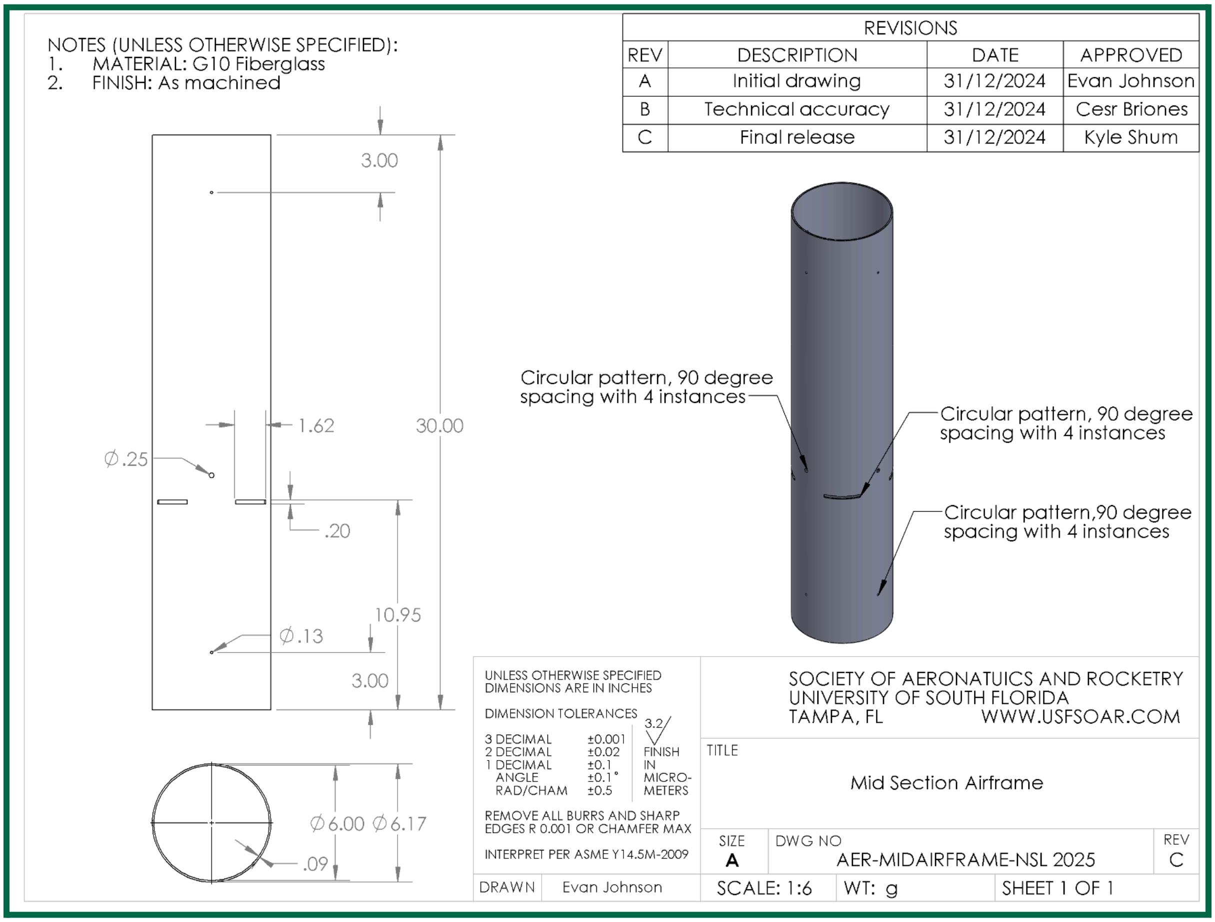


Figure 9. Mid Airframe Engineering Drawing

Finally, the Booster Section airframe is the last one from the tip of the nosecone. This section has 4 thin slots for the trapezoidal fins. This section has no other holes, given that the booster coupler will be bonded with epoxy to this component. It is 19 inches in length.

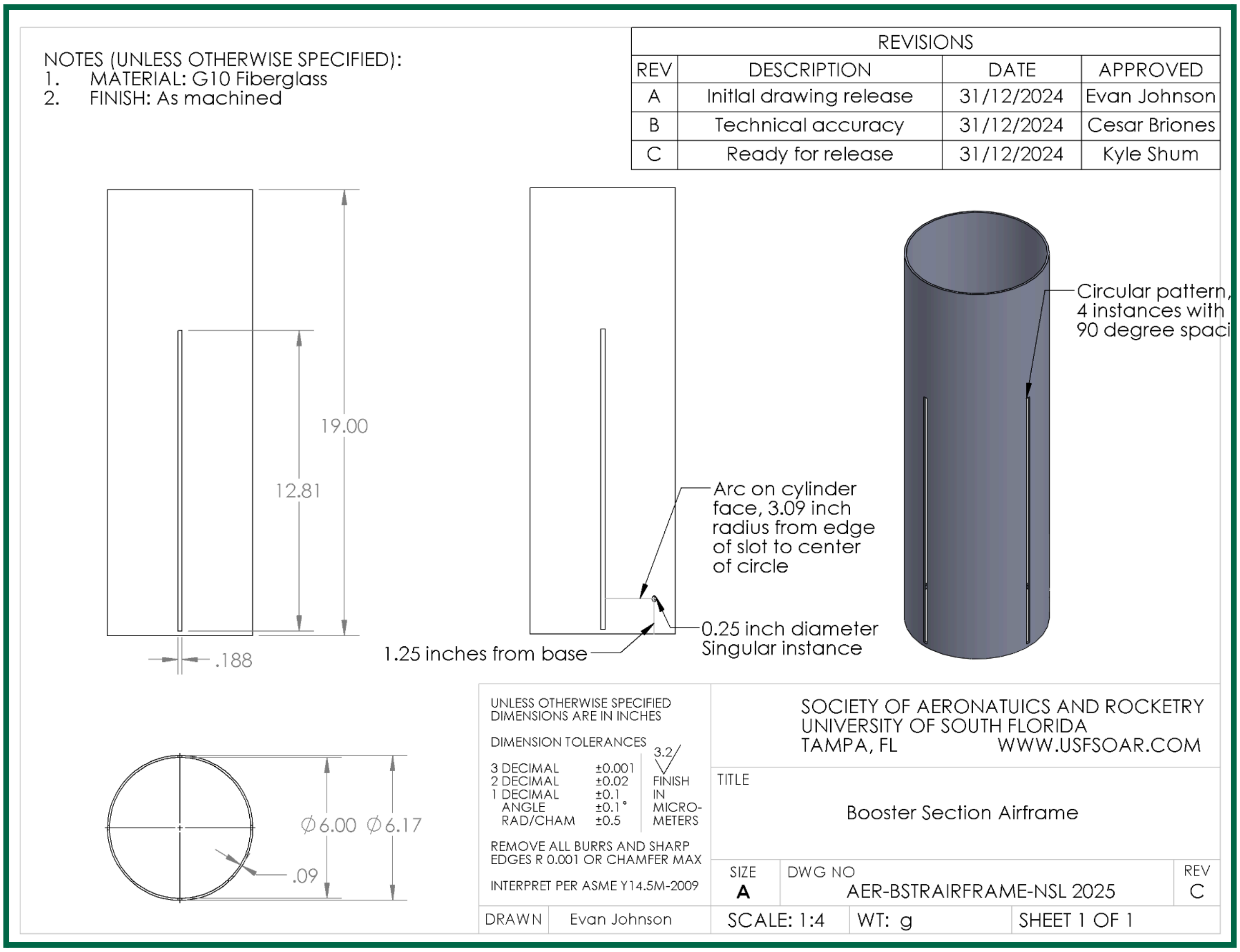


Figure 10. Booster Airframe Engineering Drawing

3.1.3.2.3 Fins

The fins are fundamental for the vehicle's flight success. They provide a resistance to the flow, moving the center of pressure far enough so the vehicle becomes stable. These passive stabilizers have to be aerodynamic and efficient. The vehicle uses 4 fins 90° from each other. They go through the airframe up to the motor tube, surrounded by centering rings. Finally, they are bonded to the parts using JB Weld. A fillet is done in between the sides of the fins and the airframe, providing more structural integrity. The fin will be machined out of a carbon fiber sheet. They are located at the end.

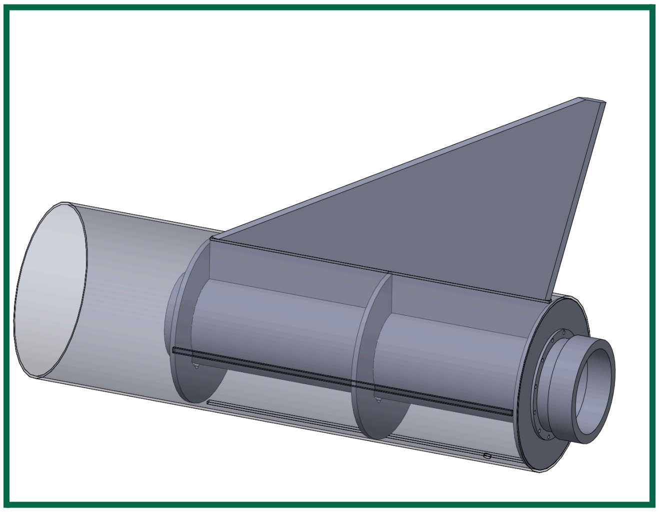


Figure 11. Fin in Booster

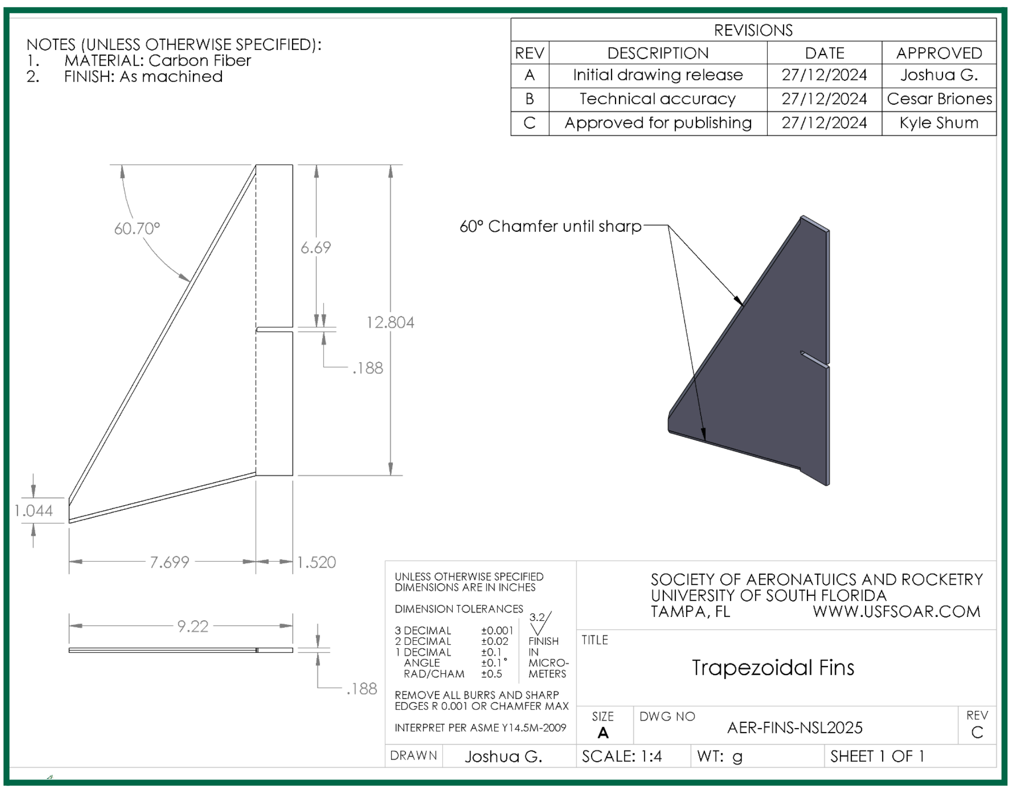


Figure 12. Fin Engineering Drawing

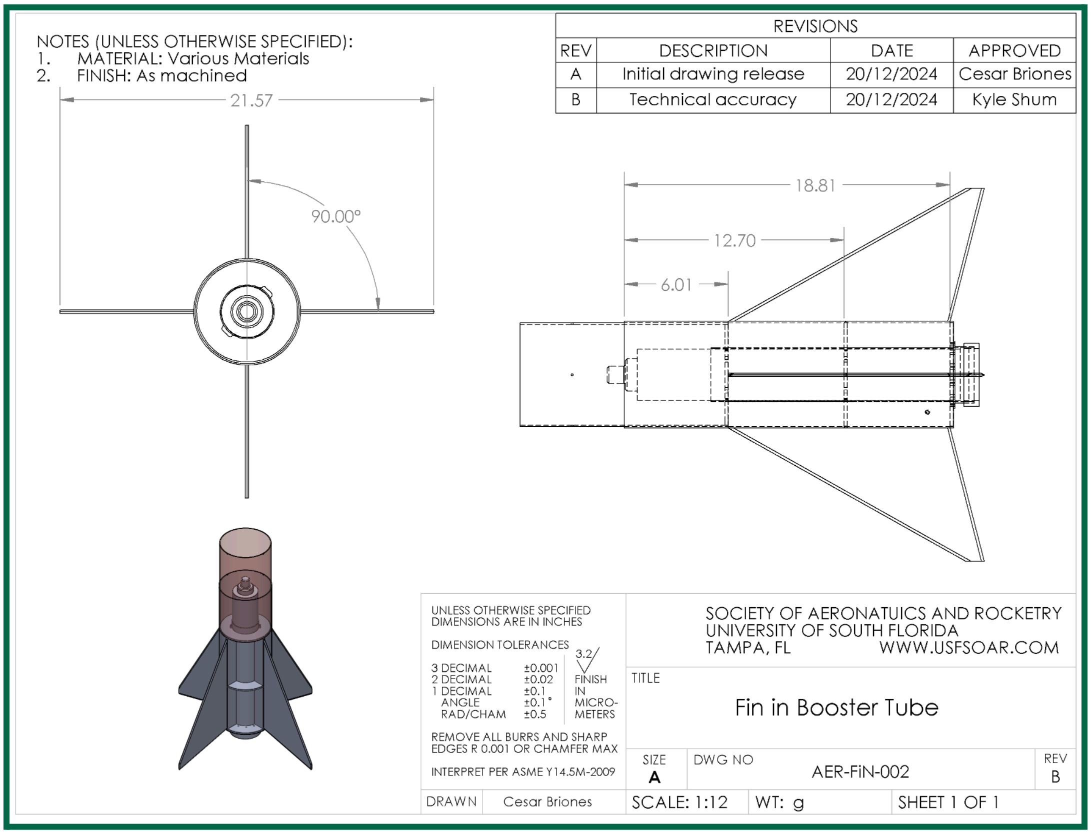


Figure 13. Fin Relative to the Booster Section Engineering Drawing

3.1.3.3 Internal Structures

3.1.3.3.1 Couplers

3.1.3.3.1.1 Payload Coupler

The payload coupler connects at one point of separation and at a permanent fixture. It is compliant with the requirements, as the point of separation has 6 inches of coupler inside of the mating system, and the nosecone shoulder has 3 inches going into the nosecone. The material for this coupler is Carbon Fiber and is 20.25 in long. It has 4 slots spaced 90° from each other. The purpose of the slots will be explained in the payload section. There are only 4 0.125 in holes for 4-40 shear pins. The remaining holes are for semi-permanent fixtures. ¼-20 bolts will be run through.

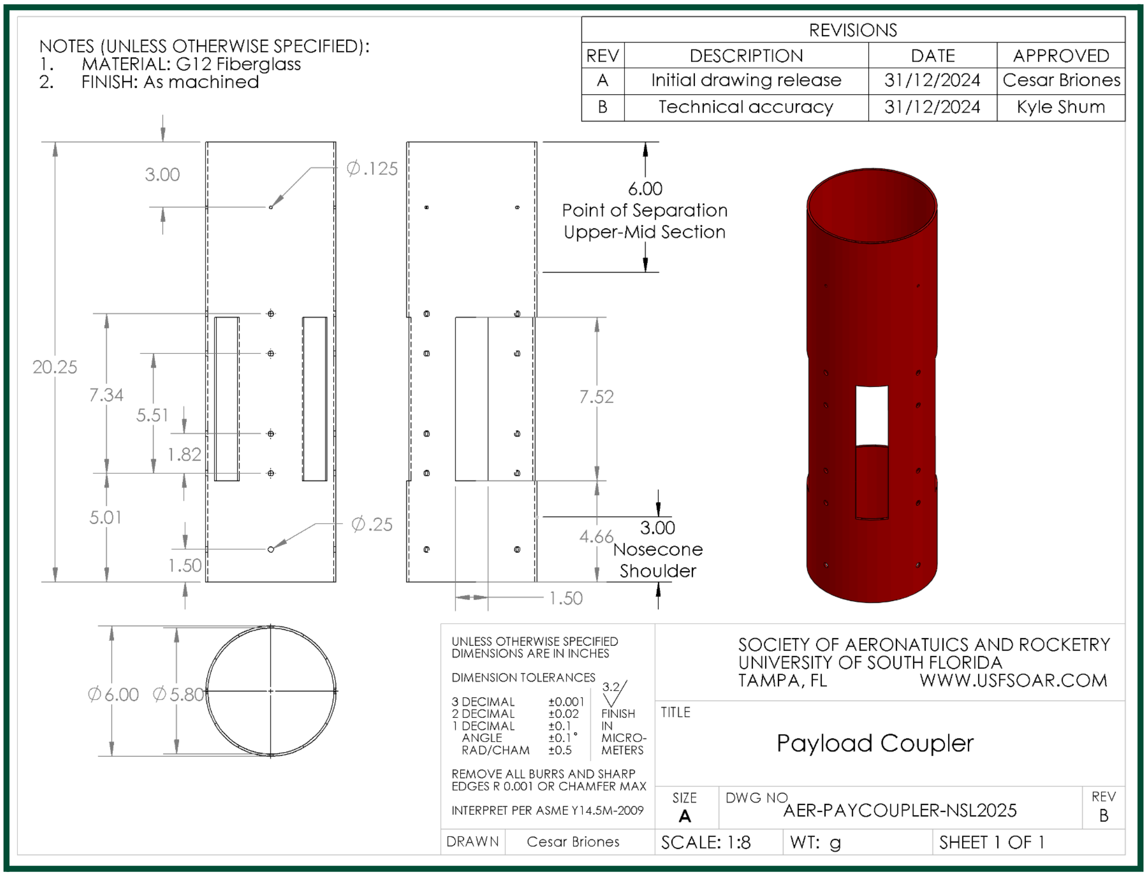


Figure 14. Payload Coupler Engineering Drawing

3.1.3.3.1.2 Booster Coupler

The booster coupler is located at a point of separation. It is compliant with the 6-inch requirement. In contrast to previous coupler designs, this coupler is permanently fixed into the booster airframe. Given that this coupler will house no internal components, there is no need for threaded rods or bulkheads. Therefore, the team has decided to merge the coupler and the airframe by bonding them with JB Weld. The 6 inches into the Booster airframe will be permanently bonded. The four small holes in the exposed area are for 4-40 nylon shear pins.

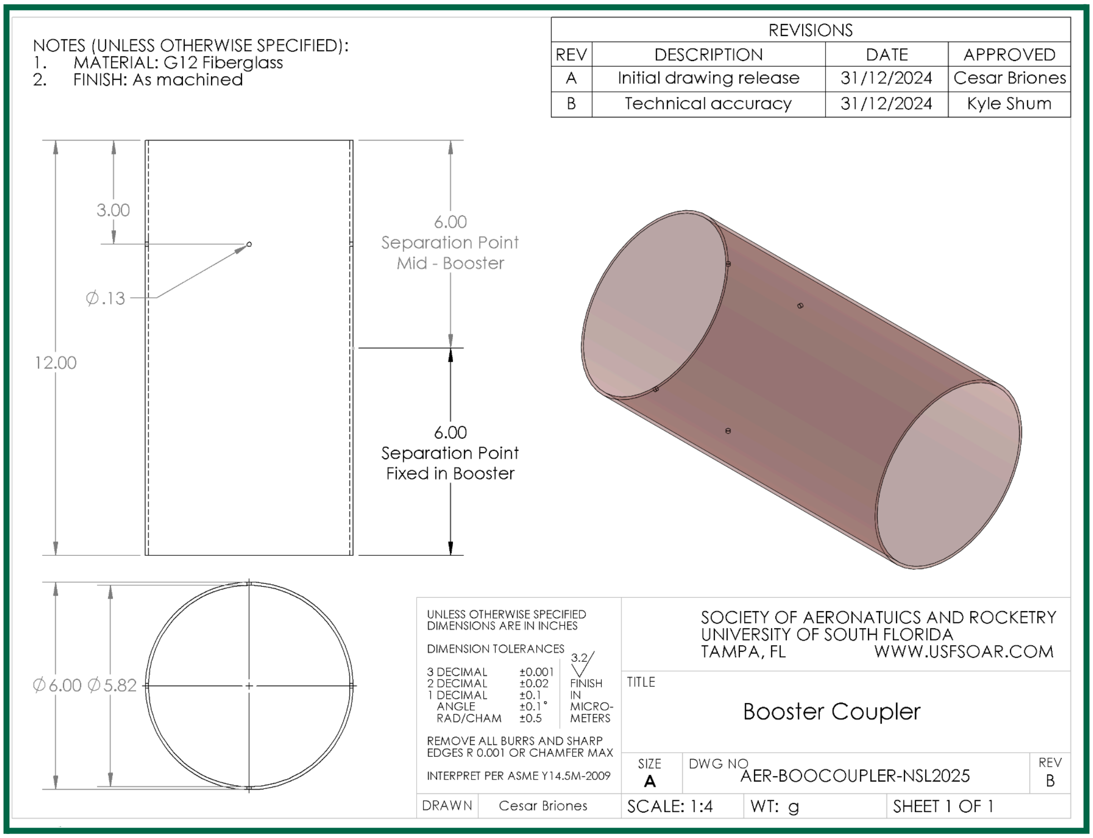


Figure 15. Booster Coupler engineering drawing

3.1.3.3.2 Stringer Support bars

The stringers were designed around the Airbrakes system. The main purpose of this component is to consistently keep the bottom plate in the same location and to serve as the main structural component that faces the snap force in the Mid Section. Four stringers are placed around the avionics bay assembly and replace the previously used threaded rods. An advantage of using this system compared to the threaded rods is the consistency when aligning the system. The previous design was based around fixing a nut in the threaded rod and then using that as the main point of reference. The stringers completely remove this issue, as the children parts are directly bolted to the stringer at a location that was machined with great precision. The stringers in the assembly are shown below.

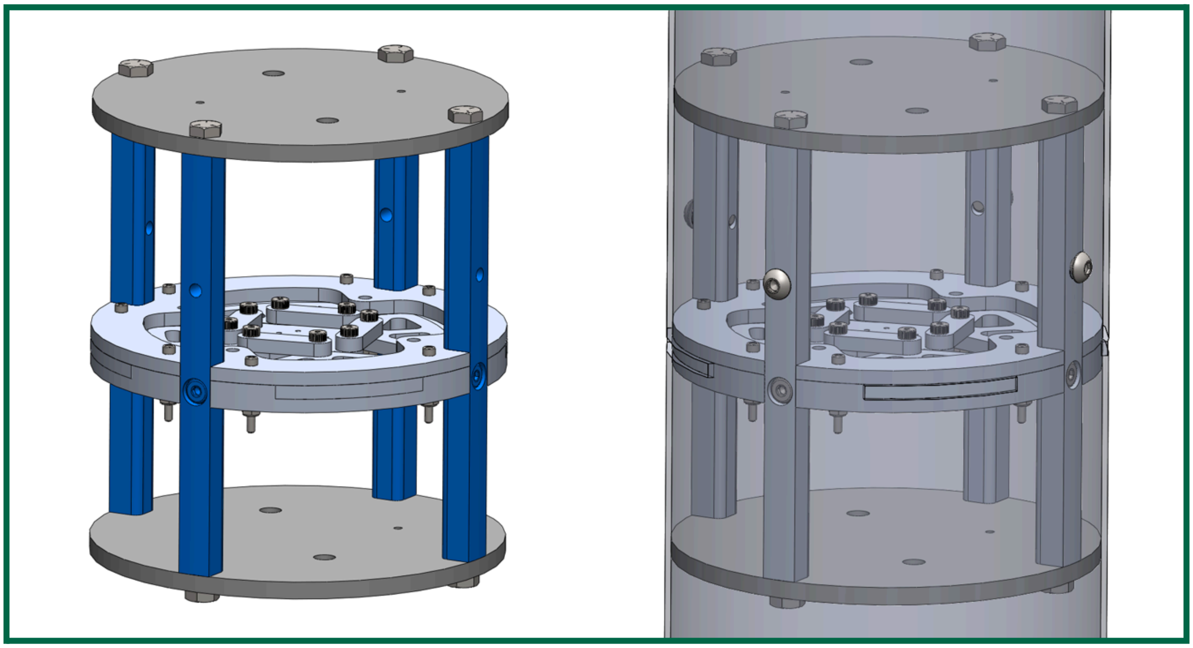


Figure 16. Airbrakes Stringers in Lightweight Assembly

The stringers are made out of Aluminum 6061-T6 and machined in a 3-axis Shapeoko HDM. It has 2 1-inch ¼-20 tapped holes at both ends, which serve as the point of connection with the bulkhead. Additionally, there is another ¼-20 tapped hole 2 inches from the top that connects the avionics bay to the airframe. Finally, there is a counterbore hole to integrate the bottom plate, crucial for the airbrake system. The integrity of this design will be later discussed (see section 3.5.1.3.1).

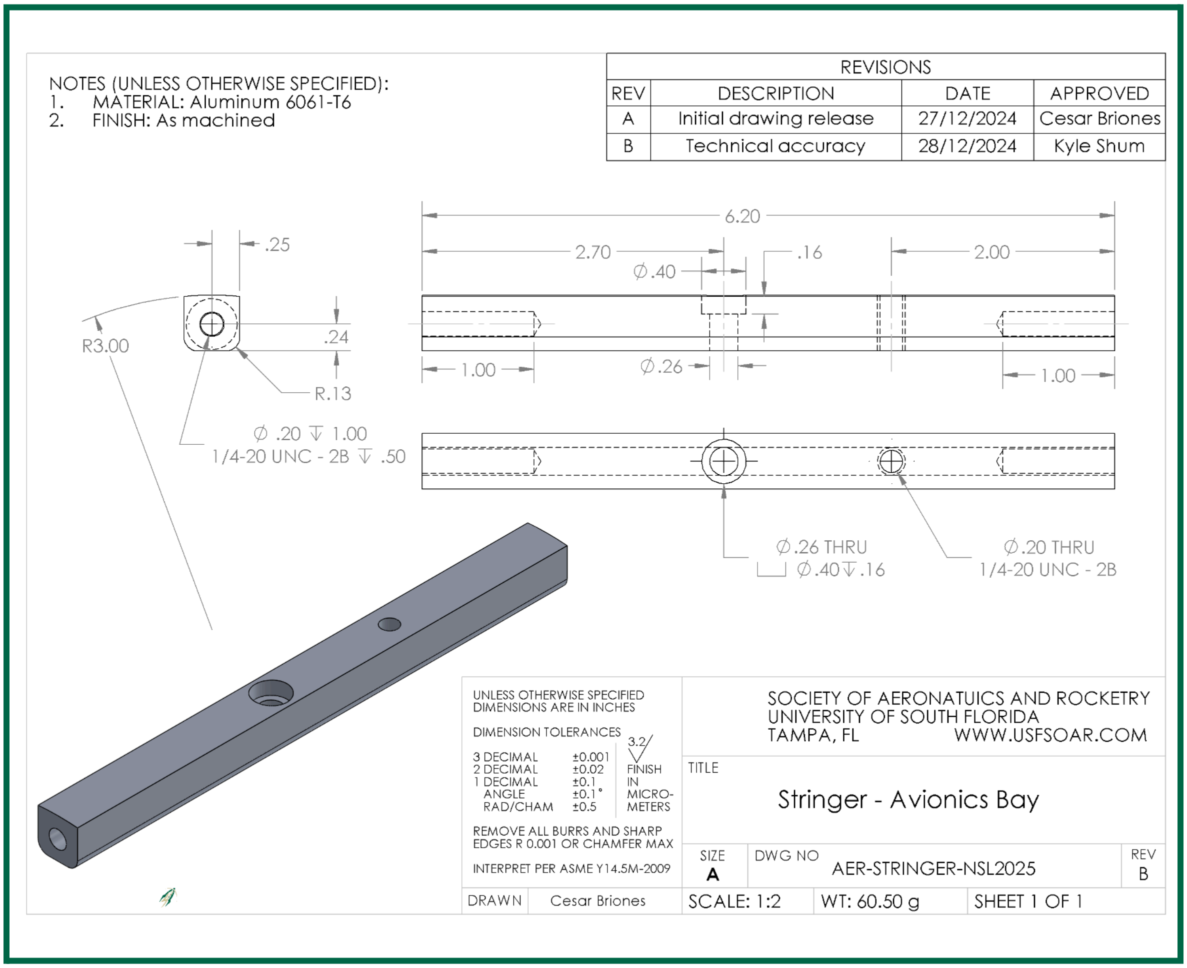


Figure 17. Stringer Engineering Drawing

3.1.3.3.3 Bulkheads

The team uses bulkheads as a way to provide structural strength and ease of assembly for sections within the rocket. Every coupler has bulkheads at both ends, being compressed towards each other through some aluminum or steel rods. They either have a lip to accommodate for assembly or just match the mating inner diameter of the airframe. However, they all have holes to fasten the retention hardware. Two examples of bulkheads and their use within an assembly are shown below.

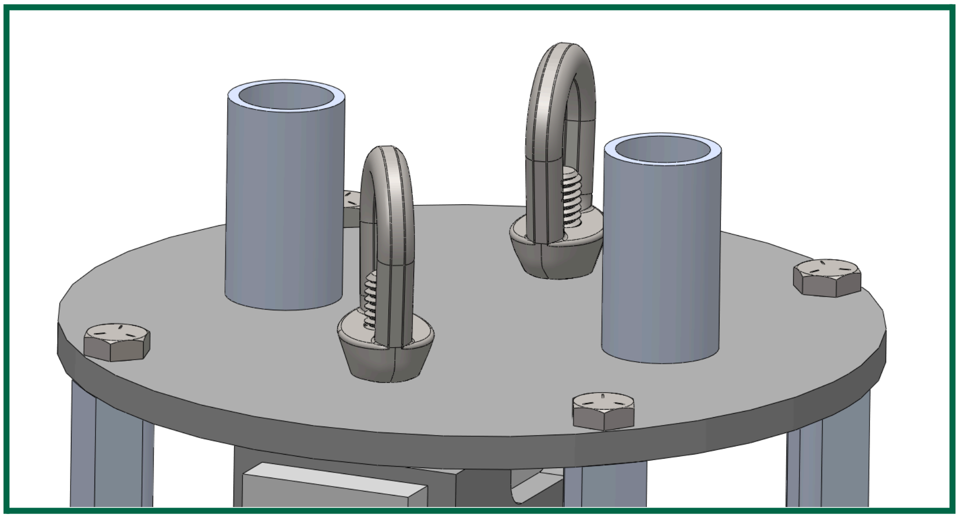


Figure 18. Bulkhead in Avionics Bay

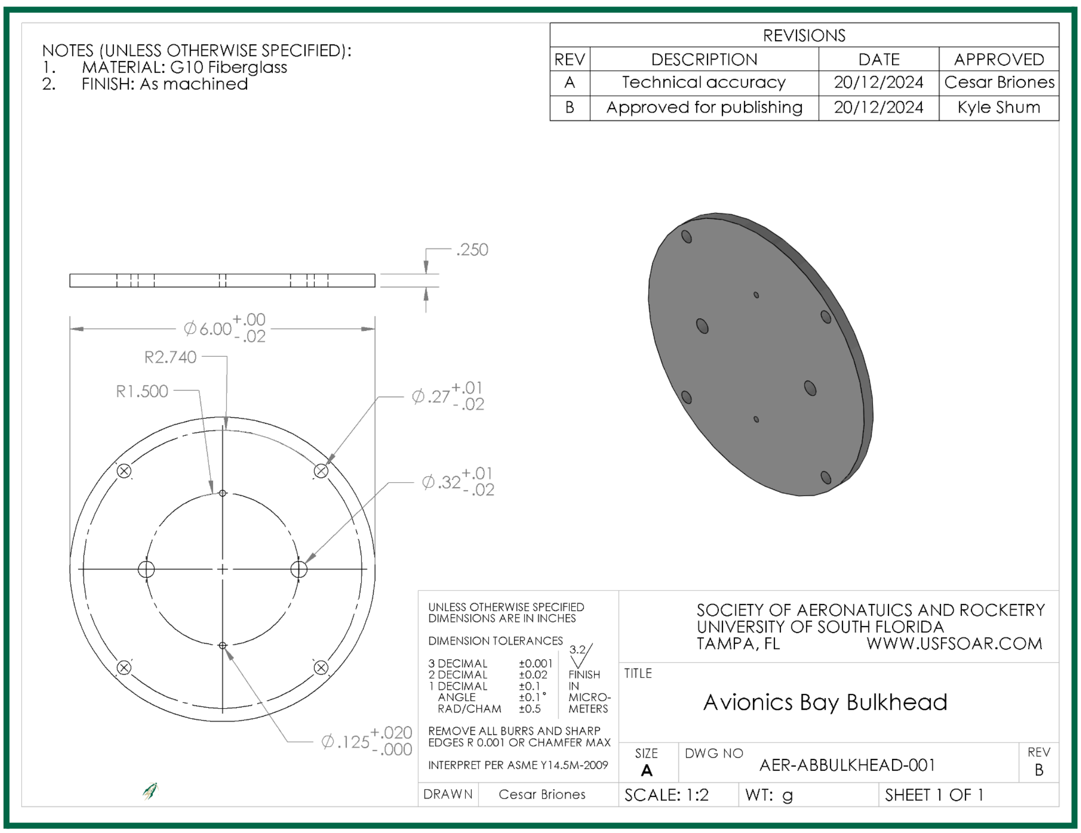


Figure 19. Avionics Bay Bulkhead

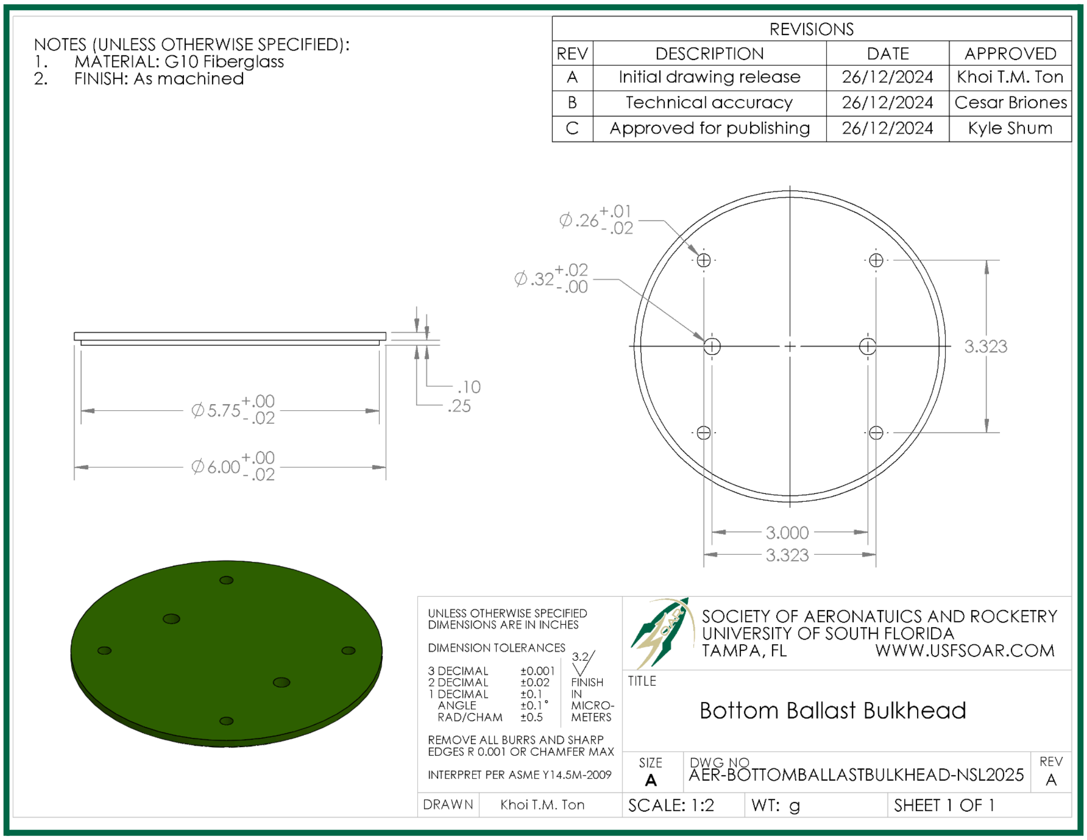


Figure 20. Ballast Bulkhead Engineering Drawing

3.1.3.4 Ballast System

The ballast system is designed to enhance stability and performance by adjusting the rocket's mass, ensuring proper balance, and maintaining an optimal center of gravity during flight. By modifying the weight distribution, it prevents instability and unwanted rotations. As the rocket consumes fuel, and the center of mass moves forward, the ballast ensures that even from the start, the stability is within reasonable margins. The ballast weight does not exceed 10% of the vehicle weight.

The ballast is placed at the top of the vehicle, where it is more effective. The ballast system consists of several 1 oz. iron weights that are placed within stackable sleds. These sleds, with a maximum configuration of up to 3, contain 16 of the small individual weights, having a maximum loading capacity of 1 lb each. The maximum ballasted configuration is 3 stackable sleds; it has a maximum capacity of 3 lb total. Each will be printed out of PLA with an infill that favors compression in the vertical direction. Each sled will be printed out of PLA with an infill that favors compression in the vertical direction. Given that the sleds are not the primary structural component, it is possible to have them made out of a weaker material. The 1 oz. weights and stackable sleds are showcased below.

Figure 21. 1 oz. Ballast Weights

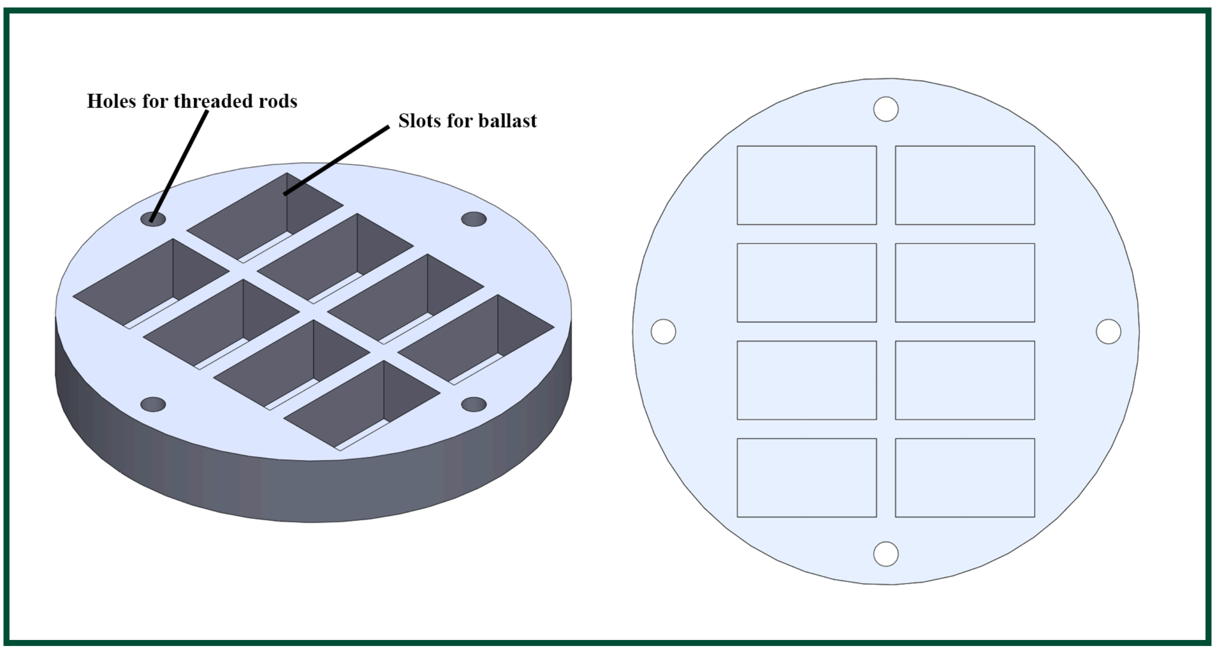


Figure 22. Ballast Sleds

The stackable ballast system allows the team to easily add or remove weights, enabling precise adjustments to the rocket's center of gravity based on mission requirements. This modular design enhances flexibility, simplifies pre-launch modifications, and ensures optimal stability and performance without requiring significant redesigns.

The entire ballast system is sandwiched in between two 0.25 in fiberglass bulkheads. Finally, threaded rods are used to provide clamping force, preventing any movement within the system that may create momentum and impact. The detailed ballast system is showcased below:

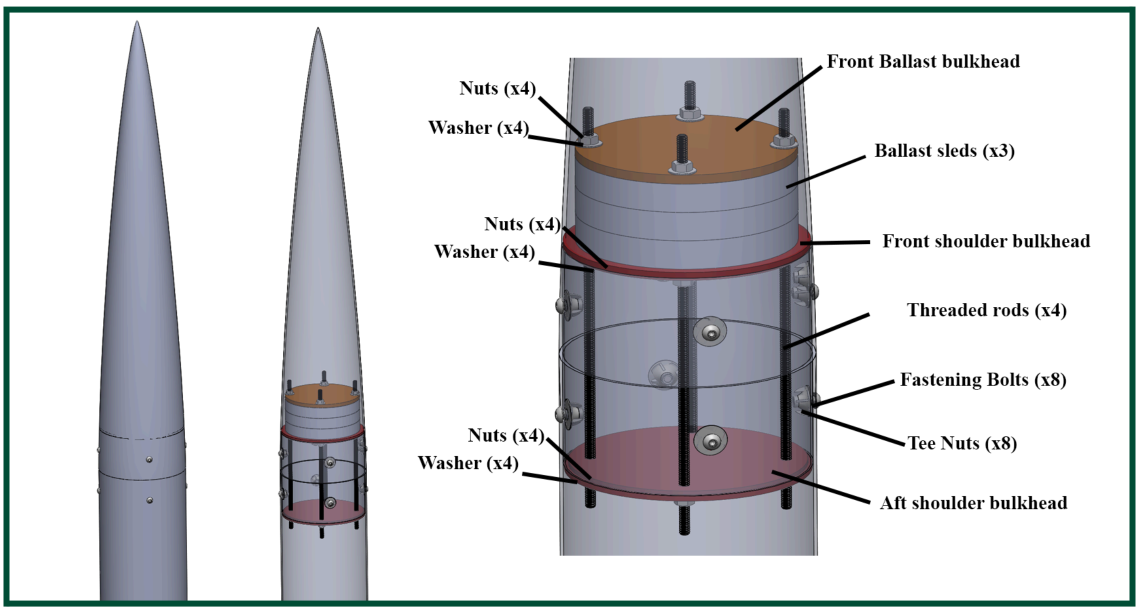


Figure 23. Ballast Assembly

The addition of the ballast shifts the rocket's center of gravity from 67.02 in to 64.36 from the nose cone, bringing it closer to the rocket's top and enhancing overall stability. The change in the vehicle's stability is shown below.

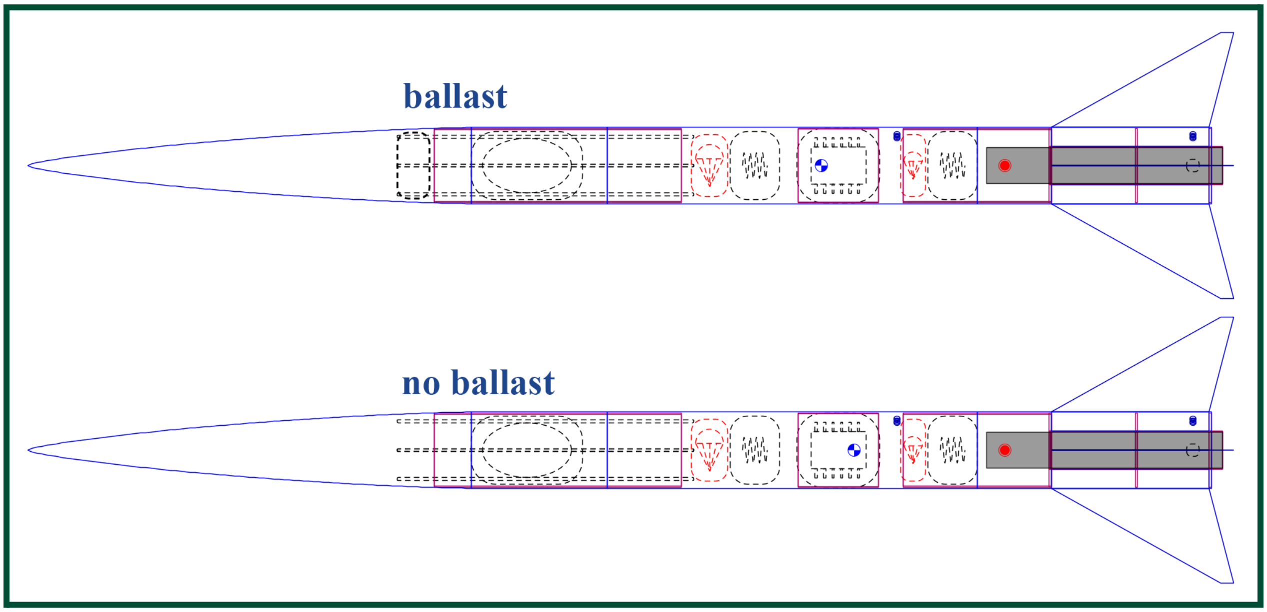


Figure 24. Ballast Effect on Center of Mass OpenRocket

3.1.3.5 Motor Mounting and Retention

3.1.3.5.1 Centering Rings

The vehicle will use centering rings as a way to keep the motor fixed and concentric with the airframe. Additionally, the centering rings will serve as fixture for the fins. Three different centering rings will be used. Two of them have holes for the shock cord, which will be attached to this section. The last one will have holes for the RA75 Aeropack motor retention.

JB Weld Epoxy will be used to bond the centering rings to the airframe, motor tube, and fins together. Proper bonding procedure will be followed, where the part is prepared by sanding, cleaning, and then adhesion.

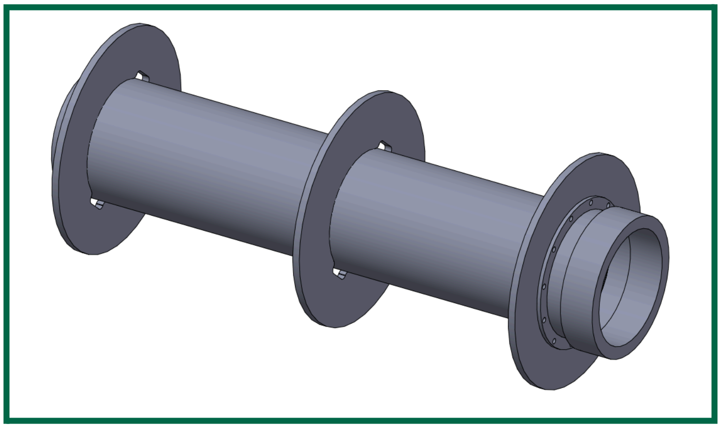


Figure 25. Motor Mount Assembly

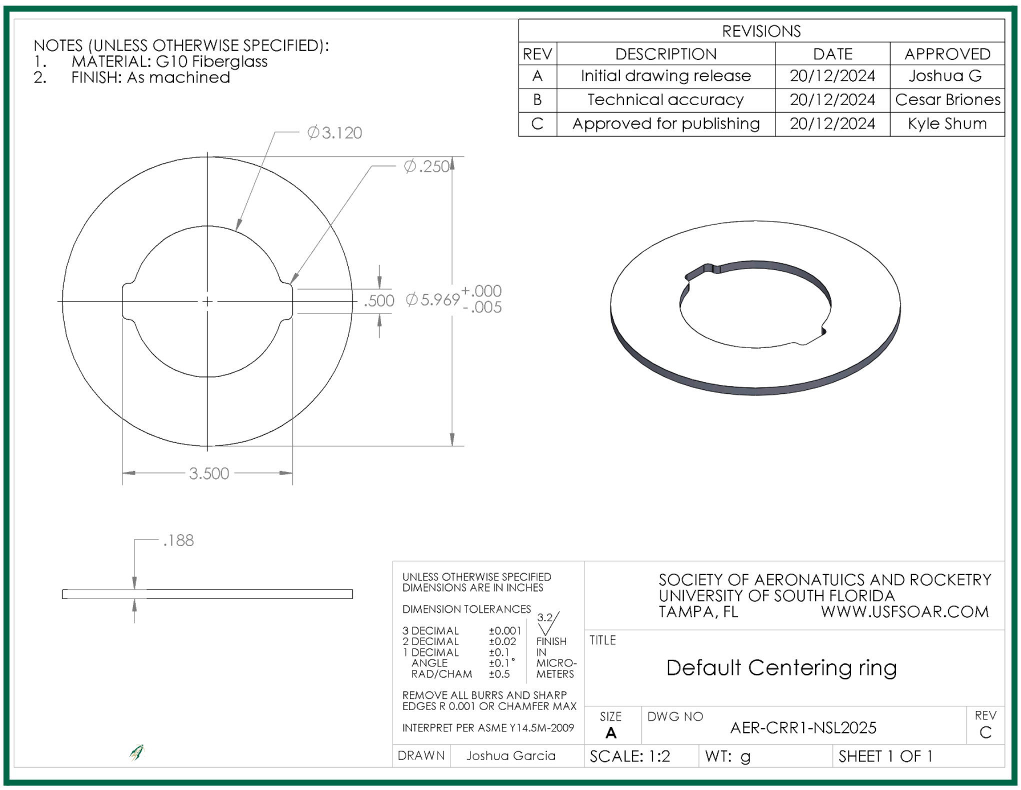


Figure 26. Centering Ring Engineering Drawing

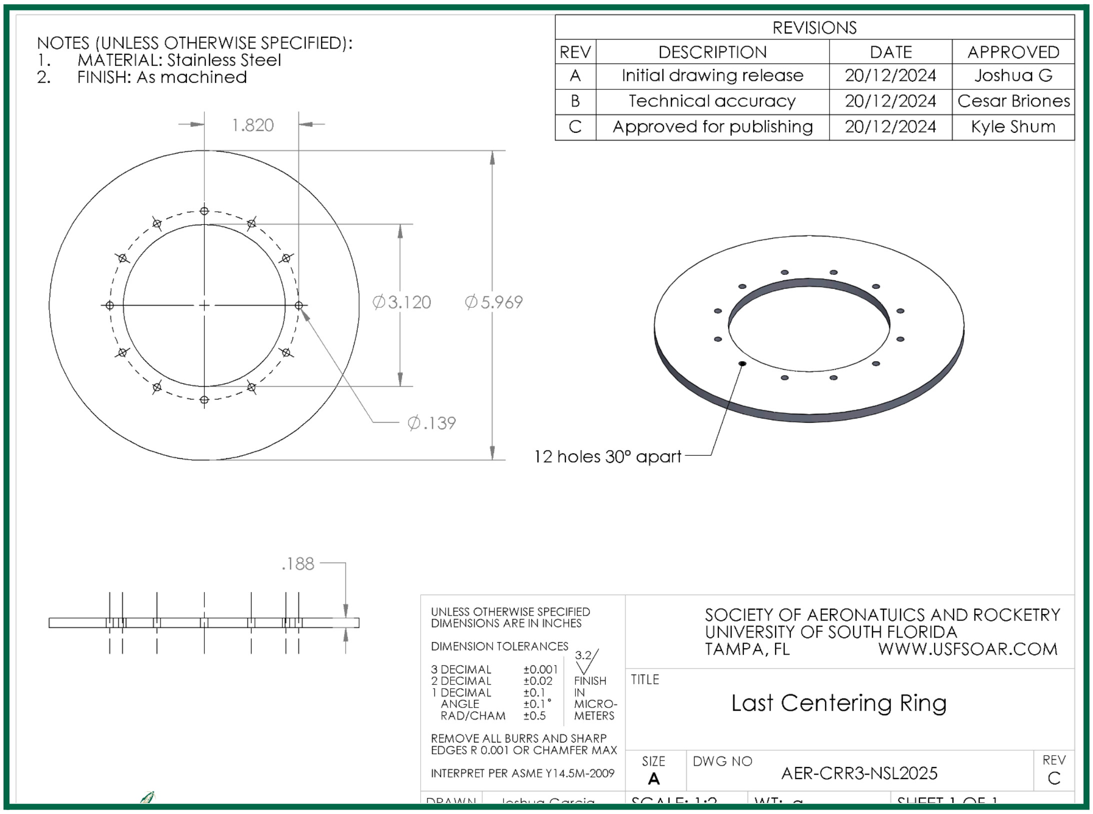


Figure 27. Last Centering Ring Engineering Drawing

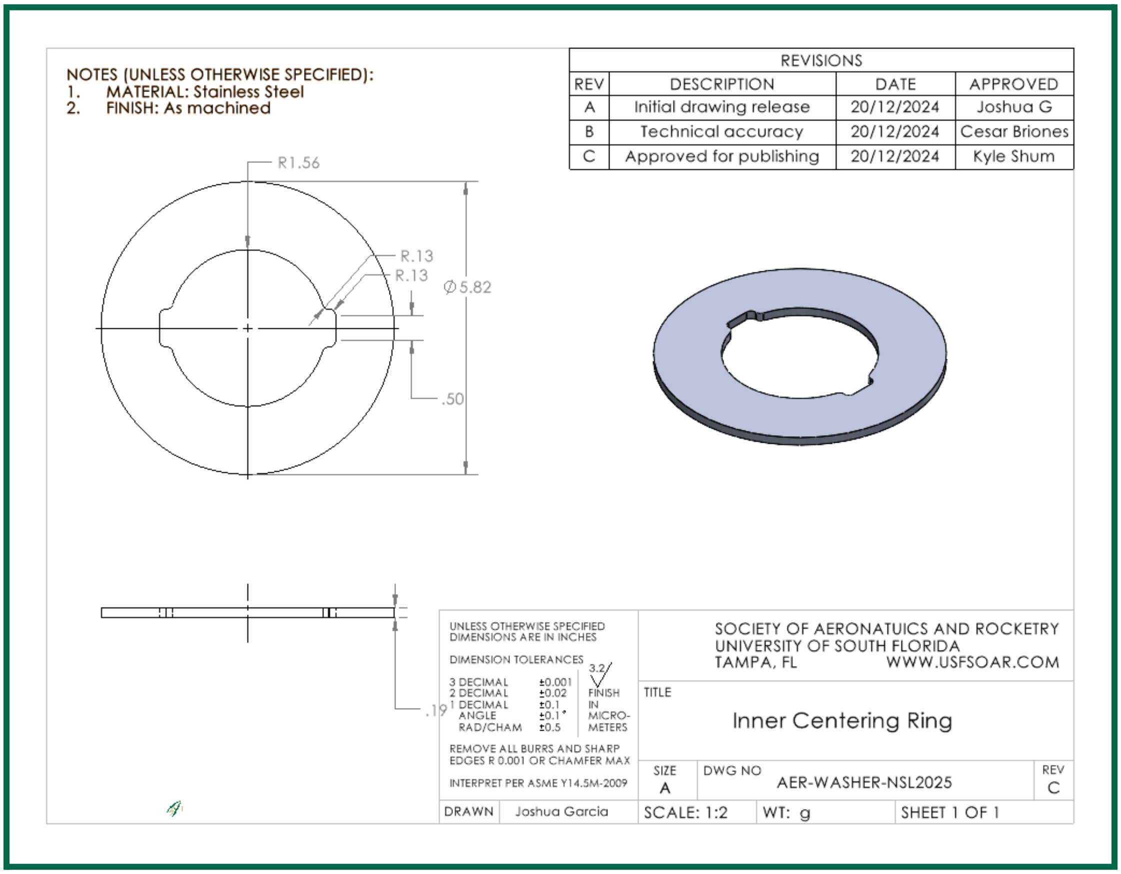


Figure 28. Inner Centering Ring Engineering Drawing

3.1.3.5.2 Aft Closure

Since the PDR, the team has modified the design of the aft closure. Previously, it had a custom-made boat tail that would increase the aerodynamics. Ever since, the team has put the weight of the system at a much higher priority level. Ultimately, this change made the choice of an off-the-shelf aft closure more appealing. The team is going to use a flanged motor retainer, Aeropack RA75. More details of the structural integrity and motor retention of this same part will be explained in a later section.

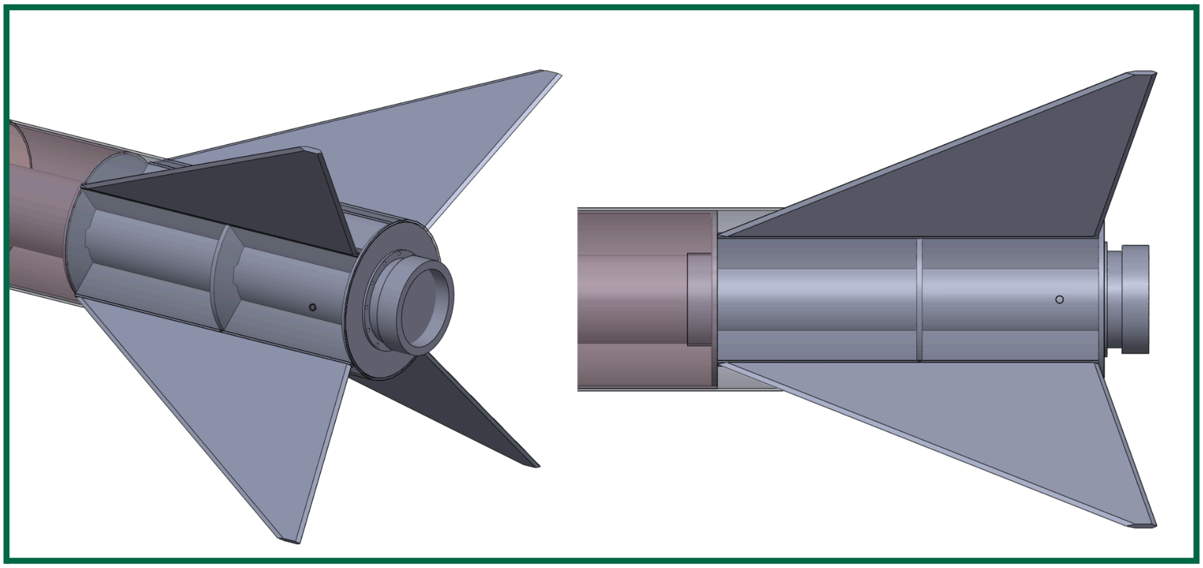


Figure 29. Aft Closure in Booster Section

3.1.4 Points of Separation and Energetic Materials

3.1.4.1 Black Powder Calculations

The formula used for calculating the required amount of black powder comes from the Ideal Gas Law. The Ideal Gas Law is an effective approach for identifying the amount of black powder, because the pressure, volume, gas constant and temperature are all known, and the mass can be solved for directly. The formulas are as follows:

$$P = F/A$$

P: Pressure (psi)

F: Force (Separation force, lbf.)

