Northville High School Aerospace Club

Project Rooni
Critical Design Review

1/8/2025

45700 Six Mile Rd, Northville, MI 48168

Table of Contents

1.0 Team Summary Page

Team:	Northville HS Aerospace Club Northville High School 45700 Six Mile Rd Northville, MI 48167	Instagram: Facebook:	@officialnhsaerospace @Northville High School Aerospace Club
Mentor:	Andrew Brown (NAR L2 108157/TRA L3 20959) Tel: 734-674-7869 andrew.r.brown@sbcglobal.net	Twitter/X: Website:	@NHSAerospace https://nhsaerospace.github.io/
Attend Huntsville:	Yes	CDR Hours:	274
Official Target Altitude: 4000 ft			
Motor Selection:	Primary: K1103X Secondary: K805G		
Size/Mass:	Sustainer:	60 in / 8.679 lbs	
	Payload:	48 in / 7.111 lbs	
	Capsule:	20.1 in / 3.21 lbs	
	Dry Mass Without Ballast:	18 lbs	
	Dry Mass With Ballast:	19 lbs	
	Wet Mass:	22.2 lbs	
	Burnout Mass:	20.82 lbs	
	Landing Mass:	20.82 lbs	
Recovery System:	Dual deploy with drogue parachute released at apogee, followed by the main parachute at a pre-programmed descent altitude. The recovery harness will include both Quicklinks and Kevlar. **Drogue:** 18” elliptical parachute, deployed at apogee with backup at apogee + 2 seconds. 30 ft ⅜” tubular Kevlar harness. **Main:** 78” elliptical parachute, deployed at 650 ft with backup at 500 ft during descent. 25 ft ⅜” tubular Kevlar harness.		
Rail Size:	1515, 12 ft		
Payload Title:	NHS Aerospace Sensor Module		
Payload Description:	A STEMnaut flight capsule capable of collecting, transmitting and meaningfully interpreting telemetry including acceleration, velocity, altitude, and crew member orientations.		

2.0 Changes Made Since PDR

2.1 Changes Made to Vehicle Criteria

Minor adjustments to the full-scale airframe design have been made since the PDR to improve flight characteristics influenced by the subscale flight behavior. This is mainly to pre-compensate for a probable shift in the center of gravity (CG) during the assembly. The adjustments include:

- Simulated static stability margin increase: The pre-construction simulated stability of the full-scale vehicle has been increased to 4.63 to accommodate potential CG shifts post construction.
- Fin height increase: The maximum fin height has been increased from 3.75 inches to 4.25 inches to provide better aerodynamic resistance during the first 1000 ft of launch.
- Booster length increase: The booster length has been increased from 4 ft to 5 ft to provide a controlled vertical ascent.

2.2 Changes Made to Recovery Criteria

The recovery subsystem for the full-scale has been adjusted to accommodate minor changes in the vehicle criteria. The changes include:

- Recovery harness attachment: The recovery harness attachment has been changed from a Y-harness to a plugged motor attachment due to the increase in booster tube length based on feedback during the PDR presentation. This removes the need for U-bolts attached to the forward centering ring and simplifies serviceability and inspection of the harness leader.
- Forward centering ring: The U-bolts holes were removed from the forward centering ring.
- Swivel: A large stainless steel swivel was added between the leader and the drogue harness. This is to prevent excessive twisting of the harness transferring to the forged eye bolt on the plugged closure possibly unthreading the eye bolt.
- COTS harness set: The vehicle is going to be using a harness set from OneBadHawk instead of fabricating our own harness set. The specification of the COTS harness is identical to the harness specification presented in the PDR.
- CONOPS adjustment: The primary main parachute deployment has been increased to an altitude of 650 ft front the previous 600 ft to provide additional margin for the parachute to deploy and inflate by 500 ft.

2.3 Changes Made to Payload Criteria

Minor changes have been made to the payload to better optimize overall performance as final design requirements are solidified and physical prints of parts are available. The changes include:

- The addition of a battery brace.
- Increase ballast holder volume.
- More secure mounting of the ballast holder to the main mount.
- Optimized heat-set insert holes (placement of electronics remain the same).
- Minor increase in various part thicknesses and fillet radii to add overall strength.

2.4 Changes Made to Project Plan

Minor changes and updates have been made to the project plan. The changes include:

- Derived requirements were updated or eliminated due to suggestions made by the panel in the PDR presentation.
- Additional funding received from Evigia Systems.

3.0 Vehicle Criteria

3.1 Mission Statement

Our team aims to gain critical rocketry-related knowledge and inspire future generations of students by uniting curiosity, innovation, and entertainment through constructing high-powered rockets.

The following criteria will be used to determine if our project is a success:

- Design and construct a rocket that is structurally sound and stable through all aspects of flight.
- Successfully use a radio link to transmit and receive useful data payload data for analysis.
- Influence and inspire enough people to ensure the sustainability of both this club and the aerospace industry.
- Successfully complete all required NASA and derived aspects of the mission.
- Complete the project in a cost-effective manner.

3.2 Final Design Selection

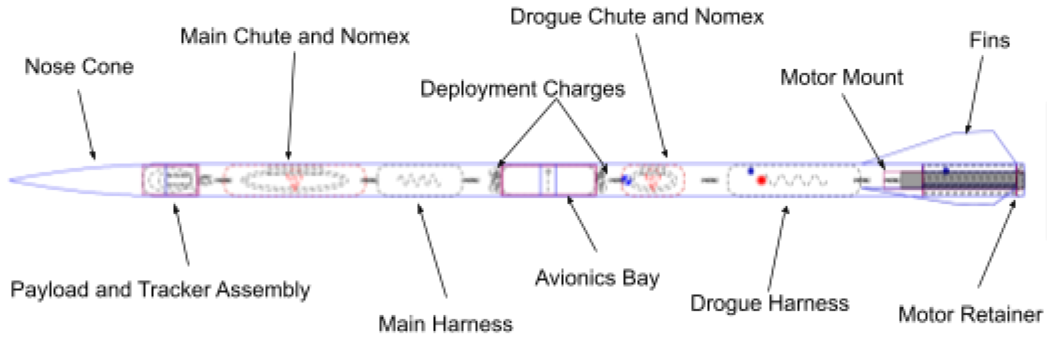


Fig. 1 - Final design topology selection

The design was fairly advanced at the time of the PDR and most design and component selections were already presented. The overall approach to the design is based on having the simplest and most reliable design to meet the NASA SLI program and the team-derived requirements. After two design choices were evaluated, namely a head-end deploy and a conventional dual deploy airframe, the conventional dual deploy best met the needs of the mission while allowing ample room for recovery and experimental payload.

In the conventional dual deploy configuration, the drogue parachute event point of separation is between the avionics bay (coupler) and the booster. This section is secured during boost by three 2-56 nylon shear pins to prevent drag and pressure separation. The main parachute event point of separation is between the nose cone and the payload tube. This is held together with three 4-40 nylon shear pins to prevent the main parachute from deploying accidentally at apogee. The deployment charges are held in charge wells on either side of the avionics bay coupler.

The center of gravity at burnout for the full-scale vehicle is 77.81 in from the tip of the nose cone.

The material set for the airframe was also evaluated during the PDR phase looking at a variety of different materials. Based on strength and robustness against moisture, (LV-C-1, LV-C-2) both carbon fiber and fiberglass met our requirements; however, carbon fiber was cost prohibitive for our budget (LV-D-5), attenuated RF transmissions (P-D-2, P-C-1), and was difficult to obtain with minimum performance improvement. Ultimately, the design requirements called for a fiberglass airframe.

3.3 Finished Component Specifications

The following components have been modelled using Onshape and represent the components for the full-scale vehicle. The components have been updated with changes determined to be necessary for the mission success.

3.3.1 Body Tubes

The entire airframe is of a uniform diameter with no transitions. Due to our experience and short design cycle, we felt a uniform diameter can achieve the required performance metrics without adding unnecessary complexity with a stepped diameter airframe.

The airframe is 4” in diameter, to allow for easy access to internal components and the payload (which has a diameter of 3.740”). A 4” diameter also provides enough space to safely pack a 6.5’ main parachute, thus minimizing the risk of damage during ejection and the failure to deploy which comes as a result of overly tight packing.

The total length of the rocket, including the nose cone, is 10.83’, with a simulated static stability of 4.63 caliber (LV-D-1) and an aspect ratio of nearly 32:1.

The booster tube has been increased in length to 5’ to increase stability and maximize the vertical orientation of the full-scale vehicle while it experiences weathercocking. This has been explained in Section 4.4 Impact on Full-Scale Vehicle.

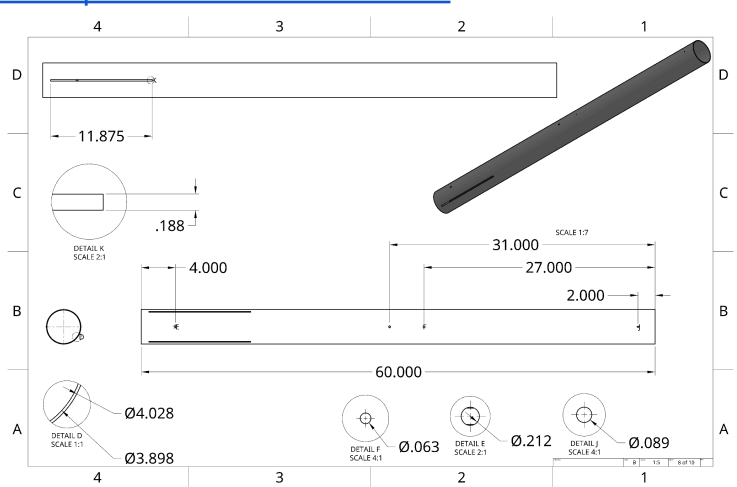


Fig. 2 - Booster tube drawing

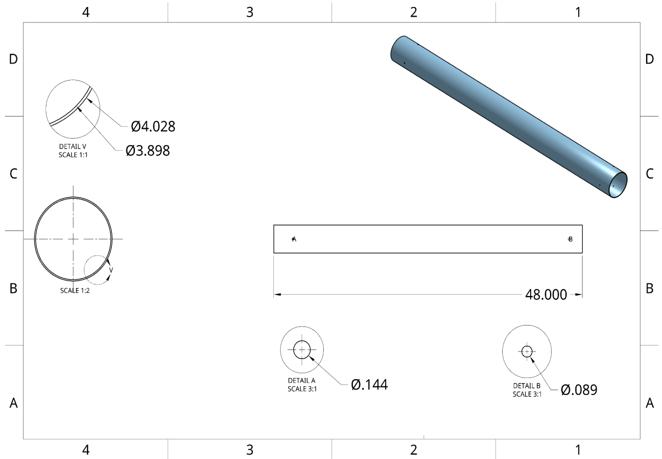


Fig. 3 - Payload tube drawing

Table 1 - Body Tube Parameters

Booster tube			Payload tube	
Parameter	**Value**		**Parameter**	**Value**
Material	FW fiberglass		Material	FW fiberglass
Length	60 in		Length	48 in
Outer diameter	4.028 in		Outer diameter	4.028 in
Inner diameter	3.898 in		Inner diameter	3.898 in
Number of slots	3			
Fin slot length	11.875 in			
Fin slot width	0.1875 in			

3.3.2 Motor Mount, Centering Ring, and Motor Retention

The motor mount is 54 mm in diameter and 18” in length. Though our motor fits a 15.77” Aerotech 54/1706 case (LV-M-1), the longer length allows for easier access to recovery hardware and a broader selection of motors.

Within the motor mount, there are three identical centering rings which act as supports. The primary attachment for the recovery device is through an eye bolt attached to the motor casing’s forward closure. This has been implemented due to the increase in booster tube length that has made reaching down difficult. The forward centering is in place to provide an additional centering point for the motor mount. It reduces the volume needed to pressurize during recovery device deployment events and acts as a force distributor for the forces faced by the motor mount during recovery deployment events.

The aft centering ring is adhered immediately below the aft side of the fin slots, while the middle centering ring is adhered immediately above the fin slots. These positions isolate the fin slot area, allowing for us to inject internal fillets for strengthening bond purposes.

The centering rings are uniform in size and have an outer diameter of 3.898” and an inner diameter of 2.228”, matching the inner diameter of the booster tube and the outer diameter of the motor mount tube, respectively.

At the aft end of the motor mount, an aluminum screw cap retainer is epoxied for strong retention and easy removal, satisfying Requirement 2.22.5.

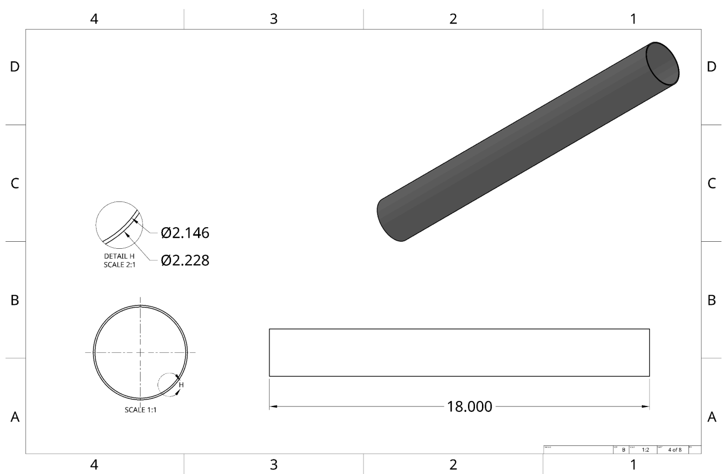


Fig. 4 - Motor mount drawing

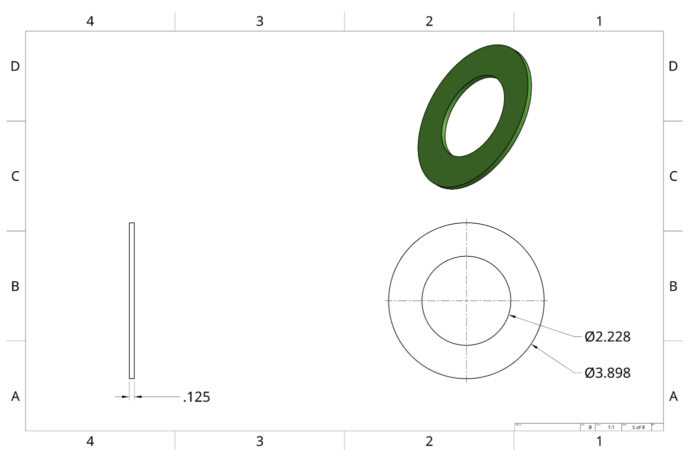


Fig. 5 - Centering rings

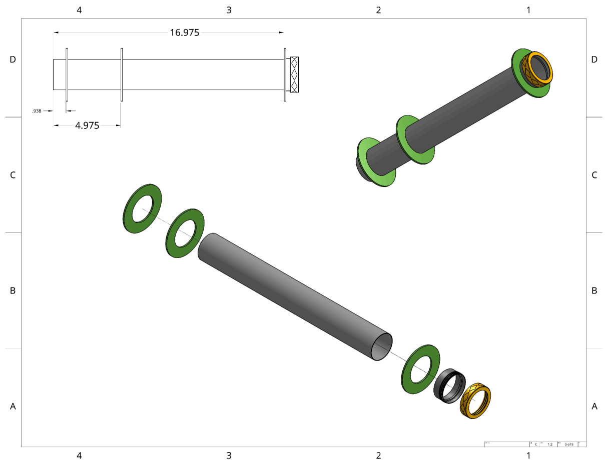


Fig. 6 - Motor mount assembly

Table 2 - Motor Mount and Centering Ring Parameters

Motor mount			Centering rings	
Parameter	**Value**		**Parameter**	**Value**
Material	FW fiberglass		Material	G10 fiberglass
Length	18 in		Outer diameter	3.898 in
Outer diameter	2.228 in		Inner diameter	2.228 in
Inner diameter	2.146 in		Thickness	0.125 in

3.3.3 Avionics Coupler

The coupler houses both the avionics equipment and the main and drogue parachute deployment charges. The coupler fits within the 4” diameter airframe with an outer diameter of 3.898”. There are several holes in the coupler for screws, shear pins, altimeter-arming access, and 3.25” vents.

With a length of 12”, the coupler has 5” shoulders extending each side into the booster and payload tubes, leaving a 2” switch band. The dimensions exceed the requirements of 2.4.1 (as well as the less stringent requirement 2.4.2) with a length 2.5x the diameter of the coupler and 1.25x the airframe diameter in contact with the body tube (2.5x if counting both ends) (LV-C-10).

The coupler sleeve, or switch band, features ventilation holes to prevent a buildup of pressure and allow access to the switches that enable the arming of the altimeters (Requirement 3.6).

The bulkhead holds all ejection charge hardware and ensures proper function during flight. The bulkhead includes holes for the threaded rods and U-bolts. Four 0.122” diameter holes secure the charge wells and another four 0.138” holes are electrical feedthroughs which connect the altimeters to the E-matches. These components have been described in 5.3.3 Recovery Hardware Selection and Sizing.

The front bulkhead connects the main parachute hardware harness to the nose cone, while the aft bulkhead connects the drogue parachute harness to the forward bulkhead within the motor mount, ensuring proper deployment of both parachutes during flight.

The coupler is secured to the payload tube with a series of #8-32 x ¼” stainless steel screws, which are threaded into the coupler with matching internal PEM nuts. The screws allow disconnection of the payload tube and coupler, thus providing access to recovery attachment points and ejection charge terminals and wells. The coupler also includes three holes dedicated for 2-56, ¼” shear pins to secure the coupler to the booster. The shear pins have been described in 5.8 Shear Pins.

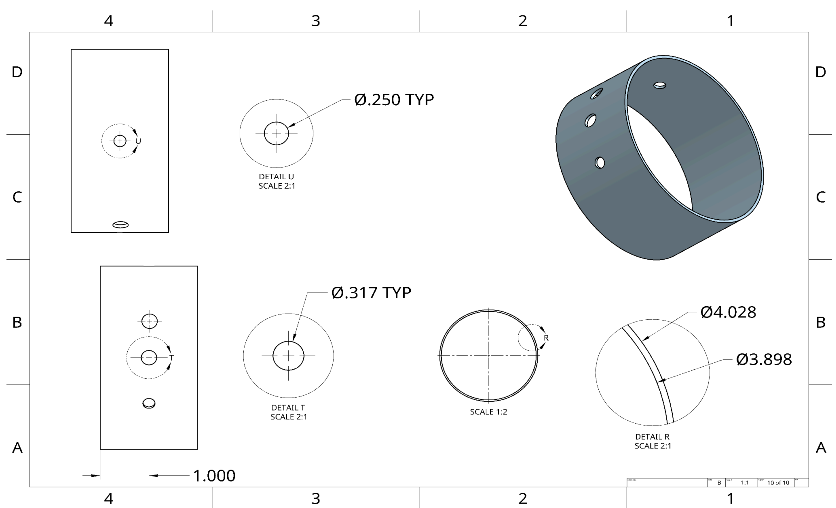


Fig. 7 - Coupler sleeve drawing

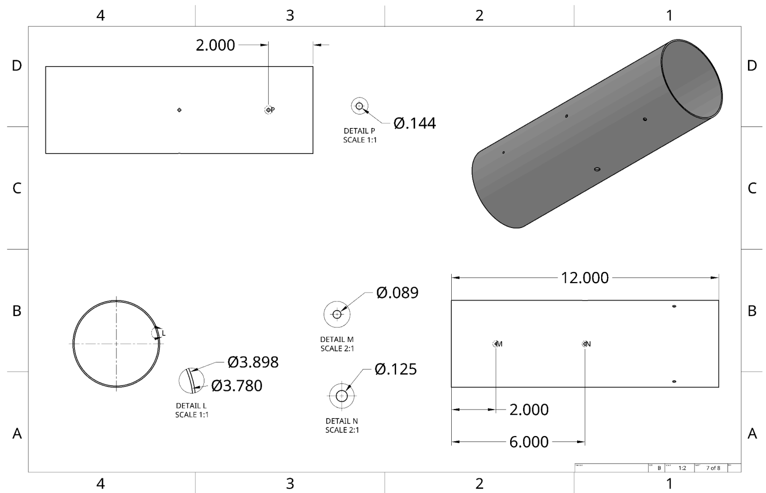


Fig. 8 - Avionics tube drawing

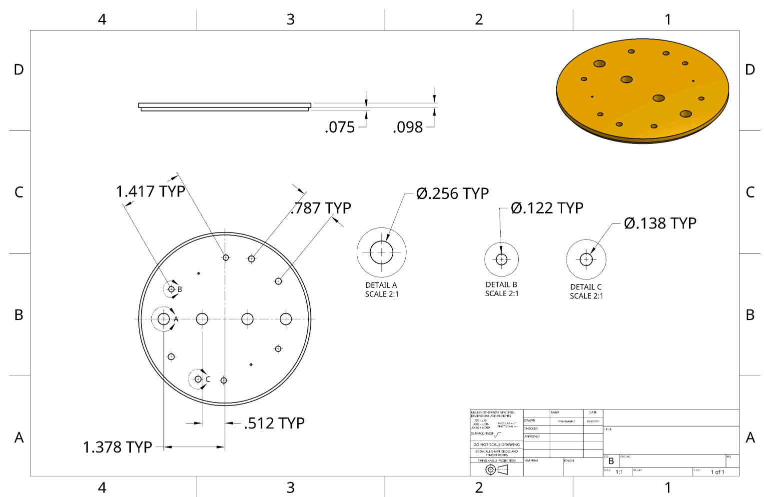


Fig. 9 - Avionics bulkhead drawing

Table 3 - Coupler/Avionics Bay Parameters

Coupler			Switch band	
Parameter	**Value**		**Parameter**	**Value**
Material	FW fiberglass		Material	FW fiberglass
Length	12 in		Length	2 in
Outer diameter	3.898 in		Outer diameter	4.028 in
Inner diameter	3.78 in		Inner diameter	3.898 in

3.3.4 Fins

The fin size has been changed from the PDR due to data analyzed from the subscale launch. The subscale flight will be described in section 4.0 Subscale (Rooni Jr) flight analysis. The vertical orientation of the rocket as it left the launch rail was approximately 70°. About 10° was expected due to the elevated winds. However, we believe that the additional 10° that was observed was due to lower than expected dynamic stability. This is detailed more in section 4.4 Impact on Full-Scale Vehicle, but the main reasons for the shift were:

- Differences in mass for physical components vs. original design values: The OpenRocket material database did not result in the same mass as the physical components. All design was performed prior to ordering components. This resulted in a shift in the center of gravity towards the aft of the airframe, decreasing stability.
- Unexpected shifting of the center of gravity during airframe assembly: While all attempts were made to estimate the amount and placement of adhesives used, the center of gravity continued to shift towards the rear of the airframe during assembly. This decreased the stability further.

In order to compensate for these potential shifts, the full-scale airframe is designed for added stability, assuming that the center of gravity will shift back a little after assembly. The fin height has been increased from 3.75 inches to 4.25 inches. This allows us to keep the trapezoidal shape while increasing the surface area of the fin. This increases the rocket's ability to withstand aerodynamic instabilities and makes it more resistant to weathercocking. The overall shape of the fin remains trapezoidal as it provides high impact resistance upon landing, induces moderate drag and is aesthetically pleasing. Trapezoidal fins are easier to bevel and analyze since they are made up of simpler shapes.

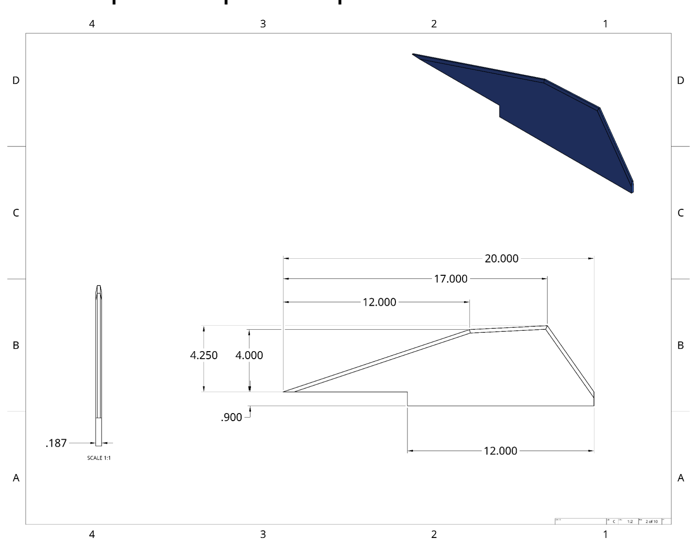


Fig. 10 - Fin drawing

Table 4 - Fin Parameters

Parameter	Value
Fin material	G10 fiberglass
Length	20 in
Max height	4.25 in
Thickness	0.187 in
Bevel angle	11.25°
Bevel distance	0.45 in
Fin tab length	12 in
Fin tab width	0.9 in

3.3.5 Nose Cone

The nose cone is a commercially available fiberglass cone which is RF transparent, allowing the tracker and payload to transmit location and data without major attenuation (LV-C-7). It is ogive in shape, 20” in length, and has a weight of 1.55 lbs.

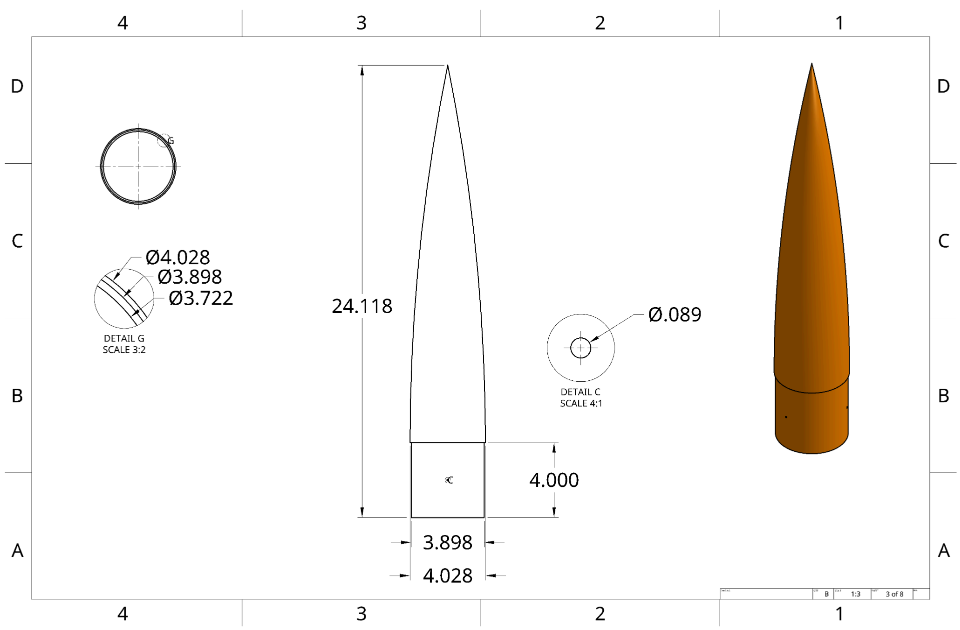


Fig. 11 - Nose cone drawing

Table 5 - Nose Cone Parameters

Parameters	Value
Length	20.118 in
Outer diameter	4.028 in
Nose cone shoulder length	7.000 in
Nose cone shoulder outer diameter	3.898 in
Nose cone shoulder inner diameter	3.78 in

3.3.6 Airframe Weight Estimate

At the time of the PDR, the airframe was not yet acquired. All weights in the original design were based on standard OpenRocket density values for fiberglass and the vendor specified geometry for the components. Since PDR, the airframe components have been acquired and their weights measured. The weight values of the airframe components are listed in the table below. As the table shows, there is a significant difference in the measured weight vs. the original calculated weights. For all of the flight analyses, the actual weight plus the best estimate for adhesives and other components will be used.

Table 6 - Preliminary Airframe Weight Estimates

Component	Original OpenRocket weight (lbs)	Actual measured weight (lbs)
Nose cone	1.28	1.55
Payload tube	2.18	3.09
Booster tube	2.18	3.69
Motor mount	0.28	0.39
Centering rings x3	0.21	0.23
Coupler sleeve	0.09	0.13
Avionics Coupler	0.48	0.50
Bulkhead x2	0.10	0.51
Trapezoidal fins	2.73	2.39
Total	**9.53**	**12.48**

3.4 Full-Scale Readiness

The subscale results will be presented in the following section. These results will show that the airframe design does fly well. However, there is room for improvement in stability. This was primarily the result of the center of gravity shifting when going between design, fabrication, and assembly. As a result, the full-scale design was modified slightly to result in higher *as designed* stability. It is expected that we will lose some of this stability during the assembly process.

Due to an aggressive program schedule coupled with difficult weather to fly, fiberglass was ordered shortly after the subscale flight and has been delivered. This includes the extended booster tube section as well as slightly larger fins. At this time, all structural components of the airframe assembly are in our possession.