A: Cross-sectional area of the compartment (inches squared)

$$V = (\frac{\pi}{4})D^2L$$

V: Volume (in^3)

D: Diameter of the compartment of black powder (in)

L: Length of the compartment of black powder (in)

$$Black\ Powder\ Mass = \frac{P * V}{R * T}$$

R: Gas constant (black powder during combustion, in*lb/lbm.*°R)

T: Temperature (combustion gas temperature, °R)

The Ideal Gas Law is used at the time the black powder charge is detonated, so all the properties are of the gas created from the black powder. R and T are the gas constant and temperature of the black powder (at the time of detonation), respectively. The volume of the gas can be calculated manually using the diameter and length of the compartment where the charge is located. Since shear pins are being used, the pressure required for separation can be calculated using the force required to break the pins. The table below shows the properties of the black powder and shear pins that the team uses, as well as the calculation for the mass of the black powder. The estimated size of the charge is 3.2 grams. Additionally, since the friction between components during separation is not fully accounted for, a factor of safety of 1.5 is applied. Therefore, the suggested size of the black powder charge for this rocket is 4.82 grams. This size must still be validated with a ground test before being launched.

Table 6. Black Powder Calculation Input Values

Black Powder Gas Properties	Value	Units
R	265.92	(in*lb/lbm.*°R)
Tc	3307	°R
Shear Pin Properties	**Value**	**Units**
Separation Force	119.2	lbf.
Rocket Design Properties	**Value**	**Units**
Area	6.5	in^2
Diameter	6	in
Length (of Compartment)	12	in
Pressure	18.338	psi
Volume	339.29	in^3
Mass of Black Powder Charge	3.2122	g
Mass (With Factor of Safety)	**4.8184**	**g**

3.1.4.2 Points of Separation Location

The vehicle has two points of separation, which separates the vehicle into 3 independent sections. The Upper Section, Mid Section and Booster Section are tethered to their next section through a shock cord and their anchor points. The system has a total of 8 shear pins, with 4 per separation point. Each point of separation is compliant with the coupler length requirement, having 6 inches of length on both mating sections.

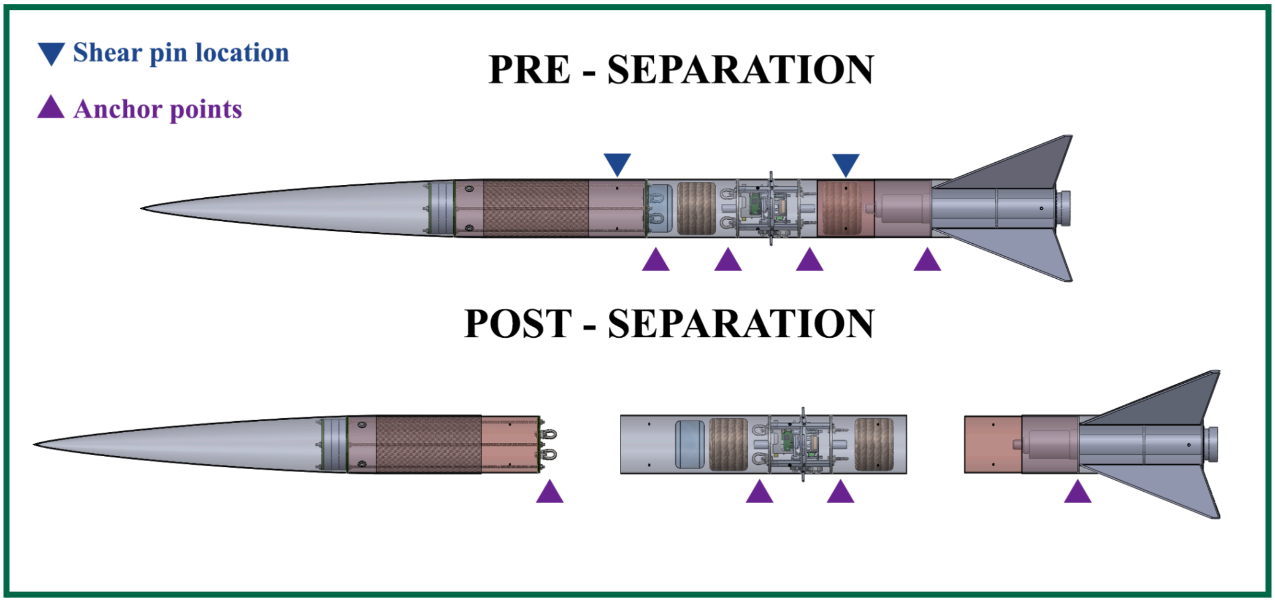


Figure 30. Points of Separation

3.1.4.3 Energetic Material Location

The team will use black powder as the energetic material that will trigger the separation of the sections. This energetic material is located in the avionics bay and powered by an off-the-shelf altimeter. Given that previously the team has suffered with the breaking of some of the charge wells, the team has decided to move forward with a custom-made aluminum charge well. It will be manufactured in a lathe from a cylindrical stock. The Avionics Bay has 4 charge wells, 2 on both sides. Each charge well will hold 4.8 g of black powder.

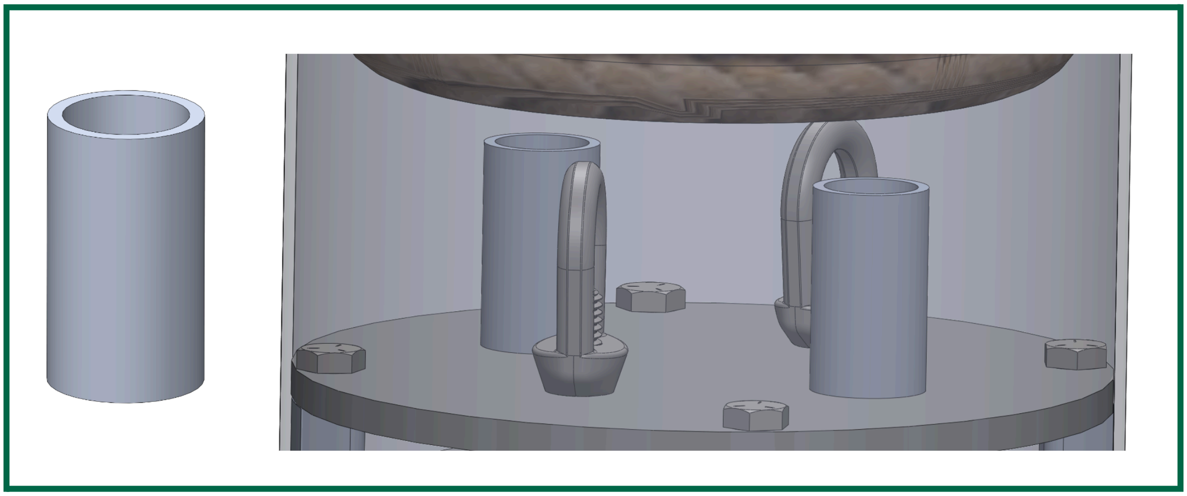


Figure 31. Charge Wells in Assembly

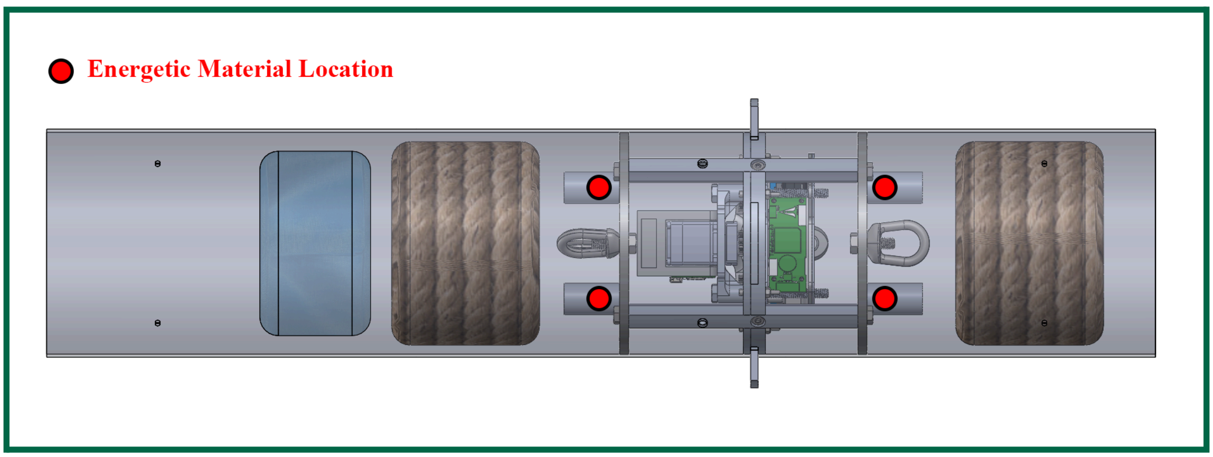


Figure 32. Energetic Material Location

3.1.5 Design Integrity

3.1.5.1 Fin Suitability

The fin design for the rocket is trapezoidal, chosen for its balance of aerodynamic performance, ease of fabrication, and practical advantages. While elliptical fins theoretically produce the least induced drag, this benefit is marginal at the smaller scale of the rocket, where profile drag is a more significant concern. Insufficient lift from the fins at high angles-of-attack can lead to inadequate restoring force and increased profile drag when the rocket strays off its flight path.

Since the coefficient of lift largely depends on the airfoil shape, trapezoidal fins are more practical because their flat surfaces are easier to sand into a precise airfoil compared to elliptical fins. Additionally, trapezoidal fins offer a good trade-off between aerodynamic efficiency and structural simplicity. Their tapered trailing edges help reduce induced drag compared to square fins while maintaining easier fabrication and alignment.

Trapezoidal fins also provide predictable performance and are structurally robust, making them well-suited for student-designed rockets. The straightforward geometry simplifies attachment and allows for secure reinforcement, ensuring the fins can withstand flight stresses. Overall, the trapezoidal fin design provides a balance of efficiency, durability, and practicality, making it the optimal choice for the rocket.

Another critical consideration in the finalized fin design is fin flutter, a phenomenon where aerodynamic forces cause the fins to vibrate at high frequencies during flight, potentially leading to structural failure. The use of fiberglass for the trapezoidal fins provides significant advantages in mitigating this issue. Fiberglass offers high strength-to-weight ratio and excellent stiffness, which helps resist the bending and torsional stresses that can trigger flutter. Additionally, the tapered design of trapezoidal fins reduces mass at the trailing edge, further decreasing susceptibility to oscillations under aerodynamic loads. By reinforcing the attachment points with strong epoxy and aerodynamic fillets, ensures the fins remain secure and stable throughout the rocket's flight, even at high speeds. This combination of material properties and design choices makes fiberglass trapezoidal fins a robust and reliable option for the rocket.

To ensure that fin flutter will not be a problem in the flight of the rocket, a rigorous analysis must be carried out. To determine the maximum velocity threshold at which fin flutter will occur, equation (1) below, derived from NACA Technical Paper 4197, is used:

$$V_f = a\sqrt{\frac{2G(AR+2)(\frac{t}{c})^3}{1.337AR^3P(\lambda+1)}} \quad (1)$$

where a is the speed of sound, G is the material's modulus, AR is the aspect ratio, P is the pressure, λ is the taper ratio, t is the thickness, and c is the root chord. To find the speed of sound, equation (2) below is used:

$$a = \sqrt{1.4 \times 1716.59 \times (T + 460)} \quad (2)$$

where T is the temperature. In order to find T, the Earth atmosphere model (3) is used:

$$T = 59 - 0.00356h \quad (3)$$

where h is the height at which T is measured. To find the pressure P, the Earth atmosphere model (4) is also used:

$$P = 2116 \times (\frac{T+459.7}{518.6})^{5.256} \quad (4)$$

where T is the temperature. To find the aspect ratio AR, equation (5) below is used:

$$AR = \frac{b^2}{S} \ (5)$$

where S is the area and b is the semi-span of the fin. To find the area of the trapezoidal fin, equation (6) below is used:

$$S = \frac{1}{2}(c_t + c_r)b \ (6)$$

where c_t is the tip chord of the fin and c_r is the root chord of the fin. Given that c_t is 1.039 in, c_r is 12.806 in, and b is 7.7 in, the area is found by equation (6):

$$S = \frac{1}{2}(1.039 + 12.806) \times 7.7 = 53.3\ in^2 \ (7)$$

Therefore, the aspect ratio AR, according to equation (5) and (7):

$$AR = \frac{7.7^2}{53.3} = 1.112 \ (8)$$

The taper ratio λ is determined with the equation below:

$$\lambda = \frac{c_t}{c_r} \ (9)$$

Given that c_t is 1.039 in and c_r is 12.806 in, according to equation (9), the taper ratio is:

$$\lambda = \frac{1.039}{12.806} = 0.081 \ (10)$$

The fin flutter speed threshold is going to be determined at the point when the velocity of the rocket is at maximum, because that is when the fins are most likely to flutter. According to OpenRocket simulations:

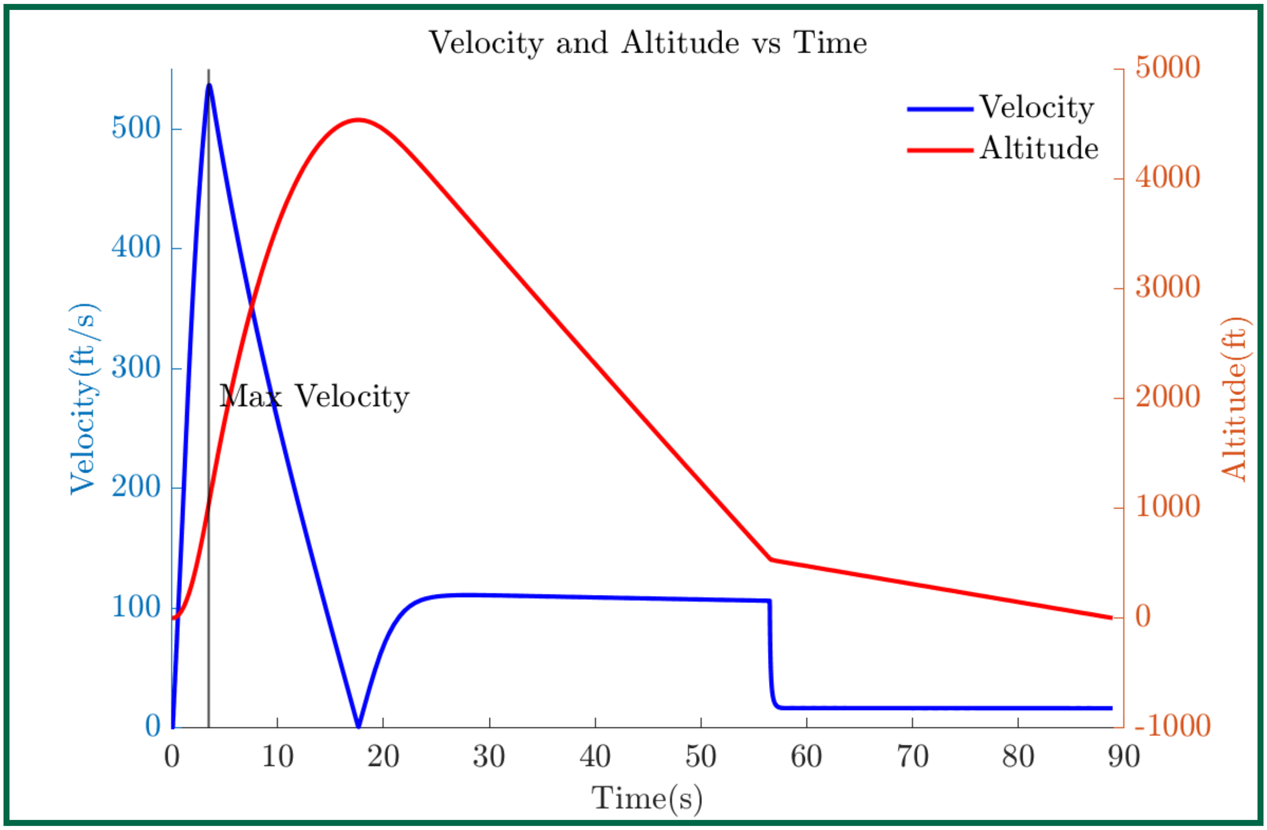


Figure 33. Maximum Velocity Graph

The maximum velocity is 536.7 ft/s, reached at 3.51 seconds from motor-ignition. At that time, the altitude of the rocket will be 1055.6 ft. The temperature at that altitude, according to equation (3) would then be:

$$T = 59 - 0.00356 \times 1055.6 = 55.24F \ (11)$$

The pressure at that temperature, according to equation (4), would be:

$$P = \frac{2116}{144} \times (\frac{55.24+459.7}{518.6})^{5.256} = 14.16 \frac{lb}{in^2} \ (12)$$

The speed of sound at that temperature, according to equation (2), would be:

$$a = \sqrt{1.4 \times 1716.59 \times (55.24 + 460)} = 1112.76 \ ft/s \ (13)$$

Another unknown is the modulus G. The material used for the fin is G10 fiberglass. According to MatWeb, the crosswise flexural modulus of G10 fiberglass is 2400 ksi, which is 2.4e6 psi. Therefore, the fin flutter speed threshold, according to the results from equation (7), (8), (10), (11), (12), (13), would be:

$$V_f = 1112.76\sqrt{\frac{2400000\times2\times(1.112+2)\times(\frac{0.185}{12.806})^3}{1.337\times1.112^3\times2038.68\times(0.081+1)}} = 1407.71\ ft/s$$

Table 7. Factor of Safety

Max Velocity from OpenRocket	Flutter Velocity Threshold	Factor of Safety
536.7 ft/s	1407.71 ft/s	2.62

The table above shows that the Factor of Safety is 2.62 for the system, which is high and demonstrates that the rocket is safe from fin flutter.

3.1.5.2 Motor Retention

The rocket motor will be encased using the centering rings and retaining rings shown in section 4.1.3.5. The retaining rings prevent the motor from sliding too far forward or aft of the intended location. The centering rings ensure that the motor tube remains stable and will not jostle around during flight. The locations of the centering rings and retaining rings are shown in the picture below, with the middle ring being 6.69" from the forward ring and 5.93" from the aft ring.

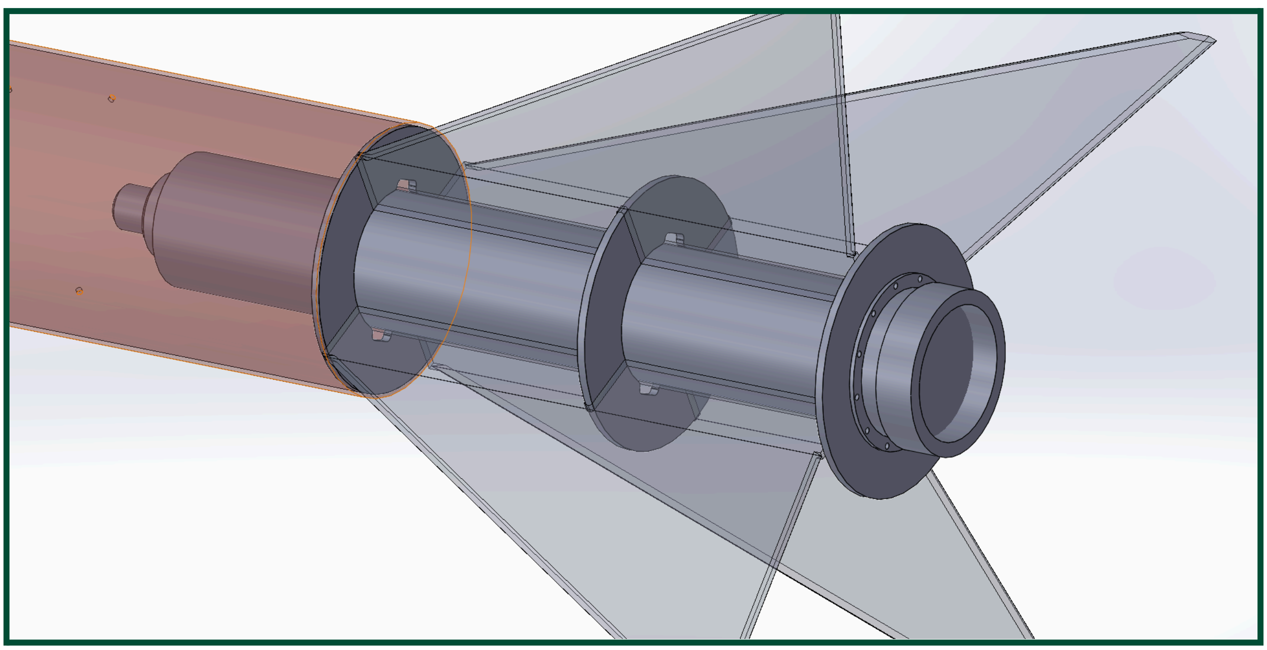


Figure 34. Motor retention

The retainer being used is an RA75 Aeropack 75mm retainer. This specific retainer was chosen due to being made of 6061-T6 aluminum, making it lightweight and durable, as well as being the necessary size to hold the motor and fit on the aft end of the rocket. The retainer also includes #6-32 screws and threaded inserts for easy installation and removal.

Figure 35. RA75 Aeropack Flanged Retainer

3.1.5.3 Snap Force

During recovery, when the main parachute deploys, the velocity of the rocket is affected very quickly by the new drag force produced by the main parachute. It drastically changes the velocity of the rocket in a direction contrary to the fall. This quick change of velocity produces a great force that affects the independent sections differently. According to OpenRocket, the acceleration at the point of the main parachute opening is roughly 400 m/s^2. Using Newton's Second Law, gives the ability to find the force at each independent section.

$$F_{total\ snap} = a * m_{landing} = 400 * 16.29 = 6516\ \mathrm{N}$$

It is important to mention that the force doesn't act equally over the entire vehicle. It gets distributed according to the respective sections and their mass distribution. Given that the rocket hangs from two ends of the parachute, the total snap force gets distributed between the Mid reaction force and Upper reaction force. Furthermore, given that the Booster Section is tethered and hanging from the Mid Section. The calculations for the Mid reaction force should have the mass of both the Mid and Booster Section.

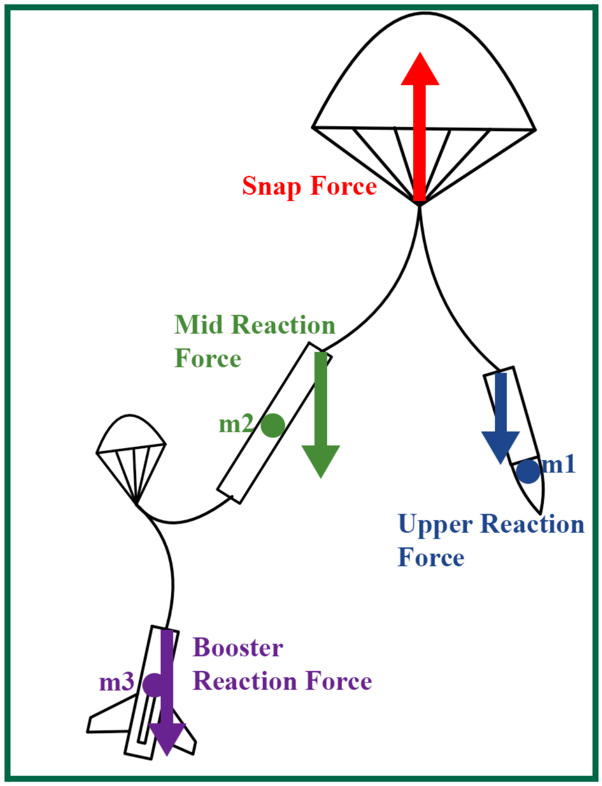


Figure 36. Snap Force Distribution

Knowing the masses of the Upper Section, Mid Section, and Booster Section to be 12.94, 11.31 and 11.66, respectively, it is possible to calculate for the maximum possible force calculations that the section will experience in tension under the main parachute deployment. The table below shows the force values.

Table 8. Maximum Force Values per Section

	Force (N)	Force (lbf.)
Upper Section	2348.7	528.0
Mid Section	4166.9	936.8
Booster Section	2114.8	475.4

3.1.5.3.1 Stringers Snap Force

Given that the stringers are the primary structural component in the avionics bay assembly, they have to be analyzed to ensure that they would endure the necessary forces. Four of them will be used in the assembly. It is possible to assume that the force would be distributed among these parts equally. Therefore, the force expected to be put on the Mid Section is divided by four.

In order to simulate the expected loads, the team has used Ansys Mechanical. The mesh was created, boundary conditions applied, and then the simulation was run. A force of 230 lbf. in tension was applied. The results are shown below.

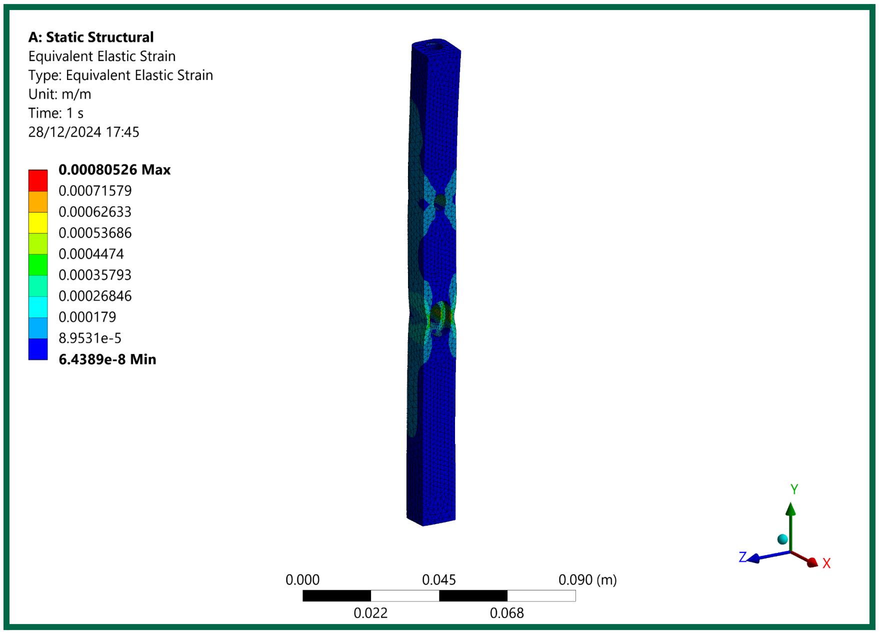


Figure 37. Stringer Strain

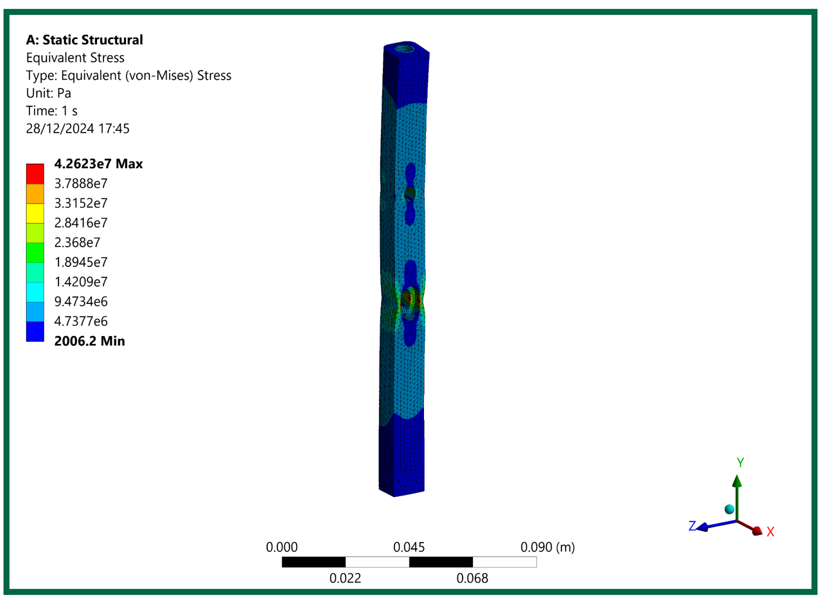


Figure 38. Stringer Stress

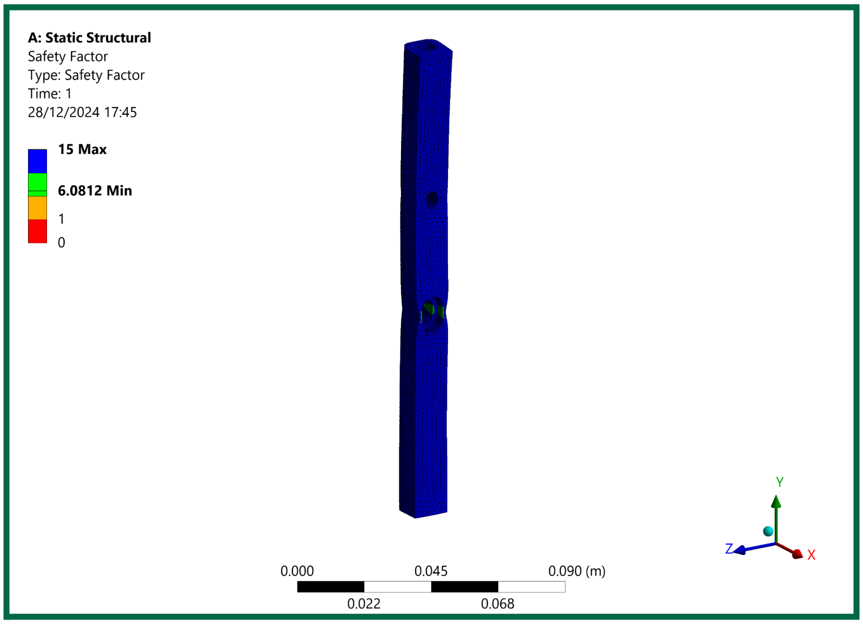


Figure 39. Stringer Factor of Safety

As shown in the simulations above, the stringers are suitable for this application. The stress concentrates the most around the holes for the bolts. However, even with these concentrations, the factor of safety is still well within a safe margin. Currently it sits at around 6.08.

3.1.5.3.2 Anchor Points

The team is using 2 Eye Nuts 3019T15 from McMaster. They are placed in the bulkheads that face a point of separation. Two of them are being used in comparison to a single U-bolt. The reason for this change is the improvement of strength and reduced weight.

Figure 40. 3019T15 Eye Nut

McMaster provides a rating of 840 lbf. Dividing the maximum expected load (Mid Section) over two, gives the individual load per part. Dividing the rating of the part by the previous found number it is possible to find the factor of safety: 1.8

3.1.5.3.3 Shock Cord

The shock cord is the most crucial part of the recovery system as it connects the independent sections together as well as the main and drogue parachutes. When the vehicle undergoes the snap force, the shock cord directly faces the maximum loading force. The team is using ⅜ Kevlar as the shock cord with a rating of 3600 lb.

The factor of safety is found by dividing the maximum loading force by the rating. It is found to be 7.6.

3.1.5.3.4 Snap Force Summary

In conclusion the vehicle most important sections are within the allowable safety ranges. The table below showcases the maximum expected load per part and their respective factor of safety.

Table 9. Force Ratings for Recovery Components

	Force (lbf.)	FOS
Stringer	234.2	6.1
Eye Nut	468.4	1.8
Shock Cord	936.8	3.8

3.1.5.4 Drag

To analyse the aerodynamics of the rocket, the team has used Ansys Fluent. A simplified design of the vehicle assembly was imported into the program, and after setting the boundary conditions, the team was able to get the maximum and minimum drag coefficient and drag forces. A reference area of 0.02683683 m^2 was used.

3.1.5.4.1 Vehicle without Airbrakes

To analyze the impact of the Airbrakes, the team had to first find the starting drag coefficient. Two planes of interest were analyzed. The plane that goes through the fins of the rocket and the planes that go through the Airbrakes. The fin plane showcases the more important details. In the figure below, the velocity of the air is seen. The air flows smoothly along the rocket except for the aft part. Given that the team is no longer using a boattail design, some turbulence and vortices are found in the aft of the vehicle. The found drag coefficient for the plain vehicle is 0.299

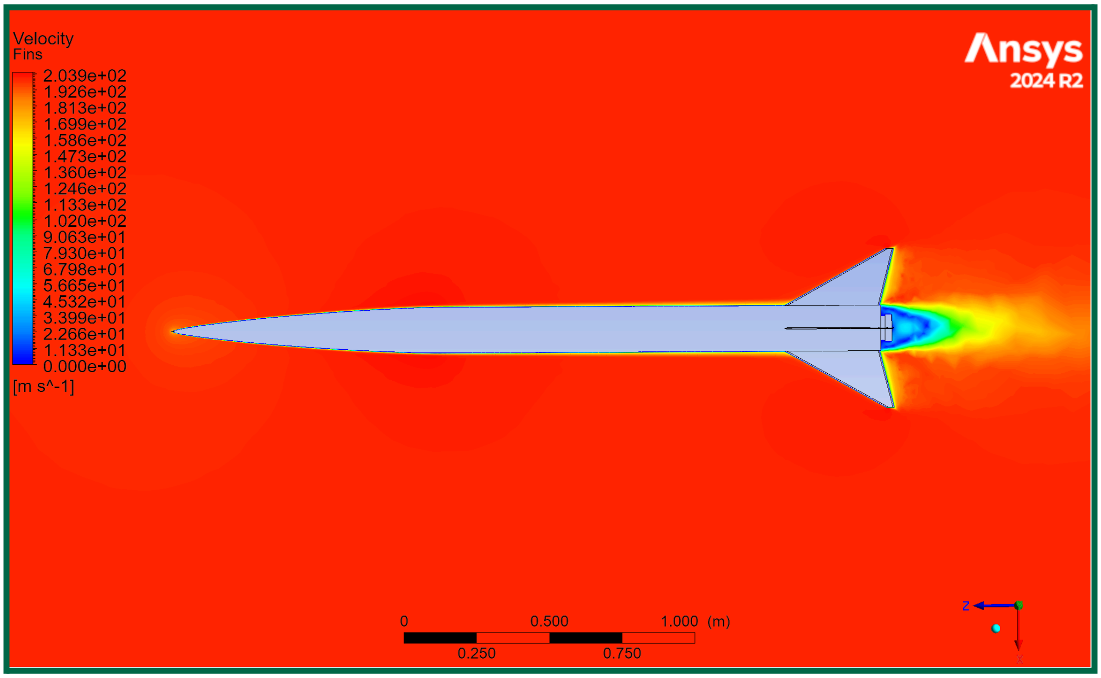


Figure 41. Velocity Plot around Plane of Fins

3.1.5.4.2 Vehicle with Airbrakes

The plane where the flow is affected the most is the plane where the Airbrakes appear. Given that the Airbrakes primary purpose is to increase drag, the team expected to see lots of turbulence along the Airbrakes section. The team performed an Ansys Fluent simulation with the geometry with the Airbrakes at 100% deployment. The results are shown below.

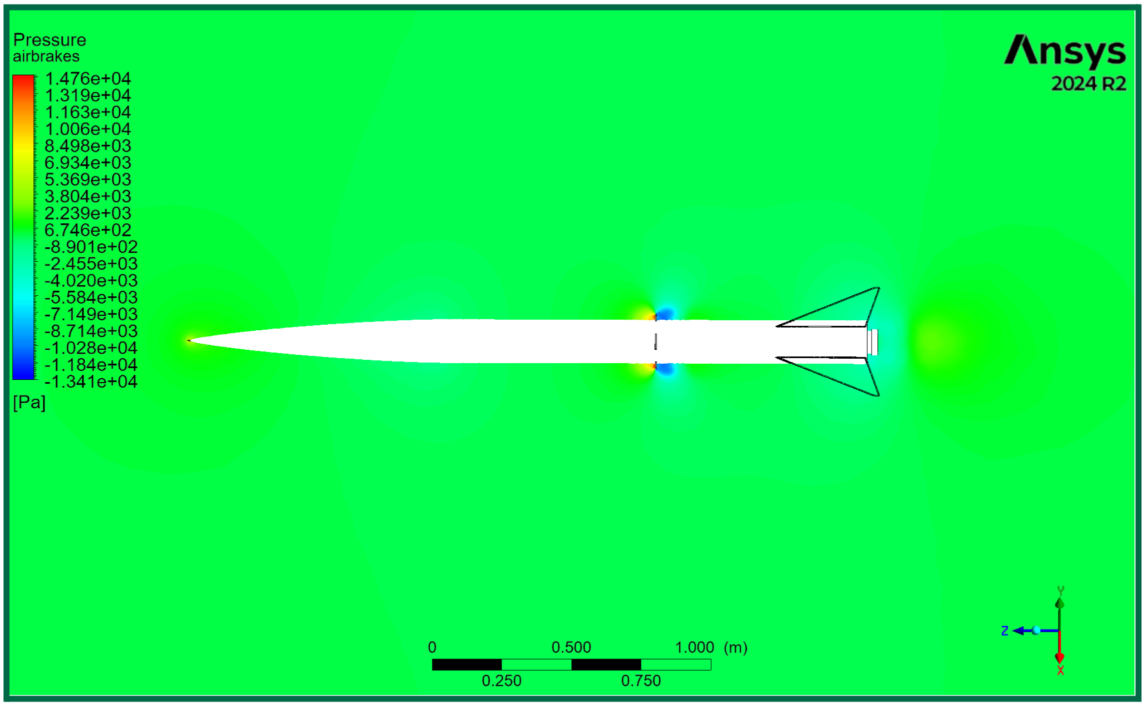


Figure 42. **Pressure Plot around Airbrakes Plane**

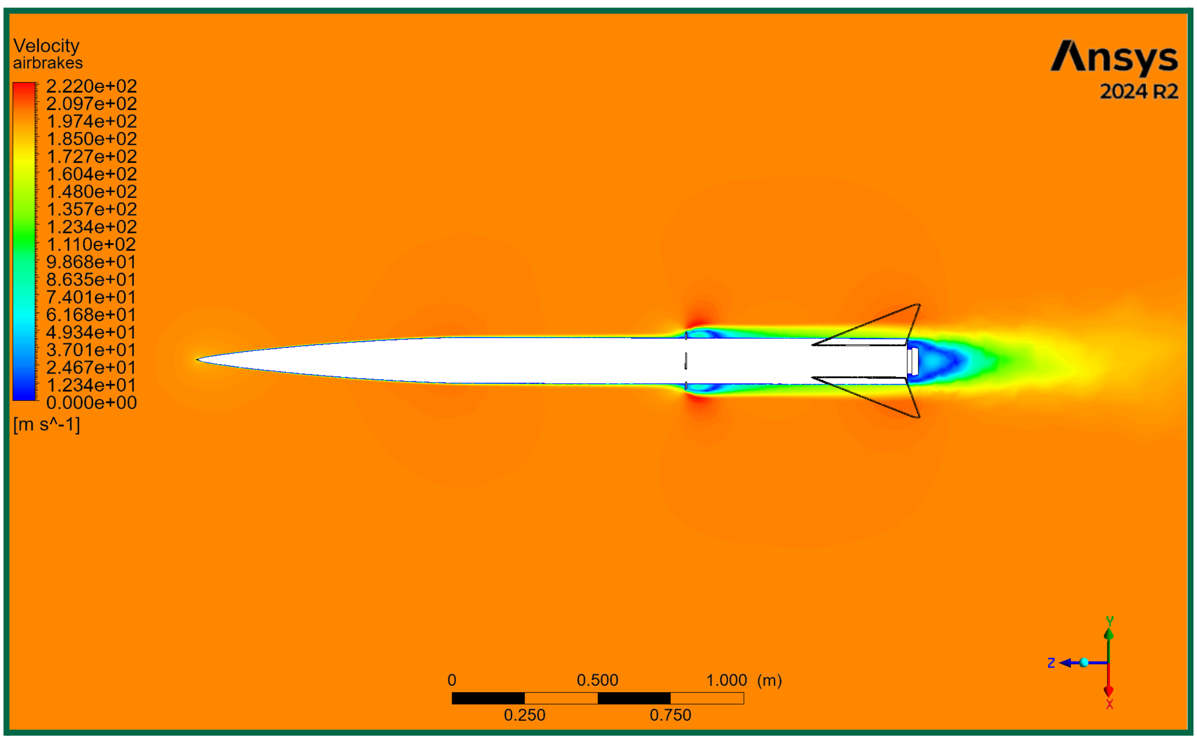


Figure 43. **Velocity Plot around Fins Plane**

The most notable thing is the great pressure increase in the front of the Airbrakes. The planar surface creates a high-pressure and low-pressure region in front and aft, respectively. This affects the flow of the air, as shown in the second velocity. Similar to the aft section, the flow is interrupted by this abrupt change in geometry, generating stronger vortices and turbulence. There is a clear difference between the flow before and after the Airbrakes. The found Cd was of 0.43

Table 10. Maximum Drag Coefficients

Category	Value
Max Cd	0.431
Min Cd	0.299

3.1.6 Projected Manufacturing Techniques

3.1.6.1 Computer Numerical Control Machining

By leveraging CNC machining, the team is able to produce intricate payload bays that optimize weight, strength, and flight performance. CNC machines can additionally work with a wide variety of materials, including aluminum, fiberglass, carbon fiber, and plastics, providing the team flexibility to select the best material for various designs. Below is the image showcasing the in-house production of parts using CNC.

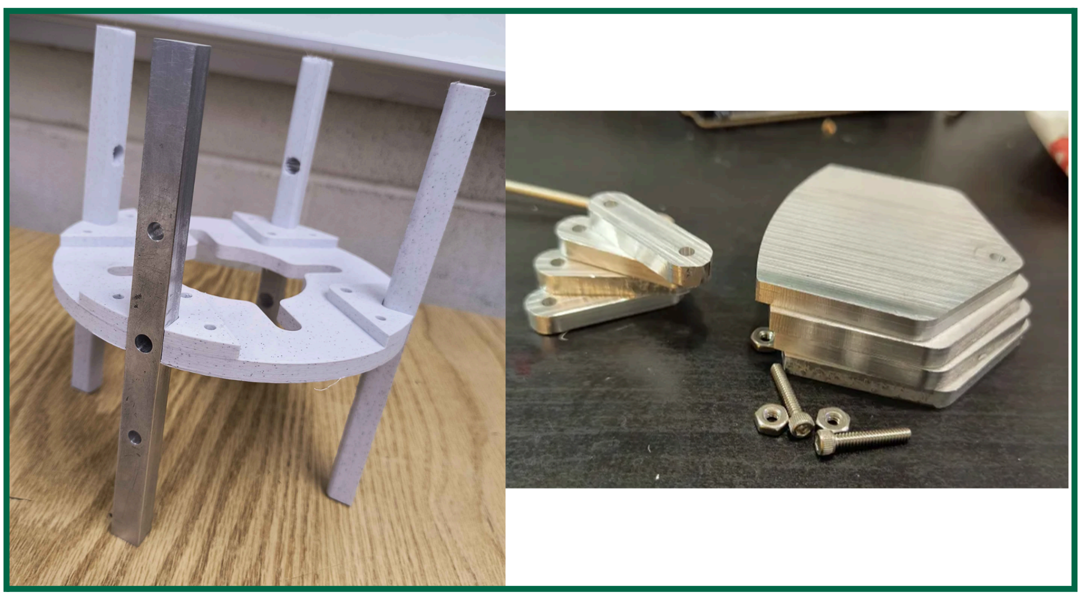


Figure 44. CNC-Manufactured Parts

3.1.6.1.1 Shapeoko HDM

The team has access to a Shapeoko HDM as the main CNC machine. The Shapeoko HDM is a high-performance CNC router designed for precision machining of materials like wood, aluminum, and brass. It features a rigid frame with T-slot workholding, HG-15 linear bearings, and 16mm ball screws for smooth, accurate motion. The 80mm water-cooled spindle offers an RPM range of 8,000 to 24,000 and can handle cutters up to 1/2 inch.

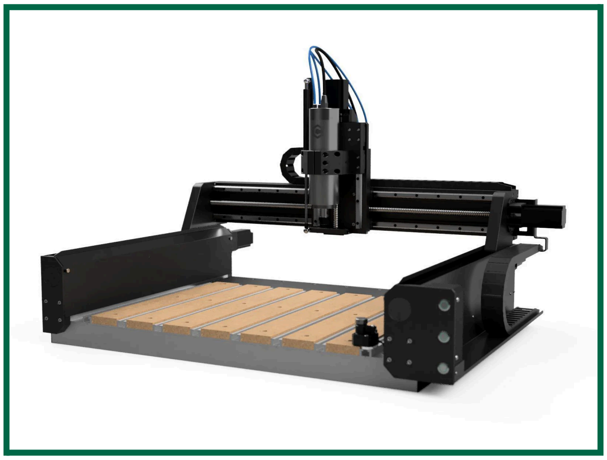


Figure 45. Shapeoko HMD CNC

The team uses Fusion 360 to make the G-codes necessary to fabricate each part. For instance, one of the most complex parts that the team expects to manufacture is the serve holder, made out of aluminum 6061. The team will machine it from a stock block, attached to a vice set. Three tools with 2 setups are required to manufacture this part. When the first setup is finished, a set of soft jaws will be used to clamp the part into the vice and then make a facing operation, removing the initial offset.

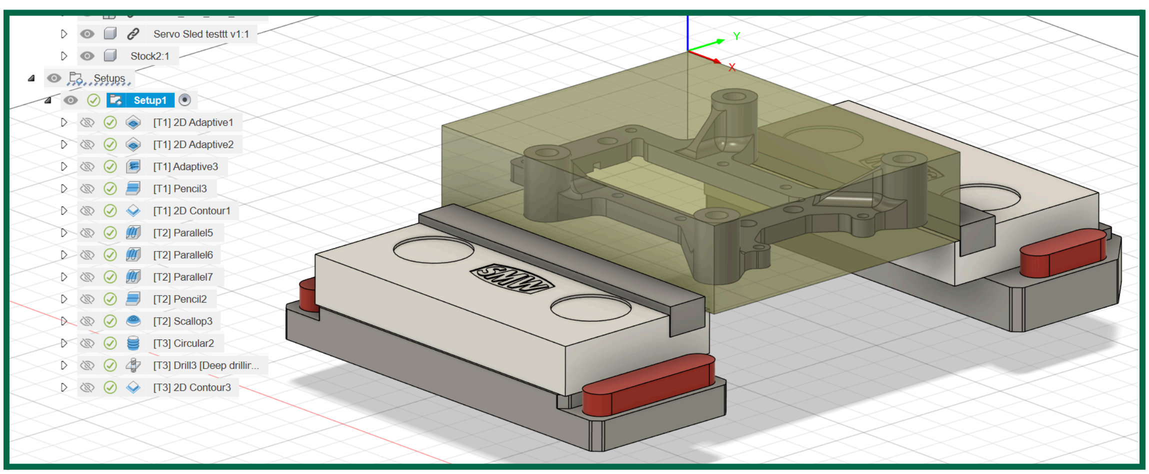


Figure 46. Fusion 360 Setup

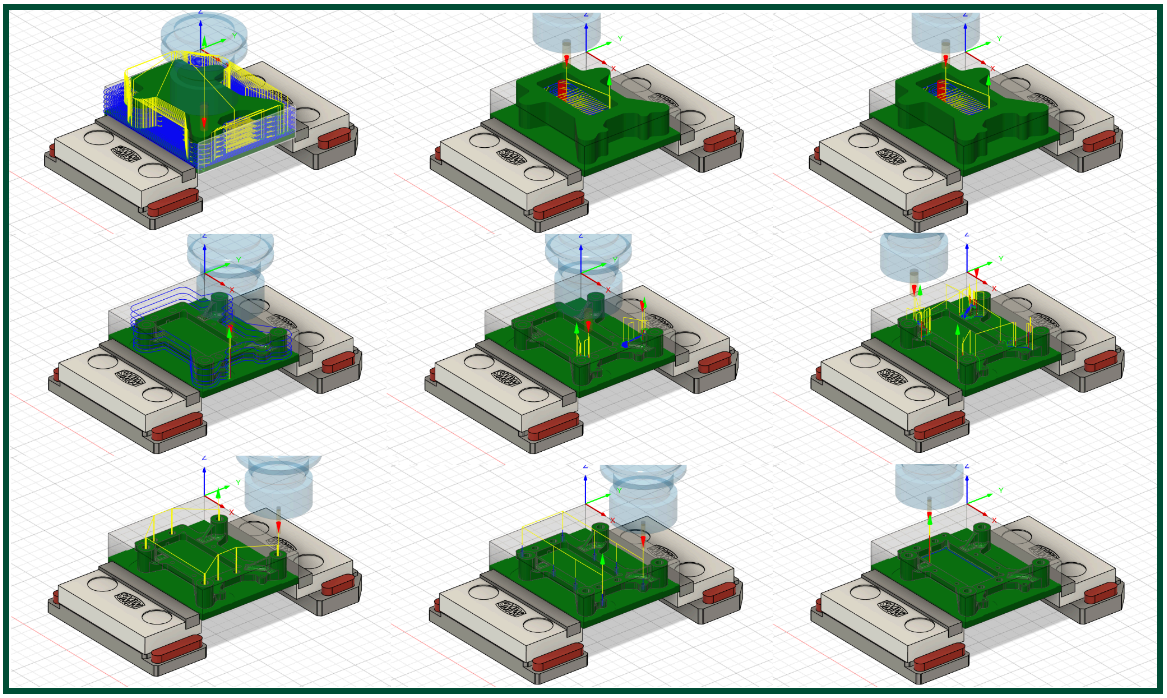


Figure 47. Fusion 360 Toolpath Operations

3.1.6.2 Adhesion Techniques

Adhesion techniques are vital for the strength and fixture of components. The team uses these techniques to bond the centering rings, motor tube, fins, and aft closure. It is crucial to follow a correct procedure to ensure the full strength of the bonding agent. Fillet adhesion was also utilised as it strengthens joints and improves aerodynamics by adding smooth, curved transitions where components meet.

3.1.6.2.1 JB Weld

JB Weld is a strong, versatile epoxy adhesive commonly used in rocketry for bonding, sealing, and repairing components. It consists of a resin and hardener that, when mixed, form a durable bond ideal for joining metal, plastic, fiberglass, and other materials. In rocketry, JB Weld is used to bond motor mounts, fins, and nose cones to the airframe when prototyping, ensuring secure attachment during test flights. It also seals joints and connections to prevent gas leakage, fills gaps for smooth aerodynamics, and repairs cracks or damage to rocket parts. Its heat resistance (up to 550°F/287°C) makes it suitable for high-temperature applications, and its high strength and durability ensure that it can withstand the stresses of launch and flight. Despite being less suitable for actual flight conditions like the Aeropoxy mentioned below, JB welding was of utmost importance in prototyping and testing out designs in the production phase of the rocket. It is still used in components that need adhesion but are not fiberglass or carbon fiber. Overall, JB Weld is a valuable tool for creating reliable, long-lasting bonds and repairs in a large array of parts that need adhesion

JB Weld is a strong epoxy adhesive. It consists of a resin and hardener that, when mixed, form a strong bond. The team will use this adhesive to bond the motor mount, fins, and centering rings. It is heat resistant up to 550°F. Despite being less suitable for actual flight conditions like the Aeropoxy mentioned below, JB Weld is easier to work with as it is more viscous and has a

3.1.6.2.2 Aeropoxy

Aeropoxy is a high-performance epoxy resin commonly used in rocketry for bonding and constructing composite materials like fiberglass and carbon fiber. It is valued for its strength, durability, and heat resistance, making it ideal for components such as airframes, fins, and nose cones. Aeropoxy is also used for filling gaps, repairing cracks, and ensuring smooth, seamless surfaces. It is usually combined with sanding and then painting another layer so as to achieve the desired aerodynamic surface for flight. Its resistance to moisture, chemicals, and UV radiation, along with its ability to withstand high temperatures, ensures that rocket parts remain structurally intact under the stresses of launch and flight. It has been used in internal tests, especially in the attaching of the fins to the rocket frame in detachment tests, the attachment of the aft to the body frame in engine tests, and structural integrity tests that were carried out throughout the development of the rocket. To sum up, Aeropoxy is essential for building lightweight, durable, and reliable rocket components.

3.2 Subscale Flight Results

3.2.1 Subscale Vehicle Design

The goal of the subscale rocket this year is to scale down full scale by approximately 50% in terms of its total size, internal systems, and altitude goal. By accomplishing this scaling, can effectively observe similar qualities full scale would exhibit during flight, while testing potential systems before implementing them into full scale. One focus of the subscale design is to test and monitor the performance of electronic sensors during flight. Analyzing the accuracy of data obtained and identifying potential problems by flight will aid the team during full scale design and ensure future flights perform as expected. The overall data obtained from subscale flight will primarily benefit the development of both payload and airbrake systems for full scale flight.

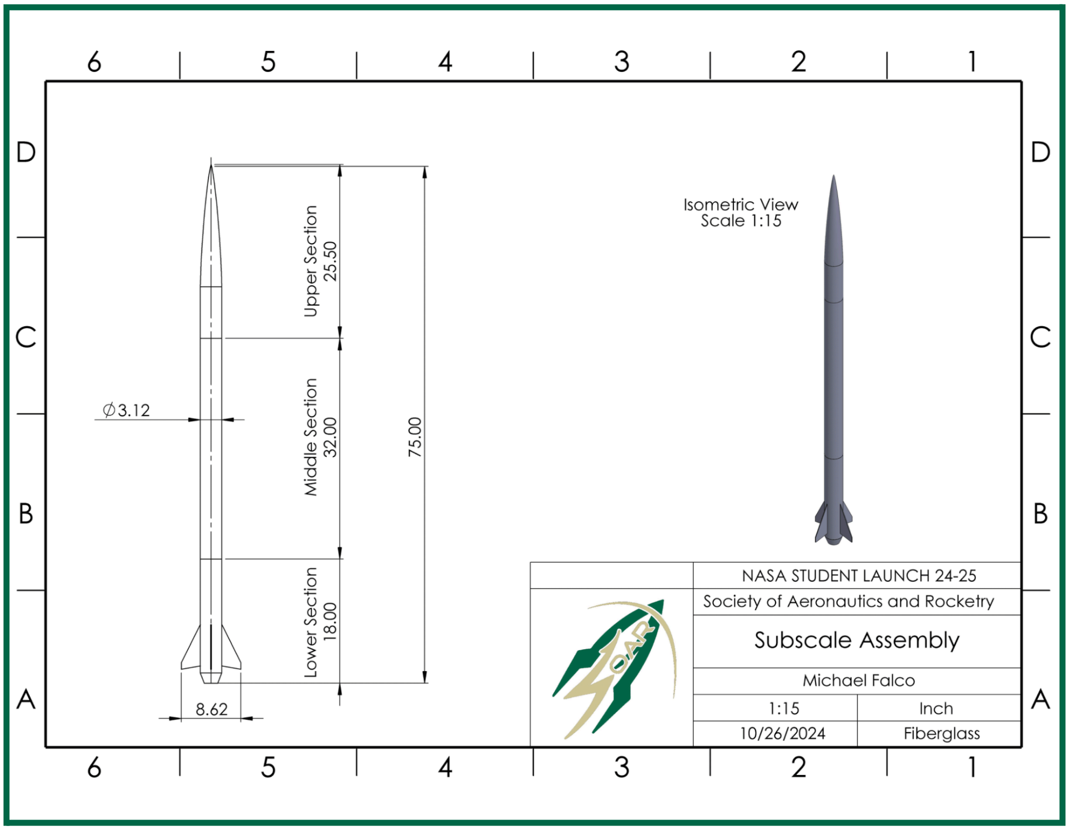


Figure 48. Subscale Assembly Engineering Drawing

3.2.2 Subscale Vehicle Recovery

The subscale and full scale parachutes, for that matter, are primarily purchased at "fruitychutes" due to their proven consistency in durability and descent rate with openrocket simulations. This year, a subscale rocket will be descending with an 18-inch drogue followed by a main parachute to safely descend itself down within a reasonable time and landing area. Similarly to full scale, both the drogue and main will deploy at 50% of what the full scale altitude would have been, also deploying with the same CONOPS to make the flight as similar as possible.

Table 11. Parachute Specifications

	Drogue	Main
Diameter (in.)	18	60
Drag Coefficient	1.55	2.2
Packing Volume (in.^{3})	9.67	38.2

3.2.3 Subscale Vehicle Motor

The subscale vehicle was launched with a Cesaroni L360 motor. The team used a readily available motor. Details of the motor are shown below.

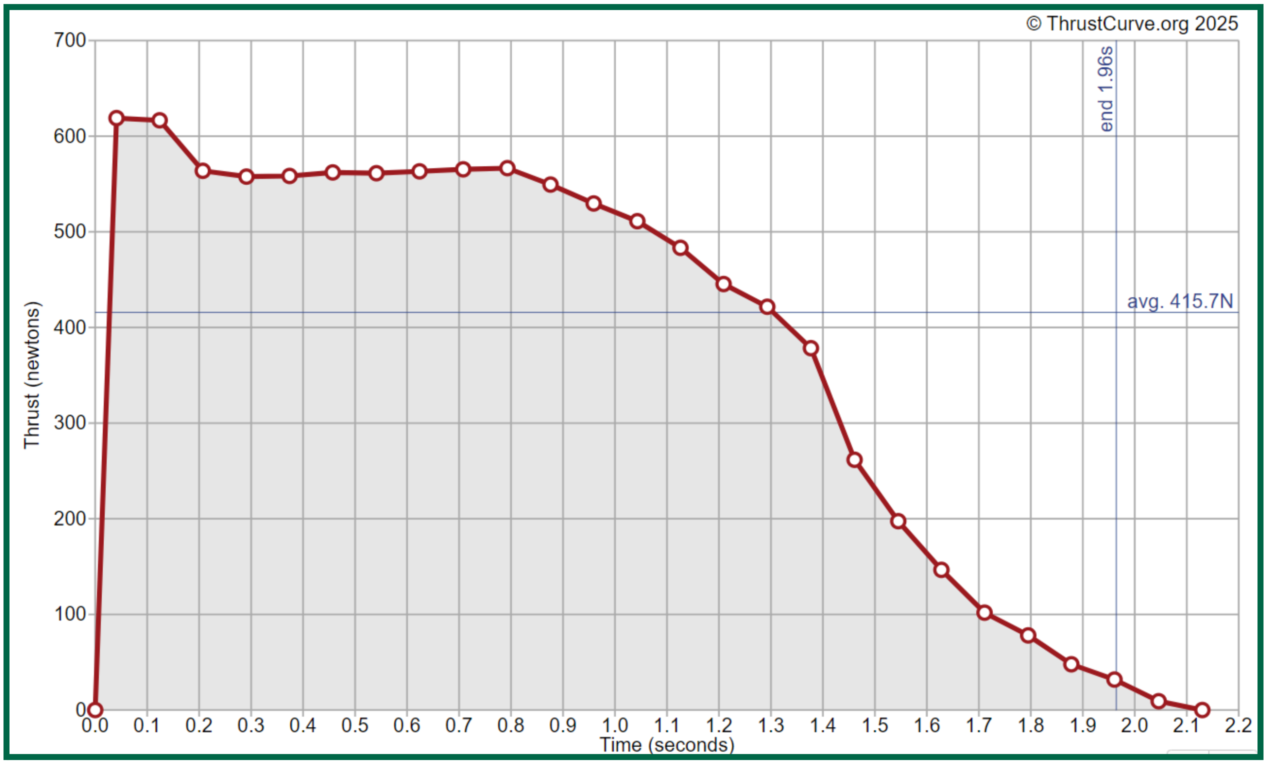


Figure 49. J360 Thrust Curve

3.2.4 Data Gathering Devices and Locations

There were two altimeters in the launch vehicle that recorded data during the subscale launch: TeleMetrum and RRC3 Sport. The TeleMetrum altimeter is a payload integrated with a GPS and telemetry link, while the Missileworks RRC3 altimeter allows for continuous data download between flights. The main purpose of these two altimeters is to record the flight profile of the vehicle, including parameters such as the vehicle's apogee, velocity, and acceleration. The team used two altimeters instead of one for redundancy in case one altimeter fails. The two altimeters used are shown below.

Figure 50. Altus Metrum TeleMetrum Altimeter

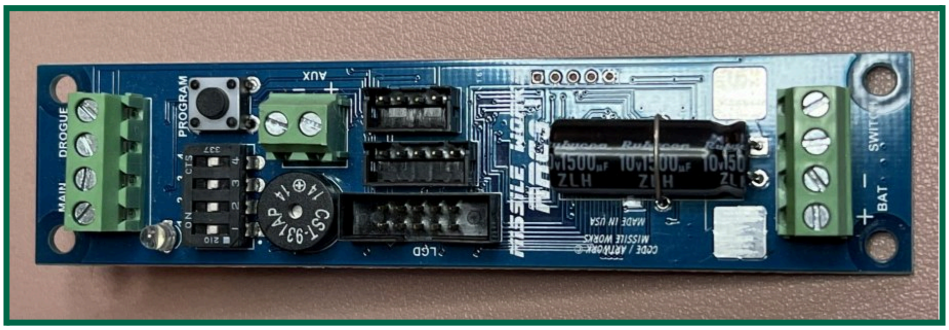


Figure 51. Missileworks RRC3 Altimeter

The altimeters were located in the avionics bay of the vehicle, as shown in the image below.

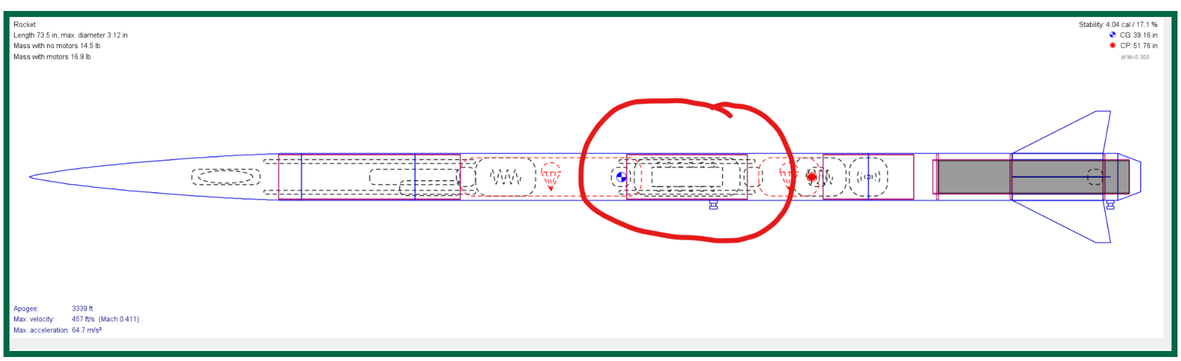


Figure 52. Location of the Altimeters in the Vehicle

3.2.5 Launch Day Conditions

The subscale launch took place on Saturday, December 21, 2024, at Varn Ranch in Plant City, FL. At the time of launch— 4 pm EST— the weather was sunny and cold with cirrus and cirrocumulus clouds covering the skies throughout the whole day. There was no precipitation. Table 5 below lists the conditions of the launch site at the time of flight.

Table 12. Subscale Launch Day Conditions

Data	Value
Apogee	2176 ft.
Maximum velocity	363 ft/s
Ascent time	11.6 seconds
Launch Rod Angle	5° (into the wind)

3.2.6 Subscale Flight Simulations

Based on the launch conditions above, a simulation of the flight was created in OpenRocket to predict the characteristics of the flight, including apogee, maximum velocity, and time of flight. The plot of height, velocity, and acceleration as a function of time is shown below.

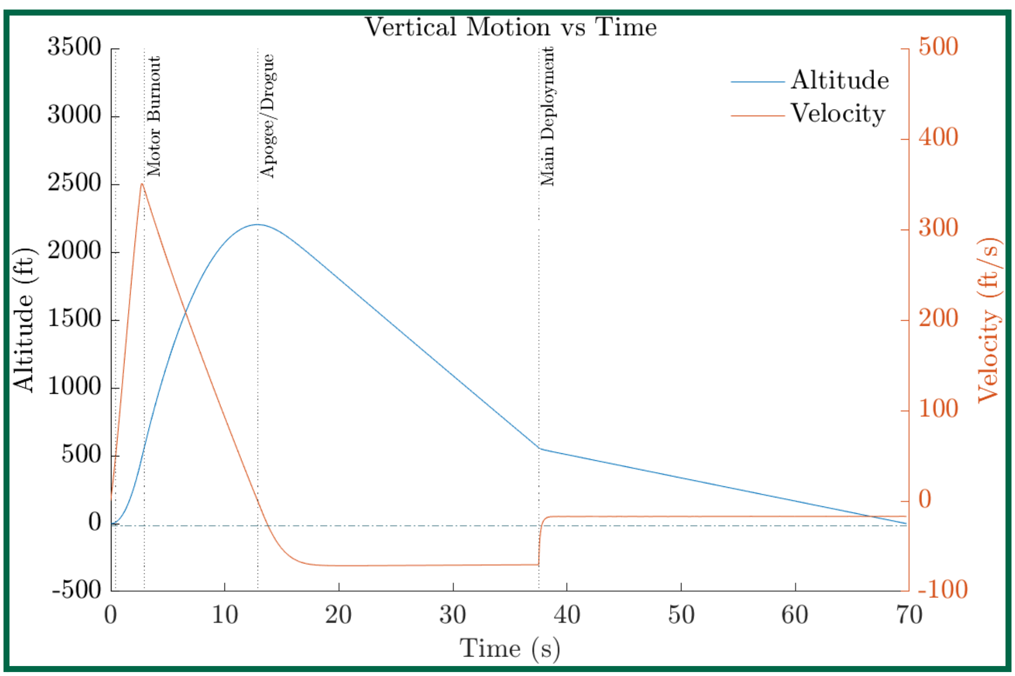


Figure 53. Subscale Simulated Altitude and Velocity Over Time

The simulated flight characteristics are shown below:

Table 13. Expected Values for Subscale Flight Characteristics

Data	Value
Apogee	2203ft
Velocity off-rail	53.7ft/s
Maximum Velocity	352ft/s
Time to Apogee	12.9s
Total Flight Time	69.7s

3.2.7 Subscale Flight Profile

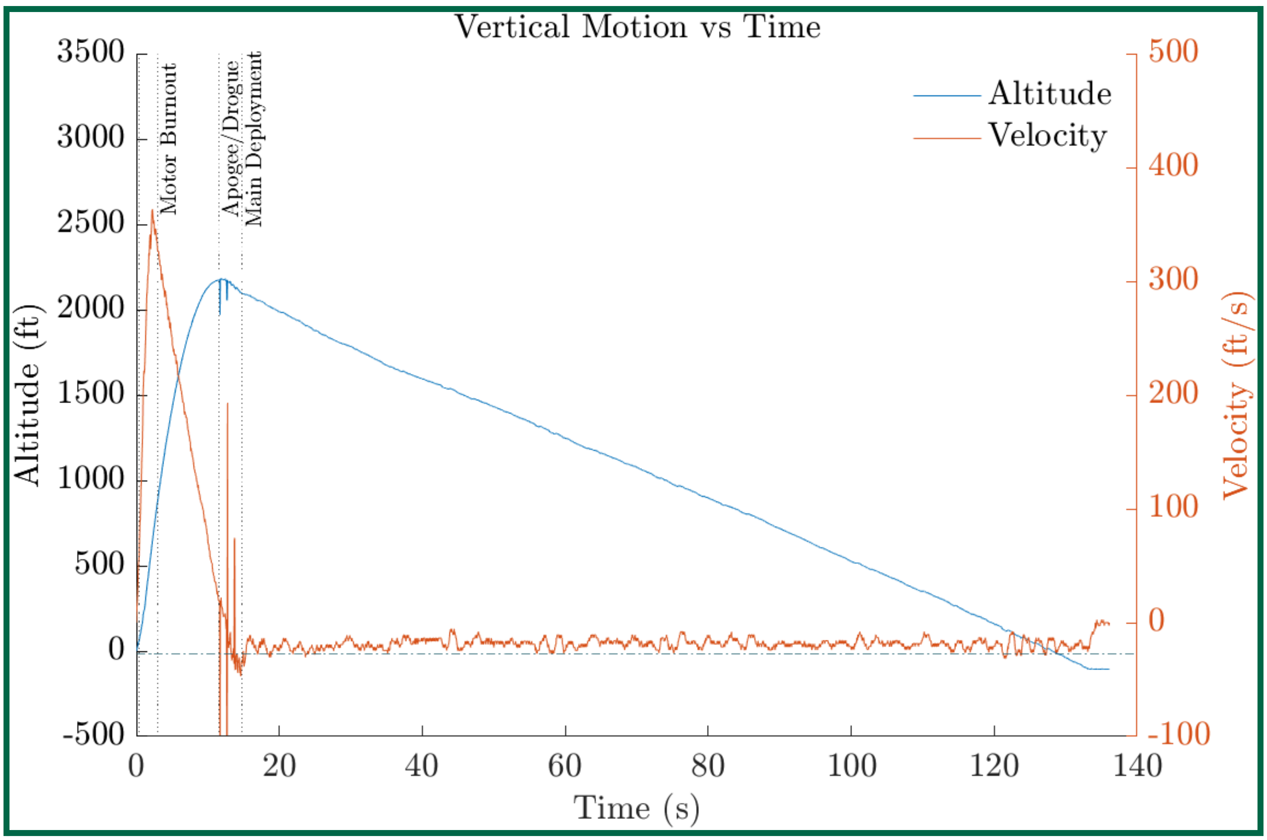


Figure 54. Subscale Launch Altitude and Velocity Profile Over Time

Shown above is the data recorded by the RRC3 after the subscale launch, showing the altitude and velocity over time of the rocket throughout the entire launch. The characteristic values for the subscale launch, such as apogee, time of flight, and timestamps for drogue and main deployment, are listed below. The main parachute, however, seems to have been deployed at a location different from what was planned.

3.2.8 Landed Configuration Pictures

During the flight, the sections separated successfully. Shown below is the subscale recovery site after the launch vehicle landed. It can be seen that the vehicle did not sustain any damage and that the deployment was successful. The pictures below were taken before any team member touched the launch vehicle.

Figure 55. Subscale Recovery Site

Figure 56. Booster Section and Drogue

Figure 57. Main Parachute

Figure 58. Upper and Mid Section

3.2.9 Subscale Flight Analysis

Table 14. Parameter Values For Subscale Flight

Data	Value
Apogee	2176ft
Velocity off-rail	59.8ft/s
Maximum Velocity	363.14 ft/s
Time to Apogee	11.6s
Total Flight Time	134s

Shown above are values obtained from the RRC3 following the successful subscale launch. These include the apogee and at what time it was reached, the velocity at liftoff and the maximum velocity, and the total duration of the flight from takeoff to landing.

3.2.9.1 Altitude

The recorded apogee of 2176 ft is very close to the simulated apogee of 2203 ft, being only a 27 ft difference. The velocity off-rail and maximum velocity were also close to the expected values, being the difference between the actual and simulated 6.1ft/s and 11ft/s off, respectively. These minor differences are most likely due to inconsistent noise, such as the friction on the rod, the wind patterns, and other minute factors, or parasitic drag from the rail guides and bolts. Below is a graph comparing the vertical displacement of the vehicle over time.

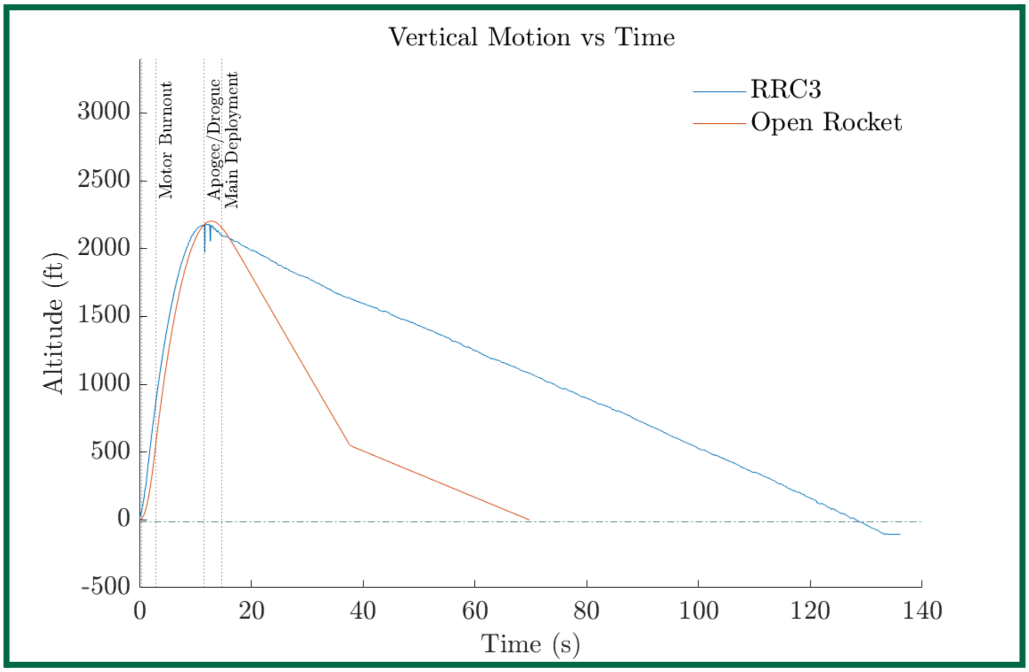


Figure 59. RRC3 vs OpenRocket Altitude Graph

As shown in the picture below, the main discrepancy happens after apogee. The main parachute deploys and slowly drifts away. The initial part, however, looks very similar. A graph focused on only the first part of the flight was made to look at these values more closely.

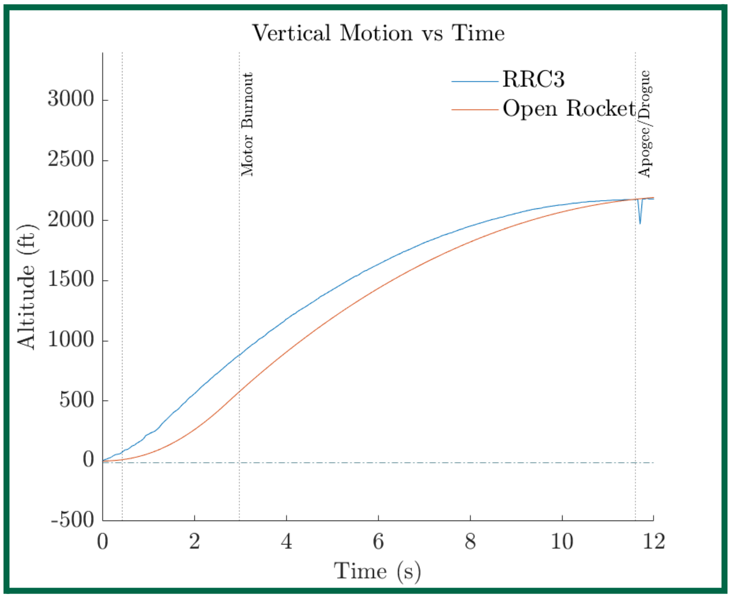


Figure 60. Localized RRC3 vs OpenRocket Altitude Graph

The behavior is very similar. The data captured from the RRC3 tells us that the vehicle's velocity starts much quicker than in the simulation, but they later converge around the same value. In conclusion, the OpenRocket model was accurate enough to predict the apogee with an error of only 1.24%.

3.2.9.2 Velocity

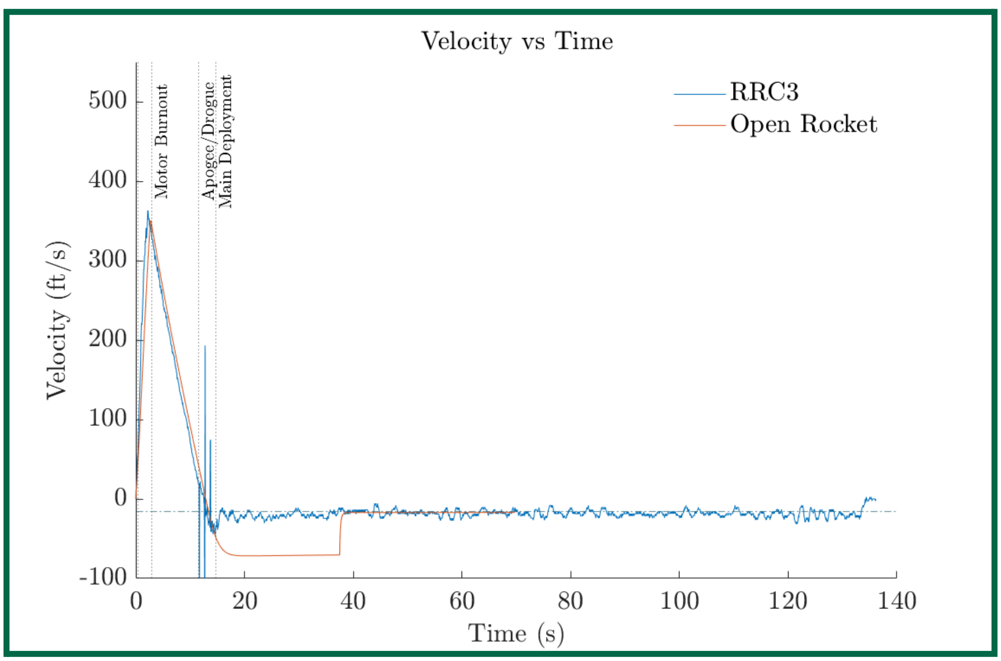


Figure 61. RRC3 vs OpenRocket Velocity Comparison Graph

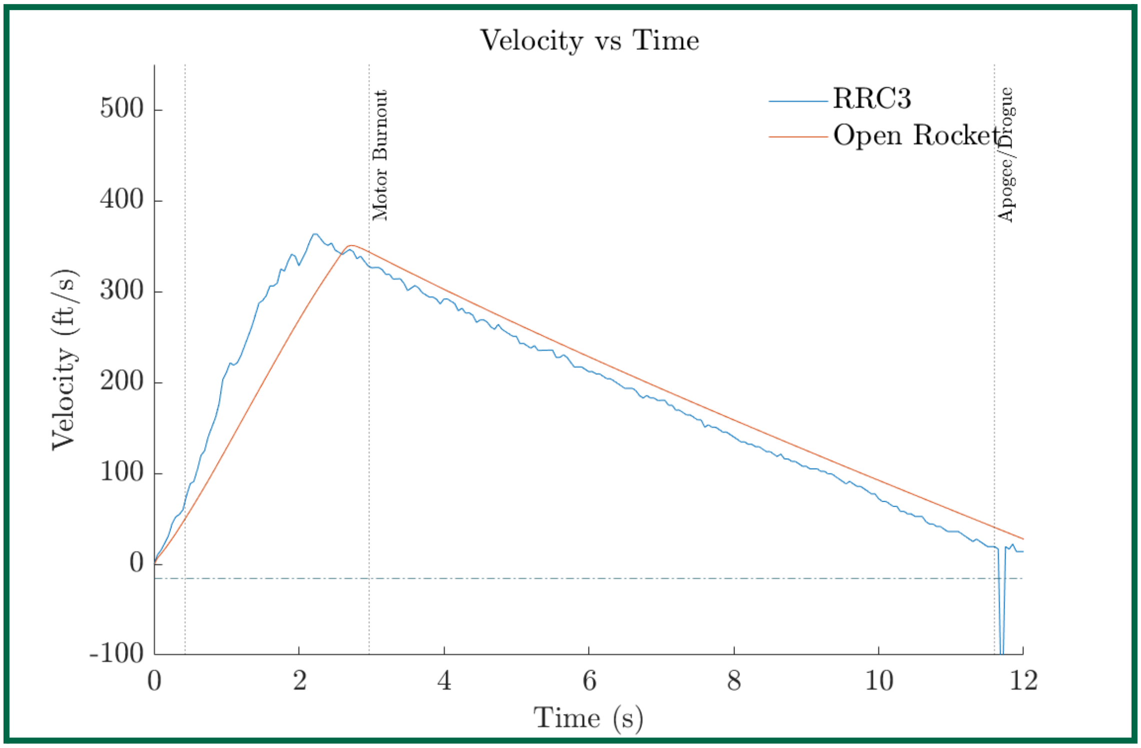


Figure 62. RRC3 vs OpenRocket Velocity Comparison Graph

Shown above are the velocity profiles of both the simulated and actual subscale launches, with the first graph covering the entire flight time and the second graph being a zoom-in on the first 12 seconds of flight. From the second graph, you can see that the RRC3 data closely lines up with the simulated OpenRocket numbers up to drogue deployment.

However, in the first graph, following drogue deployment is where the velocity profiles differ drastically. In the OpenRocket simulation, the main parachute was to be deployed at 650 feet, and so the velocity of the rocket would stay constant at -70 feet/s until the main parachute deployed. However, during the real launch, the main deployment occurred about 2-3 seconds after drogue deployment, and so its velocity hovered

3.2.9.3 Flight Time

The biggest discrepancy from the flight simulations is that the total flight time took approximately twice as long as expected, being 134 seconds as opposed to the simulated 69.7 seconds. This is due to the fact that the main parachute deployed earlier than as mentioned in the previous section. Rather than being deployed at 650 feet as was simulated, the main parachute was accidentally deployed roughly 2-3 seconds after the drogue deployment. This caused the rocket's flight duration to be drastically extended as it had to slowly descend all the way down to the ground.

Upon checking the raw flight data, troubleshooting revealed a programming issue with the altimeters. The RRC3 triggered the main parachute much earlier than the projected. The figure below shows the raw data, highlighting the time and important events.

Time	Altitude	Pressure	Velocity	Temperatu	Events
11.55	2172.684	937.7	19.33333	70.34	-
11.6	2175.592	937.6	19.33333	70.34	Drogue
11.65	2175.592	937.6	16.57143	70.34	-
11.7	1969.828	944.7	-179.381	70.34	-
11.75	2178.498	937.5	19.33333	70.34	-
11.8	2178.498	937.5	16.57143	70.34	-
11.85	2184.313	937.3	22.09524	70.34	-
11.9	2178.498	937.5	13.80952	70.34	-
11.95	2178.498	937.5	13.80952	70.34	-
12	2178.498	937.5	13.80952	70.34	-
12.05	2178.498	937.5	11.04762	70.34	-
12.1	2175.592	937.6	8.285714	70.34	-
12.15	2175.592	937.6	5.523809	70.34	-
12.2	2175.592	937.6	5.523809	70.34	-
12.25	2175.592	937.6	5.523809	70.34	-
12.3	2175.592	937.6	5.523809	70.34	-
12.35	2175.592	937.6	5.523809	70.34	-
12.4	2181.405	937.4	8.285714	70.34	-
12.45	2178.498	937.5	5.523809	70.34	-
12.5	2175.592	937.6	2.761905	70.34	-
12.55	2166.871	937.9	-5.52381	70.52	-
12.6	2175.592	937.6	2.761905	70.52	-
12.65	2056.616	941.7	-113.333	70.52	Main
12.7	2053.72	941.8	-116.095	70.52	-

Figure 63. Raw Altimeter Data Extraction

3.2.9.4 Drift

The team records the coordinates prior and They are as follows:

Launchpad GPS Coordinates: 28.09225410, -82.17611270 ($\pm$18 ft)

Landing location GPS Coordinates: 28.08981170, -82.17663800 ($\pm$12 ft)

With this information, it is possible to find the drift of the subscale vehicle. The google maps results yielded a drift of approximately 888 feet.

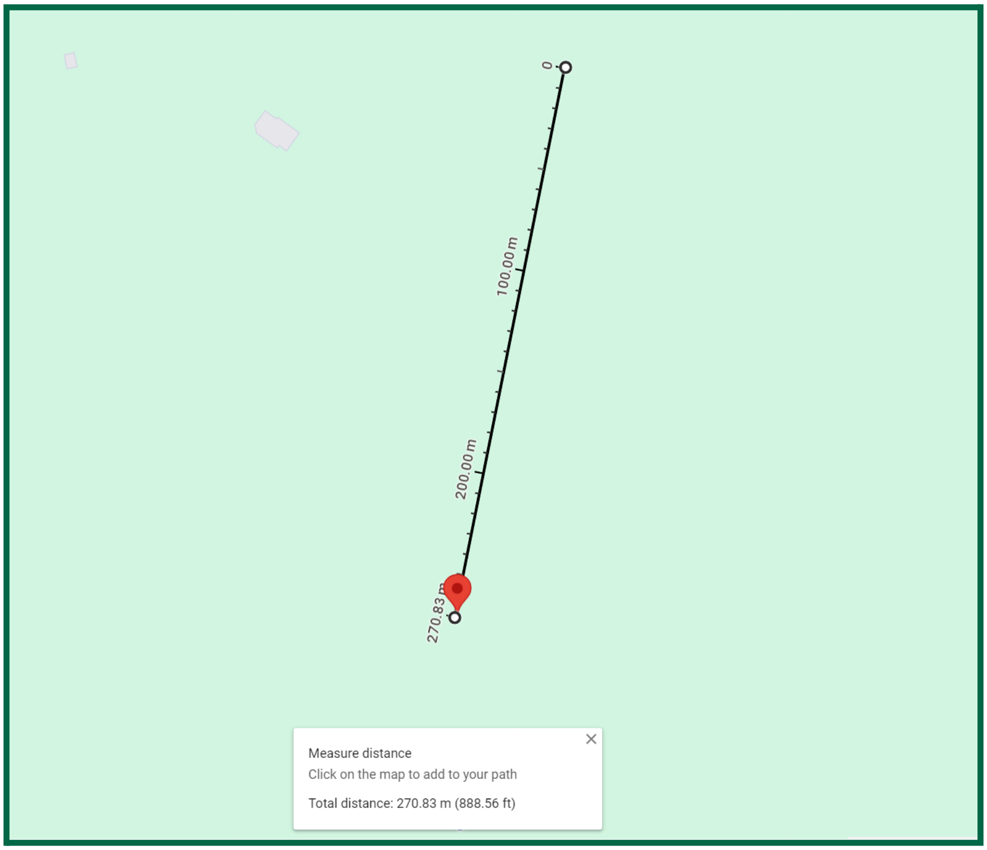


Figure 64. Google Maps Drift Calculation

3.2.10 Fullscale Scaling Factors

The vehicle was designed with a 50% reduction. This is shown by the airframe reduction from 6 in to 3 in. The length of the subscale vehicle was kept to a minimum when possible. In some cases, like in the parachute section, it was not possible to scale down the diameter and the length. This is because by halving those dimensions, the total available volume gets reduced by a factor of 8. This greatly limits the length of such sections. In other cases, like in the fins, the dimensions are pretty similar. However, the Fullscale fins were further optimized for better flight performance.

3.2.11 Fullscale Design Impact

3.2.11.1 Parachute Available Volume

Issue: Placing the main parachute in between the Upper and Mid sections was hard, leaving little space for the dog barf, which protects the parachute.

Cause: Poor planning; no factor of safety was applied when calculating the volume available for the parachutes.

Result: The team will now apply a factor of safety when calculating the available volume for the parachutes.

3.2.11.2 Machining Techniques

Issue: The team used a vertical mill to drill holes and slots in the airframe instead of the 3D-printed jig. Lack of experience with these machines caused the tolerances to be worse than with just previous methods, even though the machines are supposed to be more accurate.

Cause: Lack of experience and preparation when performing these holes. The airframe was not properly supported at both ends. Deflection was occurring when drilling holes far from the supporting edge.

Result: The team will practice with leftover stock and create jigs for the mill.

3.2.11.3 No Switchband

Issue: The team had trouble preparing the vehicle for the black powder test

Cause: Moving away from a switch band brought pros and cons. On one side, the length of the coupler was not constrained by the length of a separation point, reducing the minimum length andvehicles, saving weight. On the other hand, it made it hard to route the e-match from the charge well to through the switch holes.

Result: For future vehicles the team will be more aware of the issues of having no switchband. Fullscale design remained the same.

3.2.11.4 Booster Coupler

Issue: The booster coupler flew empty. No components were placed within this section.

Cause: The team overestimated the need for space within the rocket. All electronics and components were distributed in between the payload coupler and avionics bay. Adding components in the booster coupler would mean adding mass behind the center of mass, decreasing the stability.

Result: The booster coupler was transformed to a through coupler. Bulkheads and threaded rods were removed. The anchor point changed from a double-eye nut to a y-harness attached to the motor tube.

3.3 Recovery Subsystem

3.3.1 PDR Design Alternatives

Since the PDR, the team has decided to proceed with parachute deployment using traditional black powder. The team already has experience building rockets with black powder deployment systems, and the equipment for constructing such systems is readily available. Therefore, not switching to CO2 cartridges helps save time, money, and resources for other more critical systems, such as the airbrake and payload challenge.

For other parts of the recovery system, the team has chosen Kevlar shock cords due to their availability. Parachute protection methods include Nomex wrapping and dog barf fire protection. These decisions were made based on the trade studies presented in the PDR.

Additionally, the team has made some fundamental design changes, reducing the total landing weight of the rocket from 22.53 kg to 16.29 kg. As a result, the parachutes must also be adjusted to reduce drag efficiency to comply with NASA's recovery time requirements. The team's alternative choices for the rocket are the Fruity Chutes 18" Compact for the drag chute (drogue) and the Fruity Chutes 96" Ultralight for the main parachute, due to the overall performance and having the lowest weight in the same parachutes sector.

3.3.2 Concept of Operations

The launch vehicle consists of two separation events and is split up into three sections: upper, middle, and lower. The first separation event will utilize an 18-inch. “Fruity Chutes Compact,” deploying at an apogee of 4075 ft. The second separation event will utilize a 96-inch “Fruity Chute Ultralight” deploying at 600 ft. The current configuration for recovery ensures that the launch vehicle reaches its target altitude, descends safely, and does not drift outside the target area.

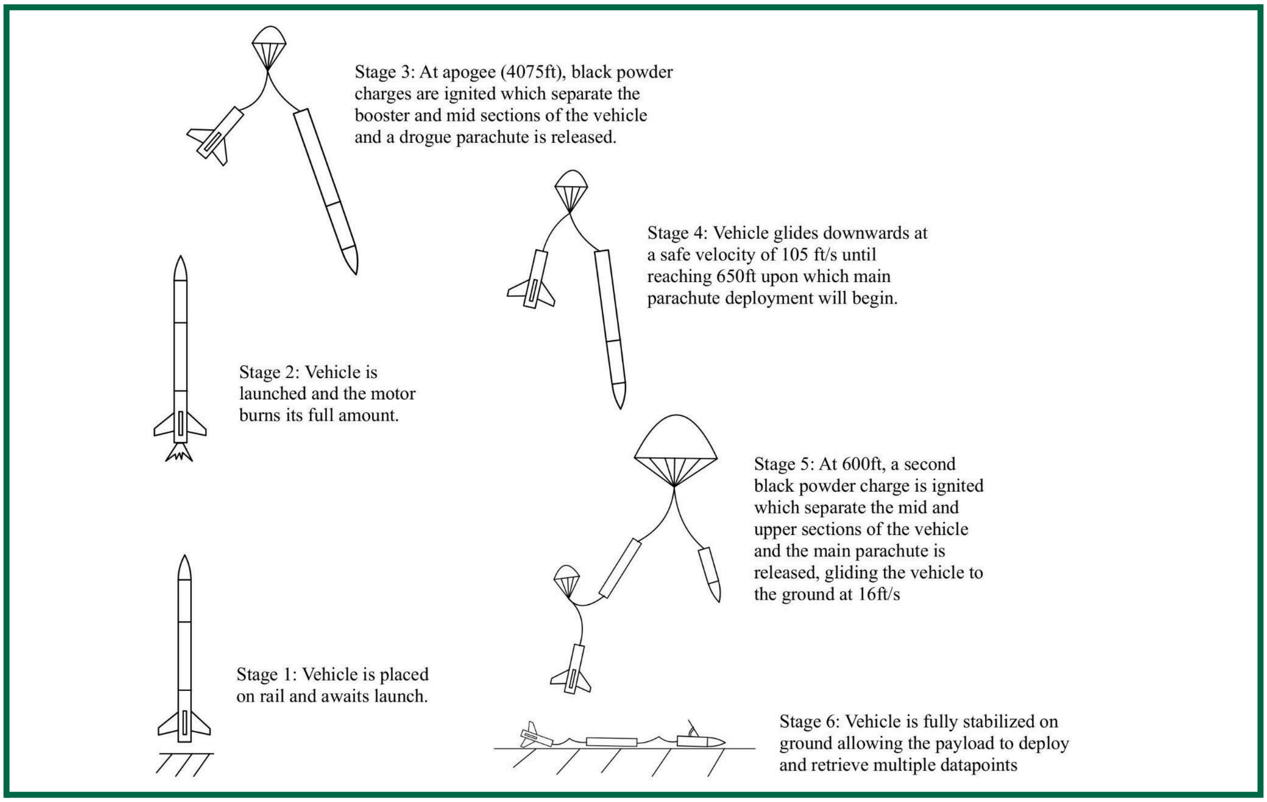


Figure 65. Concept of Operations

3.3.3 Laundry

Both the drogue and main parachutes are packed and assembled based on the same principles, differing only in their placement within specific sections of the rocket.

To ensure proper deployment of the drogue or main parachute, the system is carefully folded before every launch. The method used is as follows:

1. Manually deploy the parachute to its full size (e.g., by running against the wind, or having one person hold the main shroud lines while another holds the canopy). Ensure there are no entangled shroud lines and no visible defects on the parachute.

2. Fold the canopy: Take one shroud line and fold the material between that shroud line and the next shroud line so that the two shroud lines align with each other. Apply slight tension to keep the parachute flat. The folded section should resemble a triangle. Continue this process until the entire parachute is folded.

3. Apply tension to the shroud lines to ensure they remain untangled.

4. Z-fold the canopy and shroud lines: Z-fold the canopy first, then Z-fold the shroud lines on top of the canopy. Ensure that the shroud lines do not overlap the canopy. This is

particularly important; due to the large snap force, the lines can wrap around the canopy when deployed, making the parachute unable to open.

5. Lightly wrap the entire setup in a piece of Nomex and temporarily secure it in place.

6. Inspect the setup before launch: Verify that the assembly is correctly folded, inspect for any defects, and remove any temporary securing elements.

The complete parachute system is connected to the upper or lower part of the rocket (depending on the parachute's position) using a Kevlar shock cord. The decision to use Kevlar is based on the material's availability and proven reliability.

The shock cord lengths are typically about 1.5 times the diameter of the parachutes (both drogue and main). The current selection for the drogue parachute is the Fruity Chutes 18" Compact, and for the main parachute, the Fruity Chutes 96" Ultralight, based on the most recent design analysis. However, since the parachutes are commercially manufactured, alternatives can easily be selected if anything goes wrong. Mathematical simulations have already been developed to calculate the appropriate requirements for the parachutes.

The shock cord is attached to the rocket via a bulkhead (see section 3.1.3.3.3).

3.3.3.1 Two Anchor Points

The team, in comparison to previous years, is using a two-system anchor point. Where the force is distributed along two separate hardware. The team found this to be beneficial not only in the mass section but also in the strength one. However, having two different anchor points requires some special connections. Given that only one shock cord is used, the team has to connect the shock cord to both anchor points at the same time. Therefore, in contrast to previous years, the team will use a double alpine hitch knot to accommodate for the double anchor points.

Figure 66. Double Alpine Hitch knot

Points where a single connection is necessary, like the main parachute and nomex, will feature a knot. The picture below shows an example of a single alpine hitch knot.

Figure 67. Single Alpine Hitch knot

3.3.3.2 Main Parachute Assembly

The main parachute assembly is located in between the Upper and Mid Sections. It deploys at 650 feet with a backup of 600 feet. The team has chosen a 96-inch Ultralight Fruity Chutes parachute. This parachute was chosen because of its small mass, packing volume, mass, and Cd. Details of the main parachute are shown below.

CATEGORY	VALUE
Manufacturer	Fruity Chutes
Model	Ultralight
Type	Toroidal
Diameter	96 in
Cd	2.2
Packing Volume	50.2 in^2
Weigh	9oz.

Table 15. Main Parachute Specifications

The main shock cord is the shock cord in the main parachute assembly. It consists of a ⅜ Kevlar cord that connects the Upper Section, main parachute, main Nomex, and Mid Section. The rating is of 3600 lb. and has a length of 300 in.

CATEGORY	VALUE
Manufacturer	Wildman Rocketry
Size	3/8 in
Length	300 in
Rating	3600 lb

Table 16. Shock Cord Specifications

Figure 68. **⅜ in Shock Cord**

The main parachute assembly uses a nomex as a way to protect the parachute from the energetics required to separate the sections. The size of the nomex is enough to go over the packed parachute from both sides when folded. The size of the nomex is 14 x 14 inches.

Finally, the full main parachute assembly is as follows: The main shock cord connects to the Upper Section through a double alpine hitch knot. After 120 in from that point, there is the main parachute single alpine hitch knot that connects to the main parachute. 30 in from that point, there is another single loop for the Nomex. Finally, at the end of the shock cord, 300 in, it connects to the mid section with another double alpine hitch knot.

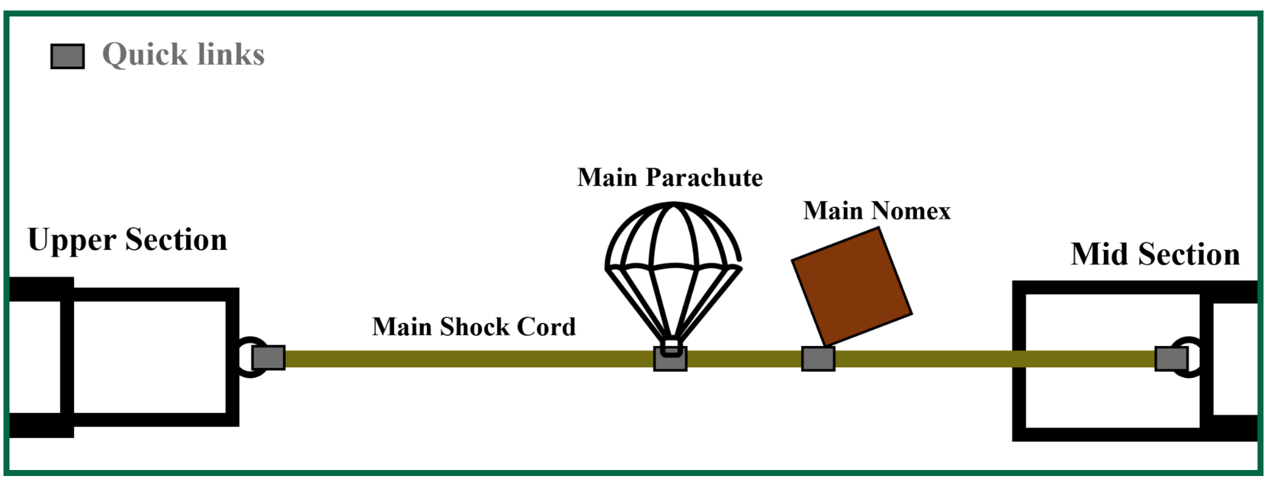


Figure 69. **Main Parachute Assembly**

3.3.3.3 Drogue Parachute Assembly

The drogue parachute is deployed at apogee, when the rocket's velocity is zero. This minimizes the snapping force caused by deployment. The drogue assembly is located in between the midsection and the booster tube. The drogue parachute was placed in this location because it occupies less volume. This allows for the much bigger main parachute assembly to be on the front, which forces the avionics bay to be closer to the aft than the front. Ultimately, this makes the Airbrakes system be placed closer to the aft of the rocket. The drogue parachute is an 18-in. "Compact Fruity Chutes" parachute. Details of the parachute are shown below.

CATEGORY	VALUE
Manufacturer	Fruity Chutes
Model	Compact
Type	Toroidal
Diameter	18 in
Cd	1.55
Packing Volume	6.4 in^2
Weigh	1.16 oz

Table 17. Drogue Parachute Specifications

The drogue shock cord has the same characteristics as the main shock cord. It consists of a ⅜ Kevlar cord that connects the Mid Section, main parachute, main Nomex, and Booster Section. The rating is of 3600 lb. and has a length of 300 in.

Similar to the main parachute assembly, the drogue parachute assembly uses a Nomex as a way to protect the drogue parachutes from the black powder. The size of the Nomex is much smaller than the previous one. Its size is 10 x 10 inches.

Finally, the full main parachute assembly is as follows: The main shock cord connects to the Upper Section through a double alpine hitch knot. After 120 in from that point, there is the single alpine hitch knot that connects to the main parachute. 30 in from that point, there is another single loop for the Nomex. Finally, at the end of the shock cord, 300 in, it connects to the midsection with another double alpine hitch knot.

Finally, the full drogue parachute assembly is as follows: The drogue shock cord connects to the Mid Section through a double alpine hitch knot. After 120 in, it connects to the main parachute through a single alpine hitch knot. Similarly, 30 in from that point, there is another single alpine hitch knot for the Nomex. Finally, at the end of the drogue shock cord, 300 in, it connects to the motor tube y-harness through another alpine hitch knot.

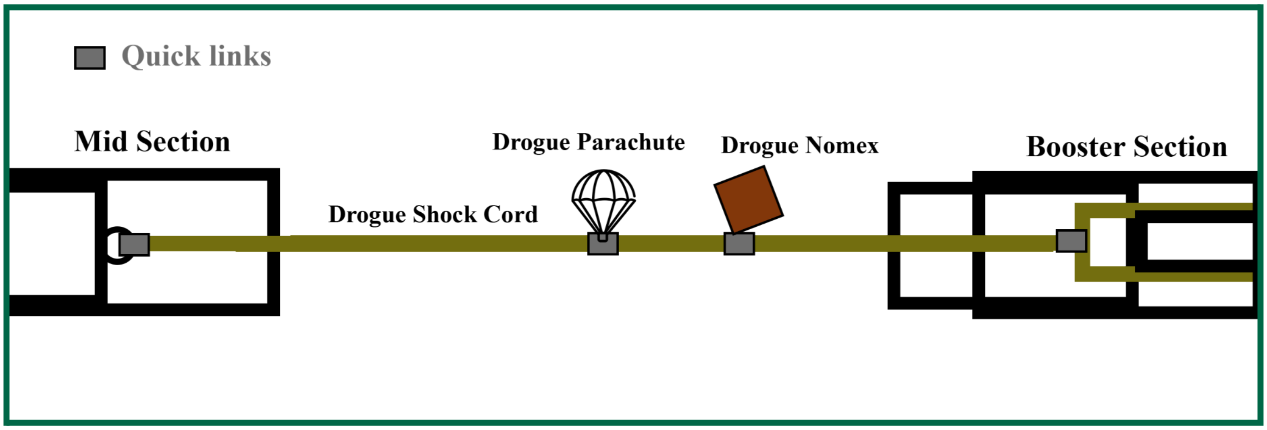


Figure 70. Drogue Parachute Assembly

3.3.4 Avionics bay

The Avionics bay is located within the Mid Section, sharing the same space as the Airbrakes system. The Upper half of the compartment is used for the Airbrakes system. The lower half is dedicated space for the avionics bay. A picture below shows the space distribution and location within the compartment. The Avionics bay is located 15.5 inches from the top of the Mid Section airframe.

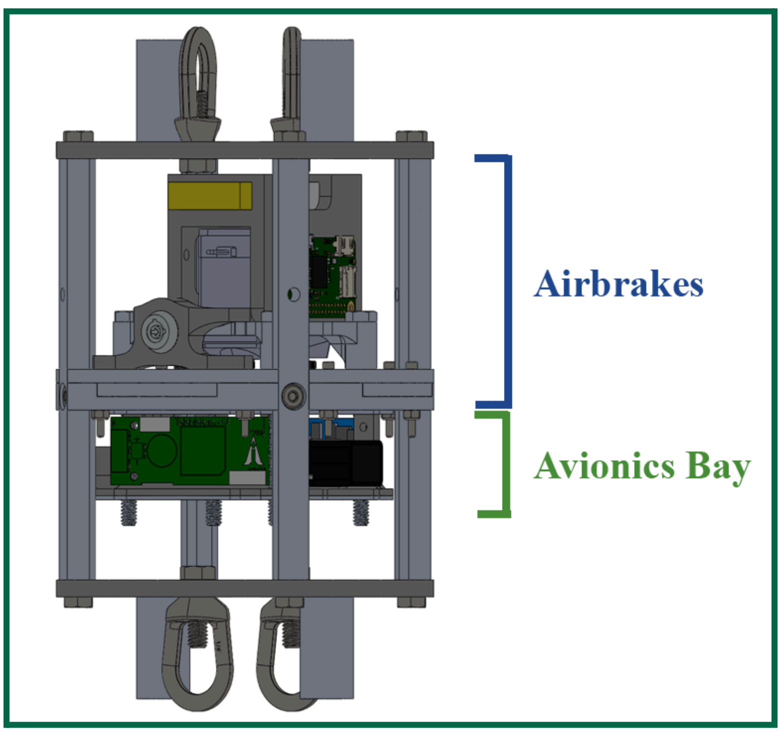


Figure 71. Airbrakes and Avionics bay division

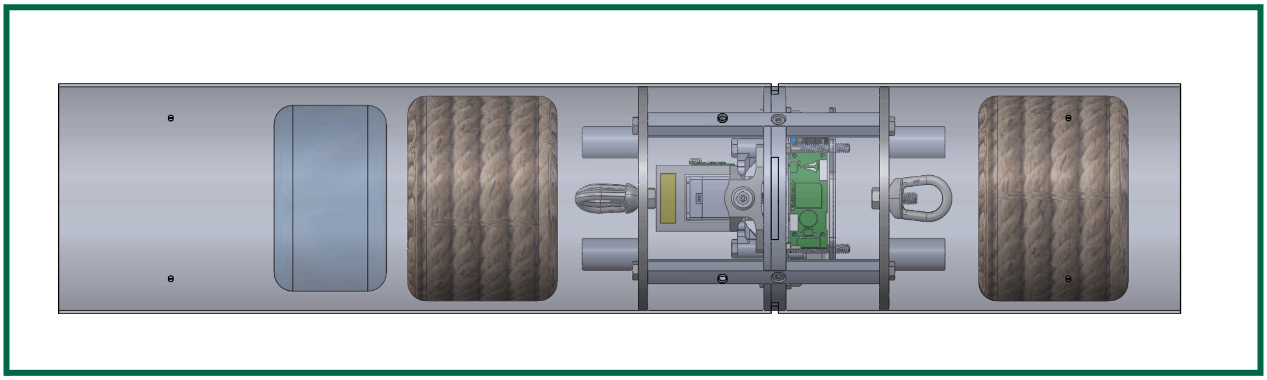


Figure 72. Avionics bay in Mid Section

The Avionics bay design required multiple iterations to land on a final design. Initially having only PLA, further reinforcement was necessary. By adding a plate of aluminum 6061, the PLA sled had the proper strength needed to survive forces during the launch, flight, and recovery processes. After trial and error, angling the Telemetrum and creating an asymmetrical base, the highest possible packing factor within reason was achieved.

The Avionics bay houses 2 independent altimeters powered by 2 different power sources. First, it has a Telemetrum powered by a 3.7 lipo. Second, it has a Sport RRC3 powered by a 9 Volts battery.

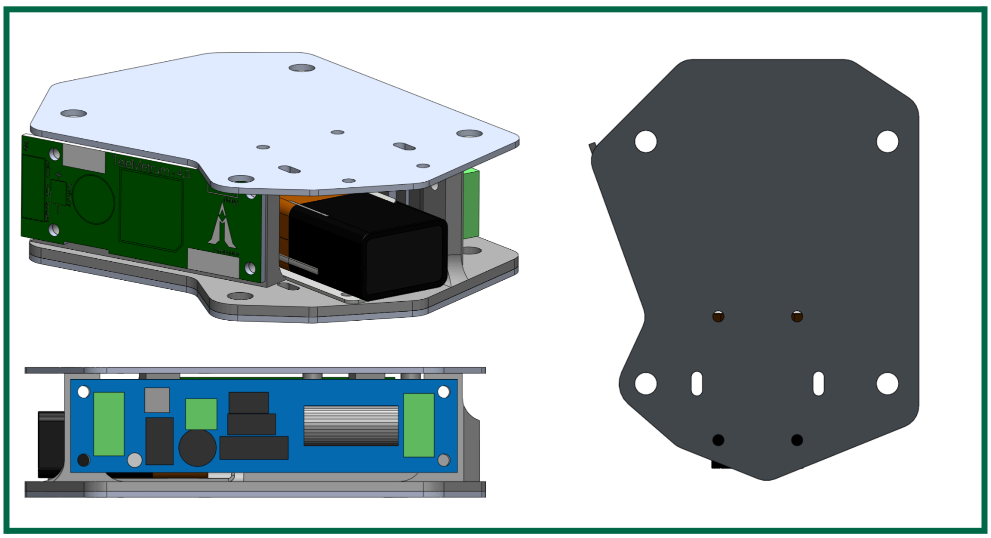


Figure 73. Avionics Bay Sle

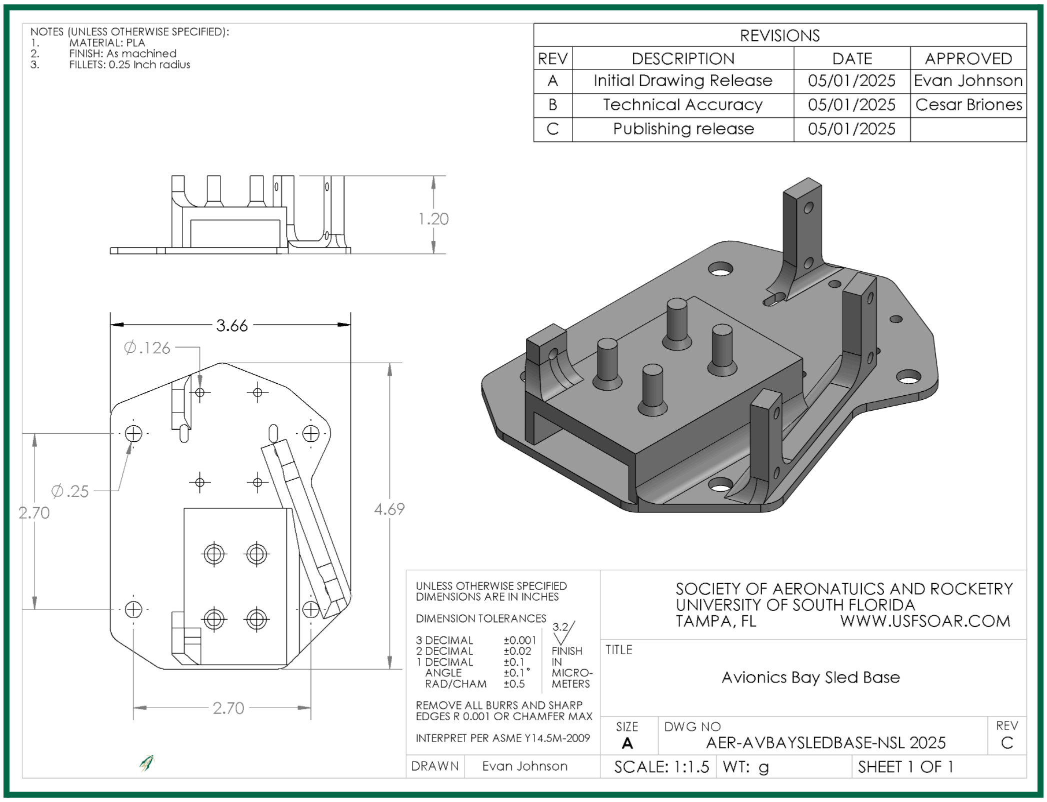


Figure 74. Avionics bay Sled engineering drawing

3.3.5 Electrical components

There are two subsystems crucial to the Recovery system: the Avionics Bay, and the Telemetry Bay. The Avionics Bay holds the two flight altimeters that are used to deploy the parachutes: the Altus Metrum Telemetrum as the Primary Altimeter and the Missileworks RRC3 as the Secondary Altimeter. The Telemetry Bay is an auxiliary set of electronics that establishes a configurable data downlink from the rocket to the ground receiver.

The Avionics Bay is located adjacent to the Airbrakes subsystem, and is contained in its own mounting sled that creates a dedicated compartment for the Avionics Bay alone. This allows the Avionics Bay to be completely independent and separate from all other subsystems, physically and electrically.

The Telemetry Bay consists of environmental sensors, including a GPS module, and a transceiver, that allows it to downlink GPS data to the Ground Station operated by the team. Though the Telemetry Bay is located adjacent to the Payload system, both systems are physically separated with a bulkhead, have independent mounting sleds, and are electrically independent. It is important to note that all sections of the rocket are designed to land tethered to each other, with the Payload being retained in the launch vehicle at all times. This means a single GPS module can be used to track the location of the entire rocket.

The Avionics Bay Flight Altimeters, and the Telemetry Bay are all electronics that are built around a printed circuit board (PCB), with the Telemetry Bay being built on custom-designed Printed Circuit Boards. This allows for all of the recovery electronics to be shielded from all electromagnetic radiation, from intentional and unintentional transmitters aboard the rocket, through the use of a common ground plane implemented into the PCB.

The Ground Station is operated by team personnel to receive data from the Telemetry Bay. It complements the Telemetry Bay by processing the received data, storing it, and displaying it on a screen in the form of charts and graphs.

3.3.6 Avionics Bay Flight Altimeters

The Primary Flight Altimeter is the Altus Metrum Telemetrum, with the Secondary Flight Altimeter being the Missileworks RRC3. These commercially available altimeters have proved to be reliable and precise in the amateur rocketry community. This is why the team chose those two altimeters, along with the added benefit of the altimeters already being in team inventory, allowing cost reduction.

Figure 75. Altus Metrum TeleMetrum altimeter

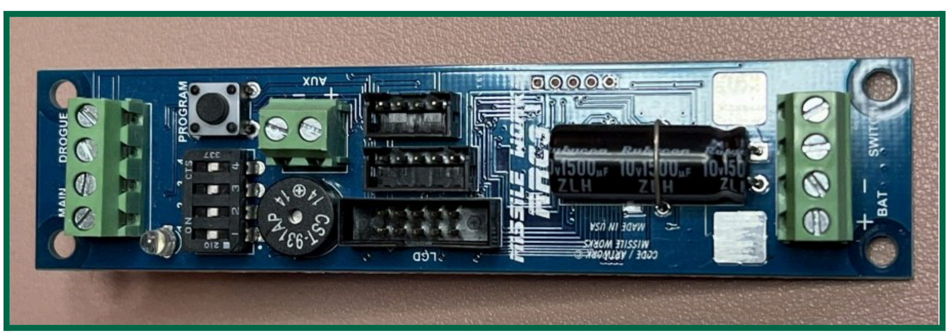


Figure 76. Missileworks RRC3 altimeter

The Altus Metrum Telemetrum is powered by a dedicated commercially available 3.7V 2000 mAh LiPo battery. The battery is connected to the altimeter through a JST-ZH connector, allowing for a secure connection directly to the altimeter. The Missileworks RRC3 is powered with a dedicated alkaline 9V battery, which is readily commercially available. The battery is placed in a 9V battery connector and secured in place to the connector with zip ties.

Each altimeter is armed through a dedicated mechanical key switch, pictured below. Historically, this type of switch has proven to be reliable for the team due to the unlikely chances of the switch being disarmed during flight.

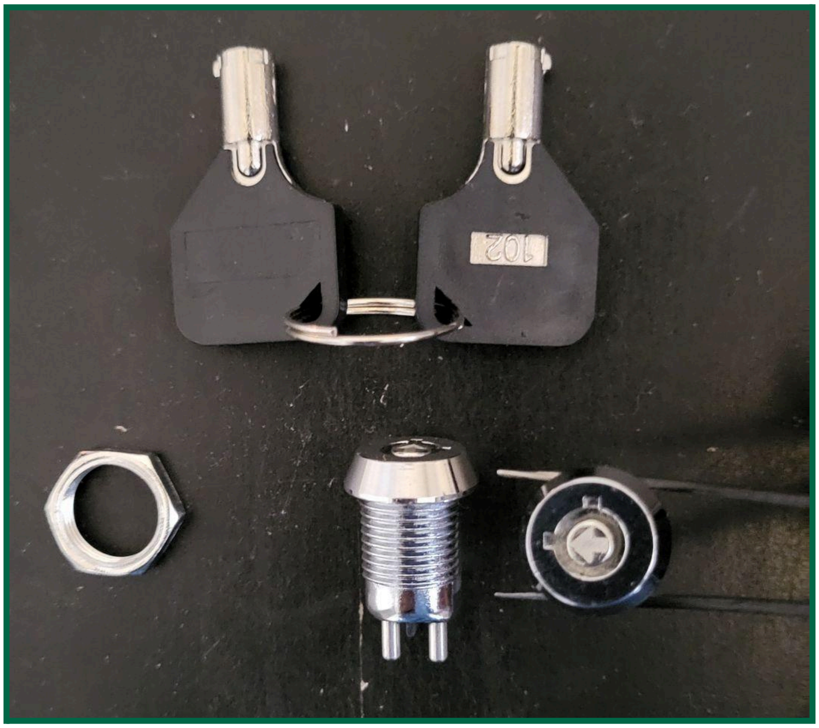


Figure 77. Mechanical Key Switches

This switch also facilitates simple installation into the 3D printed electronics sleds, with the screw threads around the exterior of the switch. The low profile of the switch allows for a smaller hole to be installed on the rocket exterior with the purpose for arming the switches after the rocket is fully assembled.