Fig. 12 - Full-scale fiberglass components ready for construction

4.0 Subscale (Rooni Jr) Flight Results

As the full-scale project is named Rooni (an anagram for the Orion Capsule), the subscale project has been affectionately named Rooni Jr.

4.1 Subscale Design and Assembly

The subscale rocket was based on an approximate 50% scaling factor from the full- scale design presented in the PDR. The 50% level allowed us to build a 2.1”, or 54 mm, airframe with 38 mm motor mount in as close to an exact geometric scaling factor as possible. The 38 mm motor mount allows for a very wide variety of suitable motors ranging from small H’s to large I’s. All CAD models and component specifications are listed in Appendix F.

Not all components can be scaled equally and not all parameters scale. For example, as one goes smaller with a body tube size, a geometric scaling of 50% provides considerably smaller scaling of mass as mass is a volumetric effect. In addition, the tube sidewalls are relatively thinner for smaller body tubes, compounding the difference in mass. As a result, while most major aerodynamic parameters have been scaled by 50%, not all physical parameters are scaled correctly. Also, several components, such as trackers, altimeters, batteries, etc do not scale at all. The proportion of the body tube lengths have been adjusted to set the as-designed CG in the exact same relative position as the full-scale. Please note that these were based on design values with a reasonable margin of error. The main differences are:

- Subscale masses were based on actual fiberglass masses
- Full-scale models were based on modeled masses within OpenRocket’s standard density values for manufacturer specified dimensions.
- Adhesive weights and distributions were estimated.

In addition, the surface finish of the subscale rocket is based on painting and clearcoat in suboptimal, cold conditions. The full-scale will have a polished clear coat, reducing aerodynamic friction where the subscale’s paint surface is slightly rough due to spraying paint in cold temperatures and not having time to polish the clearcoat.

Table 7 - Subscale Airframe Scaling Parameters

Parameter	Dimension	Geometric scaling factor	Mass scaling factor	Notes
Booster body tube	Diameter	50%	15%	• Length not exact to match CG. • Mass does not scale exact (volume vs. linear)
	Length	57%		
Payload body	Diameter	50%	14%	• Length not exact to match CG.

tube	Length	43%		• Mass does not scale exact (volume vs. linear).
Avionics coupler	Diameter	50%	18%	• Length larger than 50% to accommodate the avionics bay.
	Length	58%		
Motor mount	Diameter	70.4%	24%	• Motor mount diameter scaling is restricted due to availability of motors. • 38 mm motor mount selected as it provides the widest range of comparable motors to full-scale.
	Length	67%		
Centering rings	Outer diameter	50%	19%	• As the motor mount is not a perfect scaling, the inner diameter is not as well. • Standard centering rings available from vendor are all ⅛”.
	Inner diameter	70.4%		
	Thickness	100%		
Fins	Overall shape	Identical shape, scaled 50%	11%	• Exterior shape is identical with uniform geometric scaling • Fin tabs could not be scaled uniformly due to motor mount restrictions.
	Fin tabs	Length scaled 50%, depth 33%		
	Fin thickness	50%		
Nose cone	Overall shape	Identical shape factor	38%	• Nose is identical in shape (5:1 ogive) with scaling for reduced diameter.
	Diameter	50%		
	Length	50%		

The subscale demonstration was as much of a “dress rehearsal” for the full-scale as it was a verification of the stability of the design. The subscale demonstration vehicle had all of the same functionality of the full-scale flight vehicle minus the payload. Additional nose weight was added to emulate the flight effects of the payload. The functionality included full redundant dual deploy using the same models of flight computers that will go into the full-scale. The airframe used the same base material sets, while the parachutes and recovery system used scaled versions. Even the GPS tracker used was identical to what will fly in the full-scale flights. As a result, this demonstration flight served as an introduction to preparation for launch, evaluation of checklists, the complexity of dual deploy, and the ground testing demonstration.

The subscale was built using the construction methods stated in Section 5.1, Construction Methods, in our 2025 SLI Proposal. These methods included:

- Fiberglass preparation for optimum bonding.

- Selection of epoxies used for structural integrity and resistance to heat where appropriate.
- Proper use of epoxy additives to modify their properties.
- Injected internal fillets for maximum coverage.

Fig. 13 - Motor mount preparation, payload tube screw holes

After the airframe was assembled, the rocket went through the deployment charge demonstration verification, or "ground testing."

Fig. 14 - Ground test result - drogue ejection

The results of the ejection charge ground testing are shown below. It should be noted that the drogue had one 2-56 shear pin and the main had three 2-56 shear pins. There was a substantial difference between the hand calculations, the spreadsheet, and the final ground test results. The ground testing took a few iterations to determine the adequate amount of black powder to ensure enough separation to pull the recovery cleanly from the airframe, but not too much to overextend the recovery harness.

Table 8 - Subscale Black Powder Ground Testing Results

	Hand calculations	Spreadsheet calculations	Final values based on test (primary/backup)
Drogue Parachute	0.2 g	0.4 g	0.9 g / 1.1 g
Main Parachute	0.6 g	1.0 g	1.0 g / 1.2 g

The original design used vendor specified dimensions and OpenRocket standard density values for fiberglass, actual masses for recovery components, and best estimates for epoxy masses. Once fiberglass components were delivered, the masses were updated and results were recalculated. This shifted the center of mass slightly towards the rear of the launch vehicle. The airframe assembly was distributed among members that had less experience with rocketry. As a result, some of the internal fillets were more on the “robust” side, adding even more weight to the aft side of the launch vehicle. More details on the shift of the center of gravity and its impact will be presented in Section 4.3 Subscale Flight Analysis.

4.2 Subscale Flight Conditions and Observations

Fig. 15 - Subscale launch at Tripoli Mid-Ohio

The subscale launch occurred on December 7, 2024 at Tripoli Mid-Ohio (TRA Prefecture 31, South Charleston, OH), under weather conditions typical of the Midwest, where unpredictable weather patterns often reduce opportunities for launches. The Tripoli Mid-Ohio field is a flat, open farm field where the corn has been harvested.

Table 9 - Subscale Launch Conditions

Condition	Value		Comments
Temperature	28° F		
Barometric pressure	30.26 in-Hg		
Wind speed (overall, gust)	12 mph	17 mph	Initial wind on launch day was 12 mph, during the subscale launch a gust brought winds to 17 mph
Ground Altitude	1087 ft		
Latitude	39.85°		
Longitude	-83.66°		
Cloud Cover	20-30%		
Lower Cloud Ceiling	22,000 ft	8,000 ft	First estimated to be 22,000 ft but closer to 8,000 ft near launch.
Rail Size	1010	8 ft	
Motor used	I161W		Chosen to keep the rocket comfortably under the cloud ceiling.

The preparation of the rocket followed the draft pre-flight checklist (8.1 Launch Preparation and Operating Procedures). As part of our pre-launch checklist, the CG was measured in the field by balancing the rocket and identifying the point of equilibrium. This method provided a rough estimation, as precise measurements were challenging due to the launch conditions. The CG was estimated to be 35.0 inches from the tip of the nose cone. The distance between the CG and the CP was measured to be 4.25 inches. Given the 2.1” diameter airframe, this sets the stability at 2.0 caliber.

After the pre-flight checklist was completed, the rocket was inspected by the RSO. All questions regarding the construction and flight readiness were answered and the rocket was loaded onto the pad following 8.1.10 Setup on Launch Pad Checklist. The launch system did not use a rail with adjustable angles. The pad was oriented with the rail 90° vertical.

Table 10 - Stability Measured at Field vs. Simulation

Method	CP	CG	Stability
OpenRocket	39.25 in*	32.8 in	2.9 caliber
Measured at Field	39.25 in*	35.0 in	2.0 caliber

* CP was assumed from OpenRocket Simulations

Fig. 16 - Rocket inspection by Tripoli Mid-Ohio Prefect Andrew Kleinhenz (left), and Rooni Jr being loaded onto the pad (right)

Fig. 17 - Launch of subscale, Rooni Jr, on an Aerotech I161W on 12/7/2024

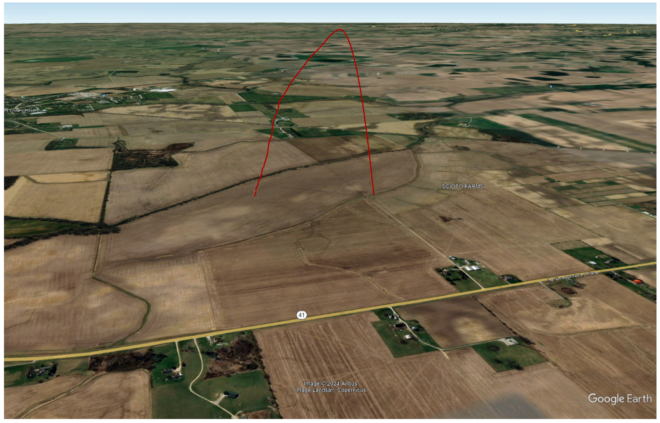


Fig. 18 - GPS flight profile of subscale launch

Fig. 19 - Post flight landing of Rooni Jr. All parts attached and intact after nominal recovery

The initial weather predictions showed an average wind speed of 10-15 mph. However, field conditions also showed fairly large wind gusts. The wind was blowing from northwest to southeast. This was extremely close to the safety limit of 20 mph winds. As the rocket launched, it moved in an arc orthogonal to the wind. Slight weathercocking was expected due to the unusually high winds during the launch. However, the arcing exhibited was greater in magnitude and in a different direction than modeled values. Rooni Jr. arced 20 degrees from vertical. Apart from the initial anomaly of arcing, the rocket achieved a maximum altitude of approximately 2150 ft. The rocket deployed its drogue chute at apogee and the backup charge was observed to fire approximately 2 seconds after primary ejection. Due to extreme wind conditions, the main primary deployment event was set at 450 ft and the secondary event at 350 ft. The main parachute was deployed with the primary ejection charge and the secondary ejection charge was observed a few seconds later. Rooni Jr descended to the ground 1619 ft from the launch pad. No damage was observed to any part of the rocket. The figure above shows the final landing state of the rocket. As the rocket was spread out over 40 ft with a long recovery harness, and the airframe blended in with the corn field, zoomed photos are also included for each section.

Fig. 20 - Post flight team photo of subscale flight

4.3 Subscale Flight Analysis

There were some discrepancies between the altimeter data, the GPS data, and the simulated results. The following section includes data and analysis from the subscale flight and attempts to address these differences.

4.3.1 Raw Data from On-Board Electronics

The subscale project was flown with two data logging altimeters/flight computers (Eggtimer Quantums) as well as a GPS tracking unit (Featherweight GPS Tracker) which also had data logging capability. These units also calculate the vertical velocity based on the change in altitude vs. time and record this value as well. The graphs below show the raw data measured by the electronics on board the subscale vehicle.

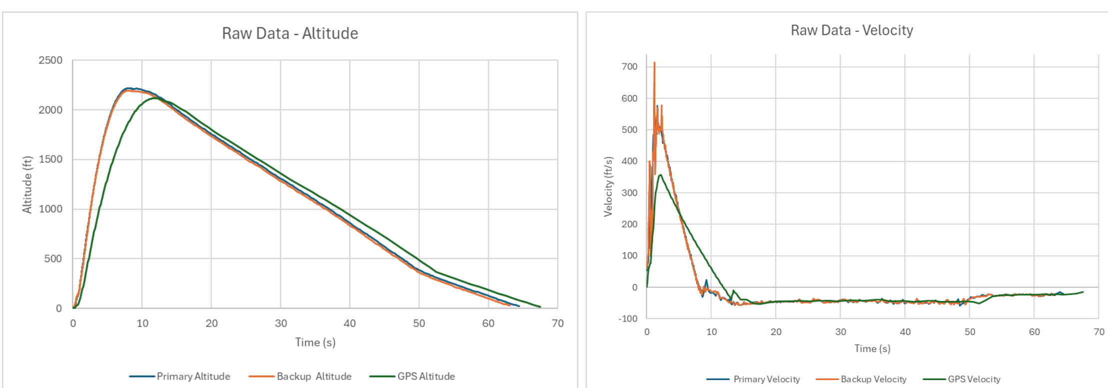


Fig. 21 - Raw measured data for altitude and velocity

Table 11 - Extracted Maximum Altitude and Velocity from Raw Data

Device	Maximum Altitude	Maximum Velocity
Primary Altimeter	2217 ft	587 ft/s
Backup Altimeter	2194 ft	579 ft/s
GPS Tracker	2118 ft	357 ft/s

The extracted maximum altitude and velocities are shown in the table above. There is a considerable difference in the overall shape and amplitude of the altitude and velocity values between the two methods. Overall, the difference between the two altimeters is fairly close (about 1%). The difference in the velocity values between the altimeters is largely due to noise spikes in the data. The accuracy and interpretation of these measurements will be discussed in the next section.

4.3.2 Corrected Data from On-Board Electronics

The altimeter fundamentally measures barometric pressure and converts this value to altitude. The equations used for the conversion are based on a standard temperature of 59° F. For any values outside of this temperature, a correction factor needs to be applied to find the actual altitude as the altimeter does not correct for this. Below is the equation that corrects the altitude recorded by the Eggtimer Quantum altimeters.

$$Altitude_{Corrected} = \frac{Altitude_{Raw} \times \left(273.1 + (Temp - 32) \times \frac{5}{9}\right)}{288.15}$$

As the temperature of the launch was 28° F, the reported altitudes from the two altimeters were actually higher than the actual altitude. Below is a graph comparing the raw altitude data to the temperature corrected altitudes.