The wiring of the Avionics Bay allows for complete redundancy between the two altimeters to ensure timely drogue and main parachute deployment. Pictured in the wiring diagram below, two e-matches are used for the drogue deployment, and two for the main deployment.

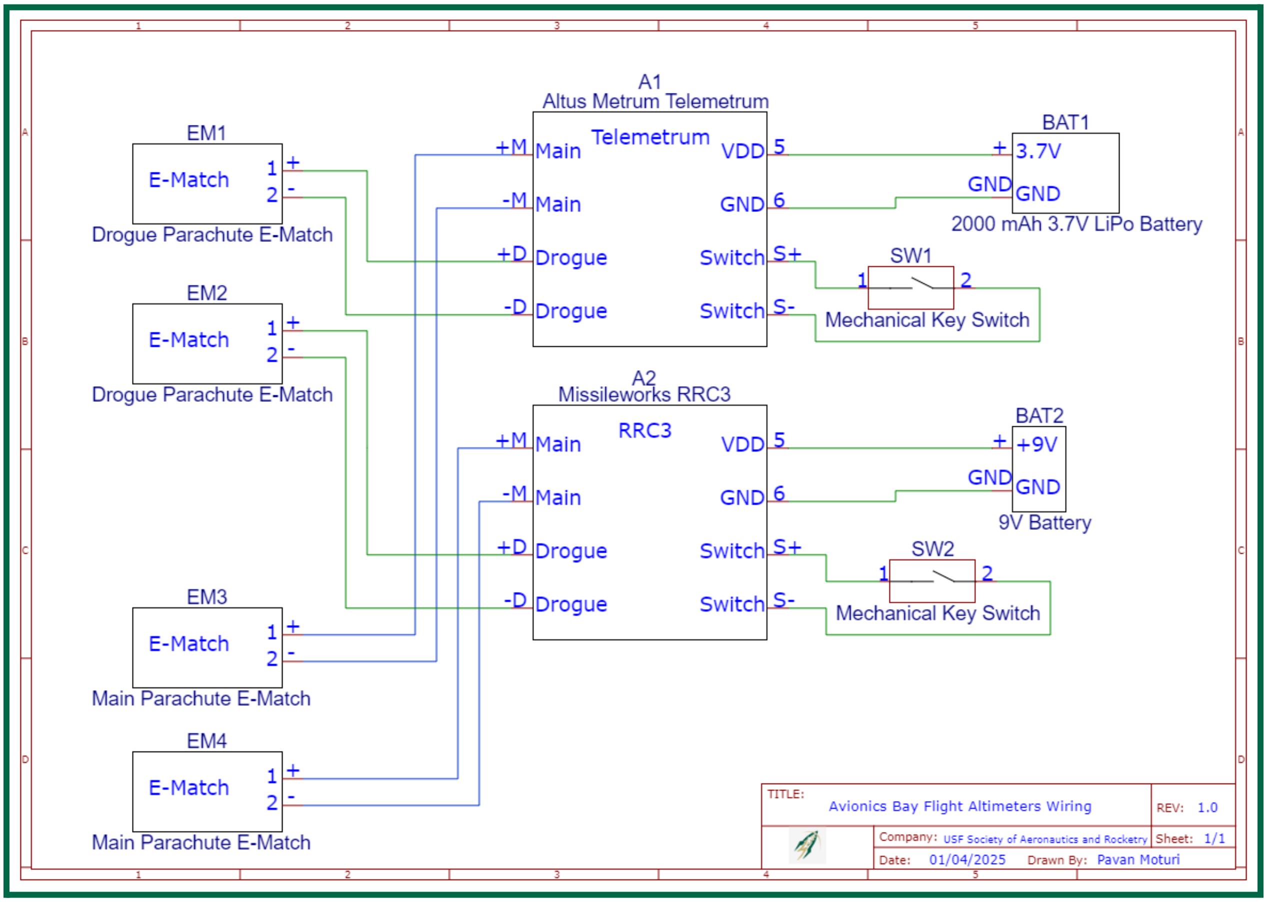


Figure 78. Altimeter Wiring Diagrams

Each altimeter has an e-match connected to the main terminals, and another to the drogue terminals, allowing both altimeters to operate independently. The dedicated mechanical key switch and power supply for each altimeter is also depicted in the diagram.

3.3.7 Telemetry Bay

The data that is recorded in the Avionics Bay Flight Altimeters is vital to understanding what happened during flight, but it can typically only be retrieved after landing. Furthermore, some of this data such as the GPS coordinates of the rocket, is needed to retrieve the rocket in the first place. For this reason, the team opts to implement a Telemetry Bay subsystem in the rocket that records the following environmental data (including GPS coordinates) using onboard sensors. Then, it stores the data to the onboard microSD card, and transmits the data to a custom-built ground station operated by the team. This facilitates tracking of the rocket's location, and visualizing flight dynamics while the rocket is in the air.

Table 18. Data Obtained from Telemetry Bay

Data	Format	Sensor
Absolute Orientation	Quaternion	Adafruit BNO055
Angular Velocity Vector	3-Dimensional Vector	Adafruit BNO055
Acceleration Vector	3-Dimensional Vector	Adafruit BNO055
Magnetic Field Strength Vector	3-Dimensional Vector	Adafruit BNO055
Linear Acceleration Vector	3-Dimensional Vector	Adafruit BNO055
Gravitational Acceleration Vcetor	3-Dimensional Vector	Adafruit BNO055
Temperature	Integer	Adafruit BNO055
Temperature	Integer	BMP390
Pressure	Integer	BMP390
Altitude	Integer	BMP390
Timestamp	Integer	Adafruit Mini GPS PA1010D
Latitude	Integer (with E/W designation)	Adafruit Mini GPS PA1010D
Longitude	Integer (with E/W designation)	Adafruit Mini GPS PA1010D
Speed Over Ground	Integer	Adafruit Mini GPS PA1010D
Course Over Ground	Integer	Adafruit Mini GPS PA1010D
Date	Integer	Adafruit Mini GPS PA1010D

The Telemetry Bay utilizes a SeeedStudio XIAO ESP32-S3 microcontroller as the processor of the system. In the table below are the various peripherals that are connected to this system.

Table 19. Telemetry Bay Peripherals

Name	Type	Purpose
Adafruit BMP390	Environmental Sensor	Inertial Motion Unit
Adafruit BNO055	Environmental Sensor	Record temperature and pressure
Adafruit Mini GPS PA1010D	Environmental Sensor	GPS Module
microSD Card Reader	Data Storage	Store data to an onboard microSD card
Digi XBee Pro S3B 900HP	Transceiver	Communicate to Ground Equipment
RunCam Split 4 v2	Video Camera	Record flight footage

The ESP32-S3 runs on a Real-Time Operating System (RTOS), namely the Espressif Internet of Things Development Framework (ESP-IDF) FreeRTOS operating system. This allows for the creation of multiple software-defined tasks that each have a single purpose. This modular approach allows for the software to be developed and tested in components, simplifying development and testing. Below is a diagram of the software of the system, with each colored box being a different RTOS task. Software constructs like queues, mutexes, and semaphores are utilized to facilitate data exchange and synchronization of the various tasks.

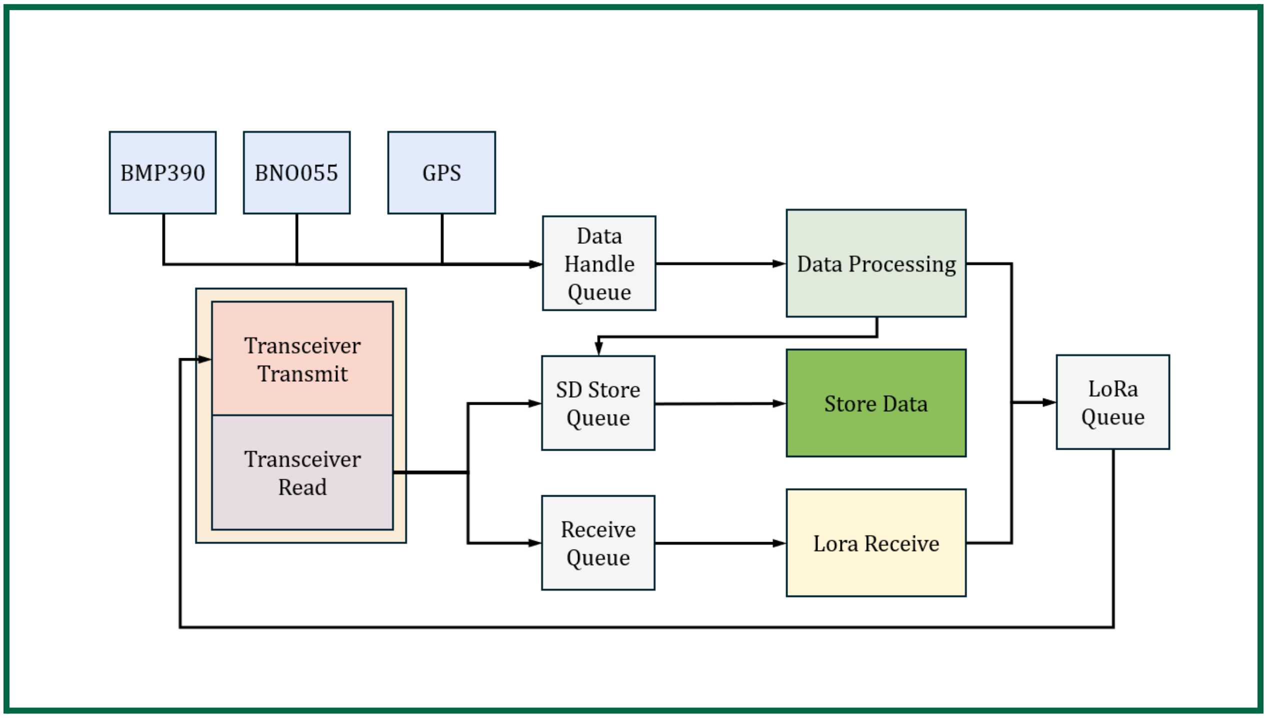


Figure 79. Telemetry Bay Software Flowchart

The system collects data from the BMP390, BNO055, and GPS modules and feeds it to the Data Processing task. This task checks the data for any errors, sends it to the SD card task, and passes it to the Transceiver task. This is the task that interfaces with the Digi XBee Pro S3B 900HP, a transceiver that operates on the 902-928 MHz frequency band. This task transmits any messages that need to be transmitted from the system to the ground equipment and then listens for incoming messages. These messages are commands from the ground station that are used to control the data output from the system. The commands are passed to the receive task that identifies the command and executes the appropriate actions. This is outlined in the communication protocol diagram below, which lists all of the possible commands that the ground station sends and the actions that the Telemetry Bay takes. It is important to note that all of the data from the environmental sensors is also saved to an onboard microSD card through the Store Data task.

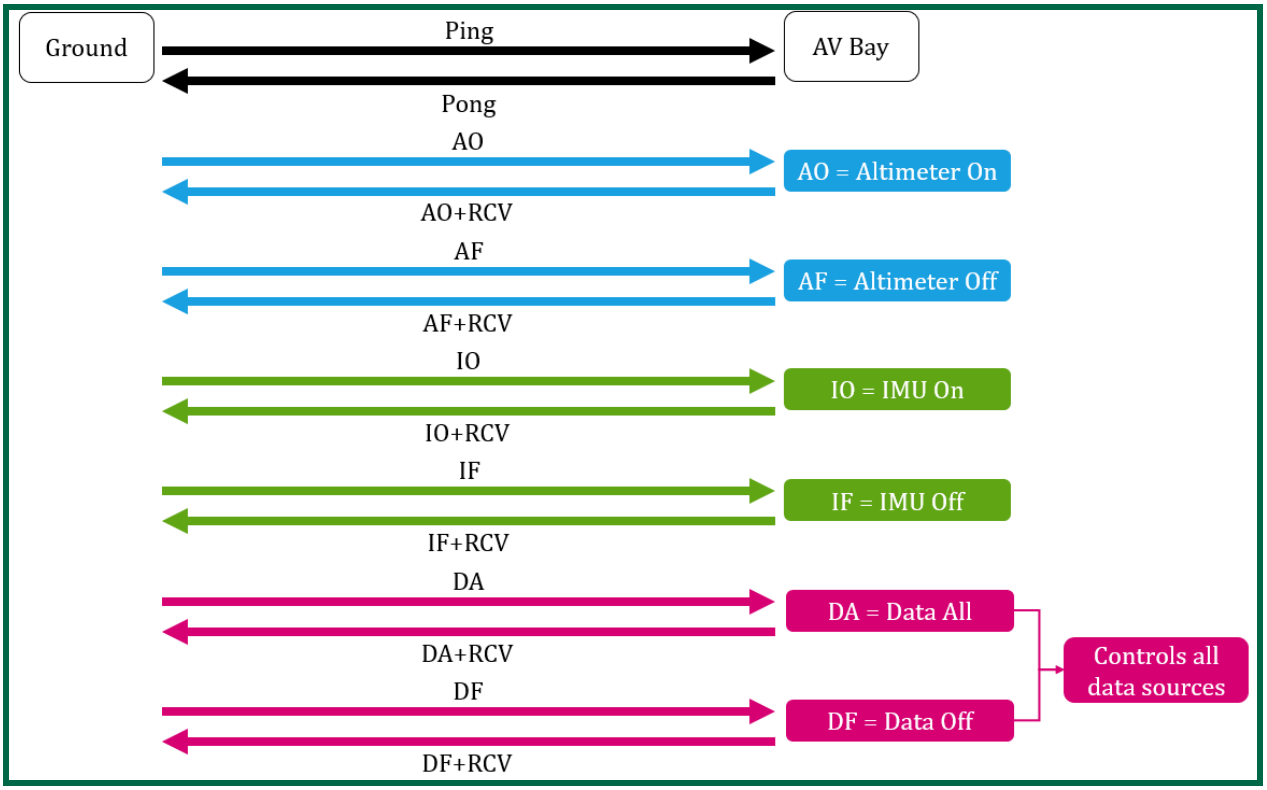


Figure 80. Telemetry Bay Communication Protocol

Though the Telemetry Bay has the logic implemented to receive and act upon commands given by the team, these commands exist solely to control the data flow and types of data. This enables customized operation of the system and efficient debugging.

The Telemetry Bay serves as a power source for the RunCam Split 4 v2 video camera, which serves to record footage of the flight with the camera and store on an independent SD card that is separate from the Telemetry Bay SD card.

The prototype of the subscale Telemetry Bay resembles the design depicted above, but without a GPS module and with the Reyax RYLR998 transceiver operating on the 902-928 MHz frequency band. This transceiver was utilized for development purposes with the goal of optimizing other software processes before focusing on optimizing the transceiver. The prototype was developed around a custom-designed Printed Circuit Board, allowing for improved reliability of connections, and a smaller overall size. Below are the custom-designed PCBs for the system, followed by a picture of the system fully assembled.

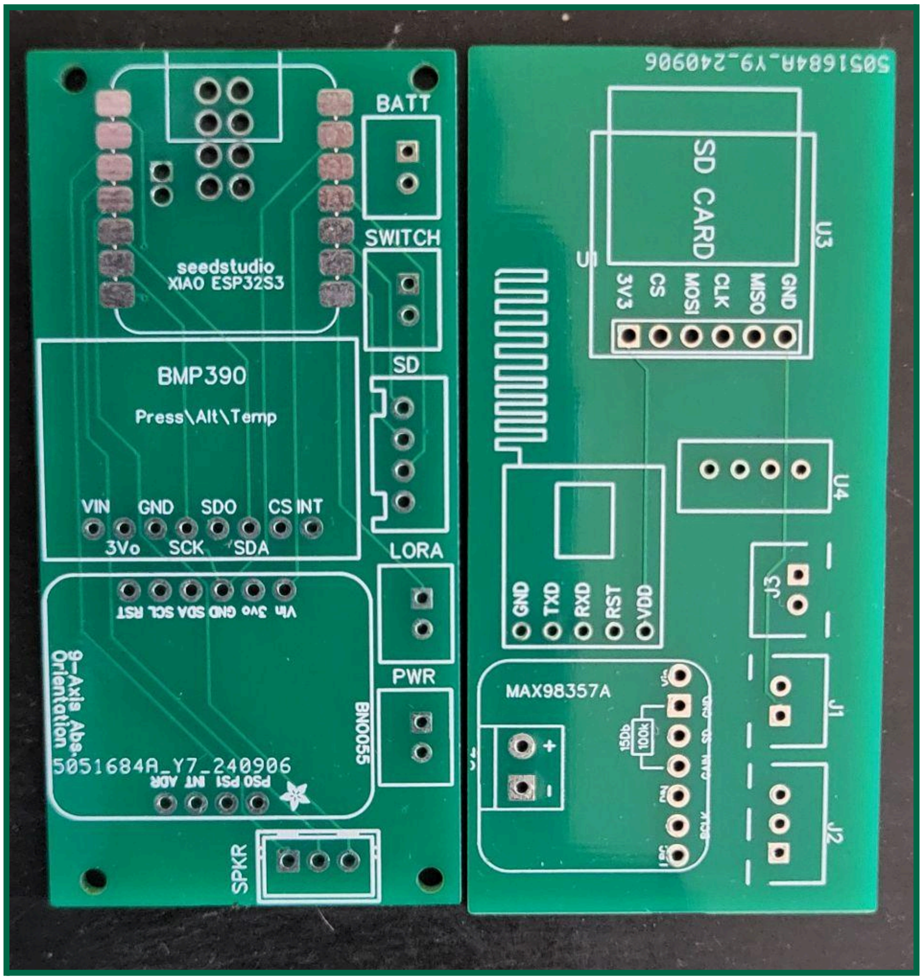


Figure 81. Custom-Designed PCBs for Telemetry Bay

The PCBs were designed using the EasyEDA software and printed using the JLCPCB service provider, located in China. From there, the completed PCBs are shipped overseas to the team. Due to potential price increases that come with the changing political climate, the team is working to design the final iteration of the custom PCBs for the Telemetry Bay before prices rise. Below is a picture of the completed system before the subscale launch attempt, without any connecting wires. The white sled was custom designed for the subscale Telemetry Bay and 3D printed out of PLA. Connections were made with JST-XH connectors, which are known in industry for their reliability.

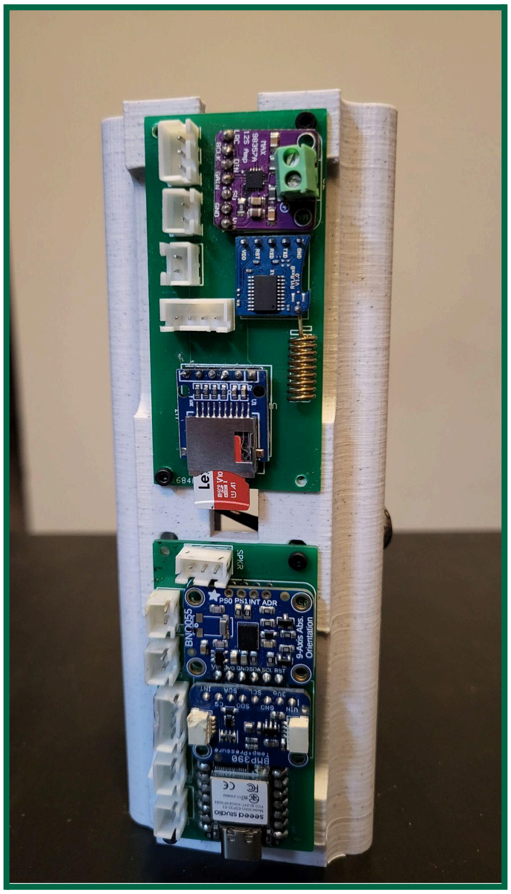


Figure 82. Telemetry Bay before Subscale Launch

The transmission criteria for the system is that it must be capable of transmitting data during flight. This means at a maximum distance of 6000 feet, which is the maximum apogee allowed in Student Launch, and while in motion. The data from the Telemetry Bay is expected to be received by the Ground Station predicted intervals, with little to no corruption of the data. Though the team utilized the Reyax RYLR998 LoRa transceiver on the subscale Telemetry Bay, the decision to use the Digi XBee Pro S3B 900HP transceiver for the final iteration of the system was made. This decision was made after testing showed that the Reyax transceiver was incapable of transmitting at a range higher than 1900 feet and incapable of transmitting/receiving while in motion. The Digi XBee transceiver offers higher data rates than the Reyax transceiver, going as fast as 10-100 kBps, all while operating with a lower overall current draw. This added performance comes with the drawback that the Digi XBee transceiver is twice as large as the Reyax transceiver.

The team has conducted minimal field tests to identify the functionality of the Digi XBee transceiver and is concerned about the lack of performance capabilities of the transceiver while both in motion and at the desired range of 6000 feet. Because of this, the team is preparing for the possibility of designing a custom antenna to boost the RF functionality of the transceiver. This would connect to the solder pads on the module designed to facilitate a custom antenna. The Digi XBee Pro 900HP transceiver complies with all FCC regulations and maintains the equipment authorization granted to it when it remains in its default configuration, but this is not the case once a custom antenna is connected to it. The addition of a custom antenna that significantly changes the radiation properties of the transceiver effectively makes the antenna-transmitter system a home-built transmitter. In accordance with FCC Regulation 47 CFR 15.23, equipment authorization is not needed for this device, with it remaining in the possession of the team at all times and being the sole of its kind. Good engineering practices and compliance with FCC regulation 47 CFR 15.23 will be observed in the construction of the antenna. The Effective Isotropic Radiated Power (EIRP) of the antenna-transceiver system will remain below the 250 mW power limit during flight set by Student Launch.

Should the Digi XBee Pro S3B 900HP prove to be capable of transmitting data at a minimum range of 6000 feet and do so while in motion, then the need for a custom antenna to boost the RF capabilities of the transceiver is eliminated.

3.3.8 Ground Station

The Ground Station is a custom-built ground computer with an Nvidia Jetson Nano serving as the core of the system. Attached to it as a peripheral is the component that interfaces with the transceiver. This component is the SeeedStudio XIAO ESP32-S3 microcontroller connected to a Digi XBee Pro S3B 900HP transceiver and an Adafruit Mini GPS PA101D GPS module.

The main objective of the Ground Station is to receive the data from the Telemetry Bay, and visualize it on a screen. Because the Telemetry Bay transmits GPS location data to the Ground Station, the team can effectively track the location of the rocket in real-time.

On top of displaying the data that is directly transmitted from the Telemetry Bay on a screen, the Ground Station completes calculations on the data to derive other information about the rocket. An example of this is utilizing the data from the GPS module connected to the Ground Station and comparing it to the GPS data from the Telemetry Bay. Then, it calculates the distance and heading to travel to navigate to the rocket in real time.

3.3.9 Tracker Operating Frequency

The Telemetry Bay subsystem serves as the locating tracker of the rocket, due to the GPS functionality implemented in the system. It uses the Digi XBee Pro S3B 900HP, which operates in the 902-928 MHz frequency range, and has FCC ID MCQ-XB900HP.

This is the only tracker that is implemented on the rocket due to all components of the rocket landing tethered together, with the addition of the payload being retained within the launch vehicle.

3.4 Mission Performance Predictions

3.4.1 Motor Choice

The team has chosen the Cesaroni L995 for the NSL 2025-26 competition. Details of the motor are shown below.

Table 20. Motor Specifications

Category	Value
Manufacturer	Cesaroni
Designation	L995
Motor Type	Reload
Diameter	75 mm
Length	486 mm
Total Weight	3,591 g
Prop Weight	1,913 g
Avg Thrust	996.5 N
Initial Thrust	1,404.50
Max Thrust	1,404.5 N
Total Impulse	3,618.00
Burn Time	3.6 s

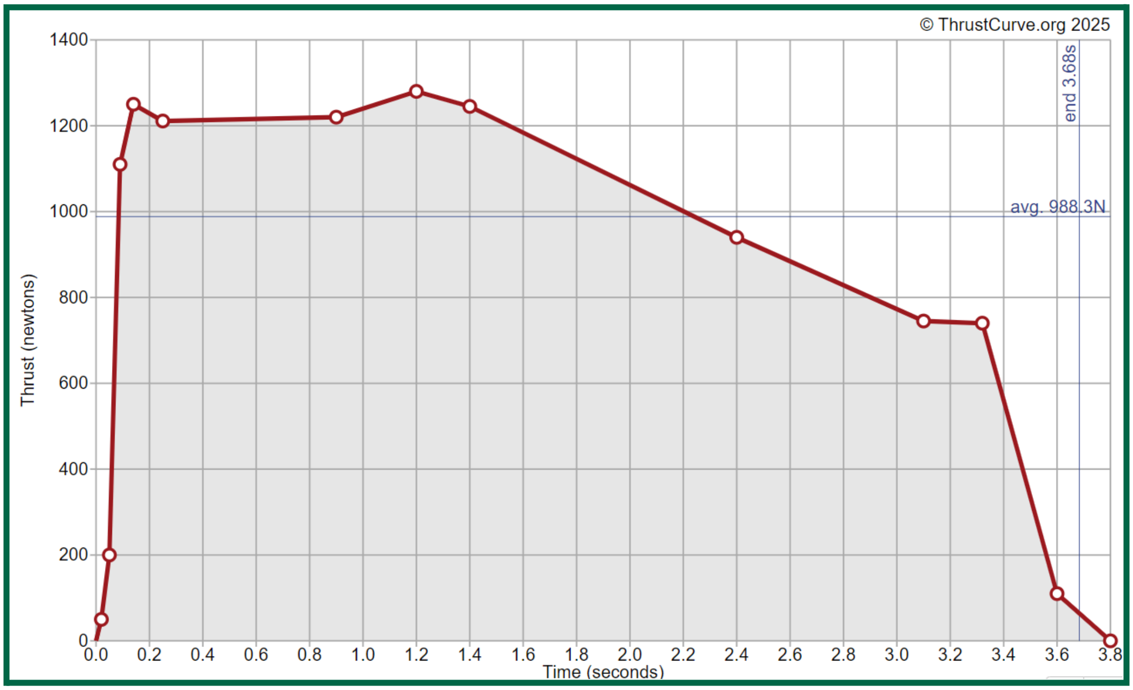


Figure 83. L995 Thrust Curve

3.4.2 SImulation Methods

OpenRocket software was used to simulate the flight profile using the most up-to-date full-scale vehicle model. This program was selected due to the team's familiarity with its interface and its proven reliability and accuracy in previous competitions. Per NASA CDR requirements, multiple simulation profiles were conducted at three launch rail angles: 0, 5, and 10 degrees. Each profile was tested across a range of wind speeds from 0 to 20 MPH, in 5 MPH increments.

For these simulations, the latitude and longitude of the launch vehicle were specified as 34.7° N and 86.6° W, corresponding to Huntsville, Alabama. The launch rail length was set to 144 inches, and the temperature and pressure were defined using international standard atmospheric values. All other parameters were held constant to ensure consistent results.

3.4.3 Flight Profile Simulations

3.4.3.1 Flight Altitude

Flight altitude results are shown in three graphs corresponding to each rail angle simulation. These graphs illustrate the impact of rail angle on the maximum altitude under varying wind conditions.

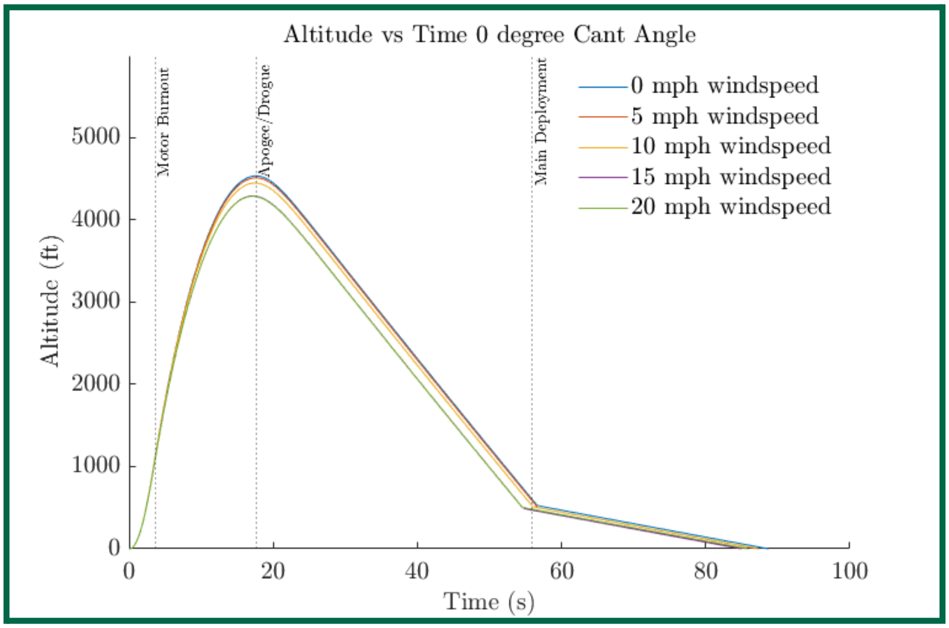


Figure 84. Simulated Altitude vs Time for Various Wind Speeds at 0° Rail Angle

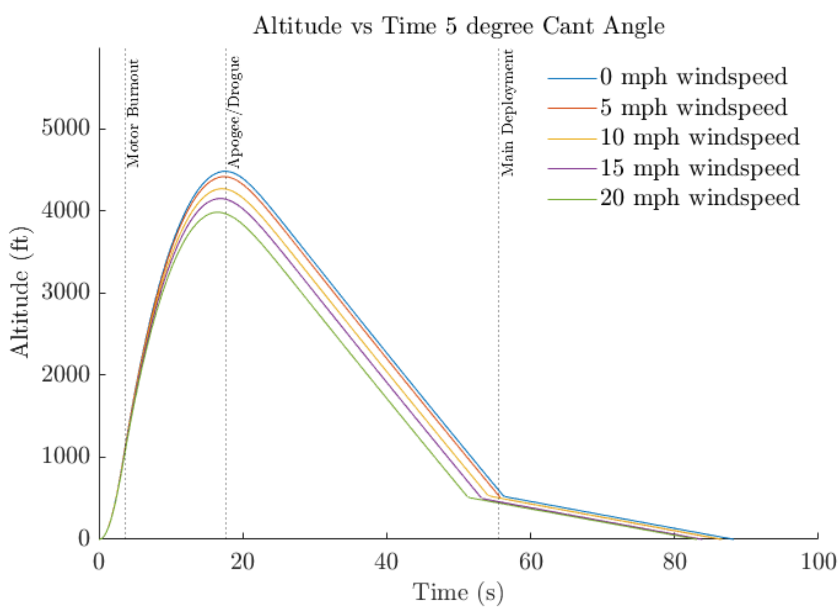


Figure 85. Simulated Altitude vs Time for Various Wind Speeds at 5° Rail Angle

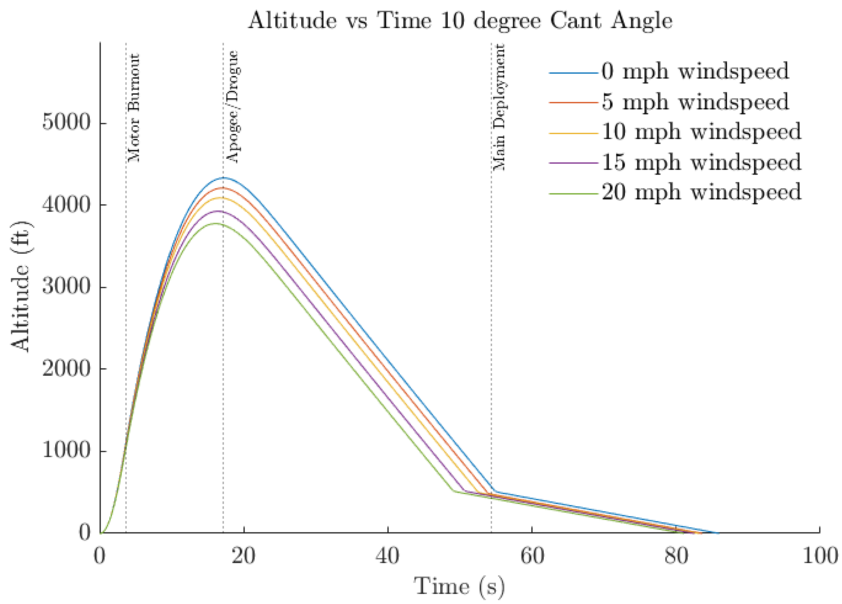


Figure 86. Simulated Altitude vs Time for Various Wind Speeds at 10° Rail Angle

Table 21. Simulated Apogee for Various Flight Conditions

Wind speed	Launch Rail 0° (ft)	Launch Rail 5° (ft)	Launch Rail 10° (ft)
0 MPH Wind	4537	4486	4334
5 MPH Wind	4513	4421	4212
10 MPH Wind	4450	4274	4093
15 MPH Wind	4293	4254	3930
20 MPH Wind	4290	4008	3779

Even though the team has tried to optimize altitude by reducing the weight of the rocket, launching at high rod angles and high rail velocities greatly affect the altitude the rocket is able to achieve. Therefore, the team will look forward to avoiding launching at high rod angles when there is a high wind speed. Given that the rod angle directly affects the drift of the rocket, the team will always launch in the direction of the wind to minimize Drift. Additionally, the maximum calculated Drift analysis yielded a value lower than the 2500 ft limit. USLI requirement 3.11.

3.4.3.2 Flight Velocity

The flight velocity analysis results are presented through graphs for each rail angle simulation. These graphs illustrate the impact of varying wind conditions and rail angles on the flight velocity across the entire flight profile.

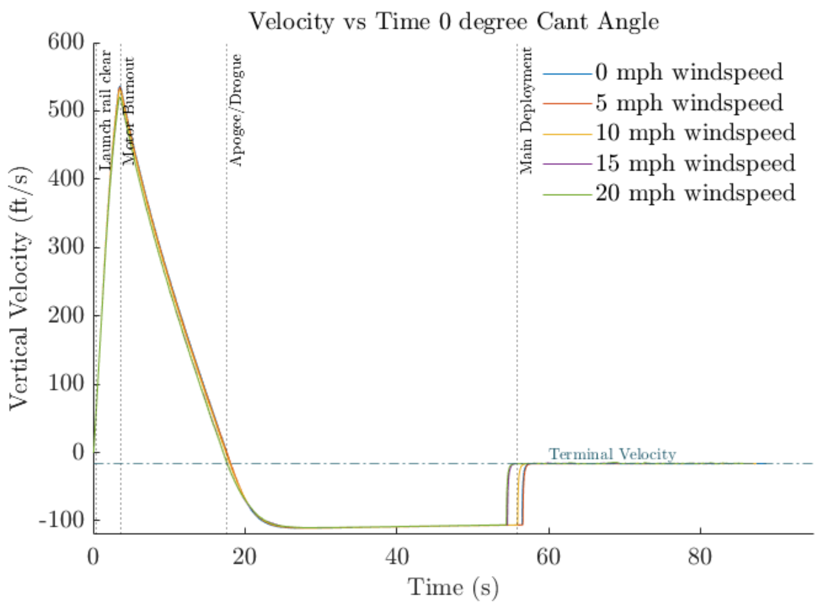


Figure 87. Simulated Vertical Velocity vs Time for Various Wind Speeds at 0° Rail Angle

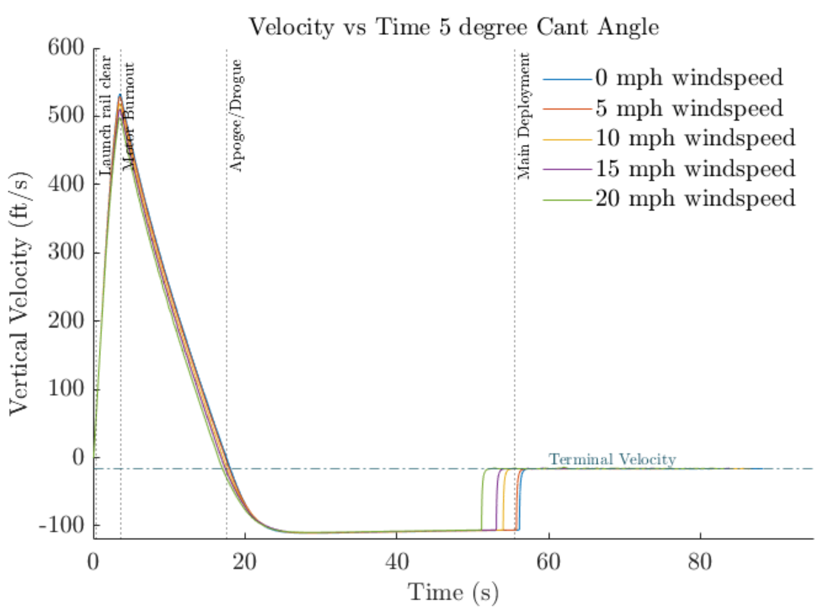


Figure 88. Simulated Vertical Velocity vs Time for Various Wind Speeds at 5° Rail Angle

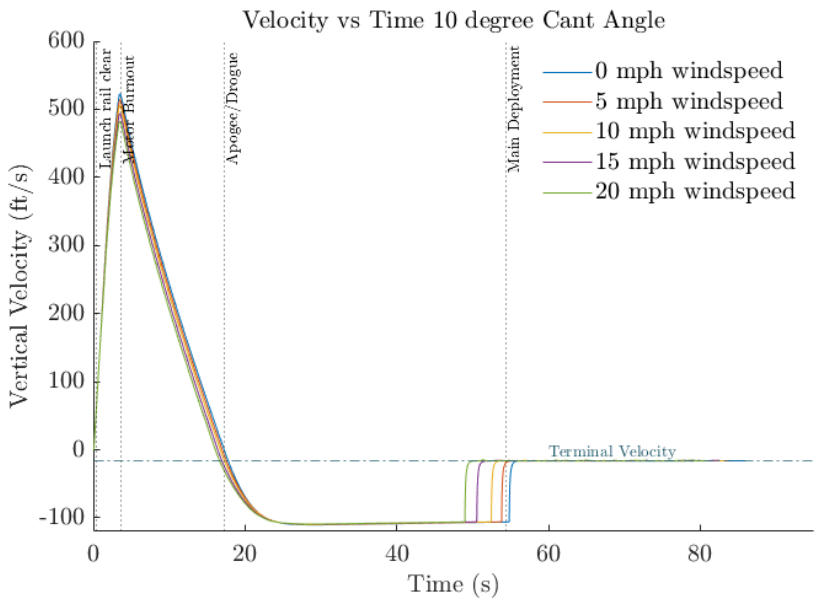


Figure 89. Simulated Vertical Velocity vs Time for Various Wind Speeds at 10° Rail Angle

Table 22. Simulated Velocity off-rail for Various Flight Conditions

Windspeed	Launch Rail 0° (ft/s)	Launch Rail 5° (ft/s)	Launch Rail 10° (ft/s)
0 MPH Wind	68.868	68.914	67.172
5 MPH Wind	68.858	68.907	67.162
10 MPH Wind	68.852	68.898	67.156
15 MPH Wind	68.848	68.891	67.142
20 MPH Wind	68.848	68.89	67.143

The maximum simulated velocity across all flight conditions is 537 ft/s (Mach 0.482), meeting NASA Requirement 2.23.6, which specifies that the launch vehicle must not exceed Mach 1 at any point during flight.

3.4.3.3 Flight Acceleration

Flight acceleration results are displayed in graphs corresponding to each rail angle simulation. These graphs depict the influence of rail angle and wind conditions on the overall acceleration experienced during the flight.

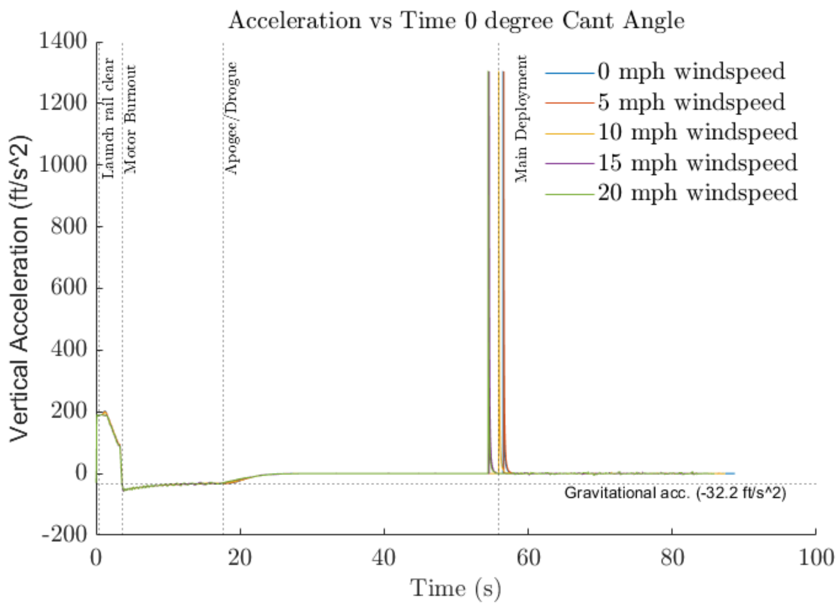


Figure 90. Simulated Acceleration vs Time for Various Wind Speeds at 0° Rail Angle

In the acceleration vs. time graph, a significant spike in simulated acceleration is observed at the moment of main parachute deployment. The unusually large magnitude of this spike, compared to the rest of the flight, raises concerns about the accuracy of the result. The team suspects that the simulation may overestimate the deceleration forces during parachute deployment, potentially leading to less reliable acceleration data. For more details regarding the deceleration forces during parachute deployment, refer to Section 3.4.7.4, Snap Force Analysis.

To address concerns about the accuracy of the parachute deployment spike, the following acceleration graphs are limited to the first 25 seconds of flight, offering a clearer view of the vehicle's performance.

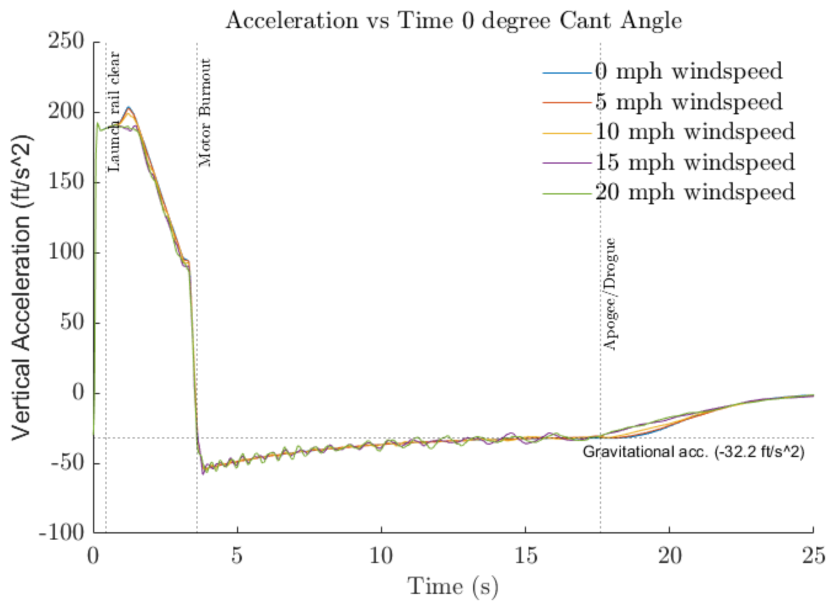


Figure 91. Simulated Acceleration vs Time for Various Wind Speeds at 0° Rail Angle (25 seconds)

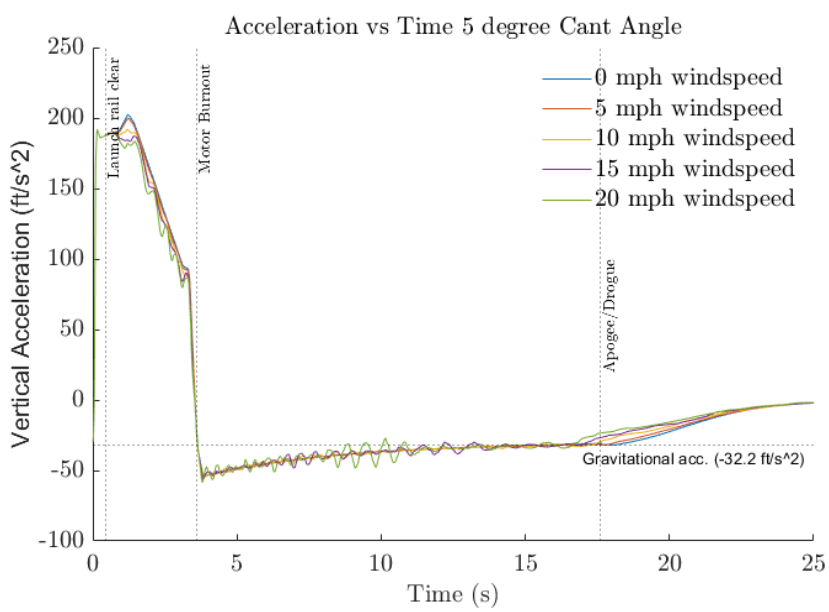


Figure 92. Simulated Acceleration vs Time for Various Wind Speeds at 5° Rail Angle (25 seconds)

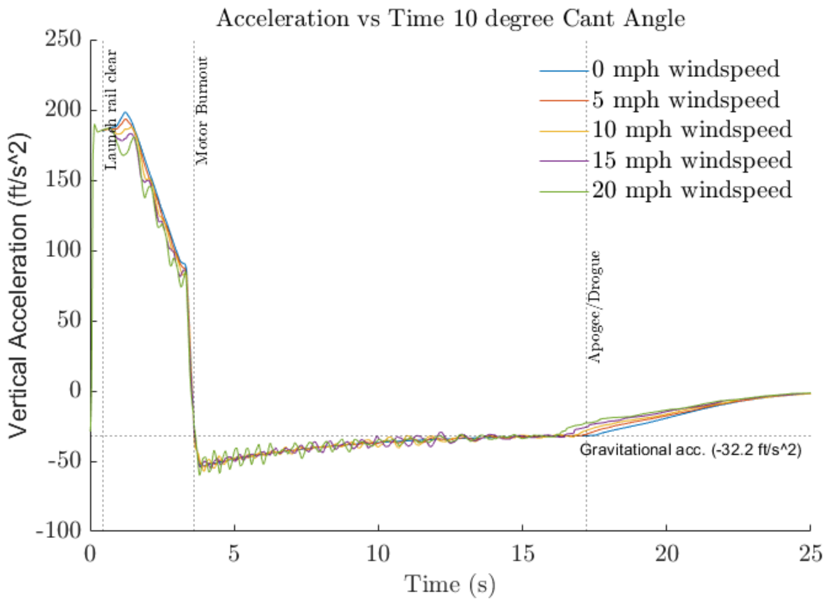


Figure 93. Simulated Acceleration vs Time for Various Wind Speeds at 10° Rail Angle

3.4.4 Stability Margins

3.4.4.1 Static Stability

The stability of the rocket was calculated using Open Rocket. Rocket stability is defined as a rocket's ability to maintain its intended flight path, keeping it from tipping, spinning uncontrollably, or veering off course. The static stability of the rocket is expressed as the equation below:

$$Stability = \frac{(CP - CG)}{d_{outer}}$$

Where CP is the distance from the tip of the nose cone to the Center of Pressure (in), CG is the distance from the tip of the nose cone to the Center of gravity (in) and d_{outer} is the outer diameter of the rocket fuselage.

The values of CG, CP, and d_{outer} from the OpenRocket model are as follows:

Table 23. Stability Margin Inputs from OpenRocket Simulation

Category	Data	units
Center of Pressure	79.24	in
Center of Gravity	64.36	in
Outer diameter	6.12	in

Plugging the above values into the equation:

$$Stability = \frac{(CP-CG)}{d_{outer}} = \frac{79.24 - 64.36}{6.17} = 2.41\ cal$$

The team has also verified that the location of the center of mass of the rocket is above the Airbrakes system. The picture below showcases the location of the center of mass and center of pressure of the rocket before liftoff.

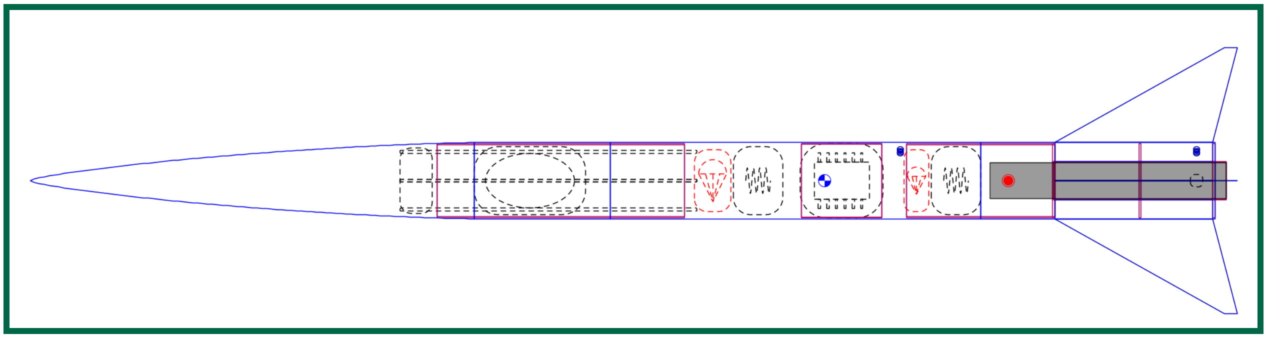


Figure 94. OpenRocket Center of Mass Relative to Airbrakes

3.4.4.2 Dynamic Stability

Dynamic stability of the rocket refers to the ability of the rocket to maintain a stable equilibrium point during flight. Since stability depends on the velocity of the rocket, and its velocity continuously changes in flight, dynamic stability must be expressed in the form of a graph over time. Below are three graphs that show CG location, CP location, and Stability margin caliber versus Time at five different wind speeds.

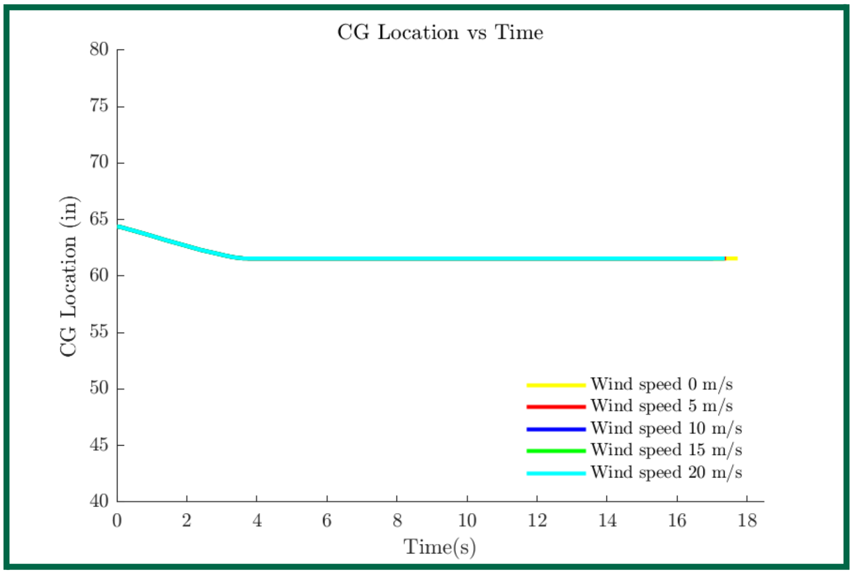


Figure 95. Graph of CG Location vs Time

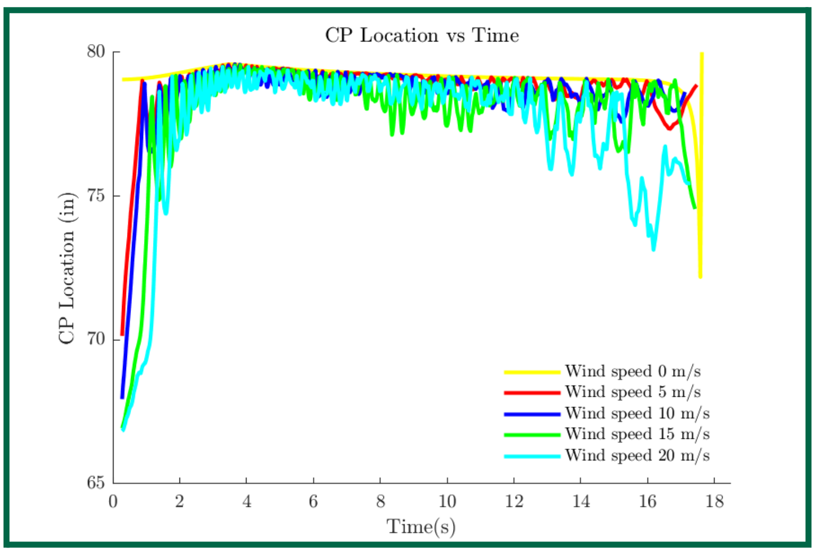


Figure 96. Graph of CP Location vs Time

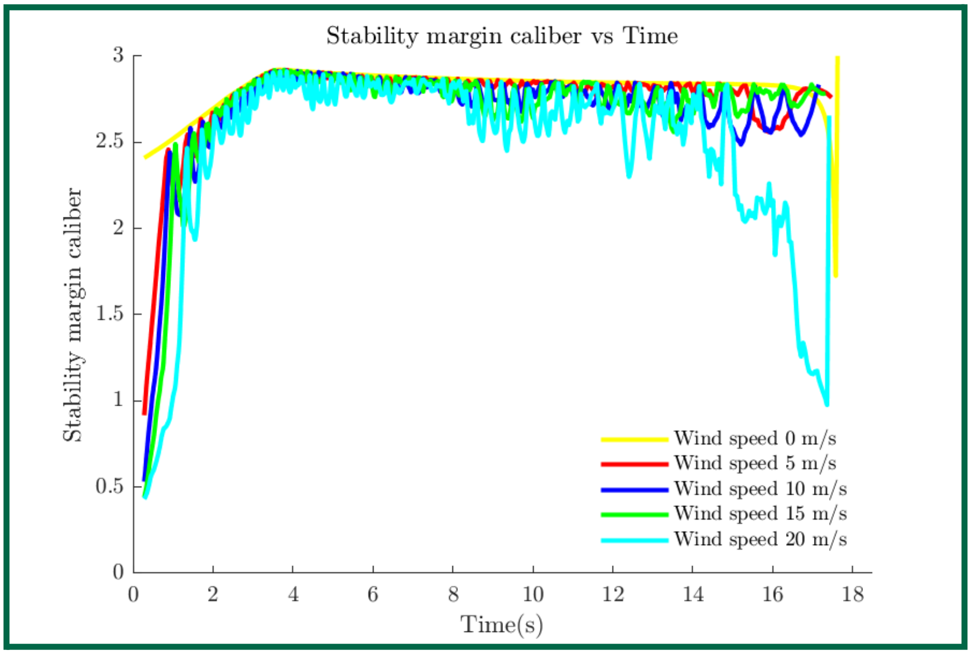


Figure 97. Graph of Stability Margin Caliber vs Time

The value seems to stall between 2.9 and 2.6 calibers post-burnout. In order to validate this number, the team replaced the motor with a simulated mass. Such simulated mass weighs the same as the motor post-burnout. This way, the team was able to validate this number. The picture of the OpenRocket model without the motor and data showcasing the stability are shown below.

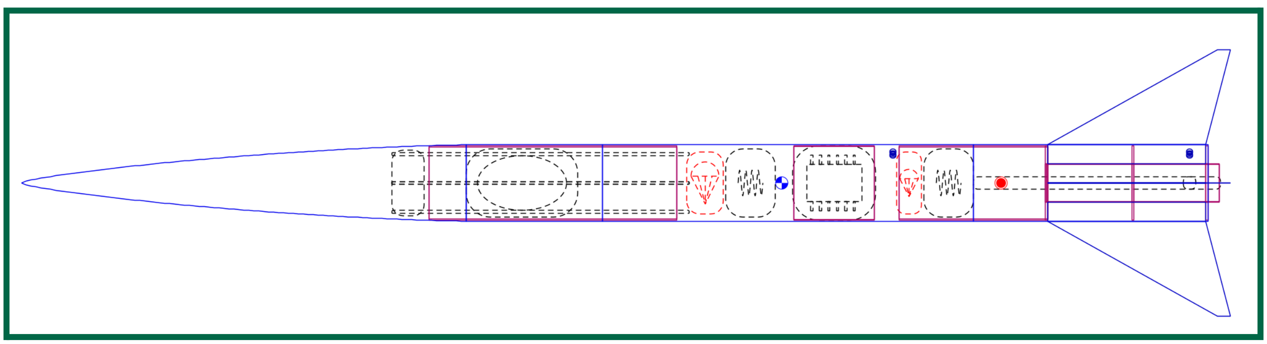


Figure 98. Burnout Mass Distribution for Stability Validation

Table 24. Stability Margin Inputs Post-Burnout

Category	Data	units
Center of Pressure	79.24	in
Center of Gravity	61.562	in
Outer diameter	6.17	in

$$Stability = \frac{(CP-CG)}{d_{outer}} = \frac{79.24 - 61.56}{6.17} = 2.87\ cal$$

3.4.4.3 Airbrakes Influence

The implementation of Airbrakes on the rocket introduces changes to its aerodynamic profile, resulting in a shift of the center of pressure (CP). Accurately accounting for this shift is essential to maintain aerodynamic stability throughout the flight. To determine the impact of the Airbrakes on the CP, Ansys simulations were conducted. These simulations provided data on the new CP location, enabling the design team to ensure that the CP remains appropriately positioned relative to the center of gravity (CG).

The Ansys Fluent simulation previously used to determine the drag coefficient of the rocket was re-used for this purpose. A new expression was created to use the already found pressure values to find the Center of Pressure. The following formula was used to find the CP location relative to the origin. It should be mentioned that for all calculations in this section, Airbrakes were deployed at 100% to calculate the maximum change of the CP.

$$CPz_{location} = \frac{\int_{rocket} Z\ P\ dA}{\int_{rocket} P\ dA}$$

Where the following values were used

P = pressure acting on the rocket's surface.

Z = distance along the Z-axis from a reference point.

dA = surface element on the rocket.

The following formula was obtained using Ansys callout references. Results are shown below.

*areaInt(Z*Pressure)@rocket/areaInt(Pressure)@rocket*

Name	Update Order	P5 - velocity	P1 - dragforce -op	P2 - cd-op	P4 - Center of Pressure
Units		m s^-1	N		m
DP 0 (Current)	19	200	283.75	0.43155	0.33667

Figure 99. Center of Pressure through Ansys Fluent

The origin was not a matter of interest when starting the Ansys Fluent drag simulations. Therefore, it was placed arbitrarily around the end of the rocket. After taking that number into consideration and subtracting the distance from the total length of the rocket, the new CP location from the tip of the nosecone can be found in inches.

$$CPz_{location} = Rocket\ length - P4 + offset = 97.77 - 13.22 + 2.36 = 86.91 \text{ in}$$

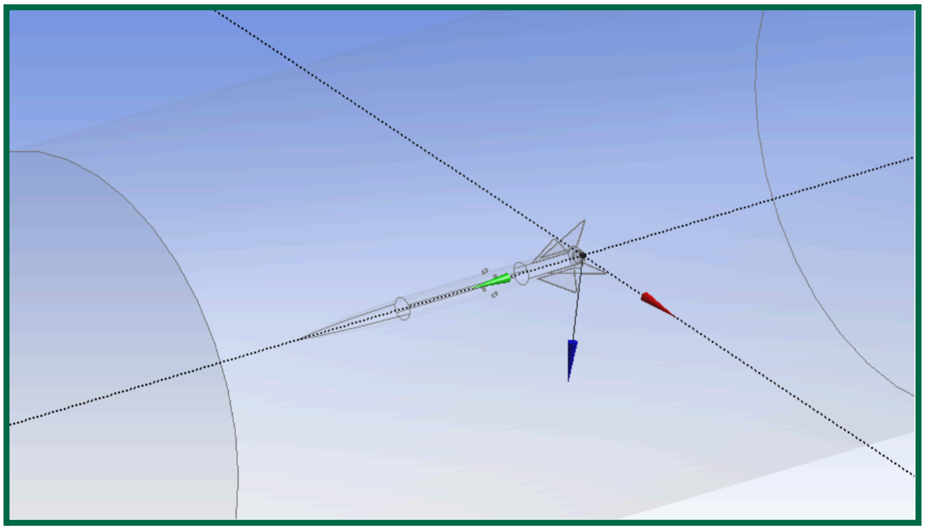


Figure 100. Origin in Simulation

Therefore, the static and dynamic stability can be calculated using this new found value.

Table 25. Stability Margins

Category	Stability Margins	CG	CP
Static	3.68	64.36	86.91
Dynamic	4.14	61.57	86.91

Finally, to ensure that the protruding section of the Airbrakes is below the center of mass, a simulated burnout motor mass was placed where the motor is. Effectively, the Airbrakes system is below the center of mass, ensuring an increase in stability rather than a decrease. A picture of the CG location is shown below.

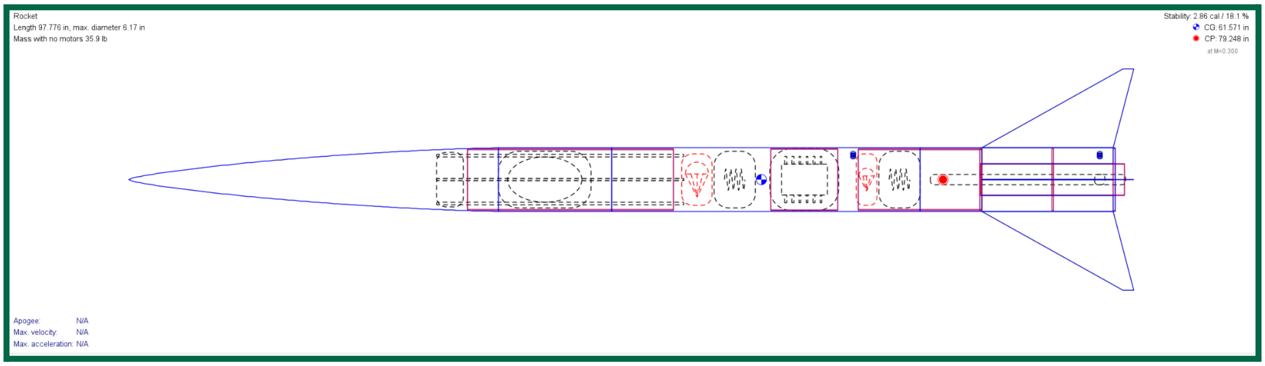


Figure 101. Burnout Center of Mass for Airbrakes Validation

3.4.5 Landing Kinetic Energy

The kinetic energy at landing for each independent section of the launch vehicle was calculated using simulated data obtained from OpenRocket to ensure compliance with NASA Requirement 3.3. The calculation employed the equation:

$$KE = \frac{1}{2}mv^2$$

where KE represents the kinetic energy, m is the mass of the section, and v is the velocity at landing as determined by the simulation.

Table 26. Simulated Kinetic Energy at Landing

Section	Mass (lb)	Simulated KE (ft-lb)
Nosecone	12.95	54.465
Mid Section	11.31	47.568
Booster	11.66	49.04

Simulation results for the worst-case scenario indicate that all sections of the launch vehicle remain well within the maximum allowable kinetic energy of 75 ft-lbf. at landing. This confirms compliance with USLI Requirement 3.3, showcasing that the design adheres to safety standards for descent and recovery.

3.4.6 Descent Time

To enhance accuracy when calculating descent time, a Simulink model was developed. Using the mathematical model:

$$F = ma$$

Set the reference system so that positive x is to the right and positive y is upward. t = 0 at apogee, y = 0 at ground:

$$F_d - P = m \cdot \frac{dv}{dt}$$

Substitute equations:

$$\frac{1}{2} \cdot \rho \cdot v^2 \cdot A \cdot C_d - m \cdot g = m \cdot \frac{dv}{dt}$$

However, this is only true above 600ft, below that, main parachute is deployed, adding another term to this equation, and making velocity essentially a step function:

$$\frac{1}{2 \bullet m} \cdot \rho \cdot v^2 \bullet A_{drogue} \bullet C_{d,\,drogue} - g = \frac{dv}{dt},\ with\ h > 600(ft)$$

$$\frac{1}{2 \bullet m} \cdot \rho \cdot v^2 \bullet A_{main} \bullet C_{d,\,main} + \frac{1}{2 \bullet m} \cdot \rho \cdot v^2 \bullet A_{drogue} \bullet C_{d,\,drogue} - g = \frac{dv}{dt},\ with\ h \leq 600(ft)$$

And needing another equation to describe h, which is only the integral of v(t). Converting everything to metrics here.

$$h = 1376.48 - \int_a^b v dt \text{ (m), predicted apogee at 4516 (ft) using OpenRocket}$$

The three equations were modeled using Simulink:

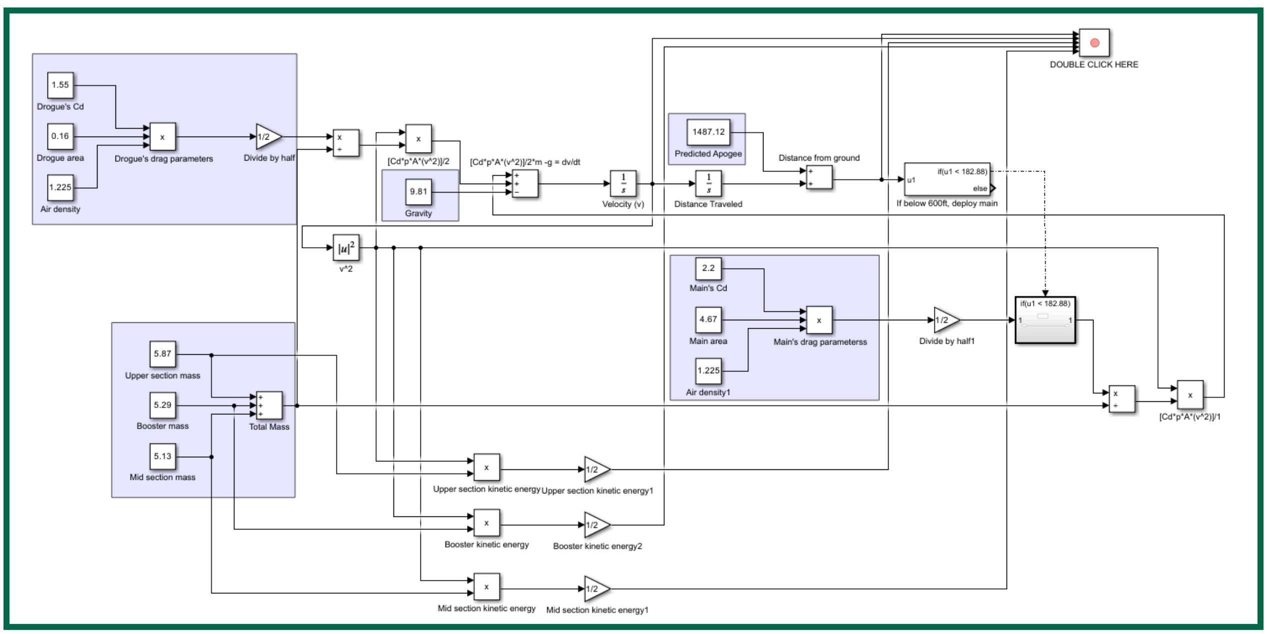


Figure 102. Simulink Block Diagram for Model of Recovery Time and Velocity

The result is then plotted:

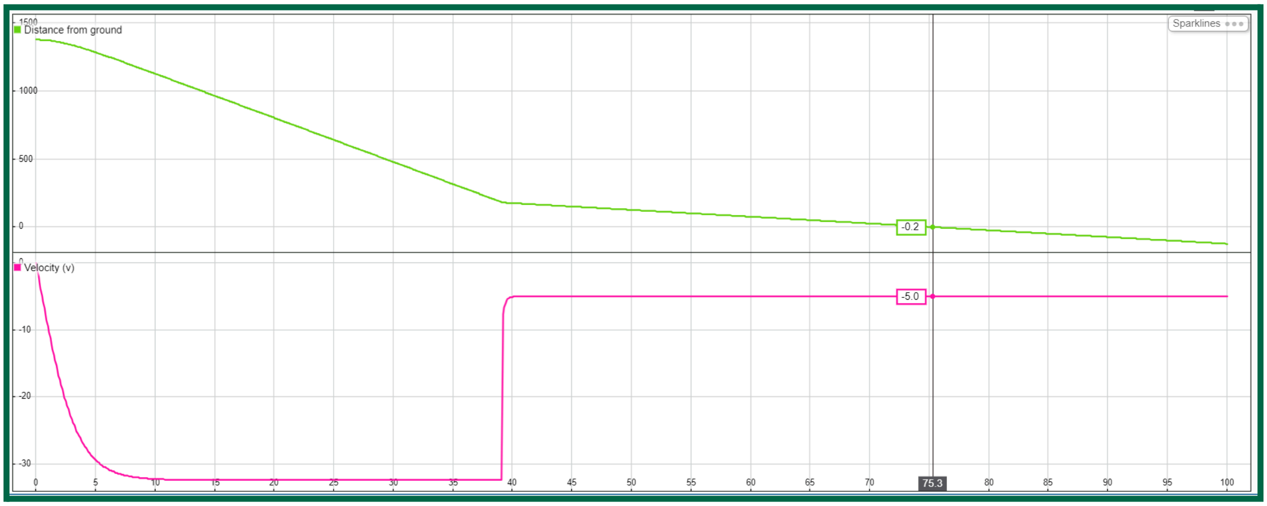


Figure 103. Simulation of Descent Time and Velocity when Predicted Apogee is 4516 ft using Simulink

Using the data cursor, the rocket is predicted to land approximately 75.3 seconds after apogee, consistent with hand calculations (higher than hand calculations value, but within expectation because hand calculations do not count for acceleration time). Cross-checking the model with other launch configurations confirms its accuracy. The -0.2 value shown in the plot results from the model's step size, which is limited to 0.1 seconds to optimize computational efficiency.

The descent time for an ideal scenario, in which all systems work flawlessly and the rocket able to reach the exact predicted high is also calculated, using predicted apogee value at 4075 ft (1242m). The predicted descent time for this case is around 70.9 seconds.

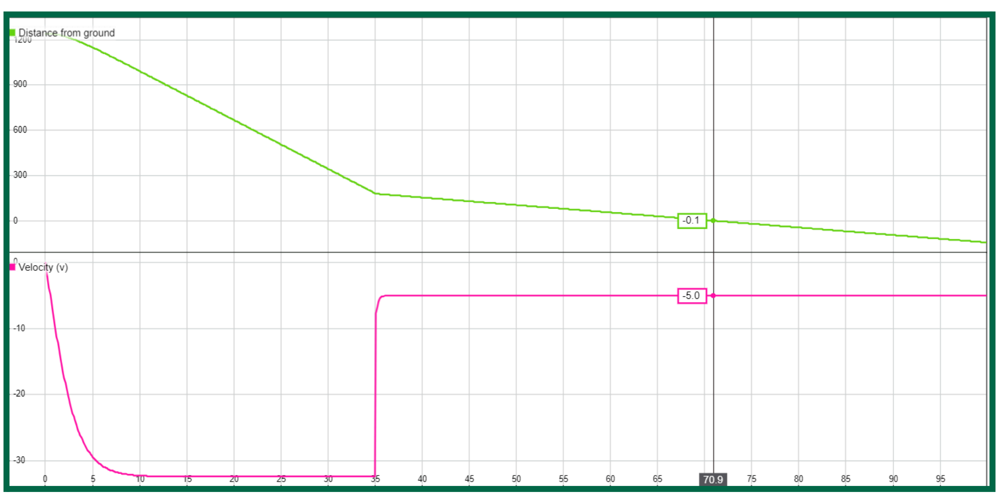


Figure 104. Simulation of Descent Time and Velocity when Predicted Apogee is 4075 ft using Simulink

Table 27. Predicted Apogee Descent Time

Category	Case 1	Case 2
Predicted Apogee (ft)	4516.00	4075.00
Descent Time (s)	75.3	70.9

3.4.7 Drift

The drift distance analysis was conducted using OpenRocket to simulate the same scenarios as those in the flight profile simulations, with varying launch rail angles and wind speeds. The results presented correspond to the best-case and worst-case scenarios. The best-case scenario assumes a 0° launch rail angle and 0 MPH wind speed, while the worst-case scenario considers a 10° launch rail angle and 20 MPH wind speed. These simulations provide insight into how rail angle and wind conditions impact the vehicle's lateral displacement during flight.

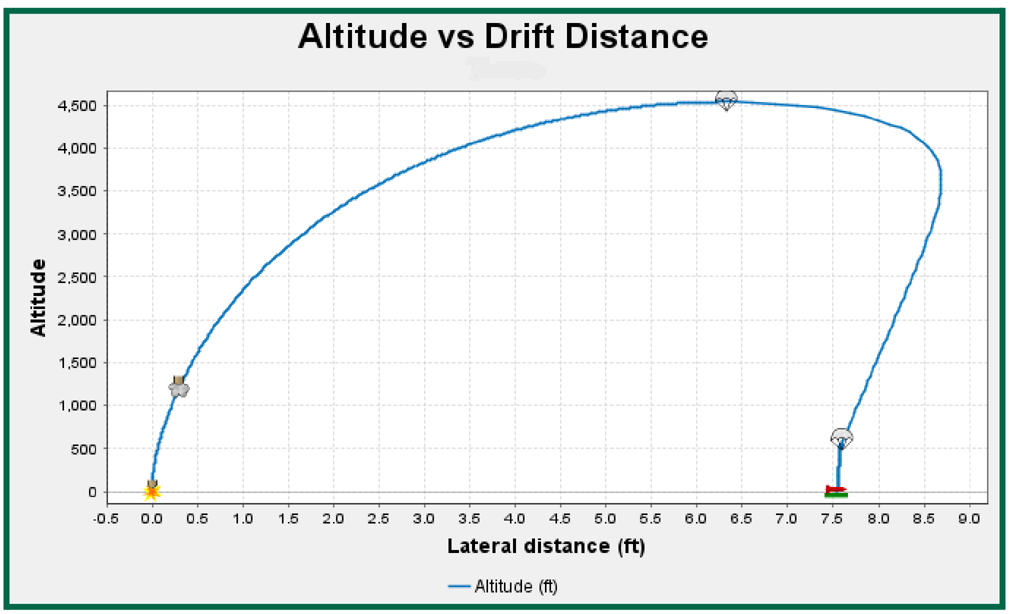


Figure 105. Simulated Drift Distance of Best Case Scenario (0° Cant angle, 0 MPH wind speed)

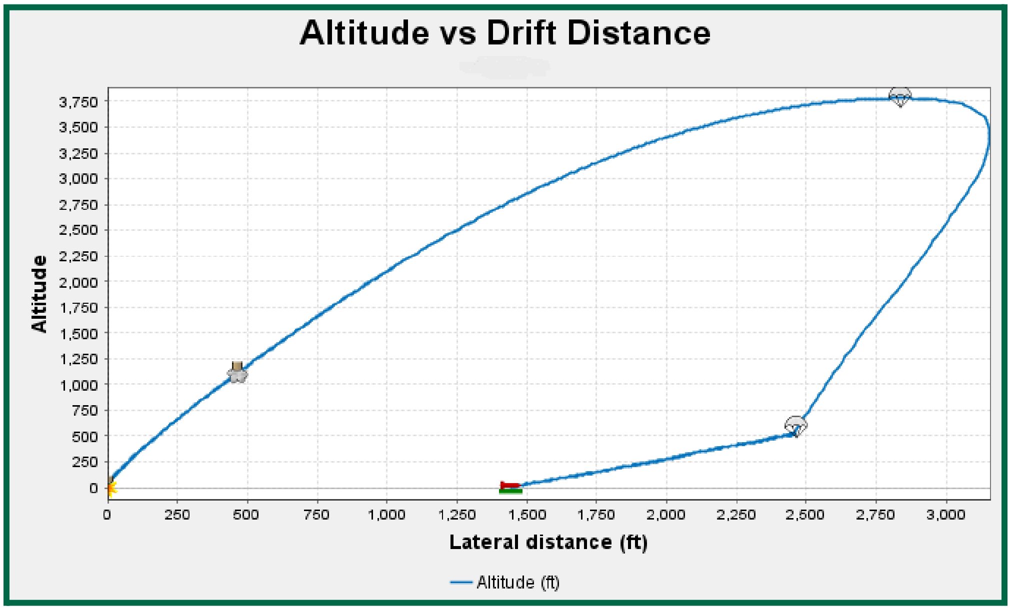


Figure 106. Simulated Drift Distance of Bad Case Scenario (10° Cant angle, 20 MPH Wind Speed)

The drift distance analysis indicates that for all simulated conditions, including the worst-case scenario, the drift remains within the 2,500-foot recovery area radius. This satisfies NASA Requirement 3.11, ensuring the launch vehicle's recovery system performs within acceptable limits for safe retrieval.

The maximum expected drift happens when the rod angle is 0° and the wind speed is 20mph. Assuming that the vehicle starts descending from the same spot if it was launched, it is possible to know the drift by multiplying the descent time times the wind speed. The following equation calculates the worst-case scenario drift.

Table 28. Drift Values

Category	Worst Drift	Best Drift
WindSpeed (m/s)	8.94	8.94
Descent Time (s)	75.3	70.6
Drift (m)	673.24	630.87
Drift (ft)	2208.80	2069.77

The drift analysis under worst-case conditions shows that the rocket's maximum drift is within an acceptable range, even under high wind speeds of 20 mph. With calculated drift distances of 2158 ft for the worst case and 2069.77 ft for the best case, these values offer a conservative estimate, ensuring the rocket will remain within recovery bounds under the most challenging conditions. This satisfies the Requirement 3.11.

3.4.8 Hand Calculations

3.4.8.1 Parachute Calculations

Objective: To determine the appropriate parachute dimensions and descent velocities to ensure a controlled and safe recovery.

- **Diameter (in):** represents the diameter of the parachute canopy. For the main parachute, this is 96 inches, and for the drogue, it is 18 inches.
- **Drag Coefficient (Cd):** A dimensionless quantity representing aerodynamic drag efficiency, assumed to be 2.2 for the main and 1.55 for the drogue.
- **Area (m^2):** The parachute canopy area is calculated as follows:

$$Area = \pi \left(\frac{Diameter}{4}\right)^2 \times 0.00064516$$

  where the diameter is in inches and 0.00064516 is the conversion factor to square meters.

- **Descent Velocity (F Velocity):** The terminal descent velocity is calculated using:

$$F_{velocity} = \sqrt{\frac{2 \cdot Weight}{\rho \cdot Cd \cdot Area}}$$

  where:

  - $Weight$: Weight of the rocket section.
  - ρ : Air density (1.225 kg/m^3 at sea level).
  - Cd : Drag coefficient.
  - $Area$: Canopy area.

For this project, the main parachute achieves a descent velocity of 5.04 m/s (16.53 ft/s), and the drogue achieves 32.02 m/s (105.05 ft/s).

3.4.8.2 Apogee and Descent Time

Objective: To verify the targeted apogee and calculate the total descent time for recovery planning.

- **Current Apogee:** The rocket is calculated to reach an altitude of 4,516 feet (1,376.48 m), exceeding the target apogee of 4,200 feet (1,280.16 m).
- **Main Deployment Altitude:** The main parachute is deployed at 600 feet (182.88 m).
- **Descent Time:**
  - **Apogee to Main:** Time for the drogue to slow the rocket's descent to the main deployment altitude:

$$Time = \frac{Distance\ (apogee\ to\ main)}{Velocity\ (drogue\ parachute)}$$

  - **Main to Ground:** Time for descent under the main parachute:

$$Time = \frac{Distance\ (main\ to\ ground)}{Velocity\ (main\ parachute)}$$

  - **Total Descent Time:** The summation of the above times results in a worst-case descent time of 73.6 seconds and a best-case time of 70.6 seconds.

3.4.8.3 Drift Calculations

Objective: To evaluate the horizontal drift of the rocket during descent based on wind conditions.

- **Drift:**

$$Drift = Wind\ Speed \times Total\ Descent\ Time$$

  - **Conversion to meters:** Drift in feet is converted to meters using:

$$Drift\ (m) = Drift\ (ft) \times 0.3048$$

3.4.8.4 Snap Force Analysis

Objective: To ensure the recovery harness and attachment points can withstand the dynamic forces during deployment.

- **Snap Force:**

$$Force\ (N) = Mass \times Deceleration$$

$$Force\ (lbf) = Force\ (N) \times 0.224809$$

where:

- $Mass$: Mass of the rocket section.
- $Deceleration$: Deceleration during deployment (estimated as 11 in/s^2).

- **Force Calculations:**
  - Nosecone: 528.0 lbf. (2,348.7 N)
  - Mid Section: 936.8 lbf. (4,166.9 N)
  - Booster: 475.4 lbf. (2,114.8 N)
- **Factor of Safety (FOS):** The structural components' safety margins are evaluated using:

$$Factor\ of\ Safety = \frac{Maximum\ Stress}{Design\ Stress}$$

3.4.8.5 Kinetic Energy of Independent Sections

Objective: To evaluate the kinetic energy during descent and ensure safe impact forces.

- **Mass Breakdown:**
  - Nosecone: 5.87 kg (12.94 lbm.)
  - Mid Section: 5.13 kg (11.31 lbm.)
  - Booster Section: 5.29 kg (11.66 lbm.)
- **Kinetic Energy:**

$$Kinetic\ Energy = \frac{1}{2}mV^2$$

In this case, it quantifies the energy each rocket section carries during descent. By analyzing the kinetic energy during drogue and main parachute deployment, the design ensures that the forces generated are within structural limits, preventing damage to the rocket and ensuring a safe recovery**.**For the main parachute descent, the kinetic energy for each section is below the acceptable threshold of 75 ft-lbf.

3.4.9 Calculation Discrepancies

3.4.9.1 Parachute Calculations

- **Variance Due To**:
  OpenRocket uses drag coefficient defaults based on idealized parachute performance and may not account for real-world deployment asymmetry or material imperfections. Hand calculations typically use experimental or manufacturer-provided Cd values, which may be more accurate for the current parachutes.
- **Impact**:
  This affects the descent velocities (F Velocity) and the total time of descent.

3.4.9.2 Descent Time and Terminal Velocity

- **Main Differences**:
  One of the main differences between OpenRocket simulations and hand calculations lies in the terminal velocity and descent time. OpenRocket, based on ordinary differential equations, reaches terminal velocity over a longer period of time compared to hand calculations, which may assume a quicker approach to terminal velocity.
- **Reason for Variance**:
  OpenRocket simulates descent with greater detail using differential equations, meaning the rocket takes a prolonged period to reach terminal velocity. This gradual approach contrasts with hand calculations, which often estimate a quicker, more idealized descent. Additionally, OpenRocket includes factors like wind speed and turbulence, which can cause fluctuations in the descent velocity during the fall, something hand calculations typically do not account for.
- **Impact**:
  The result is a shorter overall descent time in OpenRocket than predicted by hand calculations. Since OpenRocket's terminal velocity is reached gradually and includes environmental factors like wind and turbulence, the total time of descent may be affected, influencing staging times and recovery planning.

3.4.9.3 Drift

- **Reason for Variance**:
  Drift is highly sensitive to wind speeds and directions, modeled by OpenRocket using user-defined inputs or defaults. Hand calculations might use simplified wind models or estimated average values. Additionally, drift may fluctuate due to turbulence and varying wind speeds during descent. For the calculations, the worst-case scenario to consider is 20 mph winds, using the maximum wind speed to calculate the maximum drift.

- **Impact**:
  Accurate drift predictions are critical for planning landing sites and recovery logistics. By calculating the maximum drift under 20 mph winds, the recovery plan accounts for the furthest possible distance the rocket could travel during descent.

3.4.9.4 Snap Force

- **Reason for Variance**:
  OpenRocket estimates snap forces based on simulated dynamics, particularly the change in velocity when the parachute deploys. Both OpenRocket and hand calculations assume that the parachute opens instantly. In reality, however, parachute deployment is more gradual, which can affect the forces experienced during deployment. Hand calculations often simplify these dynamics or use conservative force estimates.
- **Impact**:
  Inconsistencies in snap force predictions directly influence the design and testing of structural components, such as shock cords and eye nuts. A more gradual deployment would reduce the instantaneous forces applied, which may not be accurately reflected in the current models.

3.4.9.5 Kinetic Energy (KE)

- **Reason for Variance**:
  Differences in descent velocity predictions, caused by varying Cd or wind assumptions, directly impact kinetic energy estimates. Hand calculations may use simplified velocity inputs, potentially resulting in under- or overestimated KE values.
- **Impact**:
  Accurate KE estimates are crucial for assessing rocket safety at impact, particularly near spectators.

4 Payload Technical Design

4.1 Ground Observation Signal Transmitter (G.O.S.T)

The Society of Aeronautics and Rocketry is developing a Ground Observation Signal Transmitter (G.O.S.T.). GOST will use an array of sensors to collect atmospheric and orientation data that will be transmitted using APRS to NASA's ground station. The sensor array will be exposed to the atmosphere upon landing via a door mechanism that will be actuated by a 21g servo. The doors will also allow for a clear path for the antenna to transmit and receive.

4.1.1 Success Criteria

The success of the payload mission will be determined with the following criteria:

• The GOST shall be rigidly fixed inside the launch vehicle's payload coupler during flight, so that only the doors operate quickly and accurately after landing (NASA Reqs. 4.2.2.).

• The GOST shall operate within moderate weather conditions and temperatures such that the mechanics and electronics are fully functional.

• The GOST shall protect the electronics from potential damage or residue from the recovery systems.

• The GOST shall deploy the bay doors without interfering with collection of data and transmission of said data.

• The GOST shall collect a series of measurements and readings when commands are received via RF communications or landing was detected. (NASA Req. 4.2.1.).

• The GOST shall successfully transmit a string of data to NASA's ARPS protocol transceiver (NASA Reqs. 4.2.6.).

• The GOST shall be serviceable for changes during tests and the competition.

4.2 Design Alternatives

Outlined in the PDR three main alternatives for the solution of the payload mission were discussed. The decision to use the static design that does not jettison from the rocket came at the help of trade and feasibility studies. The reliability of deployment and ease of development were a few considerations that led to this decision.

4.2.1 Concept of Operations Mechanical

Rocket Launch

As the rocket advances towards apogee, the payload system is securely held within the rocket's body by secure mounting points and reinforced stress points, this helps to prevent any interference from external conditions that could affect the data collection process. During this phase, onboard systems are set to standby, waiting to activate upon landing.

Landing and Orientation Assessment

Once G.O.S.T. grounds, the payload system shifts into its functioning state. Sensors onboard immediately determine the rocket's orientation in relation to the ground. This information directs the system to identify which one of the aviation bay doors is most optimally positioned for deployment, this ensures that the data can be collected accurately and with a high success rate.

Bay Deployment

The selected aviation bay's hatch opens, exposing the Adafruit BME280 sensor to the surrounding atmosphere. The deployment process is executed with precision to minimize disturbances that could impact the accuracy of initial readings. A brief stabilization period follows to guarantee consistent and reliable measurements.

Data Collection

Following deployment, the BME280 sensor begins gathering environmental data, such as atmospheric pressure, temperature, and humidity. These readings are systematically recorded and timestamped to create a detailed chronological dataset. This phase ensures the collection of actionable, high-quality data aligned with the mission's objectives.

Data Transmission

The sensor's collected data is transmitted to the ground station through a ham radio frequency system. The data that is collected is then measured again for redundancy and to avoid errors in the collection process; this ensures that the data arrives complete and unaltered, regardless of potential environmental challenges.

4.3 Design Overview

4.3.1 System Layout

The GOST is a self-enclosed coupler that is used structurally for the rocket along with housing the sensors and motors in order to complete the payload mission. The electronics that will be placed on the center alignment ring are the sensor array and transmitting antenna, while the motors will be affixed to the upper bulkhead using a U-Bracket shown in Figure 107.

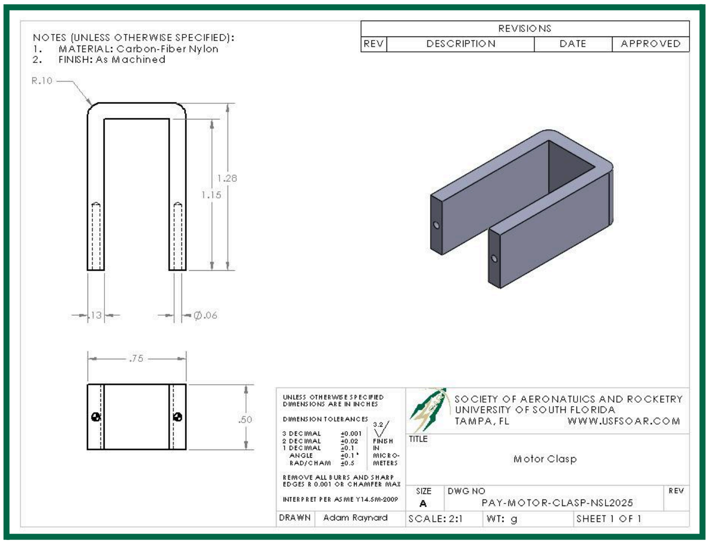


Figure 107. Motor Clamp Engineering Drawing

4.3.2 Stringer Assembly

The purpose of the stringer assembly is to reinforce the airframe since there will be cuts for payload doors. The assembly shown below in Figure 108 is made of 6061-T6 Aluminum poles that are bolted to a center plate and the two bulkheads on either side.

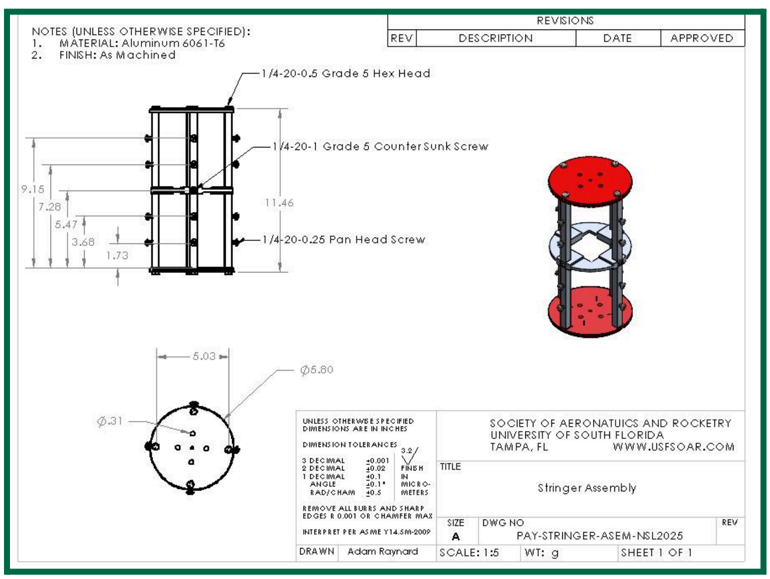


Figure 108. Payload Stringer Assembly Engineering Drawing

4.3.3 Stringer FEA and Calculations

Using Hooke's Law, the calculation of deformation is as shown:

$$\Delta L = \frac{F \cdot L}{A \cdot E}$$

Using this equation and the aluminum stringer area gives a value of deformation of psi 0.00255 inches.

Since the force of 2320 psi is acting on the stringer, with a yield strength of 40000 psi and an ultimate tensile strength of 45000 psi, the aluminum will neither plastically deform nor fracture.

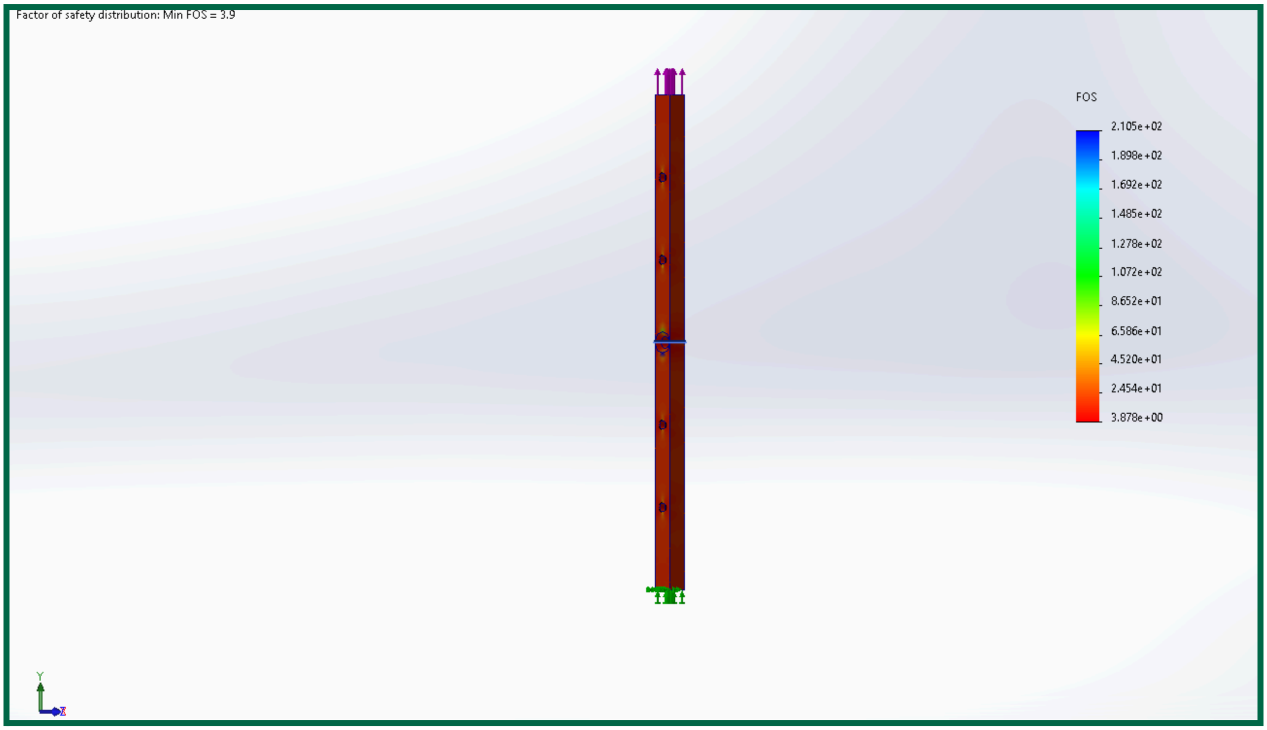


Figure 109. Stringer FOS FEA

Using FEA, the factor of safety is 3.9, which is above PAYD.1 requirement of 1.75.

4.3.4 Motor and Door Assembly

The Servo motor being used for opening the door is an 18-g variation. This servo will be able to hold the doors closed during flight since the chamfer design keeps air from getting underneath them, as shown in Figure 110.

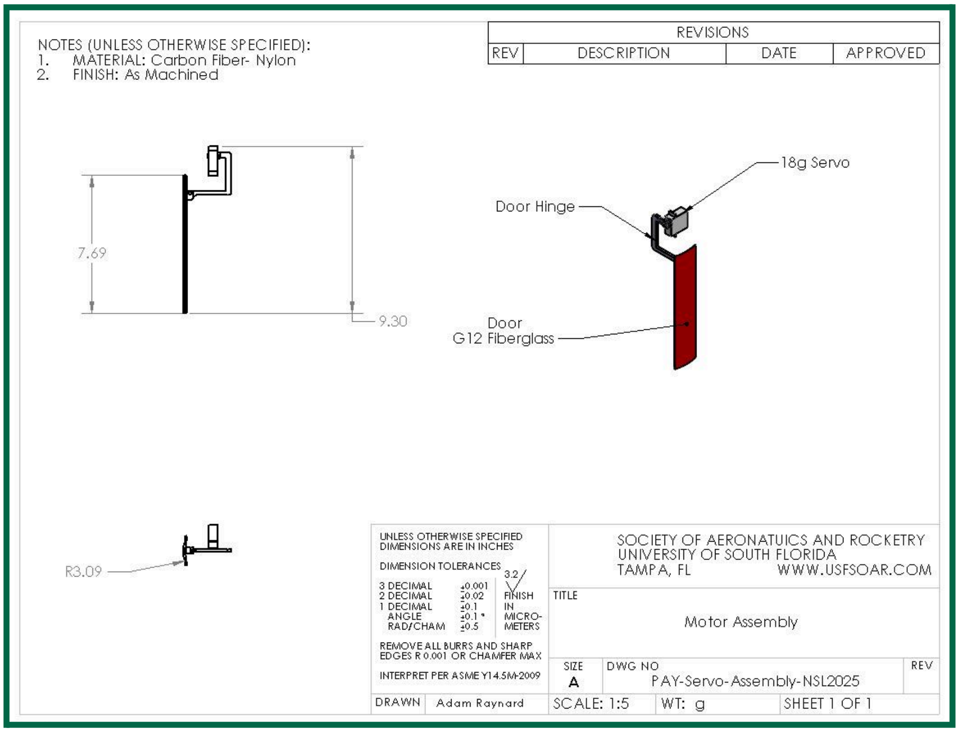


Figure 110. Servo Assembly Engineering Drawing

4.3.5 Capsule

The STEMnauts will be housed in a three-inch-tall, 3-inch-diameter cylinder. The selected STEMnauts are a Lego minifigure, a Haribo Gummy Bear, and a team-selected mascot from the year. The capsule is shown below in Figure 111.

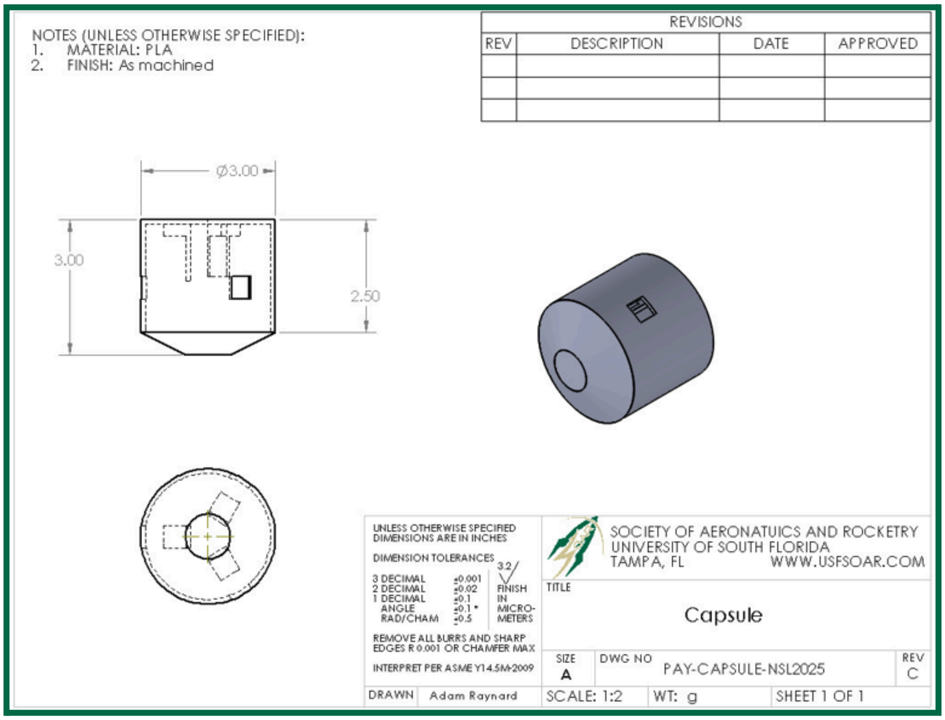


Figure 111. Capsule Engineering Drawing

4.3.6 Overview

This is the entirety of the payload system and its coupler used to mount the nose cone, as well as the separation point for the midsection.

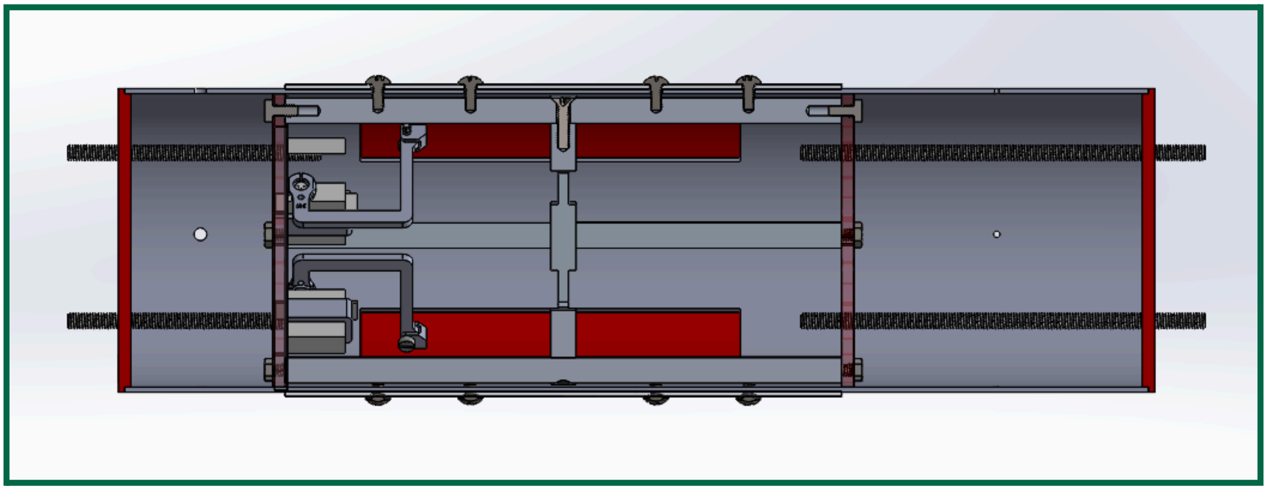


Figure 112. Payload Assembly Engineering Drawing

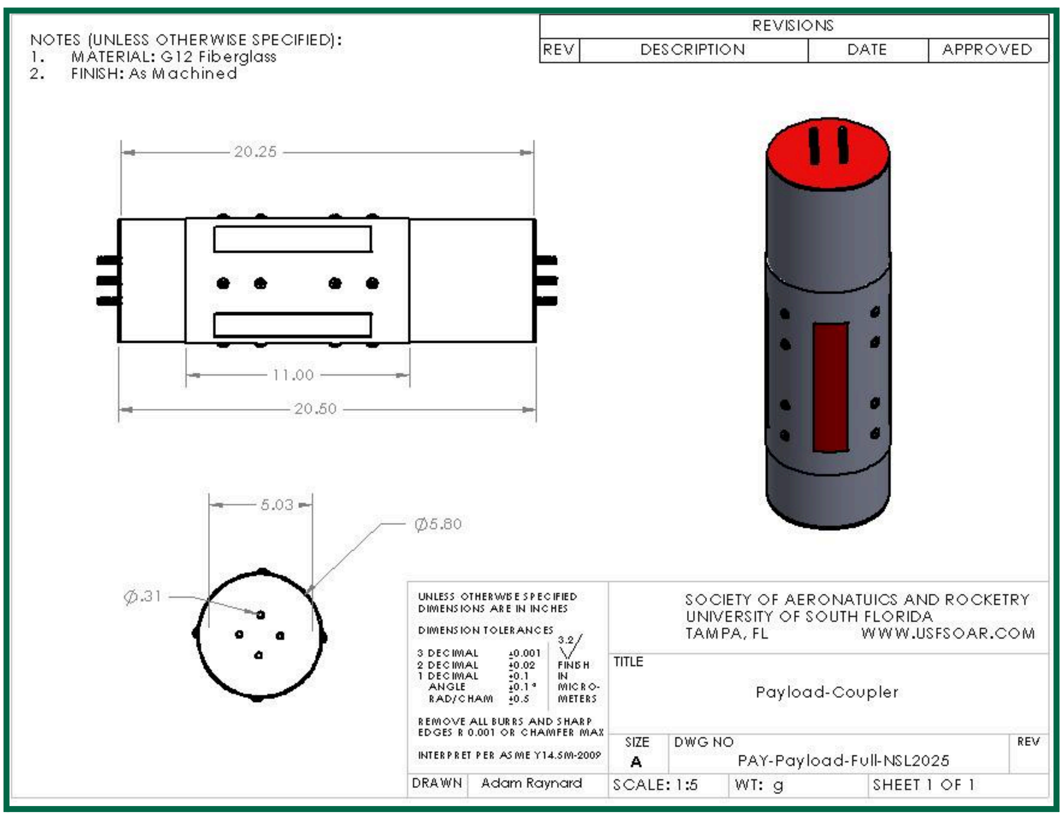


Figure 113. Payload Assembly Engineering Drawing

4.4 Retention of System

The payload retention system is depicted and outlined below in Figure 112 . This will be the same as the vehicle payload interface.

4.4.1 Vehicle - Payload Interface

The payload is held within the rocket the entire mission. Using sixteen ¼-20 by ¼ inch screws. These screws will act in shear, as shown in Figure 112.

$$UTS = Proof\ stress\ *\ stress\ area$$

Using the given formula, the ultimate tensile strength is 2700 lb*ft. Using this and the snap force, there will be a safety factor of 5.11, which is within the safety factor of 1.75 stated in requirement PAYD.1. Shear strength is considered to be 60 percent of the ultimate tensile strength, meaning the shear strength is 1620 lb*ft using the snap force, giving a safety factor of 3.

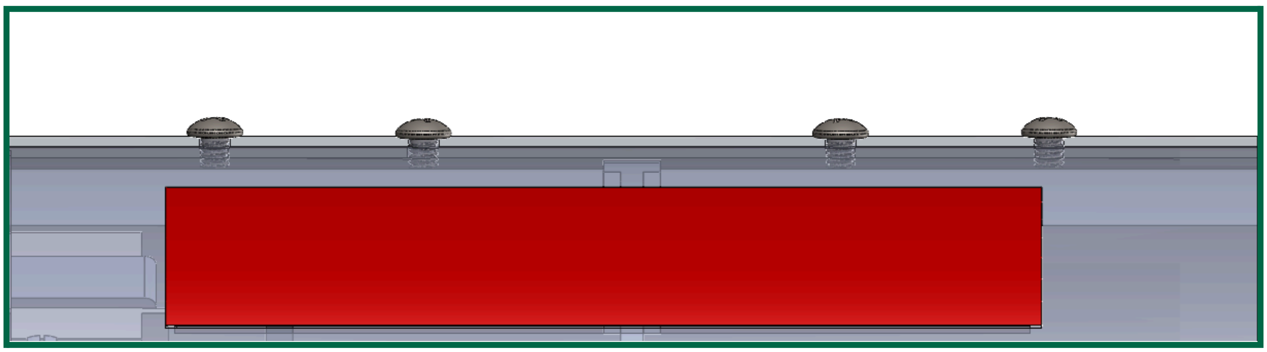


Figure 114. Bolts Retaining Payload System

4.5 Payload EECS CONOPS and Calculated Survivability Metrics

The diagram below details the data collection and actions intended for the payload electronics subsystem, to be implemented with the sensors, a microcontroller, and other hardware detailed in the following section.

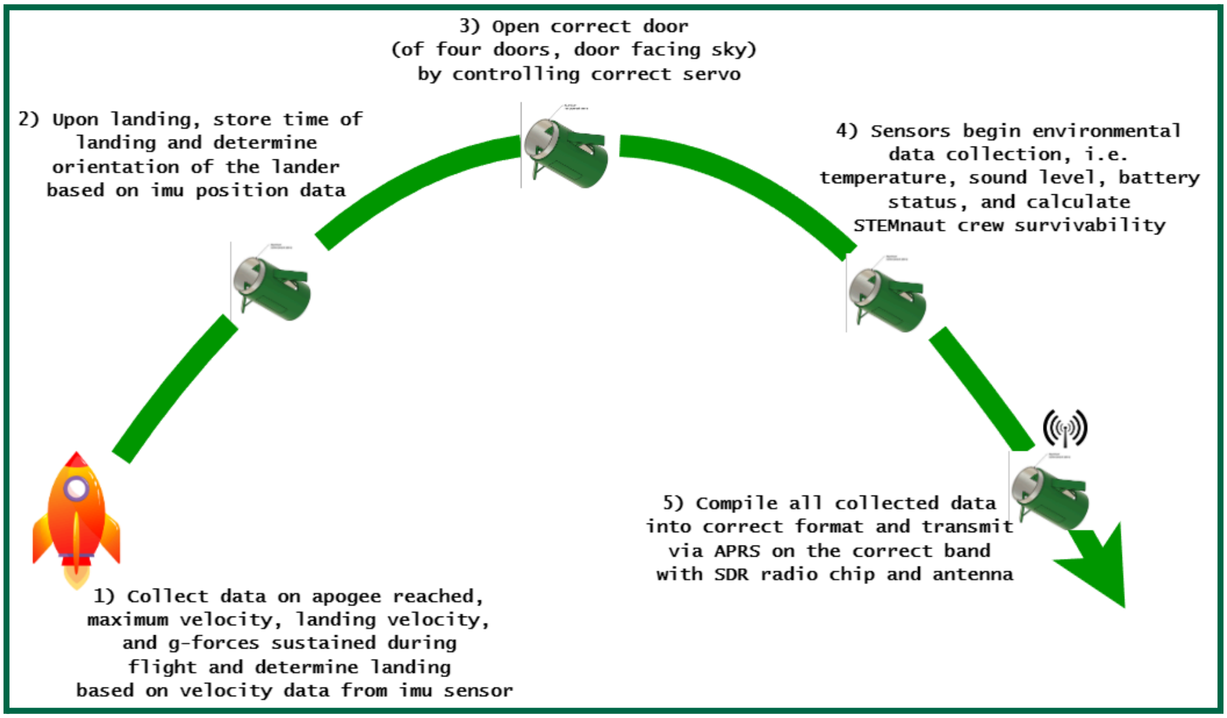


Figure 115. Payload EECS Con-Ops Diagram

STEMNaut Crew Survivability will be calculated by comparing the collected sensor and environmental data with the following metrics:

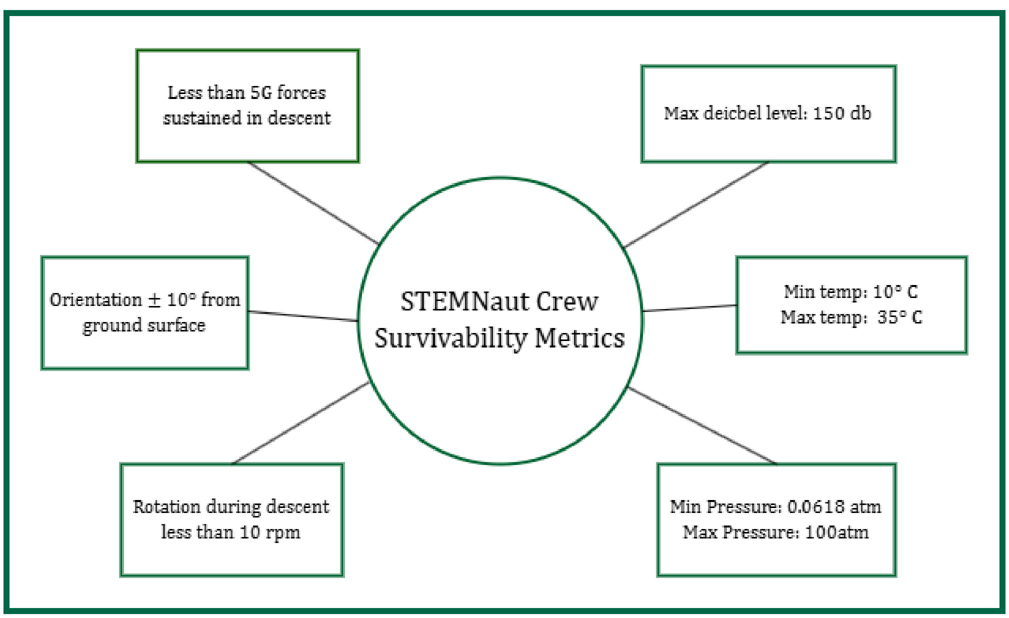


Figure 116. STEMNaut Crew Survivability Metrics

4.6 Sensors and Hardware

For the fixed G.O.S.T. design, four servos will be integrated onto each of the lander's doors to enable opening the correct door upon landing. An Adafruit PCA9865 servo controller will drive all four servos for more accurate and efficient PWM control. The IMU housing the main sensors will determine the orientation of the lander, and the program logic will use this information to actuate one of the four-door servos.

The sensors used will include an Adafruit BNO055 IMU sensor, an Adafruit BMP390 barometer, an Adafruit BME680 or temperature sensor, and an Adafruit I2S MEMS Microphone Breakout. These will measure the data pieces listed in Section 4.2.1 of the NSL 2025 Handbook of maximum and landing velocity, sustained G-forces, apogee reached, landing site temperature, and other metrics to be included in the STEMNaut survivability calculation like pressure and decibel level. Maximum and landing velocity will be determined in the active loop using the velocity readings from the IMU, as will sustained G-forces, using basic if-statement logic to update maximum values as they occur. Apogee will be determined after it occurs by similarly finding a maximum in the altitude data from the barometer data, and temperature and decibel limit will be directly fetched from the BME680 and microphone as soon as the lander is on the ground and the correct door has opened. These sensors were chosen for their affordability, ease of interfacing with the central ESP32S3 microcontroller, and their adequate level of accuracy for this payload system.

An ESP32S3 microcontroller will be the central microcontroller of the system, and it will obtain and store the needed sensor data, control the servos, and transmit with a transceiver radio chip. The ESP32 was chosen because it can be interfaced with easily for sensor control and takes up less space than other options like Arduino and Raspberry Pi boards while maintaining the same level of functionality. The four servos will be powered with two 3.7 LiPo batteries in series, resulting in a 7.4 input, and the rest of the system will be powered by a single 3.7 LiPo battery. Lithium-ion batteries were chosen over batteries used in previous years for their reliability and smaller size, allowing for better consolidation of space in the sled/electronics unit. Built-in power switches will be integrated into the payload circuit with 2-pin JST connectors in between the power and ground battery connections.

The ESP32 will transmit the acquired sensor and calculated data using APRS (Automatic Packet Reporting System) via a VHF transceiver, which is planned to be the DRA818v integrated radio chip or software-defined radio. More information about the use of the DRA818v and the chosen antenna will be detailed in the section after the schematic below.

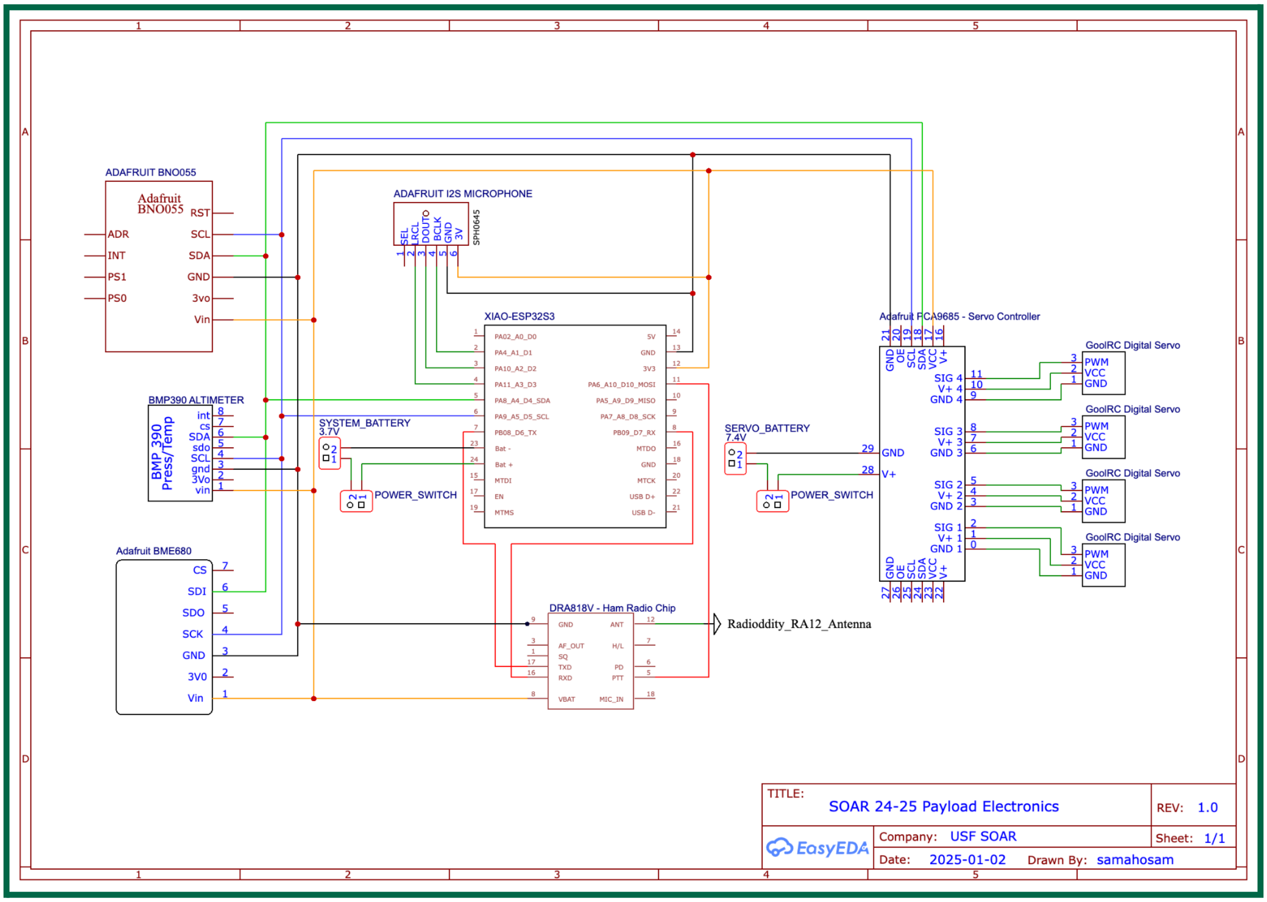


Figure 117. Payload Electronics Schematic

4.7 2M Band Radio and Antenna

The DRA818v IC chip radio functions in the 2M band range of 144 MHz to 148 MHz , as required by Section 4.2.3 of the NSL 2025 Handbook. It is preferable for its small size and easy integration with the other sensors and electronics, as the intention is for all sensors and hardware on the schematic above to be integrated on a single PCB board. The DRA818v will need a separate antenna, and as of now that is planned to be the off-the-shelf Radioddity RA12 antenna that has a gain of 2.5 dBi. Combining this gain with the initial 29 dBm TX source power of the radio chip, the ideally unobstructed signal from the radio chip should reach NASA's ground FTM-300DR transceiver with a strength of about -27 dBm, using the following calculations:

1. $P_T = P_{TX} \cdot CL_{TX} = 28.65\ \text{dBm}$

Where P_T is total TX power, P_{TX} is TX source as 29 dBm, and CL_{TX} is TX connector loss as the typical SMA connector loss of 0.35 dB (0.2 dB insertion loss + 0.15 dB reflection loss).