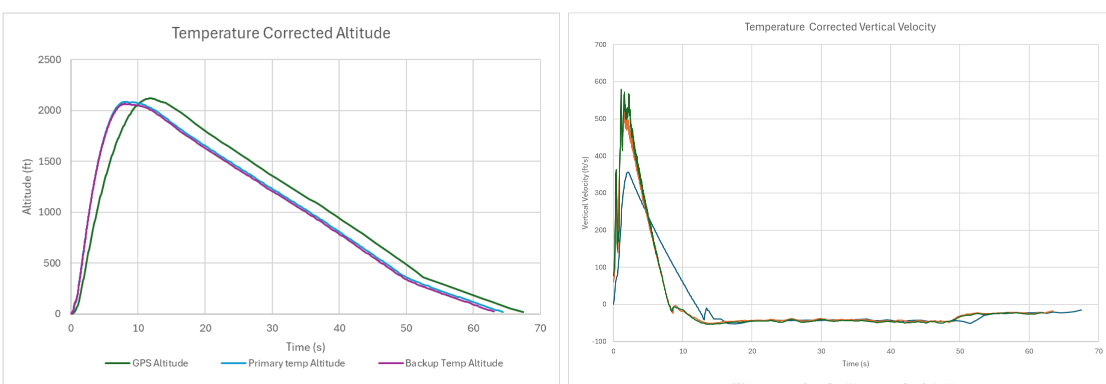


Fig. 22 - Temperature corrected altitude and velocity

Table 12 - Extracted Maximum Altitude and Velocity from Temperature Corrected Data

Device	Maximum altitude (ft)	Maximum velocity
Primary Altimeter	2084.49	551.6 ft/s
Backup Altimeter	2063.22	544.77 ft/s
GPS Tracker	2118	357 ft/s

With the temperature correction in place, the maximum altitude levels now agree well between the two altimeters and the GPS tracker. There is a minor difference at apogee, but this may be explained due to the high pressure deployment event at separation. However, the timing of the events between altimeters and GPS do not agree. This is very clear not only at apogee, but at all deployment events. It is believed that the barometric pressure sensors have a minor latency of measured altitude compared to actual altitude during rapidly changing pressures, such as during the boost and coast phase of the launch. During this period, there is a time lag as air escapes the small pressure release holes in the avionics bay. The GPS altitude measurements do not have this lag as the GPS does not rely on air pressure to determine altitude.

To match the deployment charge events with the GPS, the time for both the primary and secondary altimeters needed to be shifted approximately 3 seconds. To match the origin point to account for the lag during the boost phase, the data needed to be stretched so that the time started at time t = 0, but the deployment events matched. Below are the graphs for the time corrected and shifted altitudes and velocities for the subscale.

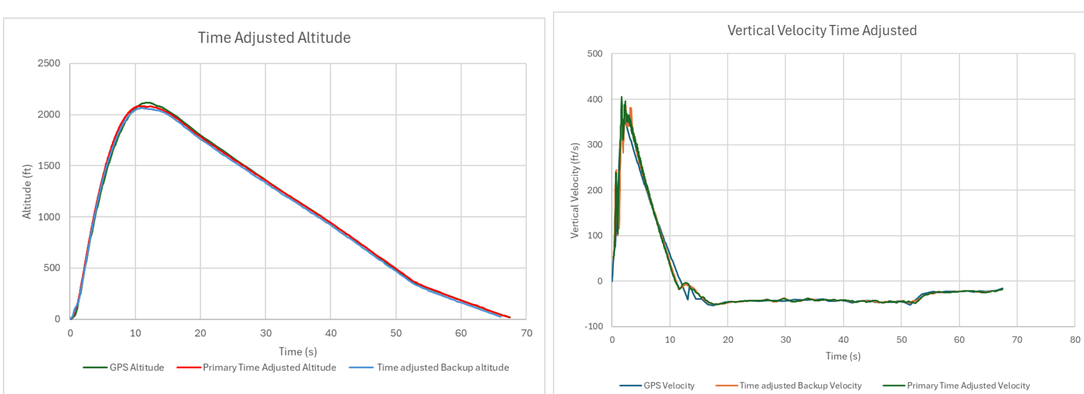


Fig. 23 - Time and temperature corrected altitude and velocity

Table 13 - Extracted Maximum Altitude and Velocity from Time Corrected Data

Device	Maximum altitude	Maximum velocity
Primary Altimeter	2084 ft	405 ft/s
Backup Altimeter	2063 ft	391 ft/s
GPS Tracker	2118 ft	357 ft/s

After adjusting the time and stretching the data, The data agrees well between both altimeters and the GPS tracker. This not only includes the amplitudes, but the overall shape of the data now lines up well. The error between the two altimeters for the altitude is approximately 1.02%. Between the GPS and the primary altimeter data is approximately 1.61%, between the GPS and the backup altimeter is approximately 2.65%. This means that the data between all electronics is fairly consistent giving us an apogee range between 2000-2100 ft.

The velocity error between GPS and the primary altimeter data is approximately 13.5%. The error between GPS and backup altimeter data is approximately 9.6%. This is again fairly consistent considering the sparse data and inherent noise levels of calculating a discrete derivative.

4.3.3 Flight Angle

As noted in 4.2 Subscale Flight Conditions and Observations, the subscale rocket had an initial shift in its velocity vector shortly after leaving the pad. By using the GPS data, we were able to analyze the flight vector vs. time and altitude. The GPS records the vertical and horizontal location vs. time and calculates the relative vector magnitudes for the velocity. By converting the vertical and horizontal velocity magnitudes into a vector angle, we can determine the vertical orientation of the rocket, assuming that the rocket is pointing in the direction that it is traveling. This data is shown below compared to the simulated result under the same field flying conditions. It should be noted that the measured field conditions were at ground level and the winds may have been greater at higher altitudes.

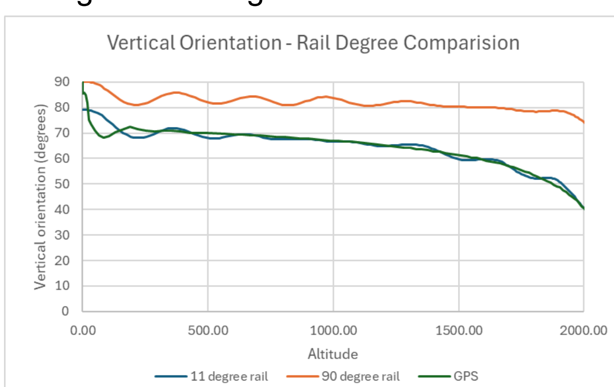


Fig. 24 - Vertical orientation simulation rail angle comparison

The subscale vehicle achieved a maximum vertical orientation of 68.69° at about 20 ft above ground. The simulations using OpenRocket and the same launch conditions indicate that we should have achieved an angle of 85-86°. It should also be noted that there were several factors that the simulation did not take into account, such as timing of wind gusts, the potential for minor variations in off-axis thrust, and friction of rail buttons. Once this initial change of orientation occurred, the flight was very straight until it reached the nose over phase right before apogee.

It should also be noted that the simulations are an approximation for real-world events and do not represent all conditions. The measured data is always the most important factor in interpreting test results. Factors that could have attributed to this include:

- Small fins: The size and shape of the rocket's fins play a critical role in stabilizing its flight path. Smaller fins reduce the rocket's ability to counteract external forces leading to higher chances of instability or a higher tilt angle in the first 100 ft after launch.
- High wind gusts: During the launch, the wind picked up from an average of 12 mph to 17 mph with potentially higher gusts based on surface wind measurements. Based on observing other flights, the wind may have been considerably higher at increased altitude.
- Reduced stability with build and preparation: The simulated static stability prior to ordering any components and assembly for the subscale was set at 3.0 calibers. Once the physical weight of the components was measured, there was a shift in the center of gravity. This was later shifted more after assembly. We found that the stability was near 1.91 caliber without nose weight. Additional nose weight was added to shift the actual static stability to 2.0 caliber.

To enhance the accuracy of the flight simulation, adjustments were made to replicate the rocket's vertical orientation as it left the launch rail. As previously noted, the maximum vertical orientation recorded by the GPS was 69°. To reflect this, the rail angle in the simulation was set to 11°.

4.3.4 Altitude Comparison of Measurements to Simulation

The onboard electronics measured the altitude during the subscale and the altitude during the subscale flight. The simulation was performed with the launch conditions mentioned in Section 4.2 and adjusted to better align with the observed flight events. The graph below compares the measured and simulated altitude data. The subscale launch was conducted on a launch rail angled at 0 degrees.

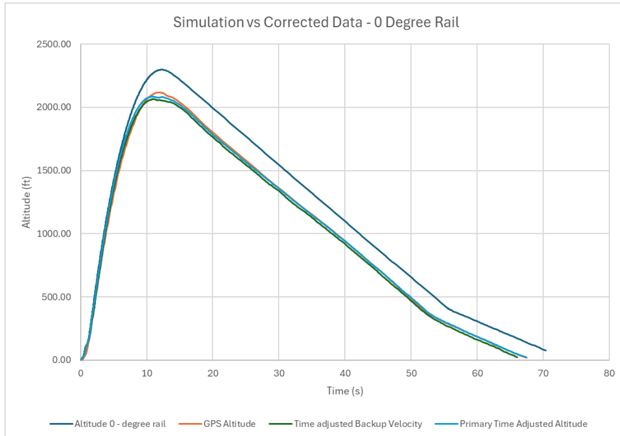


Fig. 25 - Altitude simulation comparison- 0 degree rail

The graph below shows the comparison of altitude with an adjusted rail angle of 11 degrees to mimic the behaviour of the subscale flight.

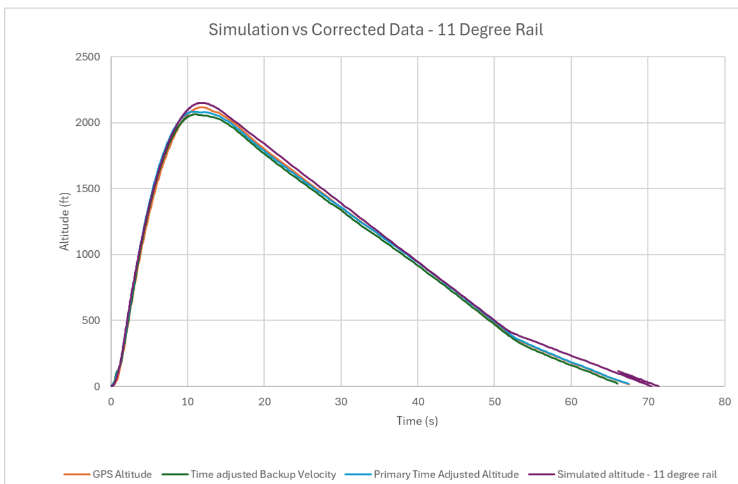


Fig. 26 - Altitude simulation comparison- 11 degree rail

Table 14 - Altitude simulation comparison

Device	Maximum altitude (ft)
Primary Altimeter	2084
Backup Altimeter	2063
GPS Tracker	2118
Simulation - 0 degree rail	2297
Simulation - 11 degree rail	2152

The 0° rail has an error of 8.5% in respect to the GPS, 10.2% in respect to the primary altimeter, 11.3% in respect to the backup altimeter. The 11° rail simulation is a better representation of the actual flight characteristics of the subscale vehicle and has an 1.6% error in respect to the GPS, 3.3% in respect to the primary altimeter and 4.3% in respect to the backup altimeter.

4.3.5 Velocity Comparison of Measurements to Simulation

The following section compares the corrected data to a simulation conducted in OpenRocket. The OpenRocket simulation has been configured to closely simulate the launch conditions during the subscale launch. Below is a graph comparing the vertical velocities recorded by the electronics on board the subscale launch to the simulation

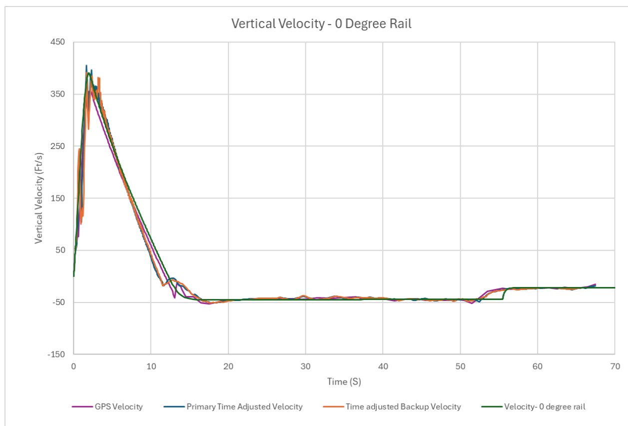


Fig. 27 - Vertical velocity simulation comparison- 0 degree rail

The graph below shows the adjusted simulation to better represent the flight characteristics of the subscale flight. The rail has been adjusted to be 11° from vertical.

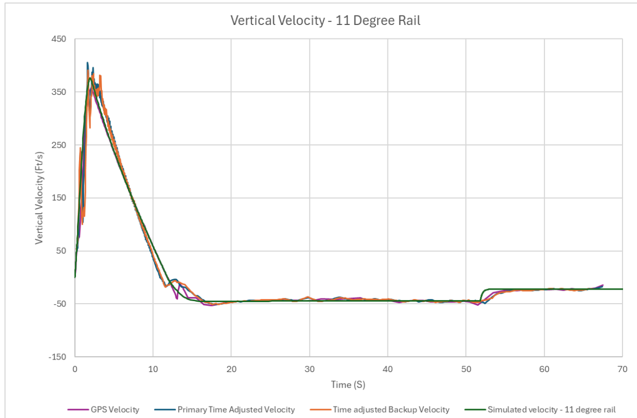


Fig. 28 - Vertical velocity simulation comparison- 11 degree rail

Table 15 - Velocity Simulation Comparison

Device	Maximum velocity (ft/s)
Primary Altimeter	405
Backup Altimeter	391
GPS Tracker	357
Simulation - 0 degree rail	390
Simulation - 11 degree rail	376

The minor change in direction of the actual flight resulted in a difference when comparing measurement to simulation. By adjusting the flight in simulation to match actual flight conditions, the data matches much better.

4.3.6 Analysis of Rates of Descent

The data obtained from the electronics for velocity is fairly consistent with the simulations as shown by the graph below. The parachute sizes selected for the subscale flight were 15 in diameter for the drogue and 26 in diameter for the main. To bring the rocket down safely and prevent structural damage to the rocket, the descent velocities were simulated to be approximately 45 ft/s for the drogue and approximately 22 ft/s.

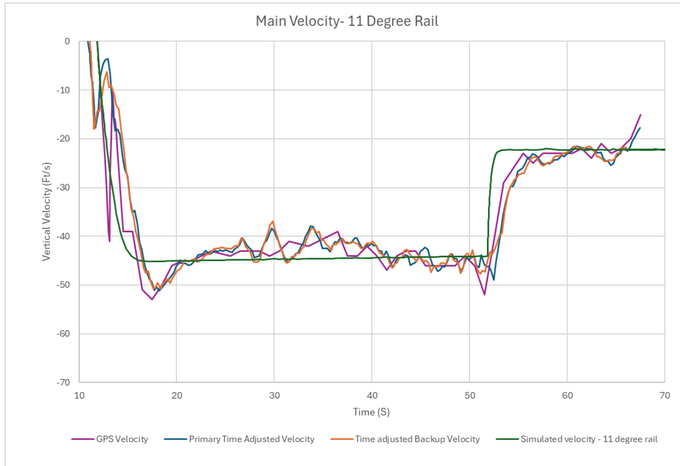


Fig. 29 - Main descent velocity - 11 degree rail

Table 16 - Descent Velocity Comparison

Device	Drogue descent velocity (ft/s)	Main descent velocity (ft/s)
Primary Altimeter	43.1	23.6
Backup Altimeter	43.1	22.9
GPS Tracker	43.5	22.1
Simulation	44.6	22.2

The table above shows the descent velocities of both the drogue and the main parachute for the subscale launch vehicle. The data is fairly consistent as there is a less than 5% error in between all electronics and the simulation for the drogue and the main parachutes. There is some variation in the descent velocity vs. time for the simulation as the simulation does not include effects such as the time required for the parachute to fully deploy and inflate. The drogue chute generally takes approximately 1 to 2 seconds to fully expand and decelerate the rocket while the main parachute takes approximately 3 to 5 seconds. Overall, the final descent velocity was approximately 22 ft/s which matches the simulations and ensures that no components get damaged due to the impact velocity.