2. $EIRP = P_T \cdot G_T = 31.15$ dBm

Where EIRP is Effective Isotropic Radiated Power and G_T is the TX antenna gain of 2.5 dBi specified in the Radioddity RA12 datasheet.

3. $L_{FS} = (\lambda / 4\pi d)^2 =$ - 61.64 dB

Where L_{FS} is Free Space Loss? λ is the wavelength of the transmission in meters, which is 2 meters for a 144 mHz frequency, and d is the distance to the NASA RX antenna, assumed to be 200 meters.

4. $P_{ChanFS} = L_{FS} \cdot EIRP =$ - 30.49 dB

Where P_{ChanFS} is the transmission's power at the NASA RX antenna, assuming a Free Space Path?

5. $P_{RFS} = P_{ChanFS} \cdot G_R \cdot CL_{RX} =$ - 27.34 dBm

Where P_{RFS} the total Free Space RX power of the transmission, G_R is the RX antenna gain of 3.5 dBi from the FTM-300DR datasheet, and CL_{RX} is RX connector loss assumed to also be 0.35 dB for an SMA connector.

-27.34 dBm falls in above the FTM-300DR transceiver's minimum RX sensitivity of -40 dB specified on its datasheet, so the chosen radio and antenna should have adequate strength for the required transmission. In the case that the DRA818v is not successfully transmitting during testing or proves incompatible with the rest of the system, the subscale payload system utilizing a Baofeng UV-5R radio and Raspberry Pi will be used instead to transmit the collected data to the NASA transceiver during the final launch. More information and a schematic for this subscale system are in the Testing section 7.1.3.2 of this document.

5 Non-scored Payload: Airbrakes

5.1 Mission Statement and Success Criteria

The goal of the Airbrakes system is to successfully control the apogee of the rocket to be as close to the target apogee as possible, which is currently set to 4075 ft. The system will utilize two mechanical flaps that protrude from the body of the rocket at a perpendicular angle and are geared by a mechanism that allows their extension in and out of the rocket to be controlled by a servo. This servo will be actuated only by an electronic control system that utilizes IMU and barometer sensors. a state machine, a PID feedback loop, a Kalman Filter, and the Runge Kutta 4th Order prediction method to iteratively change the extended area of the flaps and keep the rocket's altitude from overshooting the target. The primary success criteria of the system in its final flight will be if the recorded apogee of the rocket is within 20 ft. of the target and there is no mechanical, electronic, or software failure during launch that prevents the Airbrakes system from controlling the servo, collecting data, or making the needed calculations.

5.2 Sensors and Hardware

For the electrical implementation of the Airbrakes system, two Adafruit 9 DOF BNO055 IMU sensors will be used to get live velocity readings, and an Adafruit BMP390 barometer will be used for live altitude readings. The central control/processor will be a Raspberry Pi Zero, chosen as the microcontroller of the system for its computing power ideal for the iterative RK4 predictions and PID calculations and its smaller size compared to other Raspberry Pi boards, making it easier to integrate with the rest of the electronics in the module. To control the servo actuating the air brake flaps, a PCA9685 Servo Driver will be used for more accurate and efficient PWM signaling. The system will have two batteries, one for only the servo consisting of two 3.7V LiPo batteries in series outputting 7.4 V, and one for the rest of the system also consisting of two 3.7V LiPo batteries in series but stepped down to 5V with a converter. The batteries will be controlled by switches. Initial testing of the hardware will be done on a breadboard, but the final electronics module to be used in the rocket will be a fully integrated PCB custom-designed, printed, and soldered with all of the aforementioned components, aside from the servo. As the microcontroller of the system is a Raspberry Pi, the software of the control system will be written in Python 3.11.

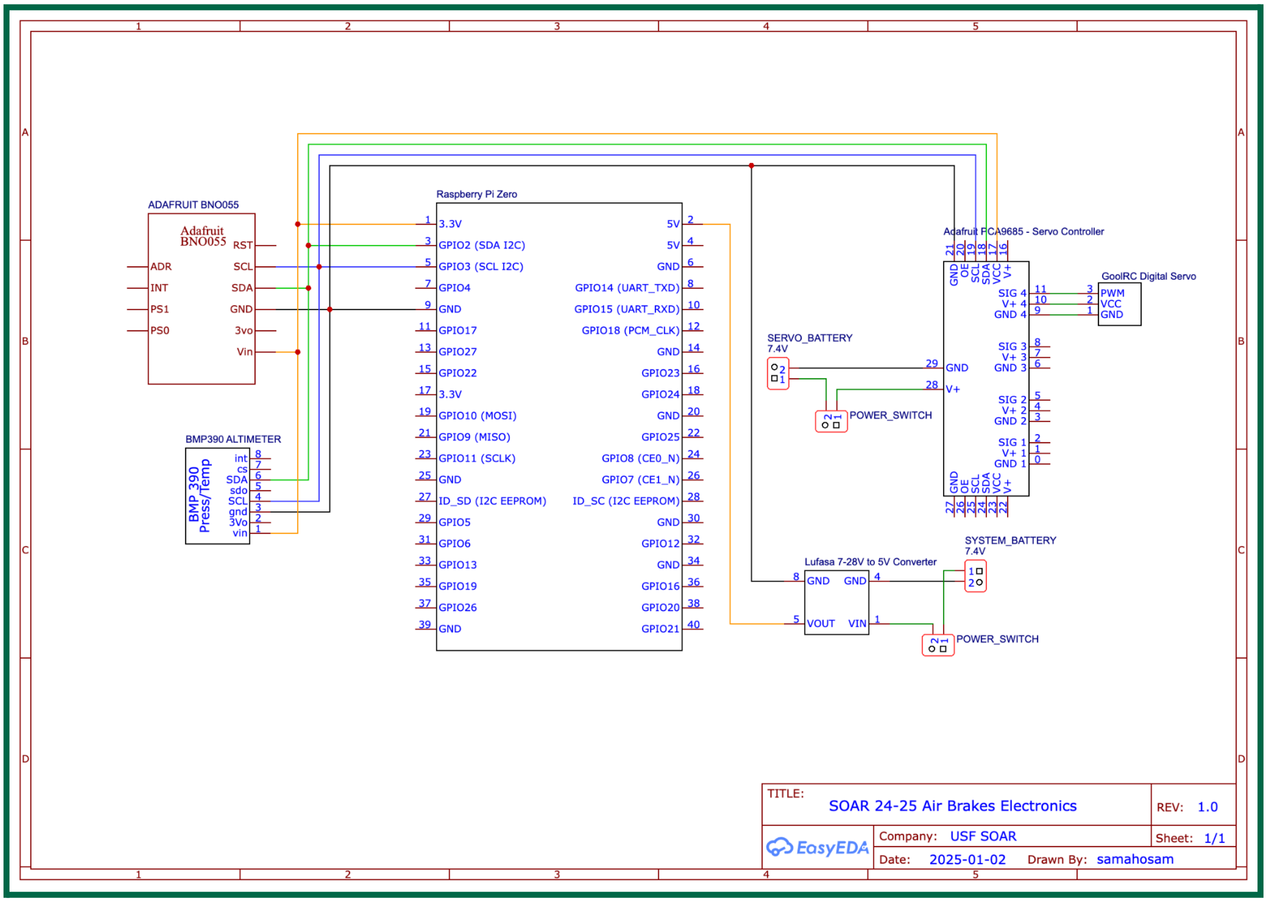


Figure 118. Airbrakes Electrical Schematic

5.3 State Machine

A state machine will be implemented in software that differentiates four states of the rocket's trajectory as they pertain to the Airbrakes system: burning fuel, active, full stop, and post-apogee. In the burning fuel and post-apogee states, the Airbrakes' flaps will be fully retracted and the servo actuation will be defaulted to zero percent, as no additional drag force is needed at these points in the rocket's trajectory. In the full stop state, they will be completely extended; at this point, the target apogee has already been passed and a maximum amount of correction is needed to make this state as short as possible. While that full extension state mitigates error retroactively once the target is already passed, the real purpose of the air brake system is to prevent passing the target apogee in the first place. So, the most critical state in the system is the active state, where the level of flap actuation will depend on predictions and calculated error correction in a PID control loop. This state will hopefully force the actual apogee to occur right around the target.

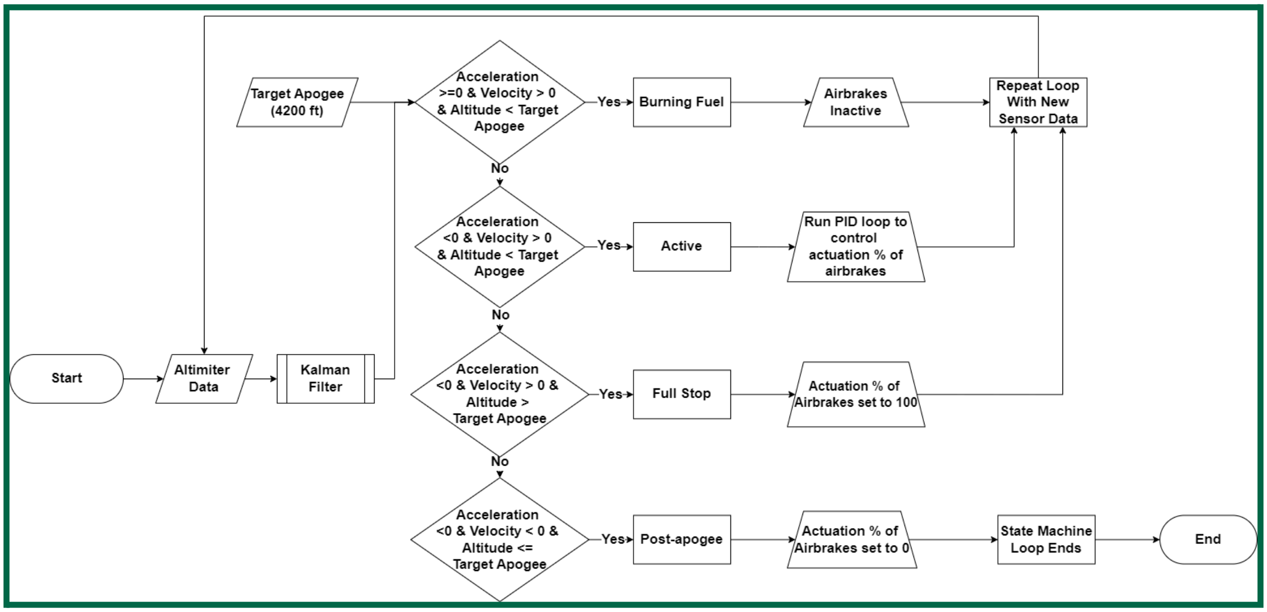


Figure 119. Airbrakes State Diagram

5.4 PID Control System

In the active state, the system will be controlled by a feedback control loop that implements a tuned PID error correction algorithm, the 4th-Order Runge Kutta (RK4) method to make predictions of the rocket's current projected apogee, and a Kalman filter to validate the input sensor data from the IMU sensors and barometer. In the code, this will manifest as a main program implementing the PID loop and two independent functions for predictions and filtering. The prediction function will directly take input data from the sensors, call the filtering function, and implement the RK4 method with the rocket's drag equation, the changing variables being current velocity, altitude, and surface area dependent on the air brake flaps. It will output a single altitude prediction per iteration of the PID loop. A PID loop was chosen for this control system because the system dynamics are unknown, and a PID control system allows for trial and error correction by tuning parameters instead of relying on an exact model.

In the main PID algorithm, the error for each iteration will be calculated as the difference of the target apogee and current apogee prediction. The PID loop will correct the error of the current iteration by calculating a net corrective gain summing the calculated error value (proportional term), the accumulative error since the first time step (integral term), and the rate of change of the error between the current and previous time steps (derivative term). Including the approximated integral of the error controls steady state error, the difference between the actual and target values when the system has reached an unchanging state. The derivative term limits overcorrection caused by the integral term, using the error's rate of change to predict future error values and adjust the net gain accordingly. The net gain will be translated to the actuation of the air brake flaps, expanding or contracting them by a small margin each iteration, with time steps of about 0.1s. Initial K_p, K_i, and K_d coefficients will be initialized before the main loop, and scale the components of the net gain before it is applied to the actuation of the flaps. The values of these coefficients need to be tuned uniquely for the system and will be determined through testing.
Net gain calculation inside loop:

$$error = projectedApogee - targetApogee$$
$$integral \mathrel{+}= error \cdot dt$$
$$derivative = (error - previousError)/dt$$
$$PID\ output = K_p \cdot error + K_i \cdot integral + K_d \cdot derivative$$
$$flap\ Position = PID\ output$$

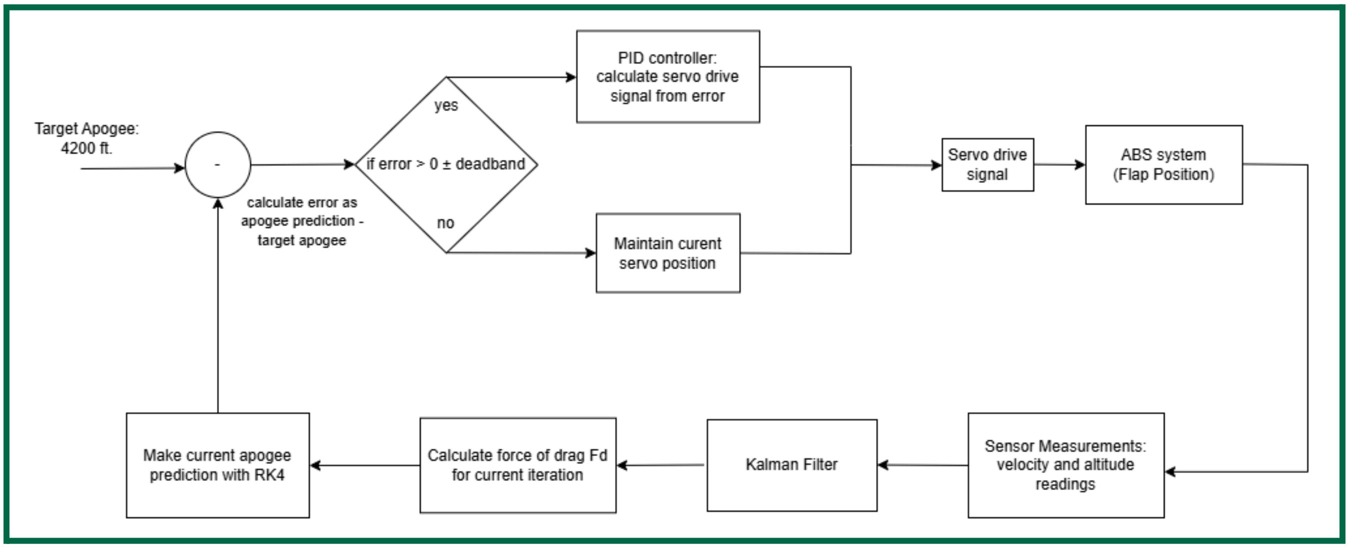


Figure 120. Airbrakes Feedback Control Loop

5.5 Apogee Predictions with RK4

The Runge Kutta methods are a means of solving ordinary differential equations, and they calculate the next value of a function by taking an average of slopes at different points across the current time step. They can be used to predict the value of a function at a future time step by performing this process iteratively, in this case with small time steps. The 4th Order Runge Kutta Method or RK4 method evaluates the derivative of the given function at four different points within the current time step, giving more information about the behavior of the curve than the lower order Runge Kutta methods and making it more accurate. The final output value in RK4 is calculated by taking a weighted average of these four slope estimates, each scaled by a specific coefficient in the RK4 formula.

In this ABS system, the RK4 method will be used to predict the instantaneous projected apogee of the rocket within the PID control loop, essentially predicting how the rocket's altitude changes over time and finding its altitude value when its velocity hits zero. To apply RK4 and get output predictions of altitude and velocity, those values need to be treated as functions of time that depend on the forces acting on them, which will be assumed to be gravity and drag from air resistance. The ordinary differential equations modeling the altitude (h) and velocity (v) of the rocket are:

$$dh/dt = v$$
$$dv/dt = (-F_D - F_G)/m$$

Fd is the force of drag on the rocket defined and calculated at the beginning of each RK4 iteration as:

$$F_D = \frac{1}{2}\rho v^2 C_D A_{R+F}$$

Where ρ is air density at sea level of 1.225 kg/m^3, v is the current velocity of the rocket from sensor reading, C_D is the calculated drag coefficient of the rocket with the air brake flaps of 0.43, and A_{R+F} is the cross-sectional area of the rocket from the tip summed with the current extended area of the air brake flaps, calculated as 29.42 in^2 + 3.74 in^2 · flap position (0-100%).

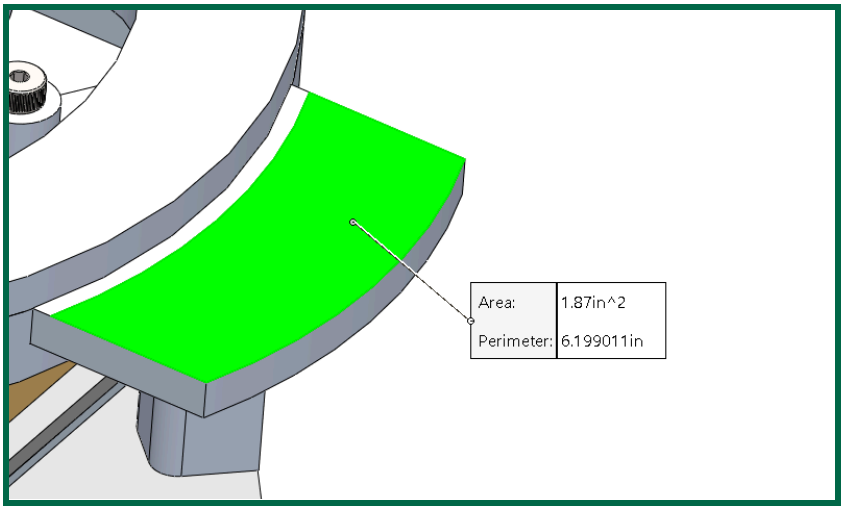


Figure 121. Airbrakes Flap Area in SolidWorks

Fg is the force of gravity (9.81m/s), and *m* is the mass of the rocket. RK4 will estimate the altitude and velocity values of the rocket over time by taking four intermediate calculations (derivatives) for each time step *Δt*, which is currently set to around 0.1-0.5s. Applying the RK4 equations with updated altitude and velocity values each time step/iteration:

$$k1 = f(h, v) = (dh/dt,\ dv/dt) = (v,\ -F_D - F_G)/m$$
$$k2 = f(t + dt/2,\ h + k1_0 \cdot dt/2, v + k1_1 \cdot dt/2)$$
$$k3 = f(t + dt/2, h + k2_0 \cdot dt/2, v + k2_1 \cdot dt/2)$$
$$k4 = f(t + dt, h + k3_0 \cdot dt, v + k3_1 \cdot dt)$$

$$h_{next} = h + dt/6 \cdot (k1_0 + 2k2_0 + 2k3_0 + k4_0)$$
$$v_{next} = v + dt/6 \cdot (k1_0 + 2k2_1 + 2k3_1 + k4_1)$$

These h_next and v_next values contain the prediction of altitude and velocity for one time step, so to get the predicted apogee value, this process will be iterated in an outer loop until the velocity value hits zero:

$while\ v > 0:$
$h, v = rk4Step(t, h, v, flapPosition)$
$t \mathrel{+}= dt$

At the end of this loop, h will contain the apogee prediction.

5.6 Kalman Filter

A Kalman filter combines measurements from a system's sensors with predictions from the system's mathematical model to produce an estimate that is more accurate than using either of those alone. This will be essential in ensuring the integrity of the velocity and altitude data by mitigating the effects of noise from the BNO055 and BMP390 sensors, as at the speed the rocket is moving noise is expected to occur. The mathematical model equation uses the raw and noisy measurements to estimate the state of those variables with greater accuracy, and the equations can be broken down into two steps: prediction and correction. The prediction step predicts the current state of the system, i.e. the altitude and velocity values, based on the previous state and the equation of motion for the rocket. It updates the error covariance matrix, which represents how uncertain the filter is about its prediction. In the correction step, the input of new measurements from the sensors corrects the predicted state, and the error covariance matrix is adjusted based on the difference between the predicted state and the actual measurement.

1. At the first measurement, initialize system state estimate vectors of velocity and altitude, and the system state error covariance matrix P_1:

   $v_1,\ h_1,\ p_1$

2. At the second measurement and for all subsequent measurements, reinitialize these values:

   $v_2,\ h_2,\ P_2$

3. For each measurement, predict the system state and system error, where A is the state transition matrix assuming velocity directly impacts change in altitude and velocity evolves based on drag and gravity, and matrix Q represents process noise or uncertainty for the system model as it fluctuates in its accuracy. The system's actual accelerations and decelerations contribute to this error. In the following step, the vector x_p is a prediction of vector x for the current time step, and matrix P_p is the prediction of matrix P for the current time step:

   $$A = ((1,\ dt),\ (0,\ 1))$$
   $$x_p = Ax_{k-1}$$
   $$P_p = AP_{k-1}A^t + Q$$

4. Compute the Kalman Gain, where H is a state-to-measurement matrix to convert the system state estimate from the state space to the measurement space.

$$K = P_p H^T (H P_p H^T + R)^{-1}$$

5. The Kalman Filter uses the Kalman Gain to estimate the system state and error covariance matrix for the time of the input measurement. After the Kalman Gain is computed, it is used to weight the measurement appropriately in two computations. Estimate new system state and system state error covariance matrix, where z_k is a measurement vector of the sensor data containing both altitude and velocity.

$$x_k = x_p + K(z_k - H x_p)$$
$$P_k = P_p - K H P_p$$

At the end of these steps, the state vector x_k holds v_k, the updated velocity estimate, and h_k, the updated altitude estimate, and these are the values that will be returned by the filtering function. The P_k error covariance matrix will not be directly used in the control loop, but will be internally used by the Kalman filter to weigh future measurements and predictions.

6 Safety

The SOAR Safety Officer for the 2024-2025 season is Lucas Folio. The Safety Officer is primarily responsible for determining, analyzing, and categorizing all possible risks that are present throughout the competition period, as well as developing mitigation techniques that effectively reduce these risks based on initial categorizations. The general responsibilities and duties involved in analyzing these risks are, but not limited to, the following:

- Safety Handbook is updated to reflect the current criteria for the 2024-2025 period.
- General practices are enforced throughout the design and fabrication process.
- Promoting a safety-focused culture throughout all usable facilities.
- Communicating with safety in mind and being a point of reference for all.
- Documentation including Standard Operating Procedures and Safety Datasheets are updated as needed throughout the period and are made available for team members.
- Establishing a proper understanding of fabrication and facility usage throughout the period.
- Determining and classifying risks through analysis and developing mitigation techniques along with proper documentation in tables.
- Developing a Standard Launch Operating Procedure and checklist tailored for each specific competition launch.
- Ensuring full compliance with mitigation techniques through verification.
- Contributing to all Safety sections for competition documentation and milestones.
- Developing and enforcing a plan for waste disposal related to hazardous and broken materials.
- Ensuring all team members follow all Tripoli, NAR, NASA, and University safety regulations.
- Ensuring all team members follow all state, county, and local safety regulations.

6.1 Launch Concerns and Operation Procedures

6.1.1 Required Launch Personnel/Participants

For each launch, a designated team member oversees a specific aspect of vehicle assembly and integration. This applies to all launches, including the final competition launch. If a member is unavailable; a temporary replacement may be assigned, except for the Level 2 Tripoli/NAR Certified Student Mentor, who must be present for all launches. If no suitable replacement is found for other roles, the vehicle cannot be launched.

TRA Level 2 Certified Student Mentor: Enrique Hernandez-Jurado

Safety Officer: Lucas Folio

Project Lead: Alvaro Lazaro Aguilar

Payload Mechanical Lead: Adam Raynerd

Payload EE/CS Lead: Chiara DeAngelis

EE/CS Telemetry Lead: Pavan Moturi

Vehicles Mechanical Lead: Kyle Shum

Vehicles EE/CS Lead: Spencer Fritz

Ham Radio Operator: Alvaro Lazaro Aguilar (KQ4FYU)

6.1.2 Inventory Checklist

In the preparation for a launch, members will be without their usual surrounding facility and must bring all the tools and utilities that they deem necessary for the launch of the vehicle. It is the safety leads role to identify what each lead must bring for their specific subsystem and provide a checklist that all members can rely on what to bring for launches. This specific checklist has been tailored for all future launches in the 2024-2025 season that SOAR will compete in.

Table 29. Tools & Hardware Checklist

Drill & Accessories	Fasteners & Adhesives	Hand Tools	Measuring & Marking
Drill	1/4"-20 Nuts & Bolts	Channel Locks	Measuring Tape
20v Drill Batteries	Quick Links	Scissors	Calipers
Drill Bit Box	Zip Ties	Allen Keys	Level
Screwdriver Set	Super glue	Clamps	Black Sharpie
	5-Min Epoxy	Tweezer Set	Silver Sharpie (Blue)
	15-Min	Knife	Pen

6.1.2.1 Electronics & Power

Table 30. Electronics & Power Checklist

Avionics & Power Sources	Batteries
Extra Altimeters	9 Volt Batteries
Power Bank	Battery Charger/Balancer
Multimeter	Eecs Av Bay Lipos

Table 31. Rocket Assembly & Recovery Checklist

Structural Components	Parachutes	Shock cord and Nomex
Shear Pins	Drogue	Spare Shock Cord
Ballast	Backup Main	Drogue Nomex
5-min Epoxy	Backup Drogue	Main Nomex
15-min Epoxy	Main Shock Cord	Spare Nomex
JB Weld	Main Parachute	
Ejection System	**Sanding & Cleaning**	**Tapes & Protective Materials**
Black Powder	Sandpaper	Electrical Tape
Dog Barf	Paper Towels	Masking Tape
E-Matches	Denatured Alcohol	Popsicle Sticks
Switch Keys		Mixing Cups

Table 32. Safety & Utility Checklist

Miscellaneous	PPE
Trash Bags	5 MIL Nitrile Gloves
Scraper	Safety Glasses
Lighter	Respirator
Ham Radio	Hearing Protection

6.2 Draft of Final Assembly and Launch Procedures/Checklists

The Final Assembly and Launch Procedures/Checklists are laid out for each subsystem based on input gathered by the Safety Lead. As leads build out their components over the season, a standard process naturally forms. By launch day, a finalized checklist is written, reflecting the Safety Lead's observations of each team's workflow. This document is a working draft that will be finalized for the vehicle's last competition launch. Each section follows a set structure to keep it clear and functional as both a checklist and a procedure, even if team members shift—except for the Level 2 Mentor, who must always be present. Each subsystem includes: a summary of its role in the vehicle, required PPE, step-by-step procedures, critical hazards if a step is skipped, and required personnel for sign-off that the above information is true, has been meticulously followed and the completion of the subsystem as a whole. Together, these elements provide a robust framework for successful rocket assembly and launch operations.

6.2.1 Recovery Preparation

After reaching apogee, the recovery phase starts. The vehicle will rely on parachutes for a controlled landing, which must be intact, properly timed, and ejected with a clear exit path. If any of these fail, the vehicle may not land safely, risking the safety of spectators or surrounding wildlife. There is also a risk to onboard functionality and data storage. The procedure below is designed to reduce the chances of recovery failure and ensure the safety of the team assembling this subsystem.

6.2.1.1 Required PPE

- ☐ Safety Glasses
- ☐ Respirator

6.2.1.2 Procedure/Checklistfollowed,

- ☐ **Packing Order:** Pack all recovery components in the right sequence to make sure the parachutes deploy cleanly without tangling or failing mid-flight.
- ☐ **Black Powder Preparation:** Load 3.3 grams of black powder into each well, one for primary deployment at the correct altitude and a backup set to deploy at a slightly lower altitude. Each well must be controlled by a separate altimeter to prevent single-point failure.
- ☐ **E-Match Insertion:** Insert an E-match into each well and connect them to the flight altimeters (Missileworks RRC3 & Altus Metrum Telemetrum). Make sure they're seated properly and have a rigid connection with continuity.
- ☐ **Shock Cord Folding:** Fold the shock cords neatly to keep them from tangling or snagging during ejection. Double-check that all attachment points are solid, parachute to quick link, av bay to quick link, and threaded U-bolt.
- ☐ **Ejection Wadding:** Pack the wadding tight enough to keep the heat from the black powder charge off the parachutes and other recovery gear. A respirator is recommended when handling the cellulose wadding.
- ☐ **Secured Quick Links:** Ensure all quick links are properly tightened and securely fastened to the shock cords, NOMEX, and threaded U-bolts. Loose or incorrectly arranged linkages can

damage the parachutes during flight or detach entirely, creating debris, both of which can result in a failed recovery.

6.2.1.3 Required Personnel

- ☐ Payload EE/CS Lead
- ☐ Payload Mechanical Lead
- ☐ Safety Officer
- ☐ TRA Level 2 Certified Student Mentor

6.2.2 Payload Preparation

The mission of the rocket, the payload, is broken down into two sections. One electronic, which is constantly broadcasting a signal on the frequency that NASA decides during the entire flight of the vehicle, and a mechanical version, which is essentially an airbrake system.

6.2.2.1 Required PPE

- ☐ Safety Glasses
- ☐ 5 Mil Nitrile Gloves

6.2.2.2 Procedure/Checklist

- ☐ **Mechanical and Electronic Integration:** Lock down all payload components, including the HAM radio and electronics. Tighten every mechanical connection and make sure electronic components are seated and secured; any loose part can shift, disconnect, or break under flight loads.
- ☐ **HAM Radio Compliance:** Confirm with the HAM radio operator that the frequency is clear and unrestricted. The operator must verify that transmissions comply with regulations and that they are acting as both the temporary control operator and station licensee. No confirmation, no integration.
- ☐ **Radio Transmission Check:** Test the HAM radio to ensure it's transmitting correctly and being picked up by another HAM radio and an SDR as backup. If the signal isn't strong, clear, and consistent over the required range, troubleshoot before moving forward.
- ☐ **Wire Management:** Check that all wiring is fully secured and exposed along the vehicle anywhere. Loose or exposed wires can tangle, short out, or interfere with other components. It is imperative this is done before the integration steps, as later this cannot be visually inspected and any possible issues may worsen.
- ☐ **Payload Electronics Check:** Power up every electronic component and confirm they're functioning properly in the fully assembled state.
- ☐ **Payload Integration:** Install the payload, including the HAM radio and air brakes, into the rocket's body tube. It should fit tight enough to stay put but not so tight that it causes misalignment. If it moves freely, it's a problem—vibrational damage or full-on structural failure can happen mid-flight.

6.2.2.3 Required Personnel

- ☐ Payload EE/CS Lead

- ☐ Payload Mechanical Lead
- ☐ Safety Officer
- ☐ Ham Radio Operator

6.2.3 Electronics Preparation

There are two main sections for the electronics subsystem in this vehicle, which are the payload and recovery sections. These systems are supported by three distinct electronics leads, Vehicle, Payload, and Telemetry, each responsible for ensuring their respective components are fully operational and properly synchronized. These three leads have their own facets of understanding that they can lead on in the subsystem while communicating with each other in order to have a successful and reliable flight performance that can be recorded and tracked.

6.2.3.1 Required PPE

- ☐ Safety Glasses
- ☐ 5 Mil Nitrile Gloves

6.2.3.2 Procedure/Checklist

- ☐ **Fully Charged Batteries**: There are two batteries being used in the vehicle, a 3.7V LiPo and an alkaline 9V. These must be fully charged when installed, and rechecked with a multimeter before integrating with the rest of the vehicle.
- ☐ **Flight Altimeters:** Conduct all checks before installing the e-matches to eliminate the risk of accidental detonation, which could endanger personnel. Verify with the Aerostructures lead that the flight altimeters are programmed to the correct launch settings to ensure seamless integration with the planned recovery procedures and CONOPS for launch.
- ☐ **Key Switches:** Verify that the key switches are fully operational. This means ensuring the key is able to comfortably turn on the switches, with the switch remaining in the locked configuration, and continuity being measured through the switch when tested with a multimeter.
- ☐ **E-Match Installation**: Confirm the proper and secure installation of the pre-attached e-matches, ensuring they are correctly connected to their designated altimeters and charge wells to guarantee reliable ignition. Visually inspect the terminal where the e-match connects to each flight altimeter, and tug on the e-match wire to ensure it is securely in place.
- ☐ **Radio Frequency Compliance**: Ensure all frequencies being used comply with FCC regulations and avoid unauthorized bands to prevent communication issues or regulatory violations.
- ☐ **Telemetry Bay Continuity Test:** Before inserting the electronics into the vehicle, test continuity: ground terminals should be continuous, and positive terminals should not connect to ground. Inspect the wiring diagram of the system and verify all connections between components are connected. If any issues are found, notify personnel to identify and repair the fault, then repeat the checklist before proceeding while wearing required PPE.
- ☐ **Transmission Check:** Verify that data is successfully transmitted for a period of two minutes by the Telemetry Bay to the Ground Station, with all components of the Telemetry Bay

functioning as planned. If a discrepancy is found, the team has a maximum of 1 hour to conduct minor software adjustments to maximize the system functionality. If the team fails to do this, then the Telemetry Bay is turned off and serves as ballast during the launch. This prevents delays from debugging the system from affecting the launch preparation time.

6.2.3.3 Required Personnel

- ☐ Payload EE/CS Lead
- ☐ Telemetry EE/CS Lead
- ☐ Vehicles EE/CS Lead
- ☐ Safety Officer
- ☐ TRA Level 2 Certified Student Mentor

6.2.4 Rocket Preparation

In order for the launch vehicle to be fully operable, it must properly secure and integrate all subsystems together to ensure a successful and safe flight. Flight characteristics such as target apogee, coefficient of drag, and weight must all be taken into account when designing any system and distributing the weight across the vehicle. Missing steps such as installed shear pins, improper payload insertion, defective black powder charges, failure to test for movement, etc. can lead to catastrophic consequences, including compromised flight performance, vehicle damage, and risks to personnel. To minimize these risks, the team has standardized multiple procedures and guidelines when preparing the rocket for launch day operations.

6.2.4.1 Required PPE

- ☐ Safety Glasses
- ☐ 5 Mil Nitrile Gloves

6.2.4.2 Procedure/Checklist

- ☐ **Separation Capability:** Confirm the booster and upper body tube can separate as intended during flight.
- ☐ **Shear Pins:** Verify that shear pins are correctly placed, secure, and tested to ensure reliable separation (black powder test conducted with the same pins).
- ☐ **Payload Installation:** Ensure the payload is properly inserted and secured.
- ☐ **Recovery System:** Confirm that black powder charges are properly fitted and all fitted are operational.
- ☐ **Mark Critical Points:** Verify the center of pressure (CP) and center of gravity (CG) are marked clearly.
- ☐ **Center of Gravity Validation:** Ensure the CG matches the software predictions and preflight calculations.
- ☐ **Airframe Fitment:** Check that all sections of the airframe are flush and properly aligned.
- ☐ **Motor Accommodation:** Confirm there is an open space for the desired motor installation.
- ☐ **Final Securing Test:** Perform a jolt test by moving the rocket up and down, checking for any audible shifting or vibrations. If movement is detected, notify the necessary personnel, disassemble the rocket, and test each section individually to locate the loose component(s).

Involve relevant leads if their components require adjustments. After resolving the issue, repeat the checklist with the appropriate PPE.

6.2.4.3 Required Personnel

- ☐ Vehicles Mechanical Lead
- ☐ Vehicles EE/CS Lead
- ☐ Safety Officer

6.2.5 Motor Preparation

The motor preparation process is one of the most critical phases of rocket assembly, directly impacting the vehicle's stability, recovery, and safety during flight. Ensuring the motor is compatible with the calculations and software and properly fitted within the motor tube is essential to prevent instability and ensure reliable performance. Any discrepancies in motor selection, improper fitment, or malfunctioning components could result in catastrophic failure, such as loss of control during flight or improper recovery system deployment.

The aft closure, retainer ring, and proper installation of the igniter all play significant roles in ensuring the motor performs as expected under flight conditions. Any failure in these steps—such as an incorrect motor, insecure casing, or a poorly installed igniter—could result in the rocket malfunctioning during ascent or recovery, posing serious risks to both the vehicle and surrounding personnel. This highlights the importance of thorough checks at each step of the process, with the necessary personnel overseeing the procedure to guarantee that every component is secure, aligned, and functional.

6.2.5.1 Required PPE

- ☐ Safety Glasses
- ☐ 5 Mil Nitrile Gloves

6.2.5.2 Procedure/Checklist

- ☐ **Motor Compatibility**: Verify that the motor corresponds with the software and calculations to ensure proper functionality.
- ☐ **Motor and Casing Fit**: Confirm that the motor and motor casing fit securely inside the motor tube without excess lateral movement.
- ☐ **Aft Closure Check**: Inspect the aft closure of the motor casing to confirm the motor is fully enclosed within the housing and forward motion of the casing relative to the motor tube is prevented.
- ☐ **Retainer Ring Installation**: Ensure the retainer ring is firmly mounted to the booster tube and effectively restricts forward movement of the motor casing.
- ☐ **Motion and Fit Test**: Rapidly jolt the booster tube to verify that the motor casing and motor remain stationary with no audible shifting, indicating proper fitting of both the retainer ring and motor casing to the airframe.
- ☐ **Igniter Installation:** Use the designated igniter from the motor kit to ensure proper deployment. Install the igniter only at the launch pad. Ground its ends on discharged metal

surface and secure it to the rocket with masking tape, avoiding contact with metallic components.

6.2.5.3 Warnings Of Hazards as a Result of Missing a Step

If a motor other than the one specified in the calculations is used, issues such as instability due to differences in weight, which can lead to an unsafe and unstable flight, may arise. To prevent a motor compatibility issue, only the motor approved during the Preliminary Design Review (PDR) and officially certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), or the Canadian Association of Rocketry (CAR) should be utilized. Proper documentation and compliance with these standards ensure both safety and adherence to regulatory guidelines.

For motor fitment and integration, the motor casing must remain secure without any lateral, forward, or aft movement. Additionally, there must be no free movement between the casing and the motor tube or between the motor and its casing. Signs of improper fitment, such as weight shifts during the jolt test or audible rattling, indicate a failure in assembly. In such cases, the entire motor assembly must be disassembled and rechecked using the aforementioned checklist under the supervision of a designated Level 2 Certified Student Mentor.

6.2.5.4 Required Personnel

- ☐ Vehicles Mechanical Lead
- ☐ Safety Officer
- ☐ TRA Level 2 Certified Student Mentor

6.2.6 Launch Pad Preparation and Igniter Installation

Proper launch pad preparation and igniter installation are critical to ensuring a successful launch. Securing the igniter, ensuring correct alignment, and confirming continuity are essential for reliable ignition of the rocket's motor. Additionally, ensuring that the launch rod is positioned correctly, the wind conditions are within safe limits, and the retainer ring has proper clearance will guarantee that the rocket can lift off smoothly and safely. Any failure to follow these steps could result in an incomplete motor burn, hindering the rocket's ability to launch or even causing a catastrophic failure. Thorough checks, including verifying continuity and proper fit, must be conducted to ensure the vehicle is ready for safe ignition and flight.

6.2.6.1 Required PPE

- ☐ Safety Glasses
- ☐ 5 Mil Nitrile Gloves

6.2.6.2 Procedure/Checklist

- ☐ **Corroded Clips:** Sand any corroded clips to ensure proper connectivity.
- ☐ **Launch Rod Alignment:** Angle the launch rod based on wind direction and the flight path of previous rockets.
- ☐ **Rail Guides Test:** Test the rail guides to ensure they move freely along the rail.
- ☐ **Wind Speed Measurement:** Measure the wind speed using an anemometer to ensure it is within safe launch limits.

- ☐ **Altimeter Continuity Check:** Turn on the altimeter and verify the correct number of "beeps" indicating continuity with the drogue, main black powder wells, and redundancy well.
- ☐ **Payload Functionality Check:** Recheck the payload functionality using a secondary communication method, such as a ham radio.
- ☐ **Retainer Ring Clearance:** Ensure the retainer ring is not in contact with the launch pad and has adequate room for the nozzle to "breathe."
- ☐ **Igniter Installation:** Insert the igniter fully into the motor until it makes contact with the forwardmost section of the motor, then secure it in place with masking tape on the rocket body and the provided motor cap from the kit, ensuring the igniter remains fixed in place.
- ☐ **Alligator Clip Connection:** Connect the alligator clips (which should be clean and corrosion-free) to the igniter and verify continuity using the provided launch control system, which will show continuity by illuminating a light corresponding to the launch pad.

6.2.6.3 Warnings Of Hazards as a Result of Missing a Step

If the retainer ring is in contact with the pad plate, it will restrict airflow and prevent the nozzle from receiving sufficient oxygen. This can lead to incomplete combustion, causing the motor to fail to generate enough thrust to lift the rocket off the pad, potentially resulting in a failed launch.

6.2.6.4 Required Personnel

- ☐ Safety Officer

6.2.7 Launch Procedure

The team isn't allowed to physically handle the vehicle during the launch procedure; however, they must follow all rules set by the launch site and the landowner. This includes listening to local personnel, the launch committee, and any other relevant authorities. This ensures everyone on-site is aware of the rocket’s status and its location is tracked throughout the flight.

6.2.7.1 Required PPE

- ☐ Safety Glasses
- ☐ 5 Mil Nitrile Gloves

6.2.7.2 Procedure/Checklist

- ☐ **RSO and LSO Preparedness:** Ensure that the Range Safety Officer (RSO) and Launch Safety Officer (LSO) have the launch card and all relevant information about the Student Mentor for the launch.
- ☐ **Environmental Conditions:** Verify clear skies for launch, ensuring no aircraft, birds, other rockets, or environmental factors (e.g., wind, lightning) pose a threat to the safety of the launch.
- ☐ **PA & Tracking:** If a Public Address (PA) system is in use, ensure the LSO counts down the launch, and at least two club members track the rocket’s flight path, events, parachute deployments, and shock cord condition. Confirm that no unintended rapid, unscheduled separations occur during flight.

- ☐ **Clear Launch Pad Area:** Ensure all personnel are clear from the launch pad and no one is in the immediate danger zone during ignition and flight.

6.2.7.3 Required Personnel

- ☐ Safety Officer
- ☐ TRA Level 2 Certified Student Mentor

6.2.8 Post-Flight Inspection

Once the vehicle completes its flight, the team must thoroughly inspect, record, and document all findings to determine the next steps for the vehicle. The only required PPE for the inspection is gloves, as a precaution against any frayed materials such as fiberglass in the case of cracking during landing or separation events. This, however, is unlikely if the recovery system functions as intended.

6.2.8.1 Required PPE

- ☐ Gloves

6.2.8.2 Procedure/Checklist

- ☐ **Landing Conditions Documentation:** Record the landing conditions by taking videos and photos of the surrounding environment. If the vehicle lands in trees or difficult-to-reach terrain, gather as much information as possible about the area and request assistance from the landowner or RSO. Do not attempt to retrieve the vehicle if doing so puts team members at direct risk.
- ☐ **Altimeter Beep Monitoring:** Listen for the altimeter beeps and record all relevant data for post-flight analysis.
- ☐ **Debris Inspection:** Before leaving the launch site, verify that no equipment, tools, or personal belongings are left behind at the landing zone, assembly area, or launch pad. Conduct a final sweep to ensure all debris is collected and properly disposed of.
- ☐ **Damage Assessment:** At the facilities where the vehicle is stored between launches, inspection and documentation are needed to assess what repairs need to be done and if any changes need to be put into action.

6.2.8.3 Required Personnel

- ☐ Safety Officer

6.3 Safety and Environment

Table 33. Personal Hazard Analysis

ID	Hazard	Cause	Outcome	Before	Mitigation	Verification	After
PH.1	Power and Hand Tools Injuries	Insufficient training, reckless use, lack of caution	Mild to severe cut to personnel (Possible hospitalization)	D2	Individuals will be required to complete safety training, follow protocols, and wear proper PPE	The Safety Lead / Present Lead will verify the training completion of the individual before starting operation. A log will be kept of machinery usage	D1
PH.2	Debris Inhalation	Improper PPE use presents debris in environment	Mild to severe respiratory damage	C3	Wear appropriate PPE, work in a well ventilated area, and implement a CNC vacuum system	The Safety Lead / Present Lead will verify that each individual is using the appropriate PPE	C1
PH.3	Eye Irritation	Improper PPE use presents debris in environment	Temporary to mild eye irritation	B3	Wear appropriate PPE, work in a well ventilated area, implement a CNC vacuum system, and have eye rinse stations available	The Safety Lead / Present Lead will verify that each individual is using the appropriate PPE. Eye rinse station are available in all facilities that the team have access to and are trained on the use and location of them	B1

PH.4	Chemical Contact	Improper handling of chemicals, resulting in spills, body contact, or inhalation	Mild to severe burns on skin, respiratory system	D3	Wear appropriate PPE and read the SDS regarding the specific chemical	The Safety Lead / Present Lead will verify that each individual is using the appropriate PPE and provide SDS of each chemical	D1
PH.5	Entanglement with construction Machines	Loose clothing, hair or accessories	Severe injury or possible death	E3	Wear appropriate PPE and secure loose clothing and accessories	The Safety Lead / Present Lead will verify the PPE and clothing of the member working with the machines.	E1
PH.6	Unexpected Machine Failure	Poor maintenance routine, incorrect use of the machine	Severe injury or possible death	E2	Perform monthly inspection of machines; have an experienced member oversee the machinery use	The Safety Lead will conduct a monthly inspection at the end of the month and ensure that no machines are used without an experienced individual	E1
PH.7	Electrocution	Improper use of electronics, working under poor conditions	Severe harm to individuals, possible explosion	D2	Have safety signs indicating hazards, ground oneself when working with high-voltage equipment, and have electronics verified before use	The Safety Lead / Present Lead will provide safety signs and assign a member to verify electronic status	D1

PH.8	Epoxy Contact	Improper use of epoxy, spill	Mild skin irritation, rashes	C3	Wear appropriate PPE to reduce chances of skin contact	The Safety Lead / Present Lead will verify that each individual is wearing the appropriate PPE and ensure all members are aware of the risks	C2
PH.9	Hearing Damage	Proximity to loud noises	Short- to long-term hearing loss	D4	Wear appropriate PPE and increase distance from noise source	The Safety Lead / Present Lead will verify that each member is wearing the appropriate PPE	D1
PH.10	Premature ignition of explosive materials (solid motor, black powder)	Mechanical shock, electrostatic discharge, contamination, and improper storage	Mild to severe injuries, burns, and possible death	D3	Motors and black powder will be kept in a firebox away from heat sources and work under the supervision of safety officer	The Safety Lead will verify the storage of the explosive materials and oversee work operations	D1
PH.11	Personnel Fatigue	Prolonged manufacturing shifts or tight deadlines	Reduced concentration, errors, and accidents	B3	Schedule regular breaks and limit work hours, follow a schedule to delegate work through the semester	Team Leads will ensure that team members do not work for prolonged times	B1
PH.12	Injury from Ballistic Trajectory	Parachute deployment failure	Severe injury, death	E2	Maintain eye contact with the launch vehicle at all times	Team will be aware of the high hazard of a ballistic trajectory	E1

PH.13	Spray Paint Inhalation	Improper PPE	Short- to long-term irritation to eyes, nose, throat, respiratory system, nausea, vomiting, and dizziness	C2	Seek a professional to paint the rocket with proper PPE and tools and will paint in a room with sufficient ventilation.	The Safety Lead ensures a professional that will follow all safety standards will paint the rocket competently	C1

Table 34. Failure Modes and Effects Analysis

ID	Hazard	Cause	Outcome	Before	Mitigation	Verification	After
FM.1	Igniter Failure	Mechanical or electrical failure	Motor is not ignited, launch vehicle does not leave launch pad	A2	Electronic match will be replaced, and launch vehicle will be inspected	Check for continuity in prior to launch	A1
FM.2	Motor Expulsion	Weak or improper retention mechanism	Falling debris, low apogee, destruction of booster section	E2	Design the motor assembly with a factor of safety of 2	Simulations and FEA will be done to validate the design	E1
FM.3	Motor Explosion	Improper motor set-up, faulty material	Severe damage to the motor airframe, inability to fly	E2	Closely inspect motors; buy from trusted vendors	Create a procedure to follow when setting up the motor	E1
FM.4	Unstable Launch Vehicle	Improper calculations, incorrect ballast weight	Unstable and unpredictable trajectory, possible recovery failure	C2	Parts will be constantly weighted during the rocket construction; apply calculation redundancy	Aerostructures lead will verify and update open rocket model with collected data	C1

FM.5	Battery Failure	Improper run time calculations, empty battery, low battery	Parachutes will not deploy, ballistic trajectory, complete loss of rocket	E2	New working batteries will be used each launch; calculations will be made to ensure batteries last for at least 3 hours, in compliance with requirements	Matlab script will be used to verify system run time, batteries will be marked after each launch	E1
FM.6	Altimeter Failure	Loose cables, low battery,	Parachutes will not deploy, ballistic trajectory, complete loss of rocket	E2	Redundancy used by having 2 separate but equal altimeter systems to ensure that there is continuity before each launch	Payload EE/CS Lead will verify electronics status and run continuity tests on all systems.	E1
FM.7	Premature Stage Separation	Weak shear-pins, misprogrammed altimeters	Rocket will separate before apogee, launch vehicle separation at high velocity, low apogee, possible recovery failure	D2	Perform black powder test for stage separation, run redundant calculations for shear pins	MATLAB and by hand calculations will be done to verify the controlled detonation	D1
FM.8	Stage Separation Failure	Improper calculations, tight fit, strong shear-pins	No parachute deployment, complete loss of rocket, ballistic trajectory	E2	Perfoseparation andowder test for stage separation, run redundant calculations for shear pins	MATLAB and by hand calculations will be done to verify the controlled detonation	E1
FM.9	Parachute Failure	Loosely attached parachutes, weak shock cord, faulty parachutes	Complete loss of rocket, Ballistic trajectory	E2	Inspect parachute for imperfections; use rated parts for the recovery assembly	The recovery lead will inspect parachutes and its proper connections	E1

FM.10	Payload Ejection Failure	Deployment mechanism failure, lack of testing, improper calculations	No payload ejection, inability to demonstrate payload, possible payload damage during landing	E2	Rigorous testing; implement emergency recovery system if failure	Payload lead will verify the effectiveness of an emergency recovery system	E1
FM.11	Early Payload Ejection	Loose payload locking mechanism,	Possible uncontrollable descent	E2	Rigorous testing of retention system	Payload lead will verify that the retention mechanism is strong enough to keep the payload in place	E1
FM.12	Payload Flight Failure	Tumbling, payload motor failure, battery failure, unstable flight	Complete loss of payload, uncontrollable descent, free-falling body	D2	Rigorous testing, emergency recovery system if failure	Payload lead will verify the effectiveness of an emergency recovery system	D1
FM.13	Low battery	Usage of incorrect batteries, improper calculations	Possible altimeter failure, possible payload failure, possible parachute deployment failure	E2	Only new batteries will be used for flights; used batteries will be labeled	The present lead will verify the label of the battery.	E1
FM.14	Bulkhead Failure	Improper calculations, lack of testing, low-quality material	Complete separation of bodies, uncontrollable descent, falling debris	E2	Tensile test will be done on couplers and avionics bays; only buy material from trusted vendors	Lead will verify the strength of the Bulk Plate with a factor of safety of 3	E1

FM.15	Fin Damage	High descent velocity, poor material choice, lack of testing	Mid to severe fin damage, replacement required	E2	Fins will be designed to endure high impact; only buy material from trusted vendors	Lead will verify the strength of the fins and calculate for the estimated ground velocity	E1
FM.16	Fin Failure	Improper attachment, poor material choice, lack of testing	Unstable flight, low apogee, possible ballistic trajectory	E2	Ensure that the fin assembly is strong enough to endure the acceleration and drag forces	Stress test and simulations will be done to validate design	E1
FM.17	Incorrect mass assumptions	Human error, improper calculations, faulty weight	Unstable flight, low apogee, possible ballistic trajectory	D2	Have two people conduct the same calculations looking for redundancy	Have a spreadsheet with both calculation results and the name of the author	D1
FM.18	Avionics Human Error	Improper altimeter usage, loose cables, improper electronic connections	Parachute failure, ballistic trajectory	E3	Have multiple checklists to minimize human error	Have multiple people go through the checklist and inspect the avionics system	E1
FM.19	Main Parachute Deployment Failure	Loosely attached parachutes, weak shock cord, faulty parachutes	Descent at a high velocity, severe damage to rocket, possible complete loss, KE impact hazard	E2	Inspect parachute for imperfections; use rated parts for the recovery assembly	The recovery lead will inspect parachutes and its proper connections	E1

FM.20	Drogue Parachute Deployment Failure	Loosely attached parachutes, weak shock cord, faulty parachutes	Possible destruction of bulk plates, increased impulse and force on rocket during main deployment, risk of complete recovery failure	E2	Inspect parachute for imperfections; use rated parts for the recovery assembly	lead will inspect parachutes and its proper connections	E1
FM.21	Tangled Parachute	Parachute misfolded in launch vehicle, human error	Parachute will not deploy, rocket will fall at high velocity, KE impact hazard	E2	Parachute will be carefully placed inside the launch vehicle and inspected before launch	Aerostructures lead will confirm proper placement before launch	E1
FM.22	Shock Cord Failure	Improper calculations, lack of testing, low-quality material	Parachute loss, possible recovery failure, high-speed descent, possible ballistic trajectory	E2	Cords will be carefully chosen based on specifications by manufacturer; only used shock cords rated for the experienced forces	Aerostructures lead will confirm calculations and perform various tests	E1
FM.23	GPS Failure	Battery failure, human error, improper calculations	Possible loss of rocket, recovery time after landing significantly increased	C2	New batteries will be used during each launch. run a checklist minimizing human error	Batteries will be marked after each launch, calculations will be verified, and vigorous testing will be performed on GPS system	C1

FM.24	Excessive Landing Speed	Wrong mass calculations, improper parachute choice	KE impact hazard, mid- to severe damage to launch vehicle airframe	E2	Verify final velocity through the use of MATLAB and Open Rocket; only parachutes with a given drag coefficient will be used	Calculations will be carefully verified and checked by multiple parachutes, which will be chosen as per manufacturer specifications	E1
FM.25	Increased mass during construction	Unconsidered extra weights	Inability to reach target apogee	B3	Launch vehicle will be weighted through the entire manufacturing phase; input recorded mass into Open Rocket software	Aerostructures lead will verify the continuing weighting of the rocket parts	B2

Table 35. Vehicle Effects on Environment

ID	Hazard	Cause	Outcome	Before	Mitigation	Verification	After
VE.1	Vehicle Affecting Wildlife	A bird or a group of birds fly into launch vehicle's trajectory	Launch vehicle kills the bird and potentially crashes into the ground if the impact caused any internal stress resulting in parachute deployment failure	C2	Decrease variance of vehicle path through an increase in stability and observe flight paths of birds in the surrounding area	Safety lead ensures that members are cautious and will avoid any disturbances to local wildlife	C1
VE.2	High-Speed Collision into Terrain	Failure of recovery system	Minor to average damages to terrain, vegetation, and fauna. Severe damage to the	B3	Ensure that the recovery system's parachutes are appropriate for the weight of the rocket	Redundant calculations will be made for the purpose of calculating the velocity on landing is within safe margin	B1

			launch vehicle.				
VE.3	High-speed collision into a Building or home	Failure of recovery system	Potentially major damage to nearby homes, businesses, and other buildings	D2	Ensure that the vehicle is launched far from residential areas or high-density urban areas.	Speak with launch coordinators for the launch site	D1
VE.4	Launch vehicle hits car	Failure of recovery system	Potentially major damage to stationary and moving cars, thus also creating the possibility of harming the driver and causing bystanders to be injured as well	E2	Ensure that the recovery system's parachutes are appropriate for the weight of the rocket and all vehicles are far away from launch site	The safety officer communicates with team members and takes responsibility of their belongings	E1
VE.5	High-speed collision into spectators or Team Member	Failure of recovery system	Potentially mortal wounds to NSL launch spectators or members of NSL teams	E2	Ensure that the recovery system's parachutes are appropriate for the weight of the rocket and all team members and spectators maintain eye contact with the vehicle at all times	Team members will be advised by the safety officer to be alert and keep an eye on the vehicle if the parachute fails to deploy	E1
VE.6	Motor Ignition Pollution	Improper motor storage. Poor quality motor	Potential fire on the launch pad	C4	Ensure that the launch pad is cleared from vegetation and flammable materials	Inspect launch pad before setting up the launch vehicle	C2
VE.7	CO_2 Emissions	Byproduct of all combustion engines	Decrease in air quality, which leads to negative effects on the environment and its inhabitants	B5	Using an efficient motor will decrease carbon dioxide emissions into the atmosphere	Vehicle lead will select a motor that best suits the needs of the launch vehicle and environment	A4

VE.8	Chemical and Hazardous Waste	Improper disposal of hazardous material	Contamination of soil, water, or air	D3	All members of the team are required to learn proper disposal methods of different chemicals and types of waste	All members of the team ensure that they are holding their peers accountable for the appropriate disposal methods	D1
VE.9	General Waste	Incompetency and laziness	Messy work environment, leading to poor productivity and thoughts	B3	Throw away general trash items such as water bottles, soda cans, food wrappers, or scrap paper	Team leads and team members hold each other accountable for their actions and make sure the workspace remains clean and orderly	B1
VE.10	Contamination from Paint	Improper Paint Selection	Volatile organic compounds released and possibly contaminate air, soil, and water in the surrounding environment	C4	Seek a professional to paint the rocket that will wear proper PPE and paint in a room with sufficient ventilation	Safety lead ensures a professional that will follow all safety standards will paint the rocket competently	C1

Table 36. Environment Effects on Vehicle Analysis

ID	Hazard	Cause	Outcome	Before	Mitigation	Verification	After
EV.1	Change in Flight Path	Wind Shear	Wind shear is difficult to predict and can cause the rocket to veer off the anticipated path during launch and cause an unpredictable descent after parachute deployment. In this descent, the vehicle can drift and possibly land in an unreachable area, causing the team to have a failed recovery.	E4	During test launches, the team will not launch in excessive wind conditions. During the NSL launch, the team will only launch if the weather permits a launch at the designated time; if not, it will be delayed until winds reside to an acceptable speed	The safety lead will monitor the weather at least 5 days before a launch to ensure the team has a successful launch	E2

EV.2	Water Leakage	Insufficient sealant of the launch vehicle components during assembly	A source of water (rain, dew, humid air) leaks into the launch vehicle and causes electronics to fail, adds weight to the rocket, and potentially causes other vehicle failures	C3	Team will not launch while it is raining or during any type of weather where rain, hail, lightning, or thunder is present. The safety lead will monitor the weather to ensure the team does not launch in inappropriate weather.	The safety lead will monitor the weather ahead of time. Vehicle lead competently checks rocket assembly before launch to ensure that there is no way for water to enter the rocket	C1
EV.3	Thermal Expansion	Hot temperatures	Thermal expansion can cause components of the launch vehicle to deform and expand; common effects of this are fractures in the material. This can cause systems in the vehicle to fail	C3	The vehicle≈25 °C and all components necessary for launch will be stored indoors at an appropriate temperature (≈25C). Launches will not be held when atmospheric temperatures are above 95F	Safety lead will monitor weather at least 5 days prior to a launch to ensure that the launch will not be in excessively hot temperatures and vehicle components will be stored properly	C1
EV.4	Thermal Contraction	Cold temperatures	Thermal contraction can cause components of the launch vehicle to deform and contract the material of certain vehicles, leading to potential vehicle system failure	B3	The vehicle and all parachutes necessary for launch will be stored indoors at an appropriate temperature (≈25 °C). Launches will not be held when atmospheric temperatures are below 30F	Safety lead will monitor weather at least 5 days prior to a launch to ensure that the launch will not be in excessively cold temperatures and vehicle components will be stored properly	B1

EV.5	Excessive Clouds or Fog	Cool air moving over a warm body of water (fog), high humidity in the atmosphere (clouds form)	Rocket launch rescheduled in order to preserve the safety of the rocket	C3	It will be the safety leads job to monitor the weather and reschedule the launch at a time when there will not be heavy cloud coverage or fog in the lower atmosphere	The safety lead will monitor the weather and efficiently communicate a launch reschedule with the team to prevent confusion and, most importantly, to ensure the safety of the rocket at all times	C1
EV.6	Lightning	Breakage of the mass accumulation of opposite charges in the atmosphere that are discharged in the form of lightning	Electrical components of the launch vehicle are damaged beyond use and must be replaced, along with probable body damage and motor damage	D1	It will be the safety leads responsibility to ensure the rocket is not launched during a thunderstorm	Safety will will monitor the weather and communicate with the team if there needs to be a launch reschedule due to lighting presence in the vicinity of launch	D1

EV.7	Air temperature	There are many factors that affect the air temperature, including distance from the equator, the coriolis effect, which is the root cause of air mass systems that move throughout the atmosphere, and cloud coverage that can affect the air temperature as well	Hot air results in a less dense atmosphere, creating less air resistance on the launch vehicle. In contrast, cold air results in more air resistance on the rocket.	A3	Monitor weather conditions and determine safe launching conditions and if the conditions are met. Ensure launch vehicle is able to experience range of air densities through resources such as software and calculation	Test launch vehicle and compare data to simulated data in order to determine if calculations are correct for given conditions	A1

Table 37. Project Risk Analysis

ID	Hazard	Cause	Outcome	Before	Mitigation	Verification	After
PR.1	Lack of Funding	Budget overruns, lack of planning, components too expensive	Termination of the project due to lack of budget	E3	Create a spreadsheet with all of the expected expenses for each subteam and plan through the year	Chief of Finance will oversee the proper budgeting and distribution of funding	E2

PR.2	Delayed Component Thereon	Shipping of critical components is delayed due to late request or long procedural times	Rocket will not be finished by the launch deadlines	E4	Team leads will order crucial components with several weeks in advance to address delays	Team leads will follow deadlines to order crucial parts	E1
PR.3	Lack of Leadership	Team lead'sThe team are not properly leading their respective team	Team will lack direction and produce low-quality, poor work	E3	Team leads will communicate with their team members to ensure a collaborative environment	Team leads will meet to discuss issues and leadership improvement	E2
PR.4	Inactivity	Members lose interest in the club	Leads overwork in order to compensate for the lack of members, poor, low quality work	D4	Team leads will host social meetings, where the team members will be able to form stronger bonds with each other	The club board will verify that member retention is a priority	D2
PR.5	Test Launch Cancellation	Launch site decides to cancel a launch event	Team is no longer able to launch at local launch site	D3	Have launch sites alternatives, and verify the status of the launch site every day 2 weeks prior to launch	The safety lead will be in charge of making a plan of contingency if the launch event is canceled	D2

PR.6	Crucial components incapacitate	Lack of proper storage, careless use of materials	The team has to order a new part and look for a replacement	D2	Have proper storage places to store important components	Leads will make the team aware of the importance of the parts and effects if lost or damaged	D1
PR.7	Interteam Miscommun ication	Subsystems are not scheduled to meet together regularly	A rocket with conflicting designs	D3	Have leads attend other subteam meetings and have a leads-only meeting to ensure that design is compatible	The club board will verify that proper communication exists between teams	D1
PR.8	Broken Manufacturi ng Machines	Improper use of machinery, lack of maintenance	Team has to look for another place to manufacture the rocket	D2	Require members to complete safety training on machine management; have the machines up to standard and maintained.	The safety lead will ensure to give the proper training to participating members	D1
PR.9	Academic Prioritizatio n	Improper time management	Little to no time to work on the project, leading to poor quality work and safety oversights	C4	Have multiple leads and members, so workload is spread amongst more people, thus reducing the necessary amount of extracurricular work	The club board will ensure that no team is overworking and being academically affected, either through stable communication with struggling students and praising a good work ethic.	C1

Table 38. Project Risk Analysis by team

7 Project Plan

7.1 Testing

Table 39. Required Vehicle Tests

ID	Title	Scheduled	Result
Vehicle Testing			
VRT-1	Subscale integration test	December	Complete
VRT-2	Subscale Demonstration Flight	December	Complete
VRT-3	Fullscale integration test	January	Incomplete
VRT-4	Bulkhead 3-point bending test	January	Incomplete
VRT-5	Stringer tensile strength test	January	Incomplete
VRT-6	Snap force simulation	January	Incomplete
VRT-7	Epoxy bonding test	February	Incomplete
VRT-8	Vehicle Demonstration Flight	February	Incomplete
Recovery Testing			
RRT-1	Subscale black powder test	December	Complete
RRT-2	Subscale parachute unfolding test	December	Complete
RRT-3	Telemetry Range Test on Reyax RYLR998	December	Unsuccessful
RRT-4	Flight Altimeter Battery Operation Test	January	Incomplete
RRT-5	Telemetry Bay Battery Operation Test	January	Incomplete
RRT-6	Telemetry Range Test on Digi XBee	January	Incomplete
RRT-7	Telemetry Motion Test on Digi XBee	January	Incomplete
RRT-8	Recovery Electronics Fit Test	January	Incomplete
RRT-9	Full Scale black powder test	February	Incomplete
RRT-10	Full Scale parachute unfolding test	February	Incomplete
RRT-11	E-match ignition test	February	Incomplete
Payload Testing			
PAYT-1	Payload Printed Prototype	December	Complete
PAYT-2	Subscale Payload Transmission Test	December	Unsuccessful
PAYT-3	Full Scale Servo Hinge test	January	Incomplete
PAYT-4	Full integration and snap test	January	Incomplete

PAYT-5	Full Scale Transmission Test	February	Incomplete
PAYT-6	Ground Broadcast Test	February	Incomplete
PAYT-7	Power Consumption/Battery Test	February	Incomplete
PAYT-8	Sensor Test	February	Incomplete
PAYT-9	Autonomy and Full deployment	March	Incomplete
Airbrakes Testing			
ABST-1	Past Launch Data RK4 Predictions Test	January	Incomplete
ABST-2	Unity Digital Twin PID Simulation Test	January	Incomplete
ABST-3	Servo Controller Test	February	Incomplete
ABST-4	Full Scale Launch Accuracy Test	March	Incomplete

7.1.1 Vehicle Testing

7.1.1.1 Subscale Integration Test

Objective: Ensure that all systems are able to be integrated in the subscale vehicle

Testing Variable: Fitting of all systems

Success Criteria:

- The team is able to integrate the full vehicle within 2 hours
- Vehicle mass is close to the simulated projected mass
- Vehicle center of mass is close to simulated center of mass
- The test is done at least a week prior to launching

Why it is necessary: The subscale integration test is necessary to confirm that all systems fit and work together as designed. It ensures the vehicle's mass and center of mass align with simulations, reducing the risk of assembly issues or performance deviations during the actual flight.

Methodology:

- Prepare integration tools prior to the vehicle integration
- Follow each subsystem lead's instruction to integrate their own system
- Test for total mass
- Test for center of mass
- Compare results to projected data

Impact: The subscale integration test verifies system compatibility, prevents assembly issues, and builds team readiness for the full-scale rocket. Failure to pass this test may require a system re-design or modification.

Status: Complete

7.1.1.2 Subscale Demonstration Flight

Objective: Validate Fullscale design and gather data for design refinement.

Testing Variable: The success of the flight

Success Criteria:

- The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale shall not be used as the subscale model
- The subscale model shall carry an altimeter capable of recording the model's apogee altitude.
- The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.
- Proof of a successful flight shall be supplied in the CDR report.
- A video of a successful flight shall be recorded

Why it is The subscale flight validates the rocket's design and performance before committing to the full-scale build. It tests stability and recovery systems and gathers flight data to identify and resolve potential issues early.

Methodology:

- Prepare OpenRocket simulations prior to flight
- Integrate the rocket following the Vehicle Lead's instructions
- Follow the launching operations instructed by the Chief of Safety
- Launch the vehicle
- Obtain pictures of landed configuration
- Collect vehicle
- Gather data from the altimeter if possible

Impact: The subscale flight ensures the rocket design works as intended, minimizes risks of failure, and provides data to improve the fullscale rocket.

Status: Complete

7.1.1.3 Fullscale Integration Test

Objective: Ensure that all systems are able to be integrated in the subscale vehicle

Testing Variable: Fitting of all systems

Success Criteria:

- The team is able to integrate the full vehicle within 2 hours
- Vehicle mass is close to the simulated projected mass
- Vehicle center of mass is close to simulated center of mass

- The test is done at least a week prior to launching

Why it is necessary: The fullscale integration test is necessary to confirm that all systems fit and work together as designed. It ensures the vehicle's mass and center of mass align with simulations, reducing the risk of assembly issues or performance deviations during the actual flight.

Methodology:

- Prepare integration tools prior to the vehicle integration
- Follow each subsystem lead's instruction to integrate their own system
- Test for total mass
- Test for center of mass
- Compare results to projected data

Impact: The fullscale integration test verifies system compatibility and prevents assembly issues. Failure to pass this test may require a system re-design or modification.

Status: Incomplete - Projected January

7.1.1.4 Stringer Tensile Strength Test

Objective: Verify the true factor of safety of the stringer

Testing Variable: Strain of the stringer

Success Criteria:

- The stringer strain is close to the simulated values
- The stringer does not fracture or fail under the test
- The calculated factor of safety is within the allowable margins

Why it is Necessary: It is necessary to ensure the stringer can withstand expected loads during flight without failing, maintaining the rocket's structural integrity and safety margins.

Methodology:

- Prepare a stringer specimen identical to those used in the rocket.
- Mount the specimen on a tensile testing machine.
- Apply a tensile load incrementally up to the maximum expected load or until failure.
- Record strain data using a strain gauge or similar device.
- Compare measured strain and ultimate load to simulation predictions.
- Calculate the factor of safety based on test results.

Impact: The test ensures the stringer can handle expected loads, preventing structural failure during flight and validating the design's safety and reliability. Failure to pass this test would require a component redesign.

Status: Incomplete - Projected January

7.1.1.5 Bulkhead 3 Point Bending Test

Objective: Verify the bulkhead's strength and stiffness under bending loads to ensure it can withstand expected forces during flight.

Testing Variable: Deflection of the bulkhead under applied load.

Success Criteria:

- Deflection remains within the allowable limit defined by the design.
- The factor of safety meets or exceeds the design requirement.
- The bulkhead does not crack, deform permanently, or fail under the maximum expected load.

Why it is Necessary: The test is necessary to confirm the bulkhead can support loads during flight without failing, ensuring the structural integrity and safety of the rocket.

Methodology:

- Prepare a bulkhead identical to those used in the rocket.
- Mount the bulkhead on a test rig designed for 3-point bending.
- Apply a force at the center of the bulkhead incrementally, simulating expected in-flight bending forces.
- Measure deflection using a displacement sensor and monitor for signs of cracking or failure.
- Record the load at which failure occurs, if any, and compare with design predictions.

Impact: The test validates the bulkhead's ability to handle bending loads, reducing the risk of structural failure during flight and increasing confidence in the rocket's overall performance.

Status: Incomplete - Projected January

7.1.1.6 Epoxy Bonding Test

Objective: Evaluate the strength of different epoxy bonding techniques under tensile and bending loads to determine the most effective method for fin attachment.

Testing Variable: strength of the bonding samples

Success Criteria:

- Bonded samples withstand the maximum expected tensile and bending loads without failure.
- Bonds show no visible cracks, separation, or delamination after testing.
- The selected epoxy technique demonstrates consistent and repeatable strength.

Why it is Necessary: This test ensures the epoxy bonds used for fin attachment can handle flight stresses without failure, maintaining the rocket's aerodynamic stability and structural integrity.

Methodology:

- Prepare test samples by bonding small pieces of the same materials used for the fins and rocket body using different epoxy techniques.
- Allow the epoxy to cure according to the manufacturer's recommendations.
- Perform tensile tests by applying a controlled force to pull the samples apart. Record the force at which the bond fails.
- Perform bending tests by applying a load at the center of the sample while supported at both ends. Record the force and observe any bond failure.
- Analyze the failure modes to identify the strongest and most reliable bonding technique.

Impact: The test ensures that the selected epoxy bonding technique provides sufficient strength for fin attachment, reducing the risk of in-flight failure and improving the rocket's overall reliability and performance. These results additionally guarantee that the vehicle can move forward with the current technique of epoxy bonding without needing to redesign segments of the vehicle or payload.

Status: Incomplete - Projected January

7.1.1.7 Snap Force Simulation

Objective: Verify that all internal components remain securely in place during the sudden deceleration caused by main parachute deployment.

Testing Variable: Movement or displacement of internal components.

Success Criteria:

- All internal components remain in their intended positions without significant displacement.
- No visible damage or loosening of components or fasteners.

Why it is Necessary: This test ensures the internal components are properly secured to withstand sudden forces during deployment, preventing damage or malfunction of critical systems.

Methodology:

- Assemble the rocket section with all internal components secured as designed.
- Attach the shock cord to a test rig and drop the system from a predetermined height.
- Inspect all internal components after the test for any movement, displacement, or damage.
- Repeat the test as needed to simulate worst-case deployment forces.

Impact: The test ensures the reliability and safety of the internal systems, reducing the risk of in-flight failures or recovery issues due to displaced components.

Status: Incomplete - Projected February

7.1.1.8 Vehicle Demonstration Flight

Objective: Ensure the full-scale rocket flies and recovers as designed, verifying stability, structure, and recovery systems.

Testing Variable: Flight and recovery success of launch vehicle

Success Criteria:

- The vehicle apogee shall be within 4000 and 6000 ft
- The vehicle's decent time shall be less than 90 seconds
- The vehicle's kinetic energy shall be less than 75 ft-lbf.
- The vehicle off-rail velocity shall be more than 52 ft/s
- The vehicle stability shall be greater than 2 cal

Why it is necessary: It's necessary to confirm that all systems function correctly under flight conditions, ensuring the rocket performs as expected during the competition launch and minimizing the risk of failure.

Methodology:

- Prepare OpenRocket simulations prior to flight
- Integrate the rocket following the Vehicle Lead's instructions
- Follow the launching operations instructed by the Chief of Safety
- Launch the vehicle
- Obtain pictures of landed configuration
- Collect vehicle
- Gather data from the altimeter if possible

Impact: The vehicle demonstration flight is a pivoting test that determines the readiness of the vehicle design. It is a flight test before the competition flight.

Status: Incomplete - Projected February

7.1.2 Recovery Testing

7.1.2.1 Subscale Black Powder Test

Objective: Verify the effectiveness of the black powder charge in generating sufficient pressure to break the shear pins and achieve proper separation of the subscale rocket

Testing Variable: separation distance and speed of the rocket sections.

Success Criteria:

- All shear pins break as intended, allowing the sections to separate cleanly.
- No damage occurs to the airframe or internal components.
- Separation is consistent with expected performance.

Why it is Necessary: This test ensures the black powder charge is correctly sized and configured to achieve reliable section separation during flight, preventing recovery system failure.

Methodology:

- Assemble the rocket sections with shear pins and install the black powder charge in the designated location.
- Set up a safe test area and secure the rocket in place to prevent unintended movement.
- Ignite the black powder charge remotely and record the separation event using high-speed cameras or sensors.
- Inspect the rocket sections and shear pin locations for any unexpected damage or irregularities.
- Repeat the test with varying charge sizes if necessary to determine the optimal configuration.

Impact: The test ensures that the separation mechanism will function during flight, reducing the risk of recovery failure and ensuring the rocket's safe descent and landing.

Status: Complete

7.1.2.2 Subscale Parachute Unfolding Test

Objective: Verify the parachutes' ability to deploy and unfold correctly when exposed to freefall conditions, ensuring reliable deployment during the actual flight of the subscale rocket.

Testing Variable: Parachute deployment and unfolding speed and completeness.

Success Criteria:

- Parachutes fully unfold without tangling or obstruction.
- Deployment occurs within the expected time frame after release.
- No damage to the parachute fabric or components during unfolding.

Why it is necessary: This test ensures the parachute system will deploy and function correctly during descent, preventing failure in the recovery phase and ensuring safe landing. It ensures correct use of parachute folding techniques.

Methodology:

- Secure the parachute to the test object (a model or section of the rocket) and ensure it's properly packed.
- Drop the object from a predetermined height to simulate freefall conditions.
- Observe the parachute's unfolding process, checking for any issues such as tangling or delayed deployment.
- Record the deployment time and observe the parachute's stability once fully opened.
- Repeat the test with multiple drops to confirm consistent performance.

Impact: The test ensures the parachute system will function as expected during flight, reducing the risk of recovery failure and ensuring the rocket returns safely.

Status: Complete

7.1.2.3 Telemetry Range Test on Reyax RYLR998

Objective: Identify the range that a signal transmitted by the Reyax RYLR998 transceiver on the 902-928 MHz frequency band can be received by a receiver operating another Reyax RYLR998 transceiver on the 902-928 MHz band.

Testing Variable: Quantitative measurement of range that a signal is received from the transmitter.

Success Criteria:

- A signal is transmitted and received at a range of 6,000 feet or farther. This range allows for data to be received at the maximum apogee that is allowable in Student Launch.
- Data is received by the receiving system without corrupted data.
- Data is received by the receiver at predictable intervals without interruption.

Why it is necessary: Determines if telemetry data will transmit between the Telemetry Bay and Ground Station during flight.

Methodology:

- Design a prototype system that transmits data with the Reyax RYLR998 on the 902-928 MHz band.
- Design a prototype system that receives the data (with a Reyax RYLR998 on the 902-928 MHz band) from the transmitting system.
- Keep the receiving system stationary and the transmitting system being the one that is moved to farther ranges. Start with the two systems next to each other. Then, move the receiving system to a further range where line-of-sight is maintained with the transmitting system. Increments can be varied, as long as line-of-sight is maintained. This is because the Reyax RYLR998 is a LoRa device, where line-of-sight between the communicating devices yields optimal performance. This is replicable of launch day conditions, where line-of-sight is maintained between the rocket and ground receivers.
- Keep moving the transmitting system farther and farther until data is no longer received by the receiving system. Then increase or decrease distance to narrow down the maximum range.

Impact: If the Reyax RYLR998 transceiver is incapable of transmitting data at the desired range, then a different transceiver must be chosen to facilitate communications between the Telemetry Bay and the Ground Station during flight.

Status: Unsuccessful

Results:

Due to the lack of robustness of the transmitting system prototype, it was kept stationary to prevent damage, and the receiving system was in motion for the test. This is still generalizable to flight conditions because the transmission and receiving of data between transceivers is reciprocal, regardless of which device is operating as a transmitter or receiver.

Testing determined the effective range to be near 1900 feet, far below the desired operating range of 6000 feet. While traveling to farther ranges to take measurements, the team kept the receiver operating. Observations were made that the receiver did not receive data while in motion. When the team stopped to take distance measurements, varied intervals from 15 seconds to 1 minute were observed until data was received. The Reyax RYLR998 operates with the LoRa protocol and calls for line-of-sight whenever possible between the transmitting LoRa device and the receiving. Despite efforts to maintain line-of-sight in the field during the test, data reception was intermittent and varied. After reaching a distance of approximately 1900 feet from the transmitting system, data was no longer received at all. Overall, the test did not meet the success criteria and instead brought a new problem to light: the transceiver is not operable when in motion.

This test resulted in identifying that the Reyax RYLR998 transceiver operating on the 902-928 MHz band is not capable of transmitting at the desired range of 6000 feet and that it is unlikely to be capable of transmitting data during flight. This means the team needs to identify, test, and integrate a different transceiver that is capable of meeting the desired range and operating in motion.

7.1.2.4 Flight Altimeter Battery Operation Test

Objective: Verify that the altimeter's battery can sustain a minimum of 3 hours of operation while on the launch pad before the rocket takes off.

Testing Variable: Battery run time of the altimeter.

Success Criteria:

- The altimeter remains functional for at least 3 hours on the launch pad without battery failure.
- The altimeter continues to provide accurate readings throughout the pre-launch period.
- There are no issues with battery life, data transmission, or device performance during the 3-hour test.

Why it is Necessary: This test ensures that the altimeter will remain operational during the pre-launch period.

Methodology:

- Fully charge or replace the altimeter's battery before the test.
- Power on the altimeter and simulate normal operational conditions while the rocket is on the launch pad.
- Continuously monitor the altimeter's performance, checking for data transmission, battery status, and system accuracy.
- Allow the altimeter to run for a minimum of 3 hours while the rocket is stationary on the pad.
- Record the exact time the battery lasts and ensure there is no data loss or malfunction.

Impact: The test ensures the parachute system will function as expected during flight, reducing the risk of recovery failure and ensuring the rocket returns safely.

Status: Incomplete - Projected January

7.1.2.5 Telemetry Bay Battery Operation Test

Objective: Verify that the Telemetry Bay can sustain a minimum of 3 hours of operation on battery power from a 3.7V 2000 mAh LiPo battery.

Testing Variable: Telemetry Bay operation time

Success Criteria:

- All components of the Telemetry Bay are supplied with a constant amount of power that does not diminish as operation time increases.
- Battery does not show visual or audible signs of thermal runaway or decay.
- Telemetry Bay remains powered and functional for a time period of at least 3 hours.

Why it is necessary: Identifies how long a 3.7V 2000 mAh LiPo battery can power the Telemetry Bay. The 3-hour margin is to ensure the system can remain powered while on the pad for an extended period of time.

Methodology:

- Use a multimeter to verify the voltage of the 3.7V 2000 mAh LiPo battery is between 3.5V and 4.2V.
- Connect the battery to the Telemetry Bay battery terminal with a 2-pin JST-XH male connector.
- Upon battery connection, start a timer. Stop the timer once the Telemetry Bay is no longer powered. This is visually noticeable when power LEDs aboard the system are no longer on or are dimmed.

Impact: Should the test determine that the 3.7V 2000 mAh LiPo battery is insufficient to power the Telemetry Bay for a period of at least 3 hours, a different battery with a higher capacity will be used. Then, this test is conducted again with the new battery to ensure it meets the success criteria.

Status: Incomplete - Projected January

7.1.2.6 Telemetry Range Test on Digi XBee Pro S3B 900HP

Objective: Identify the range that a signal transmitted by the Digi XBee Pro S3B 900HP transceiver on the 902-928 MHz frequency band can be received by a receiver operating another Digi XBee Pro S3B 900HP transceiver on the 902-928 MHz band.

Testing Variable: Quantitative measurement of range that a signal is received from the transmitter.

Success Criteria:

- A signal is transmitted and received at a range of 6,000 feet or farther. This range allows for data to be received at the maximum apogee that is allowable in Student Launch.
- Data is received by the receiving system without corrupted data.
- Data is received by the receiver at predictable intervals without interruption.

Why it is necessary: Previous tests with the Reyax RYLR998 transceiver on the 902-928 MHz band identified that the transceiver was incapable of transmitting data at the desired range. This test identifies if the Digi XBee Pro S3B 900HP transceiver is capable of transmitting at the desired range of 6000 feet.

Methodology:

- Design a prototype system that transmits data with the Reyax RYLR998 on the 902-928 MHz band.
- Design a prototype system that receives the data (with a Reyax RYLR998 on the 902-928 MHz band) from the transmitting system.
- Keep the receiving system stationary and the transmitting system being the one that is moved to farther ranges. Start with the two systems next to each other. Then, move the receiving system further in increments of approximately 100 feet. At each increment, stop motion and check data transmission. If the signal is still being received by the receiver, then continue moving farther in 100-foot increments.
- Repeat this procedure until data is no longer received by the receiving system. Then increase/decrease the distance from the receiver to narrow down the maximum range.

Impact: If the test fails, then a different transceiver must be implemented in the Telemetry Bay to reliably transmit data and receive data.

Status: Incomplete - Projected January

7.1.2.7 Telemetry Motion Test on Digi XBee Pro S3B 900HP

Objective: Identify if the Digi XBee Pro S3B 900HP (operating on the 902-928 MHz band) transceiver is capable of transmitting and receiving data while in motion.

Testing Variable: Velocity of transmitter

Success Criteria:

- A stationary receiver is capable of receiving data from a transmitter that is in motion at a speed of 20 mph or higher. The receiver and transmitter are two separate Digi XBee Pro S3B 900HP transceiver modules. The 20 mph speed is to simulate relatively fast motion, similar to that during flight.
- The received data is not corrupted and is received at predicted intervals without interruption.
- The transmitter in motion can be in motion at speeds of 20 miles per hour or higher, and the receiving.

Why it is necessary: The Telemetry Range Test on the Reyax RYLR998 showed that the Reyax transceiver was incapable of transmitting data while in motion. This test is to identify if that is the case with the Digi XBee Pro S3B as well.

Methodology:

- Design a receiving system that utilizes the Digi XBee Pro S3B to receive data on the 902-928 MHz band.
- Design a transmitting system that utilizes the Digi XBee Pro S3B to transmit data on the 902-928 MHz band. The system must be encased in a sled that secures all loose wires and electronics to prevent becoming a hazard while in motion.
- Keep the receiving system stationary adjacent to the sidewalk of a public roadway in a manner that does not obstruct traffic flow or pedestrians.
- Have a team member (the driver) that holds a valid Florida Drivers License and documentation necessary to legally operate an automobile place the transmitting system in the passenger seat of their automobile.
- The driver drives on the roadway past the receiving system at 10 mph below the speed limit while obeying all traffic rules and not obstructing the flow of traffic. While they drive by, another team member observes the receiving system to identify if data is received and if it meets the success criteria stated above.
- If the data does meet the criteria, then the driver conducts another pass past the receiving system but at a speed that is 5 mph below the speed limit, while obeying all traffic rules, and not obstructing the flow of traffic. The process is repeated, and if the data meets the criteria, then a final pass is conducted with the automobile at the speed limit of the roadway.

Impact: If the test fails, then a different transceiver must be implemented in the Telemetry Bay to reliably transmit data and receive data.

Status: Incomplete - Projected January

7.1.2.8 Recovery Electronics Fit Test

Objective: Verify the Telemetry Bay sled and the Flight Altimeters sled fit inside their respective couplers.

Testing Variable: Space and Alignment

Success Criteria:

- The sled shall be installed without the need for multiple specialty tools.
- The sleds shall require an install time of less than 2 minutes.
- Sleds are securely mounted with no loosening or misalignment.

Why it is Necessary: This test ensures that the Telemetry Bay and the Flight Altimeters sleds can be installed properly and in a timely manner to validate mechanical interfaces.

Methodology:

- Fully assemble the Telemetry and Flight altimeter sleds with all components integrated into the rocket.

Impact: Successful integration to confirm the mechanical integrity of the sleds, reducing integration assembly time, the risk of in-flight failures and ensuring mission success.

Status: Incomplete - Projected January

7.1.2.9 Fullscale Black Powder Test

Objective: Verify the effectiveness of the black powder charge in generating sufficient pressure to break the shear pins and achieve proper separation of the fullscale rocket.

Testing Variable: Separation distance and speed of the rocket sections.

Success Criteria:

- All shear pins break as intended, allowing the sections to separate cleanly.
- No damage occurs to the airframe or internal components.
- Separation is consistent with expected performance.

Why it is Necessary: This test ensures the black powder charge is correctly sized and configured to achieve reliable section separation during flight, preventing recovery system failure.

Methodology:

- Assemble the rocket sections with shear pins and install the black powder charge in the designated location.
- Set up a safe test area and secure the rocket in place to prevent unintended movement.
- Ignite the black powder charge remotely and record the separation event using high-speed cameras or sensors.
- Inspect the rocket sections and shear pin locations for any unexpected damage or irregularities.
- Repeat the test with varying charge sizes if necessary to determine the optimal configuration.

Impact: The test ensures that the separation mechanism will function during flight, reducing the risk of recovery failure and ensuring the rocket's safe descent and landing.

Status: Incomplete - Projected February

7.1.2.10 Fullscale Parachute Unfolding Test

Objective: Verify the parachutes' ability to deploy and unfold correctly when exposed to freefall conditions, ensuring reliable deployment during the actual flight of the fullscale rocket.

Testing Variable: Parachute deployment and unfolding speed and completeness.

Success Criteria:

- Parachutes fully unfold without tangling or obstruction.
- Deployment occurs within the expected time frame after release.
- No damage to the parachute fabric or components during unfolding.

Why it is necessary: This test ensures the parachute system will deploy and function correctly during descent, preventing failure in the recovery phase and ensuring safe landing. It ensures correct use of parachute folding techniques.

Methodology:

- Secure the parachute to the test object (a model or section of the rocket) and ensure it's properly packed.
- Drop the object from a predetermined height to simulate freefall conditions.
- Observe the parachute's unfolding process, checking for any issues such as tangling or delayed deployment.
- Record the deployment time and observe the parachute's stability once fully opened.
- Repeat the test with multiple drops to confirm consistent performance.

Impact: The test ensures the parachute system will function as expected during flight, reducing the risk of recovery failure and ensuring the rocket returns safely.

Status: Incomplete - Projected February

7.1.2.11 E-match Ignition

Objective: Test the ignition reliability of e-matches from the same batch to ensure they consistently fire at the expected voltage, triggering the black powder charge to separate the rocket sections.

Testing Variable: Voltage required to ignite the e-match reliably.

Success Criteria:

- The e-matches ignite consistently at the expected voltage.
- All e-matches from the same batch function properly during testing.
- There is no failure to ignite due to voltage discrepancies.

Why it is Necessary: This test ensures that the e-matches will reliably trigger the black powder charge, initiating proper separation of the rocket sections during flight, which is critical for recovery and safety.

Methodology:

- Select multiple e-matches from the same batch used for the rocket's separation system.
- Set up a controlled test environment with a power supply to apply the specified voltage to each e-match.
- Test each e-match to confirm it ignites within the required voltage range.

- Record the voltage at which each e-match ignites and check for consistency across the batch.
- Repeat the test as needed to ensure reliable ignition.

Impact: This test ensures that the e-matches will reliably fire and trigger the black powder charges, preventing separation failures and ensuring the rocket sections separate properly during flight.

Status: Incomplete **-** Projected February

7.1.3 Payload Testing

7.1.3.1 Payload Printed Prototype

Objective: Observe Full Scale Design and begin testing

Testing Variable: Durability and Space

Success Criteria:

- The model shall be a 1:1 scale of projected payload.
- The model is able to withstand handling and dynamic loads with electronics.
- Model was able to actuate a single bay door.

Why it is Necessary: The model allows for hands-on visual payload, allowing for ease of visual problems before committing to manufacturing. Iterations can be 3D printed, allowing for fast problem solving.

Methodology:

- Basic CAD model of the proposed payload.
- Slicing and 3D printing of model
- Assembly of model
- Testing and visualizing loads on payload as well as where electronics will be.
- Iterating

Impact: This verified the stringer design was more suited for the mission and allowed movement forward on manufacturing with confidence.

Status: Complete

7.1.3.2 Subscale Payload Transmission Test

Objective: Confirm functionality of the subscale Payload broadcast system after real launch conditions

Testing Variable: APRS transmission success

Success Criteria:

- The Payload successfully transmits data after landing
- The Payload data is accurate
- No mechanical or electronic errors occur between launch and landing

Why it is Necessary: This test helps to ensure the payload electronics can handle launch conditions and serves as an overall test of postflight function in preparation for full scale launch.

Methodology:

- Install payload in subscale rocket
- Activate payload system
- Receive and verify Payload transmission after launch

Impact: This test could result in redesigning Payload connections to make them more robust or changing protocols to correct for unexpected errors.

Status: Unsuccessful

Results:

The test occurred on December 12th, 2024, and involved installing a subscale payload system set to continuously transmit calculated apogee time and height using data obtained from an IMU sensor. The system consisted of a Baofeng UV-5R ham radio, a Raspberry Pi Zero, and an IMU sensor. The PTT button on the UV-5R was controlled via a transistor by a GPIO pin on the Raspberry Pi. Successful transmissions were recorded prior to launch, but flight test failure occurred due to transmissions ceasing during burnout. Encoding and decoding using the Direwolf application was implemented without issue prior to launch, and the transistor responsible for activating the radio remained intact, indicating the failure was caused by Raspberry Pi data lines getting disconnected. To correct this, reinforcing the female connectors to the Payload's Raspberry Pi as well as better securing the payload overall is planned. Fullscale launch will include a custom PCB, which will be less prone to malfunction than wired connections.

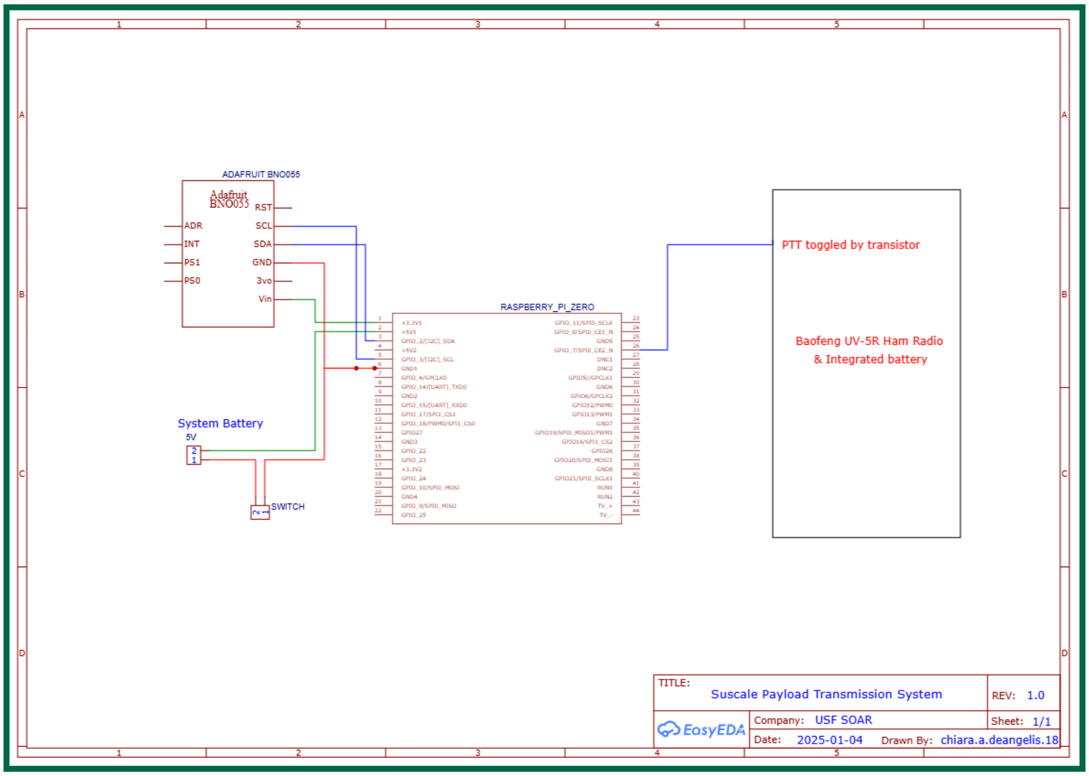


Figure 122. Subscale Payload Electronics Schematic

7.1.3.3 Fullscale Hinge Test

Objective: Observe Full Scale Design and iterate hinge

Testing Variable: Durability and operation

Success Criteria:

- The model shall be a 1:1 scale of projected payload hinge.
- The model is able to withstand handling and dynamic loads with electronics.
- Model was able to actuate a single bay door.

Why it is Necessary: The model allows for hands-on visual payload,, allowing for ease of visual problems before committing to manufacturing. Iterations can be 3D printed, allowing for fast problem solving.

Methodology:

- Basic CAD model of the proposed payload.
- Slicing and 3D printing of model
- Testing and visualizing loads on hinge.
- Iterating

Impact: This verified the hinge design is verified, suited for the mission, and allowed movement forward on manufacturing with confidence.

Status: Incomplete, projected February.

7.1.3.4 Full integration and snap test

Objective:
To verify the structural integrity and secure assembly of the payload system within the rocket, ensuring all components can withstand launch forces and operational loads.

Testing Variable:

- Fit and alignment of payload components.
- Shear and tensile forces on retention bolts.
- Structural deformation of the stringer assembly.

Success Criteria:

- Payload is securely mounted with no loosening or misalignment during simulated forces.
- Deformation within calculated limits (e.g., <0.00255 inches).
- Safety factor meets or exceeds 1.75 for retention components.

Why it is necessary:
This test ensures that the payload system can endure the dynamic forces experienced during launch and landing without structural or functional failure. It validates mechanical interfaces, retention strength, and overall system robustness.

Methodology:

- Fully assemble the payload system with all components integrated into the rocket.
- Simulate launch and landing forces using tension and compression equipment.
- Measure deformation and inspect bolts, brackets, and stringers for damage or failure.

Impact:
Successful integration and snap tests confirm the mechanical integrity of the payload system, reducing the risk of in-flight failures and ensuring mission success.

Status: Incomplete - Projected February.

7.1.3.5 Ground Broadcast Test

Objective: Ensure the payload radio system with an integrated DRA818V radio chip is capable of broadcasting data via APRS encoding with a range of at least 100 meters.

Testing Variable: Test signal reception and test signal range.

Success Criteria:

- The payload signal is received and accurately decoded.
- No irregularities or breaks in transmission are detected.
- Payload signal range meets or exceeds 100 meters.

Why it is necessary: This test ensures the Payload's core function of broadcasting environmental data after being delivered is functional and has sufficient range.

Methodology:

- Place receiver 100 meters away from the Payload and be monitoring for the Payload signal
- Activate the broadcast script.
- Record the interval and content of the broadcast, ensuring the interval is regular and the data received is accurate.
- Move the receiver 10 meters away and check broadcast accuracy. Repeat until the broadcast is not received and measure distance.

Impact: This test could result in antenna extensions to increase maximum range or revisions of the broadcast script to ensure accurate APRS encoding and transmission.

Status: Incomplete - Projected February.

7.1.3.6 Power Consumption/Battery Test

Objective: Ensure Payload batteries can supply charge for a minimum of 3 hours followed by 30 minutes of broadcasting.

Testing Variable: Battery Life of Payload.

Success Criteria:

- Payload remains active for 3 hours or more without battery failure under idle conditions.
- Payload remains active for 30 minutes or more after 3 hours of idle.
- The payload system experiences no loss of function over the course of testing.

Why it is Necessary: This test ensures battery life will not be lost while preparing for launch or during launch window.

Methodology:

- Fully charge Payload batteries
- Activate the Payload and simulate normal conditions while on the launch pad.
- Monitor and record battery voltage for the remainder of the test.
- Allow Airbrake to remain idle for 3 hours.
- Activate the broadcast script and verify the broadcast.
- Record the amount of time the battery remains in ideal voltage range.

Impact: This test could result in either increasing or decreasing battery capacity, either to ensure continuity of power or to reduce weight in the case of excess battery life.

Status: Incomplete - Projected February.

7.1.3.7 Sensor Test

Objective: Confirm the functionality and accuracy of Payload sensors.

Testing Variable: Sensor Data.

Success Criteria:

- Accurate readings of temperature, altitude, battery voltage/current, velocity, angle, and time.
- No irregularities in sensor connections.

Why it is necessary: Testing full sensor functionality is necessary to reduce errors in the final broadcast and fulfill Payload function.

Methodology:

- Record the barometer altitude reading at a known altitude.
- Continuously monitor barometer altitude while placing it at an additional known altitude.
- Record IMU velocity at standstill and ensure it reads zero velocity.
- Accelerate IMU and verify it recorded an increasing velocity followed by a decreasing velocity as it approaches standstill. Repeat at different rates of acceleration.
- Compare recorded values to known values.

Impact: This test could result in replacing or rewiring sensors or payload redesigns to ensure its structure does not interfere with sensor readings.

Status: Incomplete - Projected February.

7.1.3.8 Autonomy and Full Deployment

Objective:
To validate the autonomous functionality of the G.O.S.T. payload system, including door actuation, sensor deployment, and data transmission.

Testing Variable:

- Door actuation timing and accuracy.
- Sensor response and data collection reliability.
- Transmission of data to the ground station via APRS protocol.

Success Criteria:

- Successful autonomous deployment of bay doors within 3 seconds of landing.
- The sensor system collects accurate atmospheric data within 2% error margins.
- Complete data packets are transmitted and received without corruption.

Why it is necessary:
This test ensures the payload's critical functionalities are performed autonomously and reliably after landing, aligning with mission requirements for data collection and transmission.

Methodology:

- Conduct simulated landing scenarios to trigger the payload system.
- Monitor servo motor operation for door actuation.
- Validate sensor readings against known environmental conditions.
- Test RF communication and data integrity.

Impact:
Proves the autonomous capabilities of the payload system, ensuring that it can execute its mission objectives without manual intervention.

Status: Incomplete - Projected March

7.1.4 Airbrakes Testing

7.1.4.1 Past Launch Data RK4 Predictions Test

Objective: Verify the accuracy of RK4 loop's apogee predictions using past launch data.

Testing Variable: Expected apogee.

Success Criteria:

- Expected apogee matches the real apogee of the prior launch data.
- The RK4 loop does not create inconsistent data or data with large fluctuations (not within 20 ft. of true value)

Why it is necessary: This test ensures the RK4 loop's ability to predict current apogee, which is used to determine the drag force the airbrakes must produce at each time step of the PID loop.

Methodology:

- Download prior launch data.
- Run the RK4Incomplete—Projected loop on data in realtime.
- Record expected apogee over time and compare it to expected apogee.

Impact: This test could result in correcting the RK4 loop if its predictions do not match the apogee of the launch data.

Status: Incomplete - Projected January 15th.

7.1.4.2 Unity Digital Twin PID Simulation Test

Objective: Verify the ability of PID feedback control loop script to accurately control Air brake flap area during simulated flight conditions

Testing Variable: Simulated apogee error (achieved vs. target apogee)

Success Criteria:

- The Airbrake PID appropriately responds to simulated input altitude and velocity data, yielding a simulated apogee error of less than 20 ft. from the target

Why it is necessary: This test ensures the airbrake PID is capable of accurately changing the flap area to the right degree and when needed to successfully reach the set apogee target

Methodology:

- Start Unity Digital Twin simulation and output velocity and altitude.
- Integrate PID python programs with simulation to receive these values and output calculated flap area for every time step of 0.1s
- Monitor flap area within the simulation and verify it is being adjusted correctly

Impact: Ensuring the PID sends accurate airbrake flap area commands ensures flight stability and accomplishes the team's goal of reaching as close as possible to a target apogee.

Status: Incomplete - Projected January.

7.1.4.3 Servo Controller Test

Objective: Confirm the functionality of the servo control system.

Testing Variable: Servo Actuation and Air brake flap extension.

Success Criteria:

- The airbrake servo is accurately controlled by the servo controller and testing script to any specified input position from 0 to 100 degrees.
- The airbrake flaps are proportionally extended with the actuation of the servo to differentiable/identifiable flap areas.

Why it is necessary: This test ensures the airbrake mechanism is responding to software control and different actuation inputs and therefore is fully functional.

Methodology:

- Activate the airbrake system.
- Extend rotor flaps to maximum length in 10 increments, then retract to minimum length in 10 increments.

- Monitor rotor flaps for accurate extension and retraction.

Impact: This test could result in rewiring or replacement of the servo controller or adjustment of flap design in the case of electronic or mechanical errors.

Status: Incomplete - Projected February.

7.1.4.4 Full Scale Launch Accuracy Test

Objective: Verify the accuracy of the Airbrakes PID control system in a real-time launch

Testing Variable: Recorded apogee error (target achieved)

Success Criteria:

- Recorded apogee is within 20 ft. of target apogee
- The ABS control system iteratively runs calculations and changes flap area within allocated time steps of 0.1s without system failure
- Control system logic does not fail due to steady state or rapid oscillation error

Why it is necessary: This test ensures the ABS control system's ability to successfully control the air brake flaps and effectively reduce apogee error

Methodology:

- Software of ABS control system has been tested with simulation as much as possible, and integrated PCB is completely assembled, tested, and ready to go
- ABS logic will run for entire trajectory of launch, with the state machine correctly initiating the PID control loop when the time is right
- Record achieved apogee and compare it to target apogee

Impact: If this test is successful, the team will hopefully benefit from an achieved apogee very close to the set target in the NSL competition.

Status: Incomplete—Projected March.

7.2 Requirement Compliance

7.2.1 NASA General Requirements

Table 40. NASA General Requirements

No.	Description	Verification	Verification Description
1.1	Students on the team will do 100% of the project. Student team members shall only be part of one team in any capacity. Teams will submit new work. Excessive use of past work will merit	Inspection	Students will be responsible for completing all parts of this project. Student leaders will review designs and documents on a regular basis to ensure nothing is

	penalties.		being copied from the previous year
1.2	The team will provide and maintain a project plan to include, but not be limited to, the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	Inspection	SOAR's President, Alvaro Lazaro Aguilar, will be responsible for providing and maintaining the project plan. The Safety Officer, Lucas Folio, will be responsible for providing and maintaining risk mitigation.
1.3	Team members who will travel to the Huntsville Launch shall have fully completed registration in the NASA Gateway system before the roster deadline. Team members shall include:	Inspection	By the end of the fall semester and early spring semester, a confirmation poll will ensure registration of all members is complete prior to travel to Huntsville.
1.3.1	Students shall be actively engaged in the project throughout the entire year;	Inspection	A list of all active students working on the project will be identified and updated
1.3.2	One mentor shall be identified for the team	Inspection	The team will identify one mentor.
1.3.3	No more than two adult educators shall be identified to participate with the team	Inspection	The team will identify one or two adult educators.
1.4	Teams shall engage a minimum of 250 participants in Educational Direct Engagement STEM activities. These activities can be conducted in person or virtually. To satisfy this requirement, all events shall occur between project acceptance and the FRR addendum due date	Inspection	The team will plan a minimum of two K-12 outreach events.
1.5	The team shall establish and maintain a social media presence to inform the public about team activities	Inspection	The team will continue to utilize SOAR social media accounts, including Instagram and LinkedIn, to post about projects, updates, and events for USLI. These social media accounts will be managed by SOAR's Chief of Marketing, Emily Ho.
1.6	The team shall provide any computer equipment necessary to perform a video teleconference with the review panel.	Inspection	The team will utilize university wifi and computer equipment to perform video teleconferences.
1.7	All teams attending Launch Week shall be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5–10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day conditions.	Inspection	The launch vehicle will be launched using the provided 12-foot rail. The team will abide by the required cant specified on launch day.

1.8	Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The team mentor shall not be a student team member. The mentor shall maintain a current certification and be in good standing class through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of two flights in this or a higher impulse class prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend Launch Week in April.	Inspection	The team has identified Enrique Herndandez as the mentor. He is TRA certified and will attend the required launches.
1.9	Teams will track and report the number of hours spent working on each milestone.	Inspection	The team will utilize an hour tracking table for each milestone.
Deliverable Requirements			
1.10.1	Teams shall email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone.	Inspection	All deliverables will be completed earlier than the due date, and the student leader will make sure deliverables are submitted by the due date by email.
1.10.2	Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) will be provided action items to be completed following their review and will be required to address action items in a delta review session. After the delta session, the NASA management panel will meet to determine the teams' status in the program, and the teams will be notified shortly thereafter.	Inspection	The team will be careful to review and address any action item assigned after a milestone

1.10.3	All deliverables shall be in PDF format.	Inspection	All deliverables will be converted into PDF format prior to submission.
1.10.4	In every report, teams will provide a table of contents, including major sections and their respective subsections.	Inspection	Inspection will confirm that each deliverable contains a table of contents.

7.2.2 Launch Vehicle Requirements

Table 41. Launch Vehicle Requirements

No.	Description	Verification	Verification Description
2.1	The vehicle shall deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). Teams flying below 3,500 feet or above 6,500 feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.	Analysis, Demonstration	OpenRocket simulations will be used to calculate launch vehicle apogee. Demonstration flights will confirm that the apogee remains within the required range.
2.2	Teams shall declare their target altitude goal at the CDR milestone. The declared target altitude shall be used to determine the team's altitude score.	Inspection	The target altitude will be calculated during the development of the CDR and included within the deliverable.
2.3	The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Analysis, Test	A recovery system will ensure that the system is fully recoverable and reusable with little to no damage. The recovery systems will be tested on launch days and analyzed using OpenRocket Simulations.

2.4	The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Inspection	The launch vehicle will have three sections: booster, mid, payload, and falling nosecone.
2.4.1	Coupler,airframe shoulders that are located at in-flight separation points shall be at least two airframe diameters in length. (One body diameter of surface contact with each airframe section).	Inspection	Coupler (at in-flight separation) length will be a minimum of 12 inches when measured.
2.4.2	Coupler,airframe shoulders that are located at non-in-flight separation points shall be at least 1.5 airframe diameters in length. (0.75 body diameter of surface contact with each airframe section.)	Inspection	Coupler (at non-in-flight separation) length will be a minimum of 9 inches when measured physically.
2.4.3	Nosecone shoulders that are located at in-flight separation points shall be at least ½ body diameter in length.	Inspection	Nosecone shoulder will be a minimum length of 3 inches when measured.
2.5	The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	Demonstration	The team will practice rocket preparations prior to Launch Day to demonstrate that the vehicle can be prepared for flight within 2 hours.
2.6	The launch vehicle and payload shall be capable of remaining in launch-ready configuration on the pad for a minimum of 3 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.	Demonstration, Test	All critical on-board components will be tested to ensure that they can withstand 3 hours of delay and still perform properly.
2.7	The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system. The firing system shall be provided by the NASA-designated launch services provider.	Inspection	The vehicle will be inspected to confirm that it can launch using a standard 12V DC firing system.
2.8	The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch provider).	Inspection	External circuitry and special ground support will not be used.
2.9	Each team shall use commercially available e-matches or igniters. Hand-dipped igniters shall not be permitted.	Inspection	Inspection of the igniter will confirm that the team is using a commercially available igniter.
2.1	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP), which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association	Inspection	A Cesaroni L995 motor will be used; this can be confirmed through inspection of the motor.

	(TRA), and/or the Canadian Association of Rocketry (CAR).		
2.10.1	Final motor choice shall be declared by the Preliminary Design Review (PDR) milestone. 2025 Student Launch Handbook & Request for Proposal USLI General and Proposal Requirements	Inspection	A Cesaroni L995 motor will be used; this information will be included in the PDR.
2.10.2	Any motor change after PDR shall be approved by the NASA management team or NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment shall not be approved. A scoring adjustment against the team's overall score shall be incurred when a motor change is made after the PDR milestone. The only exception is teams switching to their secondary motor choice, provided the primary motor choice is unavailable due to a motor shortage.	Inspection	A change control request will be submitted upon the change of motor selection. Motor selection will not be changed within deliverable documents unless a change request is approved.
2.11	The launch vehicle shall be limited to a single motor propulsion system.	Inspection	The launch vehicle will be designed with a single motor propulsion system.
2.12	The total impulse provided by a College or University launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	Inspection	Inspection will confirm that the selected motor is L-class.
	Pressure vessels on the vehicle must be approved by the RSO and shall meet the following criteria:		
2.13.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1, with supporting design documentation included in all milestone reviews.	Inspection	There will be no pressure vessels onboard the vehicle.
2.13.2	Each pressure vessel shall include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	Inspection	There will be no pressure vessels onboard the vehicle.
2.13.3	The full pedigree of the tank shall be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization, depressurization, and the name of the person or entity administering each pressure event.	Inspection	There will be no pressure vessels onboard the vehicle.
2.14	The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit. A rail exit is defined at the point where the forward rail button loses contact with the rail.	Analysis	The distance between the center of Pressure and Center of Gravity will be calculated to ensure a proper margin. Rocket stability will be optimized through rocket

			design and integration.
2.15	The launch vehicle shall have a minimum thrust-to-weight ratio of 5.0:1.0.	Analysis	The thrust-to-weight ratio will be calculated by hand using the average thrust provided by the motor and the vehicle weight.
2.16	Any structural protuberance on the rocket shall be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) cause minimal aerodynamic effect on the rocket's stability.	Inspection	The only structural protuberance aside from a camera housing (which will cause minimal effect on stability) will be the Airbrakes system. The Airbrakes system will be located aft of the burnout center of gravity.
2.17	The launch vehicle shall accelerate to a minimum velocity of 52 fps at the rail exit.	Analysis	OpenRocket simulations will be used to calculate the velocity.
2.18	All teams shall successfully launch and recover a subscale model of their rocket. Success of the subscale is at the sole discretion of the NASA review panel. The subscale flight may be conducted at any time between the proposal award and the CDR submission deadline. Subscale flight data shall be reported in the CDR report and presentation at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).	Test	A subscale model of the rocket will be designed, built, and launched prior to the CDR. All recorded data will be included in the CDR.
2.18.1	The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale shall not be used as the subscale model.	Test, Inspection	The sub-scale model will be tested to show full capabilities during a launch. Inspection will confirm that the sub-scale and full-scale rockets are two separate rockets.
2.18.2	The subscale model shall carry an altimeter capable of recording the model's apogee altitude.	Test	The altimeter's capability to record apogee will be tested during flight.
2.18.3	The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.	Inspection	Inspection of this subscale rocket by a team leader will confirm that this rocket is not the same as a rocket from a previous year.
2.18.4	Proof of a successful flight shall be supplied in the CDR report, including: Altimeter flight profile graph(s) OR a quality video showing successful launch, recovery events, and landing as deemed by the NASA management panel are acceptable methods of proof. Altimeter flight profile graph(s) that are not complete (liftoff through landing) will not be accepted. Quality pictures of the as-landed	Inspection	Inspection of the CDR will confirm that altimeter flight profile graphs or a quality video showing successful launch, recovery events, and landing are included. Quality pictures of the landed configuration and all sections of the vehicle will also be

	configuration of all sections of the launch vehicle shall be included in the CDR report. This includes, but is not limited to: nosecone, recovery system, airframe, and booster.		included in the CDR.
2.18.5	The subscale rocket shall not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4” diameter, 100” length rocket, your subscale shall not exceed 3” diameter and 75” in length.	Inspection	The subscale rocket will be measured to confirm that the dimensions do not exceed 75% of the full-scale rocket.
Vehicle Demonstration Flight			
2.19	All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown for their competition launch. The purpose of the vehicle Demonstration Flight is to validate the launch vehicle’s stability, structural integrity, recovery systems, and the team’s ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.).	Demonstration	A demonstration flight with the full-scale rocket will take place at a local launch site prior to the deadline.
2.19.1	The vehicle and recovery system shall have functioned as designed.	Analysis, Inspection	Analysis prior to launch using calculations and OpenRocket software will confirm that the recovery system will function properly prior to launch. Inspection during flight will confirm proper functioning of the recovery system.
2.19.2	The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year’s project.	Inspection	Inspection of this fullscale rocket by a team leader will confirm that this rocket is not the same as a rocket from a previous year.
2.19.3	The payload does not have to be flown during the full-scale vehicle Demonstration Flight. The following requirements still apply: 1. If the payload is not flown, mass simulators shall be used to simulate the payload mass. 2. The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.	Inspection	If payload is not flown, the team will inspect the rocket to confirm that a mass simulator located in the designated payload area is present.