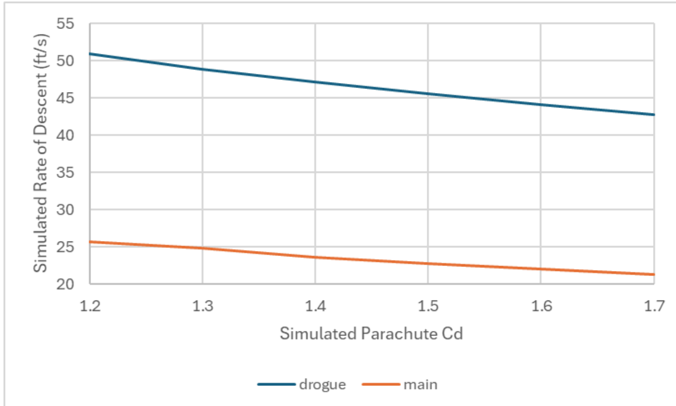


Fig. 30 - Simulated Rate of Descent vs. Cd Value

Both the drogue and the main parachutes were fabricated by A. Brown Design. This is the same vendor and parachute geometry that we intend to use for the full-scale flights and provide a good test platform for determining the Cd values of the parachutes. To extract the parachute Cd value from the measured descent rates, simulations were run by varying the Cd values of the main and drogue parachutes. Comparing these simulated values to the actual measured values, we can determine that the Cd of the parachute geometry values used are between 1.5 and 1.6. As both of the parachutes are based on 0.707 aspect ratio elliptical parachutes, this matches well with published data from Fruity Chutes and Front Range Rocket Recovery.

4.3.7 Analysis of Recovery Drift

The total drift from the launch pad to the final landing pad of the rocket was recorded as 1617 ft via the on board GPS. The graph below shows the comparison between the measured data and the OpenRocket simulation for drift. For simplicity, this analysis is based on drift after apogee. Note that the winds were high, and we have no means of measuring wind speed above ground level.

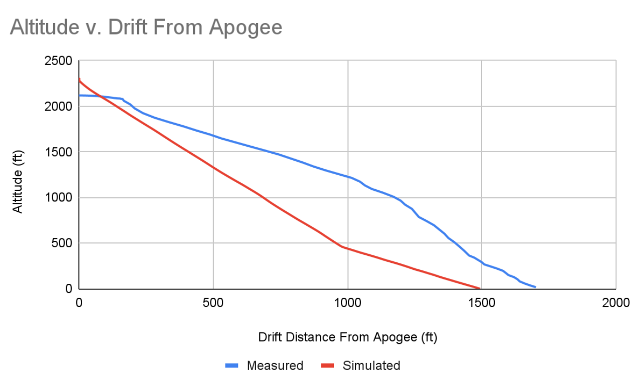


Fig. 31 - Subscale measured and simulated altitude vs. drift distance from apogee

The OpenRocket simulation returned a total drift from apogee of 1493 ft. Compared with our flight data, this gives up an absolute error of 208 feet, and a percent error of 14%. As a simulator, OpenRocket can not account for all launch conditions, such as significant bursts of wind or long lulls in the wind, which would affect the drift distance. Additionally, wind is simulated in OpenRocket as a one-dimensional force, whereas in reality wind is three dimensional; this can be seen in the different slope across the plot of the measured data caused by wind forces that were not parallel to the rocket's motion.

4.3.8 Estimation of Coefficient of Drag

The coefficient of drag is a critical parameter in rocket design as it directly affects the turbulence caused by uneven surfaces on the rocket. OpenRocket is capable of calculating the coefficient of drag based on the rocket's geometry, surface finish and flight conditions. Since the simulation results for the subscale rocket closely match the flight data obtained from the onboard electronics, the coefficient of drag derived from the simulation serves as an accurate approximation of the aerodynamic performance of the vehicle

Table 17 - Subscale Coefficient of Drag

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Total (Rocket)	**0.004 (0%)**	**0.132 (0%)**	**0.49 (0%)**	**0.625 (1%)**
Nose cone	0.001 (0%)	0 (0%)	0.057 (0%)	**0.058 (0%)**
Payload tube	0 (0%)	0 (0%)	0.144 (0%)	**0.144 (0%)**
Switch Bandd	0 (0%)	0 (0%)	0.008 (0%)	**0.008 (0%)**
Booster tube	0 (0%)	0.132 (0%)	0.205 (0%)	**0.337 (0%)**
Freeform fin set	0 (0%)	0 (0%)	0.025 (0%)	**0.025 (0%)**
Rail Button aft	0.001 (0%)	0 (0%)	0 (0%)	**0.001 (0%)**
Rail Button forward	0.001 (0%)	0 (0%)	0 (0%)	**0.001 (0%)**

The simulated coefficient of drag for the subscale rocket under the launch conditions was determined to be 0.625. This simulation was conducted using the "Regular Paint" surface setting in OpenRocket since the subscale was not polished prior to launch. This is an accurate representation as the airframe was painted in substandard conditions (cold, humidity, and lighting) and resulted in a very rough final paint. A higher Cd indicates a lower aerodynamic performance due to the surface roughness and imperfections in paint.

Table 18 - Coefficient of Drag for Subscale Components, 50% Upscale

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Total (Rocket)	**0.006 (0%)**	**0.132 (0%)**	**0.478 (0%)**	**0.616 (1%)**
Nose cone	0.001 (0%)	0 (0%)	0.055 (0%)	**0.056 (0%)**
Payload tube	0 (0%)	0 (0%)	0.139 (0%)	**0.139 (0%)**
Coupler sleeve	0 (0%)	0 (0%)	0.007 (0%)	**0.007 (0%)**
Booster tube	0 (0%)	0.132 (0%)	0.198 (0%)	**0.329 (0%)**
Fin set	0 (0%)	0 (0%)	0.026 (0%)	**0.026 (0%)**
1515 wildman rail button	0.003 (0%)	0 (0%)	0 (0%)	**0.003 (0%)**
1515 wildman rail button aft	0.002 (0%)	0 (0%)	0 (0%)	**0.002 (0%)**

An exact 50% upscale of the subscale rocket was created to analyze how scaling affects the coefficient of drag. Using the same conditions that the subscale rocket was simulated in, the scaled up rocket showed a slightly reduced coefficient of drag of 0.616. This is comparable to the subscale with a difference of 0.09 which can be attributed to subtle differences that do not scale exactly. These simulations are effectively close enough to suggest that the full-scale behavior will replicate the subscale.

Table 19 - Final Full-Scale Coefficient of Drag (Polished Paint)

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Total (Rocket)	**0.005 (0%)**	**0.132 (0%)**	**0.375 (0%)**	**0.512 (1%)**
Nose cone	0.001 (0%)	0 (0%)	0.034 (0%)	**0.035 (0%)**
Payload tube	0 (0%)	0 (0%)	0.122 (0%)	**0.122 (0%)**
Coupler sleeve	0 (0%)	0 (0%)	0.005 (0%)	**0.005 (0%)**
Booster tube	0 (0%)	0.132 (0%)	0.152 (0%)	**0.284 (0%)**
Fin set	0 (0%)	0 (0%)	0.021 (0%)	**0.021 (0%)**
1515 wildman rail button	0.002 (0%)	0 (0%)	0 (0%)	**0.002 (0%)**
1515 wildman rail button aft	0.002 (0%)	0 (0%)	0 (0%)	**0.002 (0%)**

The final full-scale design complete with all changes includes a polished and buffed surface which significantly reduces drag by minimizing the irregularities caused by paint and fiberglass. To mirror this in the simulation, the "polished mirror surface" setting was chosen in OpenRocket which caused the coefficient of drag to reduce to 0.512 as shown in the image above.

The surface finish of the rocket impacts its apogee. The table below shows a comparison between the surface finish settings in OpenRocket. The simulation is also being conducted under the subscale launch conditions.

Table 20 - Surface Finish Apogee Comparison (Full-scale)

Simulation	Apogee (ft)
Regular paint	3706
Finished/polished surface	4032

The difference between a polished surface and a painted surface is approximately 300 ft. A polished surface reduces the amount of imperfections that cause drag and eventually boost the rocket's performance. There is some error attributed to this estimation as it is an OpenRocket simulation, a more thorough estimation on the effect of surface finish will be conducted after the full-scale flights by analyzing real world data.

4.4 Impact on Full-Scale Vehicle

The subscale flight data provided valuable insights into the design and the performance of the full-scale rocket highlighting key areas for improvement. The subscale rocket's flight characteristics, analyzed in section 4.3 Subscale Flight Analysis, revealed differences between simulations and the actual flight performance, prompting necessary design changes for the full-scale rocket

Increase Stability

The subscale rocket's CG shifted significantly from the original design values to the actual constructed values due to the difference between vendor supplied masses and the actual masses as well as uncertainty in the construction methods. Initially, the stability was simulated to be approximately 3.2 caliber. After measuring component masses and assembly, the rocket stability shifted to approximately 2.7 caliber. After final rocket preparation, the stability of the subscale vehicle was approximately 1.91 caliber prior to adding nose weight. Additional nose weight was added to shift the CG and recover some stability to 2.0 caliber. This value was below the NASA required minimum of 2.0 caliber for stability.

To mitigate the impact of such inconsistencies and to prevent understability in the full-scale vehicle, the stability margin has been increased to 4.3 caliber. The intent is to pre-compensate the design knowing that there is a reasonable probability that the CG will shift with actual component masses and construction. It is estimated that with a design of 4.3 caliber, the stability will reduce to 3.0 to 3.5 caliber after construction. The largest risk to over stability is increased weathercocking. The risk to understability is far more catastrophic with a potentially unsafe flight.

Fin Size Adjustment

The subscale vehicle's fins were designed as an exact 50% scale model of the full-scale fins. During the flight, the subscale vehicle exhibited an unexpected tilt of approximately 20 degrees from vertical as discussed in 4.3.3 Flight Angle. It should be noted that the deviation from vertical was in a plane orthogonal to the wind direction indicating that this was probably not weathercocking. The behaviour was attributed to the smaller fin area, which made the subscale rocket to be more prone to instability.

The full-scale vehicle's fin size has been increased by an inch which enhances the stability. Larger fins will provide greater resistance to aerodynamic instability and reduce the likelihood of significant deviations from a vertical flight path.

Booster tube size modification

The full-scale featured a booster tube length of 4', which has been increased to 5'. This increases the overall stability by moving the CP slightly more back and shifting the CG slightly more forward which increases the static stability margin. This adjustment, combined with the increased fin size contributes to a much more stable flight configuration

Ideal Stability

While simulations in OpenRocket offer useful insights into the design of the rocket, they do not fully account for real world component variation and environmental factors. To ensure optimal stability, it is important to prioritize vertical orientation of the launch vehicle over the simulated stability. Vertical orientation directly influences the rocket's aerodynamic performance and flight characteristics and its importance for mission success.

5.0 Recovery Criteria

5.1 Recovery System Target Values

The main recovery criteria based on requirements section 3 are:

- The rocket lands in a safe, controllable manner to be reused (req. 2.3).
- The time between apogee and landing is less than 90 s (req. 3.12).
- The drogue is deployed no later than apogee + 2 s (req. 3.1.2).
- The main is deployed no lower than 500 ft (req 3.1.1).
- The maximum kinetic energy of any landing section is less than 75 ft-lbf (req. 3.3).

This section details the target values for the major descent milestones. How these occur will be detailed in a later section, 5.2 Recovery CONOPS.

The safest time to deploy the drogue is at the point where the airframe has its lowest total velocity. This minimizes the magnitude of the rapid deceleration that occurs as the drogue is deployed. This time happens right at apogee when the vertical velocity is zero and the horizontal velocity is at a minimum.

The target value for the main deployment is 650 ft. This provides adequate margin above the minimum of 500 ft. The main parachute usually takes about 2-3 s to deploy and begin decelerating the airframe. In addition, the airframe is stretched out over 45 ft of shock cord. This allows ample time to decelerate and extend the harness length prior to approaching the landing.

The total descent time from apogee to landing is required to be less than 90 s; however, there are a number of unknown elements such as changes in barometric pressure, the presence of thermals, and wind. Therefore, the derived requirement R-D-1 sets our maximum descent time at 80 s. Allowing a 150 ft margin to main parachute deployment and a 18 ft/s main parachute descent velocity, we can calculate the time for and velocity of drogue descent. This was hand calculated for proposal and PDR, but due to minor vehicle specification changes and for consolidation, a spreadsheet was created and used, whose results are summarized as thus:

Table 21. Descent Characteristics

Parameter	Value
Apogee	4000 ft
Max descent velocity to meet KE req.	25.9 ft/s
Ideal main chute deploy	650 ft
Target main chute descent velocity	18 ft/s
Target drogue descent velocity	84 ft/s

Note that these are target values for designing the recovery system. A detailed analysis of performance of the recovery system is presented in 6.5 Descent Characteristics.

5.2 Recovery CONOPS

The general goal of the recovery system is to ensure the survival and safe recovery of our rocket upon landing. The specific goal is to slow the descent down to minimize or eliminate damage from impacting the ground, while also minimizing drift. This is accomplished through a dual deploy parachute system.

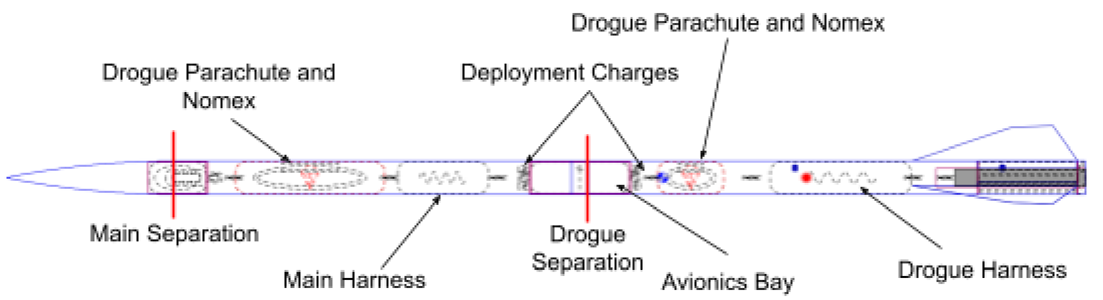


Fig. 32 - Parachute locations and separation points within rocket

To fulfill the descent requirements presented in the previous section, the rocket must reach the ground from apogee within 90 seconds, deploy its main chute at least 500 feet above the ground, and have an impact kinetic energy value of no greater than 75 ft-lbs, or a landing velocity of no more than 25.9 ft/s, as shown in the previous section, Recovery Criteria. These conditions are satisfied using a dual deploy system where a small drogue parachute is deployed at apogee, and a much larger main parachute is deployed at a predetermined altitude. This allows the rocket to descend at a fast, but controllable rate between apogee and main deployment, then descend at a slow and safe rate of descent between main deployment and landing. In addition to these primary events, a completely isolated and parallel deployment system is also running to ensure redundancy.

The concept of operations, or CONOPS, for all of the major events from take-off to landing are shown in Table 22 - Launch and Recovery CONOPS Steps. During each step, the two flight computers and the GPS tracking unit are measuring and datalogging the rocket's altitude and location (GPS only) as well as determining the necessary conditions for the recovery events.

Table 22 - Launch and Recovery CONOPS Steps

Step Number	Stage	Action
1	Launch	Monitor for launch detection
2	Boost	Monitor ascent and datalog
3	Coast	Monitor ascent and datalog
4	Apogee	Fire primary charge to deploy drogue
5	Apogee + 1.5 seconds	Fire drogue backup charge
6	Drogue descent	Expected descent rate: 85.1 ft/s
7	650 ft	Fire primary charge to deploy main
8	500 ft	Fire main backup charge
9	Main descent	Expected descent rate: 18.1 ft/s
10	Landing	Monitor GPS, retrieve rocket

Under normal flight conditions, the primary flight computer will control the preferred deployment events. Assuming the primary flight computer triggers all events as planned, the backup flight computer will fire deployment events shortly after the primary with the charges firing into an already evacuated body tube. This will be monitored from the ground as well as analyzed using the flight data after the launch. However, if something causes the primary channel to fail (8.3.2 Recovery FMEA), then the backup flight computer serves as redundancy and should trigger the necessary events.

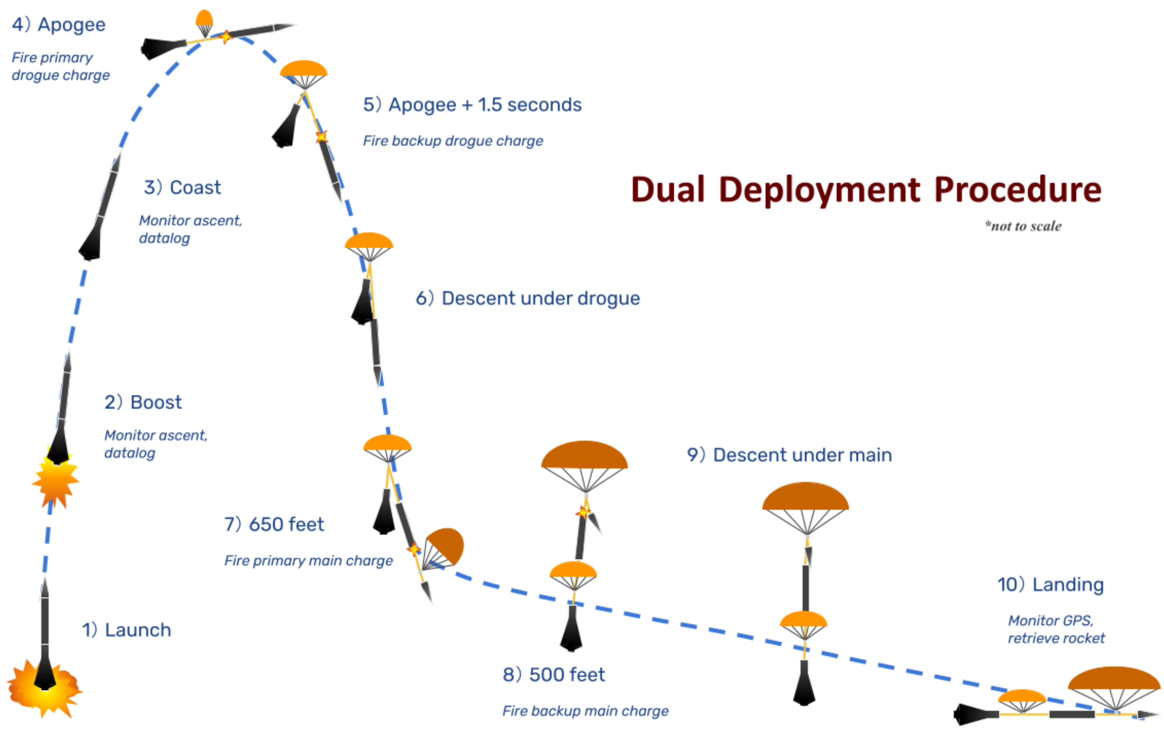


Fig. 33 - Diagram of launch and recovery CONOPS

5.3 Component Selection

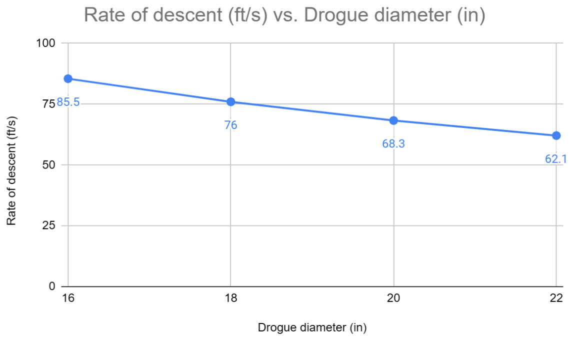
The following section includes the selection for all components in the recovery criteria. This includes parachutes and essential recovery hardware.

5.3.1 Parachute Selection and Sizing

Based on the selection process in the PDR, elliptical parachutes were chosen for both the drogue and the main parachutes. The 0.707 aspect ratio elliptical parachutes, similar to Fruity Chutes "Classic Elliptical," provide a high Cd of 1.5-1.6 and pack to a small volume; however, an elliptical parachute's asymmetrical shape causes an imbalance in the aerodynamic forces acting on the parachute, which can lead to high-speed instability. It also causes air flow instabilities which can cause the parachute to pitch, roll, or yaw, leading to unpredictable descent behavior.

To save costs and add an element of customization, our parachutes are fabricated by A. Brown Design. This is our mentor's company that makes limited custom recovery equipment for the rocketry community. Having parachutes custom made allows us to create an exact geometry and size to meet our needs. The parachute geometry is an exact scaling of the parachutes used in the subscale demonstration flight. By using scaled parachutes, we have accurate data on rates of descent and were able to extract Cd values (4.3.6 Analysis of Rates of Descent).

The plots below show the rate of descents for varying diameters for both the drogue and main parachutes.



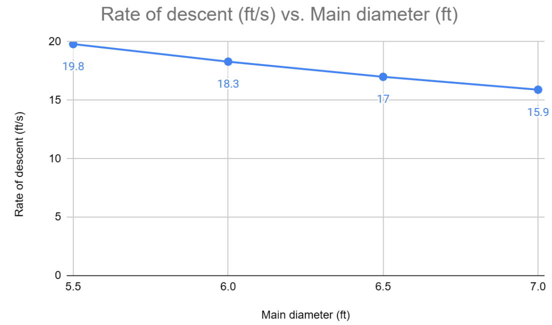


Fig. 34 - Rate of descent vs. drogue diameter (left), rate of descent vs. main diameter(right)

The drogue parachute is selected to minimize the time the rocket spends in the air while slowing the descent rate enough for the main chute to safely deploy. The main chute is selected to reduce the rate of descent to a velocity that will not cause significant damage on landing while also meeting the 80 s derived requirement (R-D-1). Based on descent time requirements, kinetic energy requirements, and simulations through OpenRocket, we determined that an 18 in drogue chute and a 6.5 ft main chute will slow down the rocket enough while also letting the rocket land in under 80 s (from apogee to touchdown).

Table 23 - Parachute Design Parameters

Parameter	Drogue parachute	Main parachute
Skirt Diameter	18 inches	78 inches
Number of Gores	8	16
Spill Hole Diameter	4 inches	16 inches
Shroud Length	21 inches	90 inches
Pattern	Full Length Gore	3 Layer Checkerboard
Colors	Pink/Grey	Black/Orange

5.3.2 Recovery Harness Selection and Sizing

The length of the harness needs to be long enough to allow the excess energy of parachute deployment to dissipate through the movement of the separated sections. If the length is too short, the separated sections will fully extend the harness with enough momentum to create a sudden shock on the components, possibly inducing a failure at one of the attachment points. By having a long harness, the separated sections have time to lose and dissipate some of the energy. A longer recovery harness also prevents zippering from an unintended high speed deployment. If the deployment occurs at a high velocity, the separated rocket has a higher chance of slowing down as individual pieces prior to the harness fully extending.

For our project, we have selected a 30 ft, 3-loop, 3/8" tubular Kevlar harness for the drogue and a 25 ft, 2-loop, 3/8" tubular Kevlar harness for the main. This is approximately 3:1 and 2.5:1 harness length to rocket length ratio. The material is ⅜” tubular Kevlar with a rated strength of 3600 lbs. More detail on the recovery chain load analysis will be presented later in Section 5.5 Recovery Load Analysis.

For multiple flights (Requirement 2.3), the recovery harness must absorb all of the loads of parachute deployment. Furthermore, it can rub against the potentially sharp edge of the airframe and is exposed to explosive charges generated by the black powder deployment charges. Due to its strength against the aforementioned conditions, Kevlar was chosen as the material. Where the alternate material, nylon, melts at 520° F, Kevlar does not melt or combust and is heat resistant to more than 800° F. Kevlar also is considerably stronger than nylon, allowing use of thinner material and thus more efficient packing.

Onebadhawk offers a COTS solution that meets all of our requirements and specifications. The manufacturer recommended usage for this harness set uses the 30 ft, 3 loop harness for the drogue and the 25 ft 2 loop harness for the main parachute. The drogue connects to the loop within the 30 ft harness. The manufacturer states that the main parachute is to be connected to the U-bolt on the nose cone.

Fig. 35 - ⅜” Kevlar harness set from OneBadHawk

5.3.3 Recovery Hardware Selection and Sizing

The recovery harness is only as good as the components used to connect it to the airframe. The entire recovery chain is exposed to burning black powder, a highly corrosive environment. For the recovery chain, we used corrosion resistant materials whenever possible, 304 or 316 stainless steel. This provides a reasonable level of corrosion resistance with adequate tensile properties.

For all of the hard point attachments to the airframe with the exception of the harness leader, we selected a ¼-20 U-bolt with backing plate (McMaster-Carr part number 8896T117). Although the failure strength was not specified, we calculated it to be approximately 5348.8 lbs of force, based on material properties and part geometry.

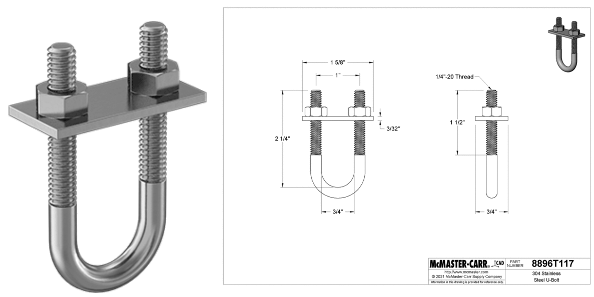


Fig. 36 - U-bolt selected for all hardpoint attachments to the airframe

Connecting the harness to a U-bolt requires some form of removable linkage to allow for cleaning and serviceability of not only the harness, but also the body tubes between flights. Quicklinks will be used for this. The quicklink selected is McMaster-Carr part number 8947t27 which is a 5/16” 316 stainless steel quick link with a rated continuous use failure strength of 2400 lbs with 4:1 safety margin. For the purposes of this report, we are converting the continuous use failure strength to peak failure by multiplying by the safety margin. This results in a value of 9600 lbs.

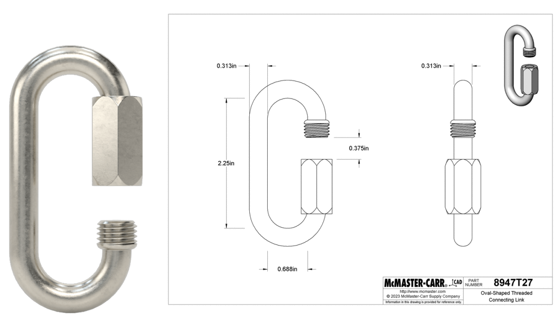


Fig. 37 - Quicklink selected for all Kevlar to U-bolt attachment points

The hardware that couples the drogue harness to the main harness through the coupler is a pair of threaded rods. Similar to the U-bolts, we are using ¼”-20 304 stainless steel hardware (McMaster-Carr part number 98804A107). This is subjected to the same failure modes of tensile failure (2674.4 lbs per rod) and thread shear failure (3408.4 lbs per rod). As the weakest point of failure is the tensile failure, and there are two rods in parallel, the threaded rod assembly would have a net failure strength of 5349 lbs.

5.4 Recovery Attachment

During the PDR, multiple methods for securing the recovery harness to the airframe were evaluated. These included:

- Using a high temperature epoxy to glue the Kevlar leader harness to the sides of the motor mount.
- Using forged eye bolts to attach the harness leader to the forward centering ring.
- Using U-bolts to secure the harness leader to the forward centering ring.

However, during the PDR presentation, it was suggested to use a tapped, plugged forward closure with an eye bolt. This satisfies the requirements of the leader being easily serviceable for inspection (R-D-6). A harness leader was fabricated using the following components:

- 5/16” Forged eye bolt with a jam 5/16” nut to secure to the plugged forward closure (McMaster P/N 33045T28, continuous load rating of 900 lbs, break peak load of 3600 lbs). The eye bolt is made from 304 stainless steel. Additionally, a small amount of medium thread-lock will be added.
- 6 ft of ½” tubular Kevlar (3500 lbs rating).
- M10 Swivel, 1900 lbs rating (McMaster P/N 3714T94, 316 Stainless Steel).