2.19.4	If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.	Inspection	The team will inspect the rocket to confirm that all external surfaces remain active during the full-scale vehicle demonstration flight.
2.19.5	Teams shall fly the competition launch motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances.	Inspection	Inspection will confirm that the motor used during the demonstration flight is the same motor that will be used during competition.
2.19.6	The vehicle will be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast shall not be added without a re-flight of the full-scale launch vehicle.	Inspection	used for the test flight will be used to confirm that it is the same weight that will be used during the competition flight.
2.19.7	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA management team or Range Safety Officer (RSO).	Inspection	Inspection will confirm that the components used during the full-scale demonstration flight are not modified (unless approved by NASA management or an RSO).
2.19.8	Proof of a successful flight shall be supplied in the FRR report, including: 1. Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement. Altimeter flight profile graph(s) that are not complete (liftoff through landing) shall not be accepted. 2. Quality pictures of the as-landed configuration of all sections of the launch vehicle shall be included in the FRR report. This includes, but is not limited to: nosecone, recovery system, airframe, and booster. 3. Raw altimeter data shall be submitted in.csv or.xlsx format.	Inspection	Inspection of the FRR will confirm that proof of successful flight is included in the deliverable. This will include altimeter data in the proper format and quality pictures of the as-landed configuration of all sections of the launch vehicle.
2.19.9	Vehicle Demonstration flights shall be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight shall submit an FRR Addendum by the FRR Addendum	Inspection	FRR will include proof of a vehicle flight demonstration and will be submitted before the deadline.

	deadline.		
Payload Demonstration Flight Requirement			
2.2	All teams shall successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed	Demonstration	A demonstration flight with payload will take place at a local launch site prior to the deadline.
2.20.1	The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair.	Inspection	The payload will be inspected during launch to verify that it does not deploy before intended.
2.20.2	The payload flown shall be the final, active version.	Inspection	The payload will be inspected to verify that the final version is being flown.
2.20.3	If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline, and the information is included in the FRR package, the additional flight and FRR Addendum are not required.	Inspection	The FRR will be inspected to confirm that either the above criteria have been met and included in the document or a FRR addendum is included.
2.20.4	Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.	Inspection	The FRR will be submitted before the deadline, and inspection of the document will verify that the payload demonstration flight is completed and included.

2.21	An FRR Addendum shall be required for any team completing a Payload Demonstration Flight or NASA-required Vehicle Demonstration Re-flight after the submission of the FRR Report: 2.20.1. Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly a final competition launch. 2.20.2. Teams who complete a Payload Demonstration Flight that is not fully successful may petition the NASA RSO for permission to fly the payload during launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.	Inspection	Inspection will verify that an FRR Addendum is included if needed.
2.22	The team's name and Launch Day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	Inspection	A visual inspection will verify that the launch day contact information is visible in or on the airframe and on any section of the vehicle that separates during flight that is not tethered to the airframe.
2.23	All Lithium Polymer batteries shall be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	Inspection	Inspection will confirm that Lithium Polymer batteries are either visibly marked and protected or not used at all.
Vehicle Prohibitions			
2.24.1	The launch vehicle shall not utilize forward firing motors.	Inspection	Forward-firing motors will not be included in the vehicle.
2.24.2	The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	Inspection	The selected motor does not expel titanium sponges.
2.24.3	The launch vehicle shall not utilize hybrid motors.	Inspection	The selected motor is a solid motor.
2.24.4	The launch vehicle shall not utilize a cluster of motors.	Inspection	A single solid motor will be used.
2.24.5	The launch vehicle shall not utilize friction fitting for motors.	Inspection	No friction-fitting motor will be selected
2.24.6	The launch vehicle shall not exceed Mach 1 at any point during flight.	Analysis, test	OpenRocket simulations will be used to determine the vehicle's maximum speed and ensure that it does not exceed Mach 1. Test flights will confirm that the vehicle does not exceed Mach 1

			during flight.
2.24.7	Vehicle ballast shall not exceed 10% of the total unballasted weight of the rocket, as it would sit on the pad (i.e., a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).	Analysis	The team will ensure that the ballast does not weigh more than 10% of the rocket's weight by weighing the rocket and the ballast and performing calculations to verify.
2.24.8	Transmissions from on-board transmitters, which are active at any point prior to landing, shall not exceed 250 mW of power (per transmitter).	demonstration	The team will select transmitters that comply with the power limit, plus the team will utilize equipment such as a spectrum analyzer to measure signal strength, derive power output and make sure said power is below 250 mW.
2.24.9	Transmitters shall not create excessive interference. Teams shall utilize unique frequencies, handshakes, password systems, or other means to mitigate interference caused by or received from other teams.	Demonstration	The team will utilize unique frequencies and bandwidth on its transceivers. the team will make sure to utilize software and cryptographic practices to ensure security and reliability of information packets

7.2.3 Recovery Requirements

Table 42. Recovery Requirements

No.	Description	Verification	Verification Description
3.1	The full-scale launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO:	Inspection	The recovery system will be verified to be compliant with these requirements
3.1.1	The main parachute shall be deployed no lower than 500 feet.	Analysis, Inspection	The main parachute will deploy at 600 ft
3.1.2	The apogee event shall contain a delay of no more than 2 seconds.	Demonstration	The altimeters will be set a 1 second delay for drogue deployment
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.	Inspection	The motor will not eject.

3.2	Each team shall perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale vehicles.	Inspection	The vehicle lead will perform ground ejection tests prior to each flight
3.3	Each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf at landing. Teams whose heaviest section of their launch vehicle, as verified by vehicle demonstration flight data, stays under 65 ft-lbf will be awarded bonus points.	Analysis, Demonstration	Before manufacturing, the aerostructures team will verify the validity of the projected kinetic energy.
3.4	The recovery system shall contain redundant, commercially available barometric altimeters that are specifically designed for the initiation of rocketry recovery events. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	Inspection	Two independent recovery systems will be placed in the avionics bay
3.5	Each altimeter shall have a dedicated power supply, and all recovery electronics shall be powered by commercially available batteries.	Inspection	The telemetry lead will ensure to account for dedicated power supply in the recovery system design. Additionally, the telemetry lead will select commercially available batteries
3.6	Each altimeter shall be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Inspection, Test	During launch day preparations, mechanical key switches will be inspected by the team for accessibility after rocket is fully assembled
3.7	Each arming switch shall be capable of being locked in the ON position for launch (i.e., cannot be disarmed due to flight forces).	Test	During launch day preparations, mechanical key switches will be tested by the Telemetry Lead before altimeters are armed to ensure they are operational
3.8	The recovery system, GPS and altimeters, and electrical circuits shall be completely independent of any payload electrical circuits.	Inspection	Telemetry Lead will verify that no electrical connections exist between the payload and Telemetry Bay and that the Flight Altimeters are located in a different compartment altogether.
3.9	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	Inspection	The Aerostructures Lead will ensure compliance of this requirement
3.1	Bent eyebolts shall not be permitted in the recovery subsystem	Inspection	The team will inspect the recovery system design prior to manufacture

3.11	The recovery area shall be limited to a 2,500-foot radius from the launch pads.	Analysis, Demonstration	A dual-deployment recovery system will be used to reduce the launch and landing distance.
3.12	Descent time of the launch vehicle shall be limited to 90 seconds (apogee to touch down). Teams whose launch vehicle descent, as verified by vehicle demonstration flight data, stays under 80 seconds will be awarded bonus points.	Analysis, Demonstration	The team will perform several descent time calculations for worst-case scenarios
3.13	An electronic GPS tracking device shall be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver:	Inspection	The Telemetry Lead will verify that the GPS module on the Telemetry Bay is capable of transmitting GPS data to the Ground station receiver
3.13.1	Any rocket section or payload component, that lands untethered to the launch vehicle shall contain an active electronic GPS tracking device.	Inspection	The team verifies that all sections of the launch vehicle will remain tethered together during flight, requiring the need for a single GPS tracker on the vehicle
3.13.2	The electronic GPS tracking device(s) shall be fully functional during the official competition launch.	Test, Demonstration	The Telemetry Lead will ensure that the Ground Station can continuously receive GPS data from the Telemetry Bay located on the rocket
3.14	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing):	Inspection, Test	The recovery system will be tested with all devices onboard
3.14.1	The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device or magnetic wave producing device.	Inspection	The recovery system altimeters will be contained in a dedicated avionics bay compartment
3.14.2	The recovery system electronics shall be shielded from all on-board transmitting devices to avoid inadvertent excitation of the recovery system electronics.	Inspection	Verify the recovery system employs electronics built on PCBs that utilize a common ground plane for shielding
3.14.3	The recovery system electronics shall be shielded from all on-board devices that may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Inspection	Verify magnetic wave-generating devices are not used on the rocket
3.14.4	The recovery system electronics shall be shielded from any other on-board devices which may adversely affect the proper operation of the recovery system	Inspection, Test	The recovery system will be tested with all devices onboard

7.2.4 Payload Requirements

Table 43. Payload Requirements

No.	Description	Verification	Verification Description
STEMCRAFT Mission Requirements			
4.1	Teams shall choose a minimum of 3 pieces of data from the below list to a maximum of 8 to transmit to the NASA receiver. • Temperature of landing site • Time of landing • Apogee reached • Maximum velocity • Battery check, power status • Landing velocity, G-forces sustained • Orientation of on-board STEMnauts • Calculated STEMnaut crew survivability probability • Maximum altitude	Demonstration	The team will transmit 8 pieces of data to the NASA receiver during The data to be transmitted will be (1) Temperature of landing sight, (2) Time of landing, (3) Apogee reached, (4) Maximum Velocity, (5) Landing velocity, G-forces sustained, (6) Orientation of on-board STEMnauts, (7) Calculated STEMnaut crew survivability probability, and (8) maximum altitude.
4.2	The payload shall not have any protrusions from the vehicle prior to apogee that extend beyond a quarter-inch exterior to the airframe.	Inspection	The payload will not have any protrusions from the vehicle prior to apogee that extend beyond a quarter-inch exterior to the airframe.
4.3	Payload shall transmit on the 2-M band. A specific frequency shall be given to the teams later. NASA shall use the FTM-300DR transceiver.	Inspection	The telemetry lead will ensure that the payload shall transmit on the 2-M band at the specified frequency as provided.
4.4	All transmissions shall start and stop with a team member call sign.	Inspection	The call sign "KQ4FYU" shall be used to start and stop all transmissions.
4.5	Teams shall submit a list of what data they will attempt to transmit by NASA receiver by March 17.	Inspection	The team will submit a list of what data they will attempt to transmit by NASA receiver by March 17.
4.6	Teams shall transmit with a maximum of 5W and transmissions shall not occur prior to landing	Demonstration	Components will be tested prior to integration with the vehicle to demonstrate a maximum transmission of 5 W or below.
4.7	Teams shall not transmit on the specified NASA frequency on launch day prior to landing.	Demonstration	All components that transmit radio frequencies will be tested to demonstrate the ability to transmit on a unique frequency.
General Payload Requirements			

4.8	Black powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.	Inspection	Black powder and other similar energetics will only be used for recovery.
4.9	Teams shall abide by all FAA and NAR rules and regulations.	Inspection	All FAA and NAR regulations shall be followed as outlined in the safety section of the proposal. Energetics shall not be used as deployment of the payload. In-flight recovery systems shall be the only permitted use of black power charges or similar energetics.
4.1	Any payload experiment element that is jettisoned during the recovery phase shall receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement by the RSO or NASA.	Inspection	Prior to the payload experiment element being jettisoned, real-time RSO permission shall be received during the recovery phase.
4.11	Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, shall be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.	Inspection, Demonstrati on	Either the permission to release the UAS will be confirmed through inspection, or a demonstration of a remotely controlled release system will be shown through a test flight.
4.12	Teams flying UASs shall abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112–95 Section 336; see https://www.faa.gov/uas/faqs).	Inspection	The team shall abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336).
4.13	Any UAS weighing more than .55 lbs. shall be registered with the FAA and the registration number marked on the vehicle.	Inspection	Visual inspection will confirm that any UAS weighing more than 0.55 lbs includes a marked registration number on the vehicle.
Note s	than.55An additional experiment (limit of 1) is and may be flown, but will not contribute to scoring. If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.		

7.2.5 Safety Requirements

Table 44. Safety Requirements

No .	Description	Verification	Verification Description
5.1	Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	Inspection	The Safety Officer, Lucas Folio, will use a launch and safety checklist and include the final checklists in the FRR, LRR, and all Launch Days.

5.2	Each team shall identify a student safety officer who will be responsible for all items in Section 5.3.	Inspection	The team has identified Lucas Folio as the Safety Officer.
5.3	The role and responsibilities of the safety officer shall include, but are not limited to: 5.3.1. Monitor team activities with an emphasis on safety during: 5.3.1.1. Design of vehicle and payload 5.3.1.2. Construction of vehicle and payload components 5.3.1.3. Assembly of vehicle and payload 5.3.1.4. Ground testing of vehicle and payload 5.3.1.5. Subscale launch test(s) 5.3.1.6. Full-scale launch test(s) 5.3.1.7. Competition Launch 5.3.1.8. Recovery activities 5.3.1.9. STEM Engagement Activities 5.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities. 5.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and SDS/chemical inventory data. 5.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Inspection	The safety officer will be present during all launches to monitor team activities with an emphasis on safety, implement procedures, and maintain and write risk analysis and FMEA.
5.4	During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams shall communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Inspection	The team will communicate with the RSO via email and phone calls to confirm allowance of vehicle flight configuration at the launch site prior to any launch days.
5.5	Teams shall abide by all rules set forth by the FAA.	Inspection	The safety officer will ensure that all rules set forth by the FAA are abided by.

7.2.6 Final Flight Requirements

Table 45. Final Flight Requirements

No.	Description	Verification	Verification Description
NASA Launch Complex			

6.1.1	Teams are not permitted to show up at the NASA Launch Complex outside of launch day without permission from the NASA management team.	Inspection	The team will arrive at the NASA Launch Complex during the permitted time and date.
6.1.2	Teams shall complete and pass the Launch Readiness Review conducted during Launch Week.	Inspection	The team shall complete and pass the Launch Readiness Review conducted during Launch Week.
6.1.3	The team mentor shall be present and oversee rocket preparation and launch activities.	Inspection	The team mentor will visibly be present on all launch days and oversee rocket preparation.
6.1.4	The scoring altimeter shall be presented to the NASA scoring official upon recovery.	Inspection	The team will confirm that the scoring altimeter is presented to the team mentor and range safety officer on Launch Day.
6.1.5	Teams may launch only once. Any launch attempt resulting in the rocket exiting the launch pad, regardless of the success of the flight, will be considered a launch. Additional flights beyond the initial launch, will not be scored and will not be considered for awards.	Inspection	Inspection will confirm that there has only been one launch.
Commercial Spaceport Launch Site			
6.2.1	The launch shall occur at a NAR or TRA sanctioned and insured club launch. Exceptions may be approved for launch clubs who are not affiliated with NAR or TRA but provide their own insurance, such as the Friends of Amateur Rocketry. Approval for such exceptions shall be granted by NASA prior to the launch.	Inspection	The team has confirmed that the two local launch sites that will be used for launch days are TRA and NAR sanctioned and insured.
6.2.2	Teams shall submit their rocket and payload to the launch site Range Safety Officer (RSO) prior to flying the rocket. The RSO shall inspect the rocket and payload for flight worthiness and determine if the project is approved for flight. The local RSO shall have final authority on whether the team's rocket and payload may be flown.	Inspection	The team shall submit their rocket and payload to the launch site Range Safety Officer (RSO) prior to flying the rocket such that it is inspected and deemed flight worthy for flight approval.
6.2.3	BOTH the team mentor and the Launch Control Officer shall observe the flight and report any offnominal events during ascent or recovery on the Launch Certification and Observations Report.	Inspection	Inspection will confirm that all flights are observed and any

			offnominal events are reported.
6.2.4	The scoring altimeter shall be presented to BOTH the team's mentor and the Range Safety Officer.	Inspection	The team will confirm that the scoring altimeter is presented to the team mentor and range safety officer on Launch Day.
6.2.5	The scoring altimeter shall be one of the altimeters used for recovery events.	Inspection	The team will confirm that the scoring altimeter will be used in the recovery event through design, implementation, and inspection.
6.2.6	The mentor, the Range Safety Officer, and the Launch Control Officer must be three separate individuals who must ALL complete the applicable sections of the Launch Certification and Observations Report. The Launch Certification and Observations Report document will be provided by NASA upon completion of the FRR milestone and shall be returned to NASA by the team mentor upon completion of the launch.	Inspection	The team will confirm that all three individuals have completed the applicable sections.
6.2.7	The Range Safety Officer and Launch Control Officer certifying the team's flight shall be impartial observers and shall not be affiliated with the team, individual team members, or the team's academic institution.	Inspection	The team will not be affiliated with the RSO.
6.2.8	Teams may launch only once. Any launch attempt resulting in the rocket exiting the launch pad, regardless of the success of the flight, will be considered a launch. Additional flights beyond the initial launch will not be scored and will not be considered for awards.	Inspection	The team will only launch once

7.2.7 Vehicle Derived Requirements

Table 46. Vehicle Derived Requirements

No.	Description	Verification	Verification Description
7.1	All F.O.S. should be greater than 1.75.	Analysis, Test	All subsystem components of the launch vehicle shall require verification or analysis of F.O.S. by a team lead prior to launch day operations.
7.2	Speeds shall not exceed fin flutter limits.	Analysis	Simulations analyzing fin flutter limits with expected speeds shall be conducted in order to guarantee the

			fin flutter limit is not exceeded.
7.3	All airframes with slots or reduced cross-sectional area shall be reinforced.	Inspection	Vehicle leads shall verify that all components deemed necessary (such as slots) are within team reinforcement standards prior to launch day.
7.4	A minimum of 3 bolts should be used to connect couplers with airframes.	Inspection	Vehicle leads shall verify couplers contain at least 3 bolts prior to launch day as well as for any other visible defects.
7.5	The launch vehicle shall have a minimum of 3 fins.	Inspection	Vehicle leads shall ensure the launch vehicle contains 3 fins installed properly.
7.6	The vehicle's drag coefficient, without airbrake influence, shall be less than 0.3.	Analysis	Simulations analyzing drag coefficients shall be produced by vehicle leads, providing data which ensures that the vehicle drag coefficient is less than 0.3 when neglecting airbrakes.
7.7	Payload shall be fully secured upon landing and function properly.	Inspection, Demonstration	Payload lead shall verify all systems properly function and are secure prior to launch day, additionally inspecting post-flight functionality.
7.8	The launch vehicle and internal systems shall work properly after preparation on the launch site, regardless of time elapsed.	Demonstration	All batteries, fully charged, shall be placed inside the launch vehicle shortly before the final flight, and all internal systems will be switched on to verify functionality.
7.9	The launch vehicle and internal systems shall be able to endure multiple causes of fatigue, such as cyclical loading.	Analysis	Multiple simulations will be produced by vehicle leads to ensure that all aspects of the launch vehicle can endure any expected cause of fatigue.
7.1	The launch vehicle must be able to overachieve the target altitude (4075ft) declared within the CDR.	Demonstration, Analysis	Altimeters will record launch vehicle which will be declared by team leads upon recovery. Simulations of the launch vehicle will be produced to ensure that the vehicle is capable of surpassing target altitude in its current configuration.

7.11	No subsystem shall compromise structural stability or flight performance.	Analysis, Inspection	All components of the launch vehicle during manufacturing and before launch day will be verified by multiple vehicle leads to ensure that the launch vehicle is safe to fly.
7.12	Airframe will be fully inspected and documented upon landing by multiple team leads.	Inspection	Multiple vehicle leads will inspect the launch vehicle in its original landing position to record any potential problems. The launch vehicle and its internal systems will be inspected in greater detail later on to determine the condition of the launch vehicle.

7.2.8 Recovery-derived Derived Requirements

Table 47. Recovery Derived Requirements

No.	Description	Verification	Verification Description
8.1	A vehicle lead shall verify there is enough volume to pack each parachute.	Analysis, Inspection	Proper space shall be allocated in all drawings and plans for each parachute prior to the assembly. Additionally, the lead shall verify after packing that the parachutes are secured properly.
8.2	The landing velocity of the launch vehicle shall be no greater than 17 ft/s.	Analysis	Simulations shall be produced to verify that the launch vehicle's current setup allows for a landing velocity less than 17 ft/s.
8.3	Independent sections shall land with a kinetic energy no greater than 65 ft-lbf.	Analysis	Simulations shall be produced to verify that each independent section shall experience no kinetic energy greater than 65 ft-lbf with the current setup of the launch vehicle
8.4	Each parachute shall be inspected by a vehicle lead to confirm proper folding and the removal of any temporary supports.	Inspection	A vehicle lead shall verify that each parachute is folded with proper technique and inspect the

			parachutes prior to assembly to ensure no temporary supports remain.
8.5	Flight altimeter configuration shall be inspected to ensure valid settings are programmed.	Inspection	Altimeter settings shall be inspected by the Telemetry Lead and the Aerostructures lead to ensure proper functionality.
8.6	Backup black powder charges shall contain 0.5 g more black powder than the initial charges.	Inspection	Both the initial and backup black powder charges will be precisely weighed out on a scale to verify that each backup charge contains 0.5 A margin more black powder than the initial charge.
8.7	The drogue shall descend the launch vehicle at a velocity no greater than 110 ft/s.	Analysis	Simulations shall be produced to verify that upon deployment of the drogue, the launch vehicle will descend at a rate no greater than 110 ft/s with the vehicle's current setup.
8.8	Both parachutes shall be inspected upon landing.	Inspection	Multiple leads shall document the state of each parachute in its original landing position to determine any potential damage sustained from the landing.
8.9	Total descent time shall take no longer than 80 seconds.	Analysis	Simulations shall be produced to verify that the current recovery deployment setup takes no longer than 80 seconds to completely descend the launch vehicle.
8.1	Each parachute shall be folded by at least three members with the supervision of a vehicle lead prior to the launch day.	Demonstration, Inspection	A vehicle lead shall demonstrate multiple members on the correct technique of folding a parachute and fully monitor the members during the process to ensure a proper

			fold.
8.12	Ensure the transceivers on the Telemetry Bay do not exceed a transmitting power of 250 mW.	Analysis	Verify software setting configurations to ensure the transmitter is transmitting at a power level at or below 250 mW.
8.13	Ensure the Telemetry Bay and Ground Station is operational before launch day.	Demonstration	Verify data from all sensors on the Telemetry Bay is received by the Ground Station in predictable intervals with little to no data corruption.
8.14	Ensure Telemetry Bay and Flight Altimeter batteries are sufficiently powered before launch.	Inspection	Using a multimeter, verify the voltage level of all 3.7V LiPo batteries is between 3.5V and 4.2V, and the voltage of all 9V batteries is above 8.5V.

7.2.9 Payload Derived Requirements

Table 48. Payload Derived Requirements

No.	Description	Verification	Verification Description
9.1	GOST can sustain forces of up to 1.75 times the normal operation forces.	Demonstration	Testing Payload using snap, compressive, and tensile stress.
9.2	GOST shall be stowed and all door shall be in locked position before flight as to not disrupt launch	Inspection	Verify that all doors are completely shut and locked.
9.3	GOST Batteries and electronics shall be in proper working order.	Inspection	Verify and acknowledge that all systems are responding and in working order.
9.4	GOST Shall be fixed inside of the airframe, unable to move while forces are exerted on it.	Demonstration	Test payload in upper body tube.
9.5	GOST preflight checklist shall be completed and all removed before flight hardware taken out	Inspection	Verify all marked hardware is out of payload.
9.6	GOST shall actuate only when rested on the ground post launch	Demonstration	Run code in order to verify the system is in working order.
9.7	GOST shall be completely independent of the rocket and rely on its own power.	Inspection	Verify tether cables are disconnected before flight.

7.3 Budgets

7.3.1 Overall Budgets and Funding

Budgets and projected costs are broken down into seven main categories: vehicle, telemetry, payload mechanical, payload electronics, consumables, travel, and outreach. SOAR has an overall USLI competition budget of $15,000. Each category has been allotted a certain portion of the budget. To ensure that the budget is adequately portioned, a projected cost with margin was developed for each category. Projected costs consist of all items and materials that may need to be purchased in order to complete building, manufacturing, and launching a sub-scale and full-scale rocket. A margin is included to ensure that the costs do not exceed the budget in case the actual costs are higher than the projected costs. Most categories contain a 20% margin to account for shipping costs, minor price increases, and any unforeseen additional costs or fees. An overall budget breakdown with projected costs for each category can be seen in the table below.

Table 49. Overall Budget

Overall Budget			
Category	Projected Cost	Budget	Funding Status
Aerostructures & Recovery	$2,383.73	$2,500.00	Received
Telemetry	$589.50	$800.00	Received
Payload Mechanical	$1,072.72	$1,500.00	Received
Payload Electronics	$970.03	$1,000.00	Received
Consumables	$2,000.01	$2,100.00	Received
Travel	$7,000.00	$7,000.00	Pending Approval
Outreach	$100.00	$100.00	Received
Total Costs	$14,115.99	$15,000.00	

Funding for SOAR comes primarily from the University of South Florida. While the team is confident that the budget provided is sufficient enough to complete this project, members are seeking out additional funding from other companies. Additional funding would allow for the team to use more expensive materials as well as more complex designs that require more parts. SOAR's sponsors are CAE, Five Star Pizza, Monster Energy, and Jim's Body Shop. Five Star Pizza provides pizza for all major SOAR events. Monster Energy provides free energy drinks for build days. CAE has provided SOAR with $3000 in funding. Jim's Body Shop paints the fullscale rocket free of charge.

7.3.2 Direct Costs

Direct costs include all launch vehicle subsystems and consumables. Overall, the budget for direct costs is $7,900. The launch vehicle subsystems consist of , Payload, and Telemetry.

Consumables consist of any items that are depletable, such as JB-Weld, solder, and rocket motors. This category has a budget of $2,100, and its projected cost is $2,000.01 with a 50% margin. This category contains a relatively high margin to account for higher amounts of consumables needed than projected, any last-minute launch purchases that may be needed, price increases, and shipping & handling. A detailed breakdown of the projected costs can be seen in the table below.

Table 50. Consumables Costs

Consumables				
Item/Material	Cost Per Unit	Amount	Cost	Vendor
Mechanical consumables				
L3150 Cesaroni Motor	$286.35	4	$1,145.40	Cesaroni
JB Weld	$20.00	2	$40.00	Amazon
Silicone Paste	$21.47	1	$21.47	Amazon
Sandpaper 100 grit, 25 sheets	$15.00	1	$15.00	Amazon
Goex FFFFg Black Powder, 1 lb	$31.00	1	$31.00	Midway USA
EECS Consumables				
Unleaded Solder	$0.00	0	$0.00	In storage
Leaded Solder	$0.00	0	$0.00	In storage
Solder Wick	$9.99	1	$9.99	Amazon
Breadboard Jumper Wires	$0.00	0	$0.00	In storage
Male & Female JST Connectors (large)	$6.59	1	$6.59	Amazon
PH 2.0mm Connectors Sockets Cable Kit	$15.99	1	$15.99	Amazon
JST Right Angle Board Connectors	$7.06	1	$7.06	Amazon
20 Gauge Wire spool	$17.99	1	$17.99	Amazon
Solder Paste	$9.94		$0.00	JB Tools
Flux	$9.90	1	$9.90	Amazon
Header Pins	$12.95	1	$12.95	Amazon
		Total Costs	$1,333.34	
		Margin	50%	
		Total Costs with margin	$2,000.01	

Vehicle costs consist of aerostructures and recovery costs. This category has a budget of $2,500 and a projected cost of $2,384 with a 20% margin. A detailed breakdown of this category can be seen in the table below.

Table 51. Aerostructures & Recovery Costs

Aerostructures & Recovery				
Item/Material	Cost Per Unit	Amount	Cost	Vendor
Fiberglass Airframe Stock	$279.81	2	$559.62	Wildman Rocketry
Fiberglass Coupler Stock	$71.00	3	$213.00	Wildman Rocketry
Iris Ultra 120" Standard Parachute	$596.17	1	$596.17	Fruity Chutes
24" Compact Elliptical Parachute	$70.00	1	$70.00	Fruity Chutes
Telemetrum	$300.00	1	$300.00	Locprecision
RRC3	$120.00	0	$0.00	In team storage
Bolts	$12.00	1	$12.00	In team storage
Nosecone	$180.29	1	$180.29	Wildman Rocketry
Eyebolt - B	$13.84	4	$55.36	McMaster Carr
Total Costs			1986.44	
Margin			20%	
Total Costs with margin			2383.728	

Payload costs are broken into two categories: Mechanical and Electrical. Payload Mechanical includes costs for a fixed payload as well as an ABS. The budget for payload mechanical is $1,500, while the current projected cost for this category is $893.93, including a 20% margin. A detailed breakdown of this category can be seen in the table below.

Table 52. Payload Mechanical Costs

Payload: Mechanical				
Item/Material	Cost Per Unit	Amount	Cost	Vendor or Link
Fixed Payload				
6061-T6 Aluminium Arms	$8.20	8	$65.60	McMaster-Carr
G12 Fiberglass Tube	$140.00	1	$140.00	Wildman Rocketry
G10 Fiberglass Bulkheads	$10.40	2	$20.80	McMaster-Carr
5/16 Steel Threaded Rod	$25.45	1	$25.45	McMaster-Carr
3D Printed PLA Electronics sled	$0.50	4	$2.00	Amazon
5.5" OD x 0.25" Wall x 5" ID Aluminum Round Tube 6061-T6-Extruded	$49.97	1	$49.97	Online Metals
Multipurpose 6061 Aluminum Sheet 1/8" Thick, 2" x 24"	$11.72	1	$11.72	McMaster-Carr

Hardware consumables	$24.99	1	$24.99	Amazon
Folding propellers	$15.28	2	$30.56	Amazon
MN2212 T-Motor Navigator	$46.90	1	$46.90	T-Motor
Metal Miter Gear Round Bore, 48 Pitch, 18 Teeth	$63.84	4	$255.36	McMaster-Carr
Airbrakes				
4-40 Shoulder Bolt (1)	2.76	8	$22.08	McMaster-Carr
4-40 Standard Bolt (100)	8.34	1	$8.34	McMaster-Carr
4-40 Lock Nuts (100)	8.38	1	$8.38	McMaster-Carr
Aluminum Stock (0.5'' x 0.5'' x 3')	10.47	2	$20.94	McMaster-Carr
Aluminum Stock (0.5'' x 8'' x 8'')	38.73	1	$38.73	McMaster-Carr
Aluminum Stock (0.25'' x 1' x 1')	32.59	1	$32.59	McMaster-Carr
1/4'' Socket Bolt (50)	12.57	1	$12.57	McMaster-Carr
1/4'' Oval Bolt (50)	9.78	1	$9.78	McMaster-Carr
3/16'' Hex Bolt (25)	11.81	1	$11.81	McMaster-Carr
Eyebolt: B	13.84	4	$55.36	McMaster-Carr
		Total Costs	893.93	
		Margin	20%	
		Total Costs with margin	1072.716	

Payload Electronics has a budget of $1,000 and a projected cost of $971 with a 20% margin included. This includes separate electronics for the ABS and the fixed payload. A detailed breakdown of this category can be seen in the table below.

Table 53. Payload EECS Costs

Payload EECS Costs				
Item/Material	Cost Per Unit	Amount	Cost	Vendor
Airbrakes				
Raspberry Pi Zero W	$16.00	1	$16.00	Adafruit
Adafruit BNO055 9 DOF IMU Sensor	$34.95	2	$69.90	Adafruit
Adafruit BMP390 Barometer/Altimeter	$10.95	1	$10.95	Adafruit
Adafruit PCA9865 16-Channel Servo Driver	$14.95	1	$14.95	Adafruit
GoolRC 80kg Digital Servo 270°	$35.99	1	$35.99	Amazon
Fixed Payload				
Espressif ESP32S3	$16.99	1	$16.99	Amazon

Adafruit BNO055 9 DOF IMU Sensor	$34.95	2	$69.90	Adafruit
Adafruit BME680 Temp, Humidity, Pressure	$18.95	1	$18.95	Adafruit
Adafruit I2S MEMS Microphone Breakout	$6.95	1	$6.95	Adafruit
DRA818v RF Transceiver	$20.94	1	$20.94	Amazon
Nooelec HackRF One** backup option	$319.95	1	$319.95	Noolec
GoolRC 80kg Digital Servo 270°	$35.99	4	$143.96	Amazon
Adafruit PCA9865 16-Channel Servo Driver	$14.95	1	$14.95	Adafruit
Additional costs				
2000 mAh 3.7V LiPo Batteries (packs of 4)	$23.99	2	$47.98	Amazon
Total Costs			808.36	
Margin			20%	
Total Costs with margin			970.032	

The total budget allotted to telemetry is $900. Telemetry is projected to cost $589.50. This includes all electronics associated with the avionics pay. All structures and hardware for the avionics bay is covered in aerostructures. A detailed breakdown of this category can be seen in the table below.

Table 54. Telemetry Costs

Telemetry Costs				
Item/Material	Cost Per Unit	Amount	Cost	Vendor
Telemetry Sensors				
Adafruit BNO055	$34.95	3	$104.85	Adafruit
Adafruit BMP390	$15.97	3	$47.91	Amazon
SeeedStudio XIAO ESP32S3	$16.99	5	$84.95	Amazon
SeeedStudio XIAO ESP32C3	$9.90	5	$49.50	Amazon
Adafruit Ultimate GPS Featherwing	$27.88	2	$55.76	Amazon
Reyax LoRa RYLR998	$12.60	5	$63.00	Amazon
Reyax LoRa RYLR498	$12.60	5	$63.00	Amazon
TF microSD Card Module	$5.14	2	$10.28	Amazon
Total Costs			491.25	
Margin			20%	
Total Costs with margin			589.5	

7.3.3 Travel, Outreach, and Safety Costs

SOAR will apply for a travel grant through USF's student government. The team is expecting to receive $7,000 in travel grants. In previous years, this is the amount that the team has received from USF's student government. Travel costs will cover room & board as well as gas and meals. A breakdown of the travel costs is included in the table below.

Table 55. Payload EECS Costs

Travel Expenses		
Category	Cost	Description
Hotel costs	$4,000.00	8 rooms total expected, 2 nights
Gas	$1,000.00	5 separate cars total expected ~620 mi
Food	$2,000.00	Meal reimbursements ~$100 per person
Total	$7,000.00	

Generally, outreach events for SOAR are not costly. SOAR's main means of outreach are through STEM engagement events in the community and social media. No money is allocated to social media because all accounts are free to maintain. Outreach and events are allocated $100 for all materials needed. Stem engagement events require materials such as paper, tape, markers, straws, and other easily accessible crafting supplies to keep younger K-12 students engaged. Items used for tabling events such as tables, posters, a tablecloth with the SOAR logo, and rocket parts. These items are either rented from the university's event planning center for free or already owned.

All safety items, such as gloves, respirators, extinguishers, and first aid kits, are bought using a separate general SOAR budget. These items are to be used by both the USLI competition team and the liquid propulsion team. These items are already owned and will not come from SOAR's USLI budget.

7.4 Timeline

The project timeline has been updated to reflect the team's project progress and more specific tasks moving forward. The original timeline plan with alternatives outlined in the proposal document (see Figure 120) has been implemented to address the challenges that have been encountered.

Given that the subscale launch in November was rescheduled, major adjustments were applied to the project timeline. The most notable change is the earliest feasible attempt for a Vehicle Demonstration Flight (VDF), now scheduled for February. This delay compresses subsequent deadlines, reducing the margin for testing key systems like Airbrakes. The immediate focus for January includes constructing the subscale rocket, finalizing payload research and development, and integrating an Airbrakes prototype into the vehicle for the February flight.

Depending on the outcome of February's flight, contingency plans for March and April are in place. If February succeeds, the March 8th launch will serve as an opportunity for further testing of airbrakes and payload systems. If February fails, March will serve as a critical fallback to meet the Flight Readiness Review (FRR) and VDF deadlines. Success in both February and March would shift the emphasis to software optimization and preparing replacement parts for mechanical systems, avoiding structural modifications to the rocket before the Huntsville launch. However, if February fails but March succeeds, an additional launch in April may be required to test Airbrakes with active software. Task scheduling has also been revised, with activities originally planned for late November and December now moved to January and February. Further details are provided in Section 7.4.1 alongside the updated Gantt chart

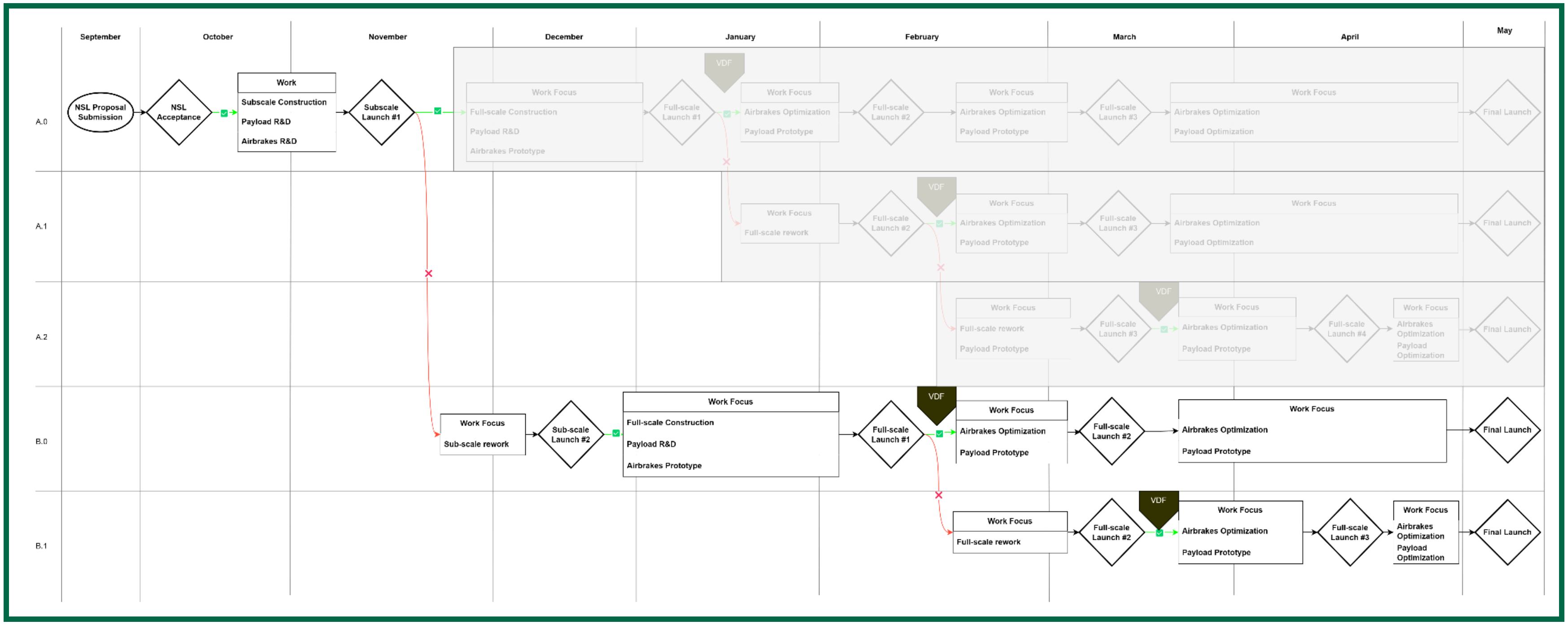


Figure 123. Timeline Overview with Alternative Options

7.4.1 Gantt Chart

The figures below detail the most up-to-date Gantt chart for the project. To provide clarity for a timeline that spans from October through May, the chart has been divided into several sections. While this division improves readability, it obscures task dependencies across sections. To address this, a star color-coding system has been introduced, allowing for easier identification of task interdependencies. By following the color of the stars, dependencies between tasks can be traced more effectively.

In addition to the dependency tracking system, the color of each task indicates the team responsible. Figure 124 provides a key for the team-specific color codes, making it straightforward to identify task ownership:

- **Admin**: Handles administrative tasks, including documentation, scheduling, and ensuring compliance with organizational and competition requirements.
- **Payload EECS**: Manages the electronics of the main payload, focusing on the sophisticated systems required for payload functionality. The division between Payload EECS and Payload Mech reflects the significant expertise required in each area.
- **Payload Mech**: Focuses on the mechanical aspects of the payload, including structural mounts, housing, and integration into the rocket body.
- **Aerostructures**: Responsible for the structural design and development of the rocket, including the airframe, material selection, and assembly.
- **Aero + EECS**: Represents the joint efforts between the Aerostructures and Payload EECS teams, particularly for the Airbrakes project, which requires a blend of structural and electronic expertise.
- **Telemetry**: Oversees all telemetry systems in the rocket and the ground station. This role, introduced this year, aims to improve the communication interface with the rocket, enabling real-time monitoring of all subsystems remotely and efficiently. This dedicated effort addresses challenges from previous years where telemetry tasks were not as centralized.
- **Vehicle**: Coordinates tasks bridging the Payload, Telemetry, and Aerostructures teams and manages integration during launches. This team ensures seamless collaboration among the subsystems for a successful launch.
- **Safety**: Maintains compliance with safety guidelines and oversees the implementation of safety protocols during construction, testing, and launches.
- **Payload (EECS + Mech)**: Represents the combined efforts of the Payload EECS and Payload Mech teams for tasks that require both electronic and mechanical expertise on the payload.
- **Aero + Vehicle**: Facilitates collaboration between the Aerostructures and Vehicle teams for tasks requiring joint efforts, particularly those related to the structural and system-wide integration.

Team Index

Team	Color
Admin	
Payload EECS	
Aerostructures	
Payload Mech	
Aero + EECS	
Unassigned	
Telemetry	
Vehicle	
Safety	
Payload	
Aero + Vehicle	

Figure 124. Gantt Chart Teams Color Coding Index

The Gantt chart organizes tasks around significant milestones, each serving as a key pressure point to focus efforts. Tasks associated with a milestone are positioned directly above it for clarity. Milestones completed before January 2025 have been marked accordingly, while any incomplete tasks have been rescheduled to align with future milestones for transparency:

Preliminary Design Review (PDR)
Due Date: October 27, 2024
Description: This milestone involved the submission of the Preliminary Design Review document, an essential deliverable outlining the initial project plans and designs. Status: Completed.

November Launch
Due Date: November 16, 2024
Description: This milestone marked the subscale launch attempt. Status: Launch couldn't be attempted, necessitating adjustments to the project timeline .

Fall R&D Showcase
Due Date: December 1, 2024
Description: An internal milestone created to encourage teams to develop prototypes by the end of the fall semester. Many tasks originally planned for this milestone were moved to later dates due to timeline adjustments. .

December Launch
Due Date: December 21, 2024
Description: A secondary subscale launch milestone introduced after the November launch failure. This milestone aimed to recover progress and ensure readiness for future launches. Status: Completed.

Critical Design Review (CDR)
Due Date: January 8, 2025
Description: This milestone required submission of the Critical Design Review document, a comprehensive update on the project's progress. Status: Expected to be completed by the time of this document submission.

February Launch
Due Date: February 8, 2025
Description: The first full-scale launch attempt. January's focus will be on tasks critical to ensuring a successful launch. Status: Pending.

Mid-semester Tests
Due Date: February 21, 2025
Description: An internal milestone established to conduct tests of telemetry and payload systems in preparation for the March launch. This milestone serves as a safeguard for critical system readiness. Status: Pending .

March Launch
Due Date: March 8, 2025
Description: Ideally, this milestone represents the second full-scale launch focused on testing airbrakes and payload systems. In less favorable scenarios, it may act as the final opportunity for a full-scale launch before the Vehicle Demonstration Flight (VDF) and Flight Readiness Review (FRR) deadlines. Status: Pending.

Flight Readiness Review (FRR)
Due Date: March 17, 2025
Description: This NASA-set milestone involves the submission of the FRR document package, a critical deliverable summarizing progress and readiness for competition. Work on this milestone will overlap with other milestones; however, it will be the primary focus after the March launch attempt is complete. Status: Pending.

Huntsville Preparations
Due Date: April 20, 2025
Description: An internal milestone set two weeks before the Huntsville competition to finalize all tasks. Efforts during this period will focus on optimizing software for payload and Airbrakes without making structural or mechanical modifications. Preparations for the rocket fair booth will also occur. Status: Pending.

Huntsville Launch
Due Date: April 27, 2025
Description: The final launch event at the Huntsville competition. All tasks are expected to be completed by the Huntsville Preparations milestone to accommodate academic commitments at the University of South Florida. Status: Pending.

Post-Launch Assessment Review (PLAR)
Due Date: May 2025
Description: The NASA-set milestone for submitting the final report on competition performance and outcomes. This document will conclude the project timeline. Status: Pending.

Task Name	End Date	Days
PDR Project Plan Section	2024-10-21	18
Airbrakes EECS Planning	2024-10-27	24
Subscale Design	2024-10-09	6
PDR Vehicle Section	2024-10-27	13
Full Scale design	2024-10-25	7
PDR Primary Payload Section	2024-10-26	5
PDR Secondary (Airbrakes) Payload Section	2024-10-26	5
PDR Review	2024-10-27	2
PDR	2024-10-28T	
Subscale Purchases	2024-10-27	14
Payload APRS Test	2024-11-16	19
RF metrics test	2024-11-09	5
November Launch	2024-11-16T	
Payload Design Test #1 : Bay doors	2024-11-30	33
Airbrakes Digital Twin Dev	2024-11-23	22
Airbrakes Component Manufacture	2024-11-23	6
Fall R&D Showcase	2024-12-03T	
Subscale AV Bay Assembly	2024-12-21	61
Subscale Assembly	2024-12-13	39
Subscale Rocket Sims	2024-12-21	5
December Launch	2024-12-21T	

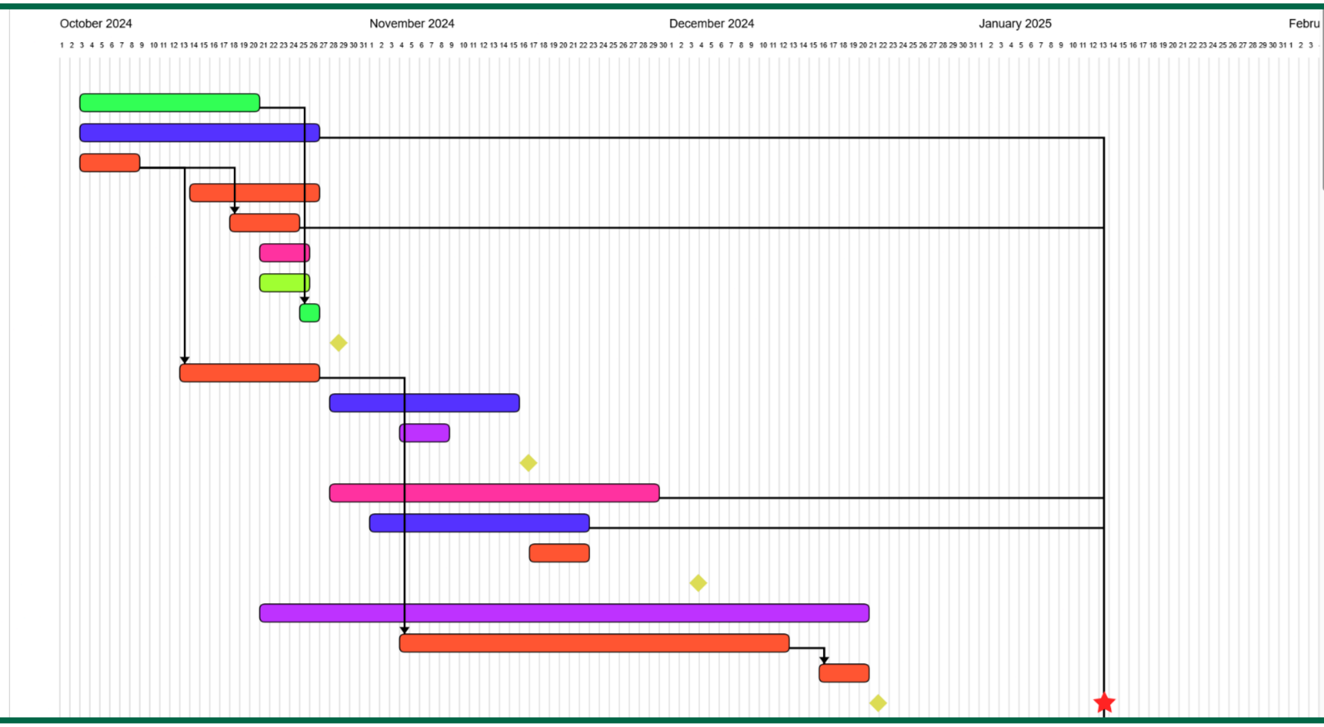


Figure 125. Gantt Chart Part 1

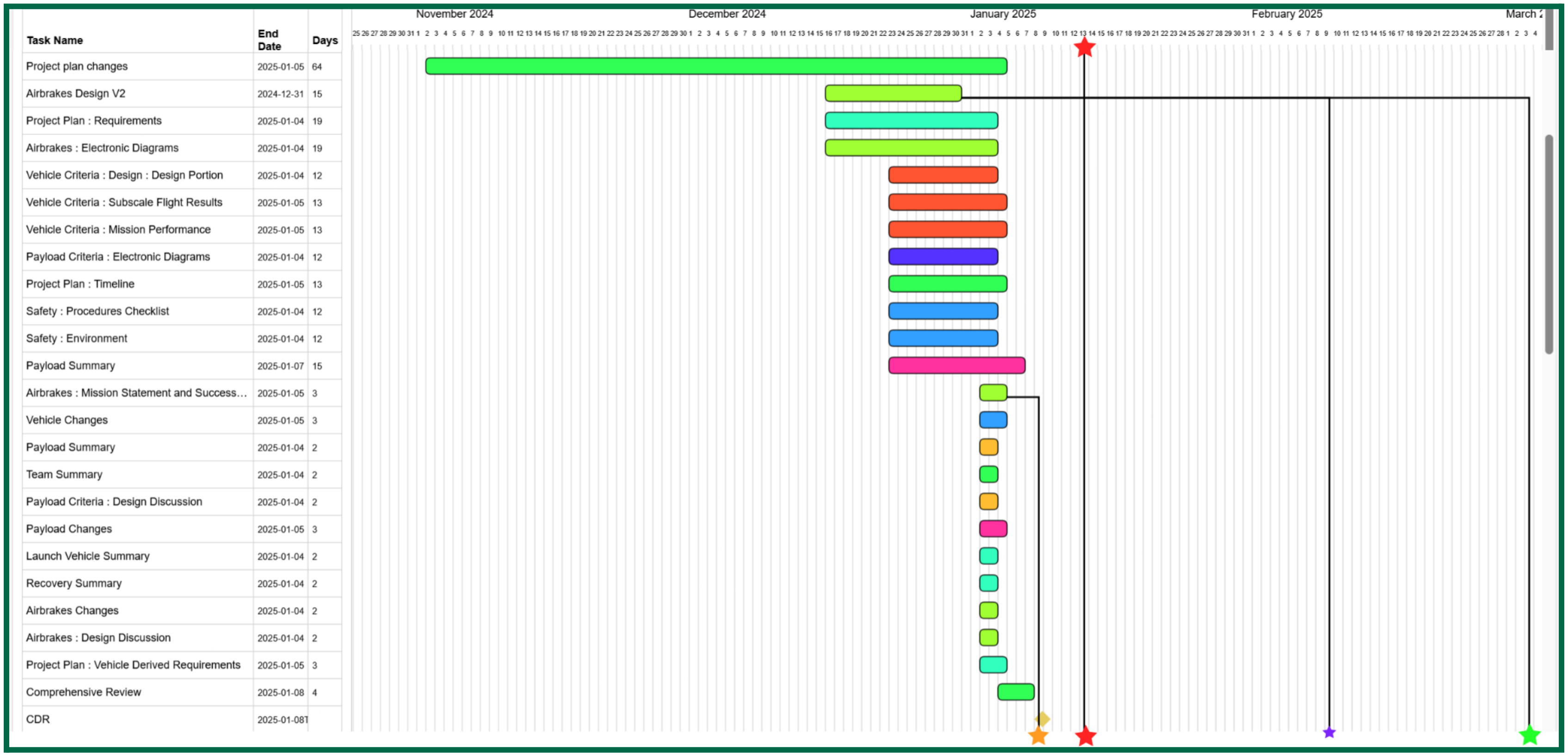


Figure 126. GANTT Chart Part 2

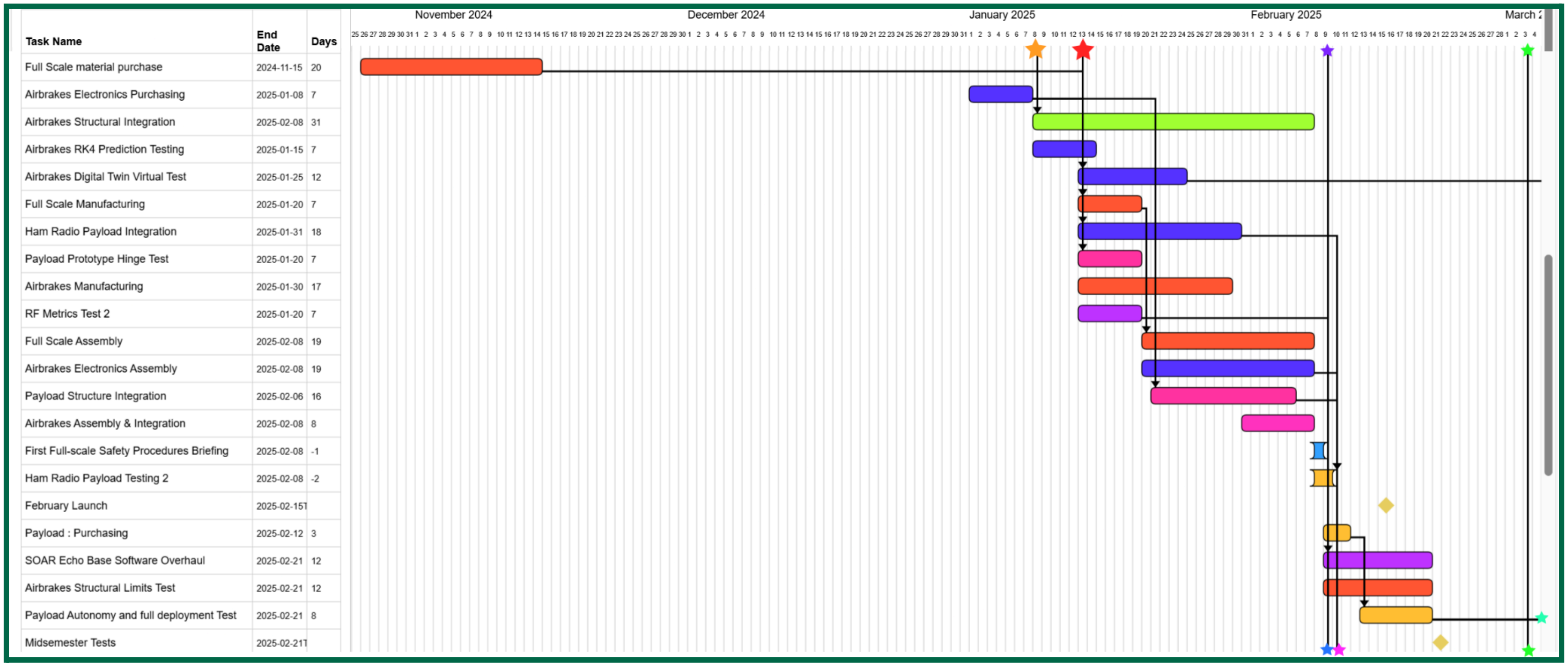


Figure 127. Gantt Chart Part 3

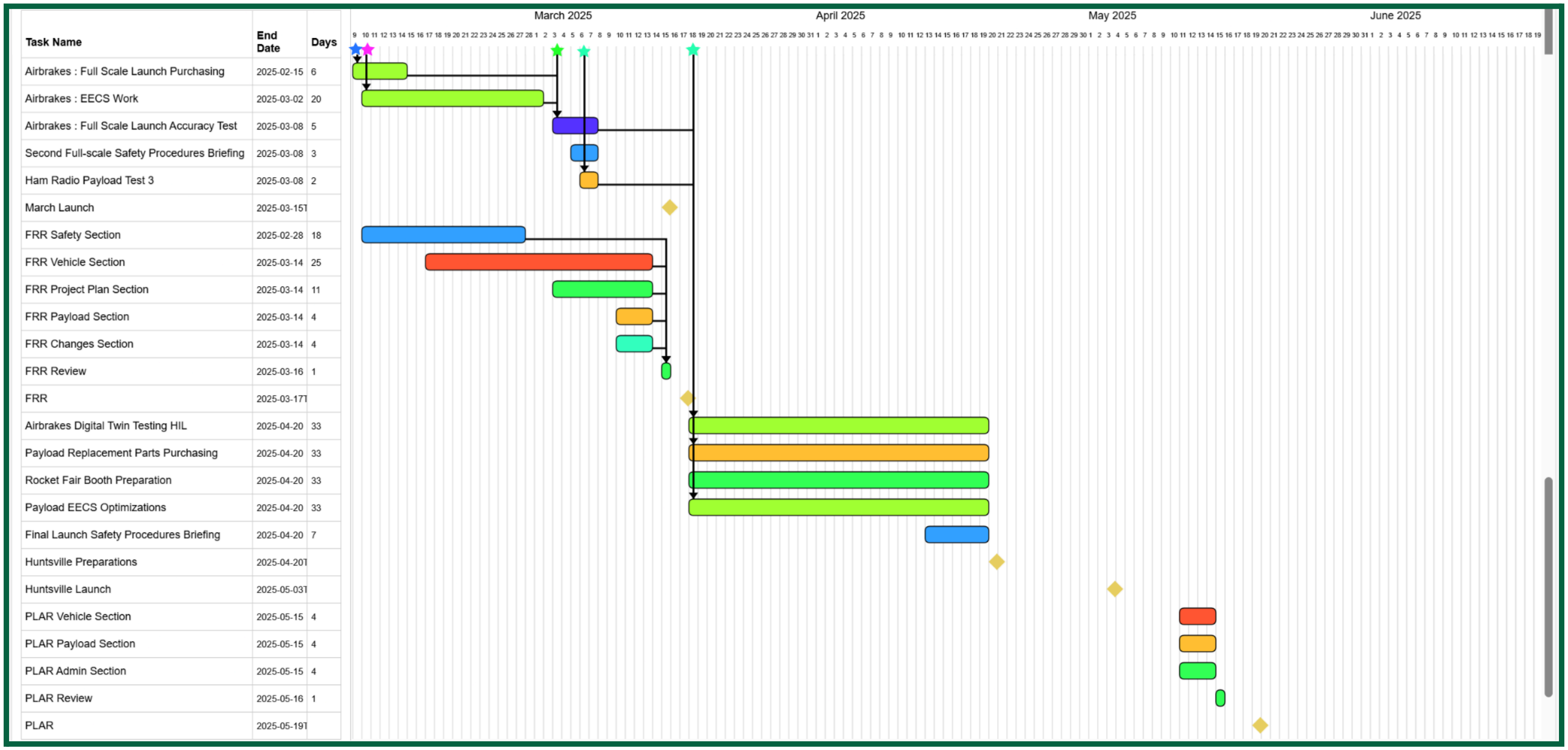


Figure 128. Gantt Chart Part 4