The Kevlar loops were stitched with 200 lbs test Kevlar line, greater than 30 stitches. Marine grade heat shrink with heat sensitive adhesive pieces were added over the exposed ends of the Kevlar to prevent any fraying.

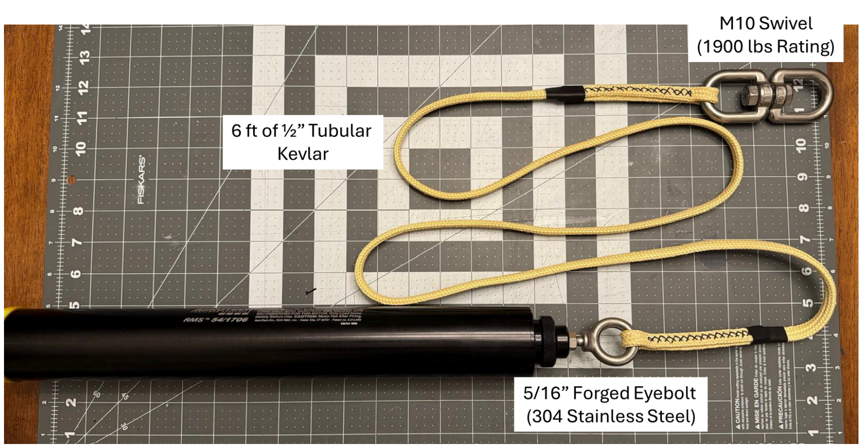


Fig. 38 - Kevlar harness leader assembly

5.5 Recovery Load Analysis

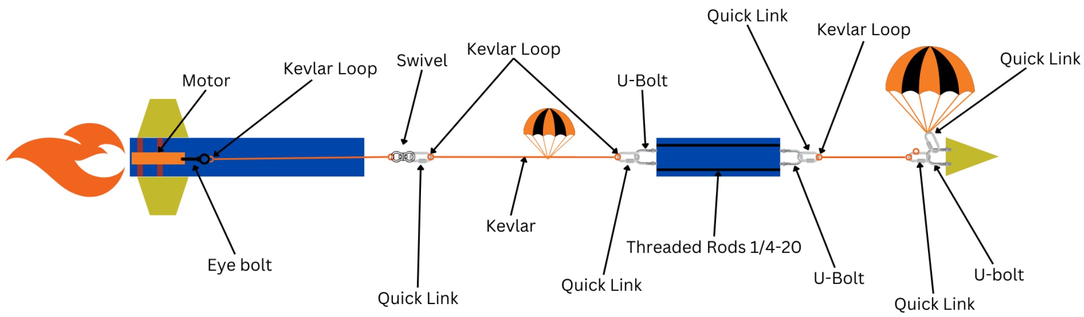


Fig. 39 - Recovery system chain

The figure above shows the components of the recovery chain. This includes all of the elements from how the Kevlar leader is attached to the base of the airframe all the way through the nose cone. As the rocket is to remain tethered during the entire recovery, the load of the recovery is absorbed through this entire structure.

Table 24 - Recovery Chain Load Analysis

Component	Vendor	Part number	Individual failure strength	Combined failure strength
Eye bolt	McMaster-Carr	33045T28	3600 lbs	3600 lbs
Tubular Kevlar loop	Custom		3600 lbs	3600 lbs
Kevlar Leader	Wildman Rocketry	Kevlar, ½ inch	3600 lbs	3600 lbs
Kevlar loop	Custom		3600 lbs	3600 lbs
Swivel	McMaster-Carr	3714T94	1900 lbs	1900 lbs
Quick link	McMaster-Carr	8947T27	9600 lbs	9600 lbs
Kevlar	Onebadhawk	Kevlar, ⅜ inch	3600 lbs	3600 lbs
Kevlar loop	Onebadhawk	Kevlar, ⅜ inch	3600 lbs	3600 lbs
Quick link	McMaster-Carr	8947T27	9600 lbs	9600 lbs
U-bolt	McMaster-Carr	8896T94	5349 lbs	5349 lbs
Threaded rods (¼-20, Stainless)	McMaster-Carr	98804A107	2674 lbs	5348 lbs
U-bolt	McMaster-Carr	8896T94	5349 lbs	5349 lbs
Quick link	McMaster-Carr	8947T27	9600 lbs	9600 lbs
Kevlar loop	Onebadhawk	Kevlar, ⅜ inch	3600 lbs	3600 lbs

Kevlar harness	Onebadhawk	Kevlar, ⅜ inch	3600 lbs	3600 lbs
Kevlar loop	Onebadhawk	Kevlar, ⅜ inch	3600 lbs	3600 lbs
Quick link	McMaster-Carr	8947T27	9600 lbs	9600 lbs
U-bolt	McMaster-Carr	8896T94	5349 lbs	5349 lbs

The table above organizes the load capacities of all individual components in the recovery chain. Failure strengths were determined from manufacturer specifications or material properties and part geometry. Based on these, the critical failure point in our recovery chain will be the swivels, with a manufacturer-specified failure strength of 1900 lbs. With the booster weighing 7.19 lbs and a 100:1 safety margin, the 1900 lbs minimum component strength greatly exceeds the target value set in R-D-2.

5.6 Avionics Design

Avionics handle all aspects of controlled recovery. Components to be used, redundancies, construction, and final assembly are detailed.

5.6.1 Altimeter

The avionics bay for our rocket will be utilizing two commercially available altimeters. Although it requires some electronics assembly, the Eggtimer Quantum meets all of our desired features at the lowest cost point. While this does add time to the project, the cost savings compensate for the difference. As of CDR, our altimeters are assembled, inspected by the mentor, and tested according to test FS-R-1 and FS-R-2.

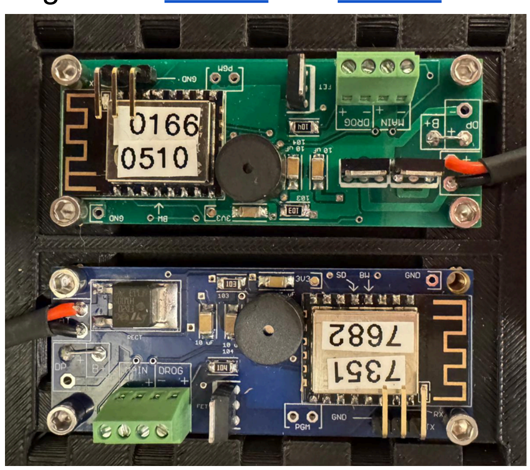


Fig. 40 - Assembled altimeters mounted to avionics bay

One major aspect of the Eggtimer Quantum that should not be overlooked is the failsafe mode. When failsafe mode is enabled, the flight computer will fire the main deployment charge if it detects a condition where the rocket is past apogee and it has reached an unsafe velocity, presumably due to drogue deployment failure. If this happened, it would probably result in a zippering of the airframe, breaking the 90-second apogee to touchdown rule and drifting outside of the allowable range. However, it would prevent a ballistic recovery, possibly preventing injury, death, or destruction of property.

The Eggtimer Quantum complies with requirements 2.22.8 and 2.22.9 for frequency and power. The Eggtimer Quantum uses a WiFi signal in the 2.4 GHz range, which does not violate our requirements for frequency. This altimeter also has a maximum power of 24 mW which is far less than the maximum transmitter power of 250 mW, making the Eggtimer a legal choice for our rocket. The altimeter uses a FCC wireless module certified under FCC ID: 2ADUIESP-12.

5.6.2 Battery Selection

Fig. 41 - 450 mAh LiPo 2S batteries

The Eggtimer Quantum consumes approximately 80 mA of current, mainly due to the WiFi module. Once assembled, we will measure the current of our units to verify. To achieve sufficient powered-on time, we propose using a 450 mAh 2S LiPo battery pack. This 450 mAh of capacity gives us approximately 5.6 hours of life. This exceeds requirement 2.6 of having greater than three hour life in the launch configuration. However, given launch conditions with possible elevated temperature or continued charge cycling, this battery life may be diminished. There are tests in the test plan to verify the operating time of the altimeter system (FS-R-6, FS-R-7). The LiPo battery pack will be clearly marked and protected in accordance with requirement 2.21.

5.6.3 Avionics System Assembly

The avionics bay assembly consists of the two bulkheads, three 3D printed components (altimeter sled, switch ring, and battery sled), and the threaded rods to tie the entire system together. The table below contains the list of individual components and their quantities in the avionics bay.

The figure below shows the assembly for the avionics bay. It includes all necessary parts.

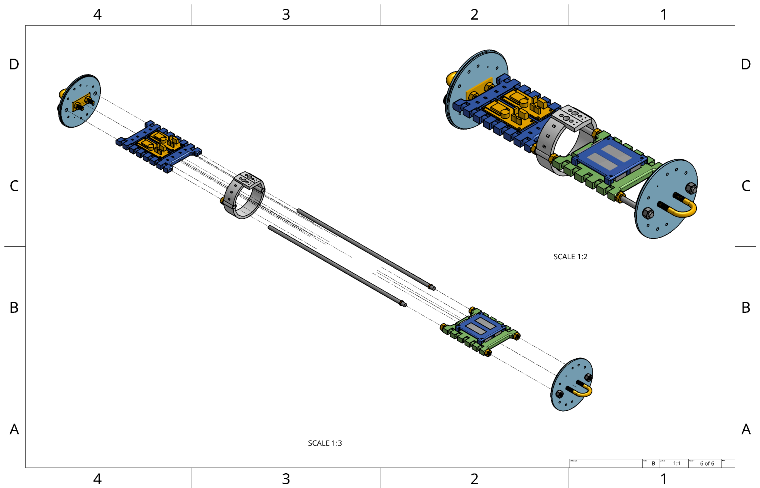


Fig. 42 - Avionics bay CAD assembly

Bulkhead

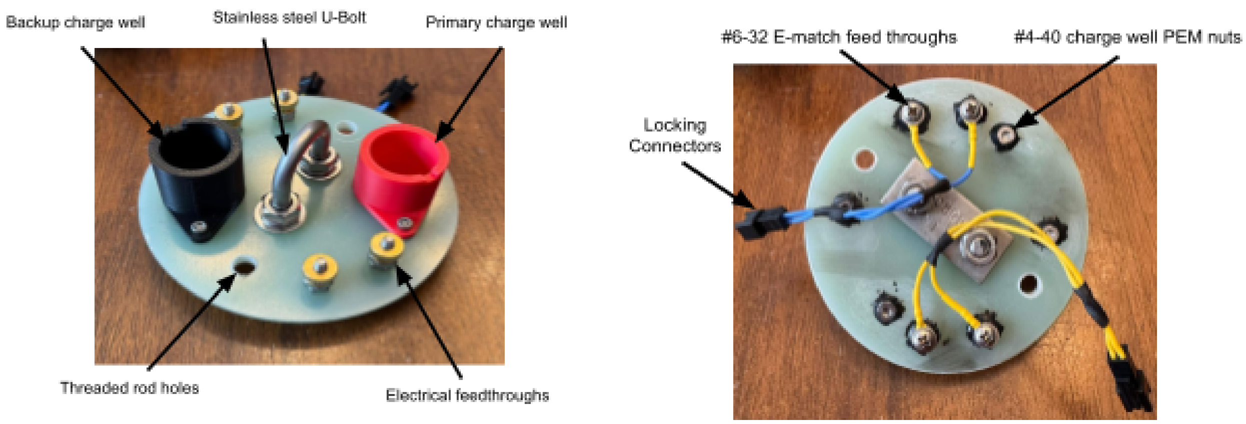


Fig. 43 - Front and back of the bulkhead

Avionics Sled

The avionics sled is located towards the front end of the avionics bay and houses the two Eggtimer Quantum altimeters. Each altimeter is responsible for a set of charges. The primary altimeter is responsible for firing the primary charges for both the drogue and the main parachutes while the backup is responsible for the backup charges for the drogue and the main chute. Each altimeter has an independent power supply and switch.

Power Switch Sled

Each altimeter is powered by an independent screw switch. Screw switches offer a secure connection and are resistant to major vibrations that could potentially turn the altimeter system (Requirements 3.6 and 3.7). Two screw switches are placed on the power switch sled. The switches can be activated on the launch field using a small screwdriver.

The figure below shows the block drawing of the avionics electronic systems. This comprises of a fully redundant system with no electrical connection between the deployment systems (Requirement 3.4).

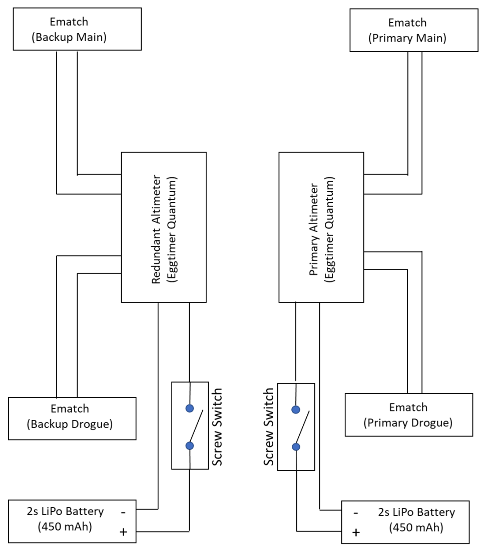


Fig. 44 - Block diagram of avionics electronic system

The figure below shows the final assembly of the avionics bay with all essential connections.

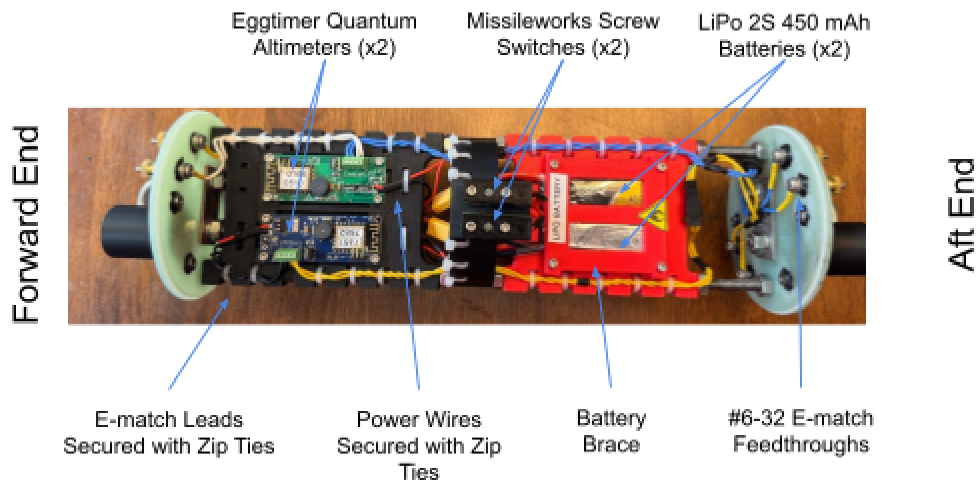


Fig. 45 - Avionics bay assembly

5.7 Tracking and Telemetry

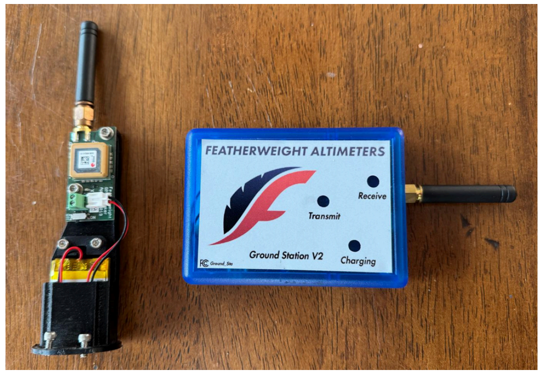


Fig. 46 - GPS tracker to be used with subscale and full-scale

To track the position and altitude of our rocket during flight, we will be using the Featherweight GPS tracker, located in the nose cone. After researching a variety of GPS units, we found that the Featherweight GPS tracker would most accurately provide us with our rocket's telemetry due to its tracking frequency of 10 GPS solutions per second and extensive range. It also integrates with a phone application, allowing us to track our rocket in real-time and review its data immediately.

The Featherweight GPS tracker manual specifies a 1S LiPo battery to supply 4.1 V to power the unit. The battery consumes an average of 86 mA of current under normal operation. The recommended battery of 400 mAh will provide approximately 4.5 hours of operation. The testing plan details a battery time analysis to check that this is valid under real-world conditions. If a larger battery is required, stepping up to an 850 mAh battery does remain an option.

The Featherweight GPS tracker meets requirements 2.22.8 and 2.22.9 by limiting transmission to 50 mW and uses a robust tracker/receiver unique addressing and handshake protocol. We will use a 917.4 MHz (Channel 19B) frequency for tracker communication.

5.8 Shear Pins

Shear pins are designed and implemented to hold the airframe together and prevent unintended separation; they are designed to break, or shear, at a specific force. The determination of force is dependent on the cross-sectional area and diameter of the pin in which the diameter has a proportional relationship with the force it can withstand. Shear pins are necessary between all points of separation of the airframe (Requirement 3.9).

As the launch vehicle ascends after launch, the motor will quickly burn out and the airframe will decelerate as it approaches apogee. During this deceleration phase, there is more drag on the lower booster than on the upper portion of the airframe, leading to more drag force applied to the lower portion than the upper and induce drag separation. After burnout, the rocket decelerates at about 59 ft/s^2. Using the assumptions of a 7 lbs upper section of the airframe and that all the drag is from the lower portion of the body tube, a pessimistic calculation results in a required force of 13 lbs of force to maintain upper airframe integrity.

Another aspect to consider is the pressure change of the airframe cavities. Assuming the airframe is sealed, the internal cavity of the airframe will reach equilibrium while sitting at ground level. Once the rocket is launched though, the outside air pressure will decrease as the altitude increases. There is about a 2 psi difference in air pressure between ground level and 4500 ft. This difference in pressure generates a force on the bulkhead. This is about 27 lbf for both the drogue and the main cavity (similar volumes, same diameter). As thus, we can calculate that about 40 lb of force is needed for the booster to unintentionally separate from the coupler. As preventing unintentional separation is safety and mission critical, we are factoring in a minimum 2:1 safety factor. A 2-56 nylon shear pin will shear between 31 and 34 lbs of shear force depending on manufacturing tolerances. To exceed the 80 lbs (40 lbs plus 2:1 safety factor), a minimum of 3x 2-56 shear pins is required.

The nose cone is also subject to pressure differences and drag separation; however, the mass of the nose cone is considerably less than the entire upper body tube assembly. As a result, it only requires about 30 lbs of resistance, but the larger concern is regarding the force generated when the drogue is deployed at apogee. If the ejection charge is too large, and the lower harness reaches its full extent too fast or if the drogue deploys at a higher velocity than planned, the momentum of the nose can generate a considerably higher force to be restrained. This would result in the main parachute being deployed at apogee, which is highly undesirable and breaks about a dozen requirements. Common practice is to take the weight of the nose cone and multiply it by a safety factor. Our mentor suggested 100:1 plus the 30 lbs due to pressure and drag differences. The nose cone weighs 1.0 lbs, so this would make the required shear force to be about 130 lbs. A nylon 4-40 shear pin has a range of 50-54 lbs to shear depending on manufacturing tolerances. Therefore, we are planning to use 3x 4-40 nylon shear pins to restrict the nose to the payload tube.

5.9 Ejection Charge Sizing

E-matches controlled by the altimeters will be used to ignite the black powder deployment charges. To ensure separation while minimizing stress to airframe components, the type and amount of black powder used will need to be optimized through calculation and ground testing.

We will be using FFFFg, or 4Fg, black powder for our deployment charges. Black “powder” is granular, and its grade is determined by the size of the grains; the more F’s there are, the smaller the grain size. The speed at which the black powder burns is determined by the surface area to volume ratio, essentially the grain size. 4Fg will be used as it combusts quickly enough that separation is not affected by vent holes in our airframe. It also burns quickly converting from solid to gas, reducing the risk of flaming particles flying about.

The nose cone will be coupled together using three 4-40 nylon shear pins, and the booster coupled using three 2-56 shear pins. Assuming the maximum value of tolerance and only the shear strength of the shear pins, basic physics and chemistry equations can be used to approximate the needed black powder amount. Force can be calculated based on pressure, *P*, and area, *A*. Using the equation F=PA, the predefined cross-sectional area of our airframe will allow us to isolate and determine P. Ideal gas law and the chemical equation for the combustion of black powder will allow us to back-calculate the moles (and thus the mass) of black powder needed. Calculations by hand were detailed in proposal and PDR; as thus hand calculations for CDR remain unchanged and are in Appendix A.

To verify hand calculations and calculate using a second tool, a spreadsheet by Speedmotion Rockets (**http://speedmotionrockets.com/Spreadsheets.html**) was used. This tool includes additional effects that were not included in our hand calculations to present a more realistic scenario: it includes pressure differences within the airframe due to the change in barometric pressure launch to apogee, and force to overcome friction and separate the airframe. As a result, some of these numbers will vary slightly from our initial calculations, but are used to verify that we are close to equivalent. Spreadsheet results are in Appendix B. Full results are summarized in the table below:

Table 25 - Ejection Charge Calculation Summary

Charge	Hand calculated amount (g)	Spreadsheet calculated amount (g)
Drogue primary	2.36	2.05
Drogue secondary	2.83	2.46
Main primary	4.55	3.30
Main secondary	5.46	3.96

All values will be rounded to the nearest tenth, due to massing precision constraints.

While in theory, our calculations are relatively accurate for the minimum force to separate a static rocket, these calculations are merely a starting point. Additional margins will be added to ensure separation at altitude and in the presence of other forces acting on the separation points.

For the backup altimeter, an additional 20% margin will be applied to ensure separation if the primary charge fails. If the primary charge is successful, then the backup charge will fire into an open tube with no detrimental effect.

A 3D printed charge well will be used to hold the recovery charges. Since the charge well will hold approximately 5 cc's of black powder and 4Fg powder packs at approximately 1 cc/gram, the charge well will safely hold the calculated 3.96 g and 2.46 g of black powder for drogue ejection and main parachute ejection, respectively. The E-match is installed with the head in the middle of the well, filled with a premeasured mass of black powder, then the remaining space will be filled with fire resistant cellulose insulation. The well is then sealed with electrical tape to contain its contents. To ensure optimal packing, the height of the charge well may be modified for the main parachute charge.

6.0 Mission Performance Predictions

The mission performance predictions have been updated since the PDR to include:

- Changes to fin sizes (3.3.4 Fins) and booster body tube length increase (3.3.1 Body Tubes) from lessons learned in the subscale demonstration flight (4.4 Impact on Full-Scale Vehicle).
- Updated masses from actual fiberglass component weights (3.3.6 Airframe Mass Estimate).
- Updated parachute Cd values from subscale extracted data (4.3.6 Analysis of Rates of Descent).
- All values presented are based on "as designed" with our best estimates. Once the airframe is constructed, these predictions will be repeated using final masses and center of gravity.

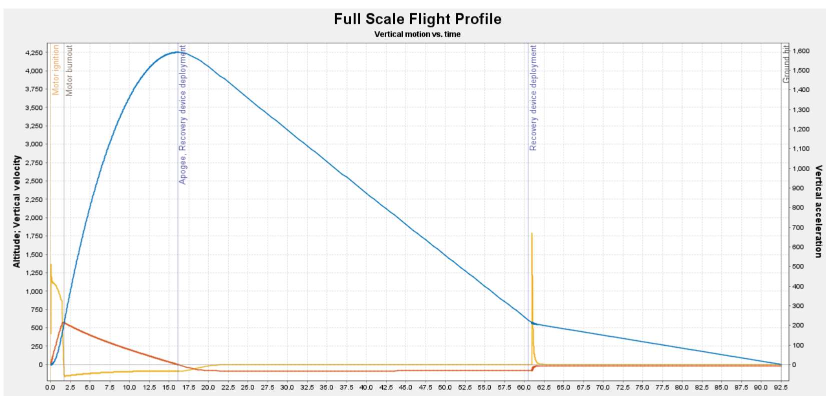


Fig. 47 - Nominal full-scale flight profile

6.1 Kinematics

The image below shows the basic simulation setup in OpenRocket. It is set up to simulate a variety of conditions that could occur on launch week in Huntsville.

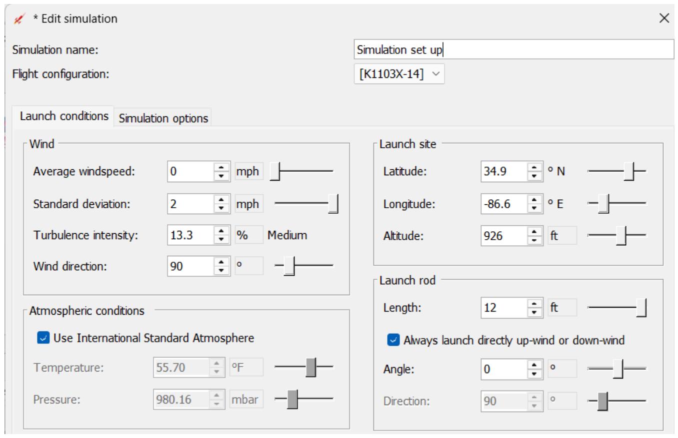


Fig. 48 - Simulation setup in OpenRocket

The coordinates of the launch site were determined through Google Maps. For the conditions of launch, the rail angle is kept constant at 0°, wind speed standard deviation at 2 mph, wind direction at 90°, and turbulence intensity at the default OpenRocket value. Per simulation, wind speed was varied.

6.1.1 Altitude

Altitude simulations were conducted using an average of three OpenRocket simulations. These trials utilized launch parameters expected of the conditions the full-scale could encounter during the final launch week in Huntsville. Below is a graph and a table summarizing the average apogee of the full-scale rocket under varying wind speeds for both the primary and secondary motor configurations.

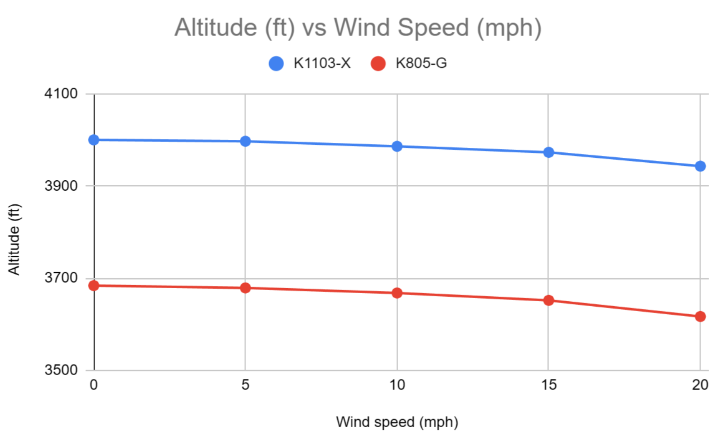


Fig. 49 - Altitude vs. wind speed full-scale

Table 26 - Altitude vs. Wind Speed Full-Scale

Wind speed	Average apogee - K1103X	Average apogee - K805G
0 mph	4000 ft	3684 ft
5 mph	3997 ft	3679 ft
10 mph	3986 ft	3668 ft
15 mph	3973 ft	3652 ft
20 mph	3943 ft	3617 ft

The altitude simulations for the K1103X motor fall within a range of 3900 to 4000 ft, while those for the K805-G motor lie within a range of 3600 to 3700 ft. These results were consistent across all three trials conducted. As discussed in section 4.3 Subscale Flight Analysis, OpenRocket simulations are not exact and include a general error margin of approximately 10%.

6.1.2 Velocity and Acceleration

The velocity during the ascent phase of the rocket was simulated and shown in the plots below. Requirement 2.22.6 states that the launch vehicle must not exceed Mach 1 during flight, while Requirement 2.17 mandates a minimum rail exit velocity of 52 ft/s for the full-scale vehicle.

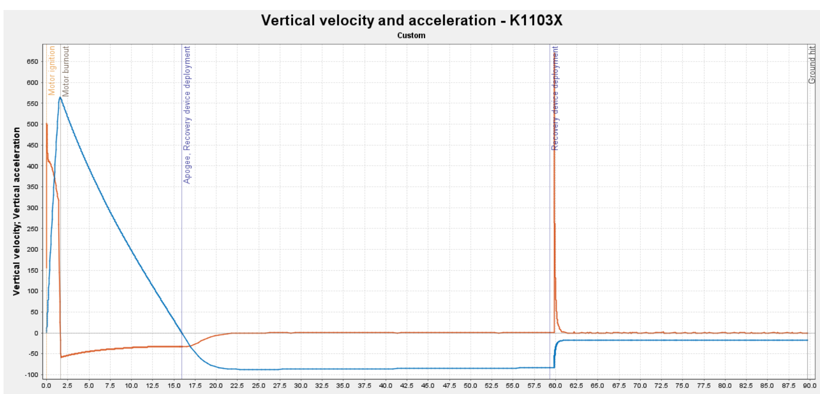


Fig. 50 - Vertical velocity and acceleration profile - K1103X

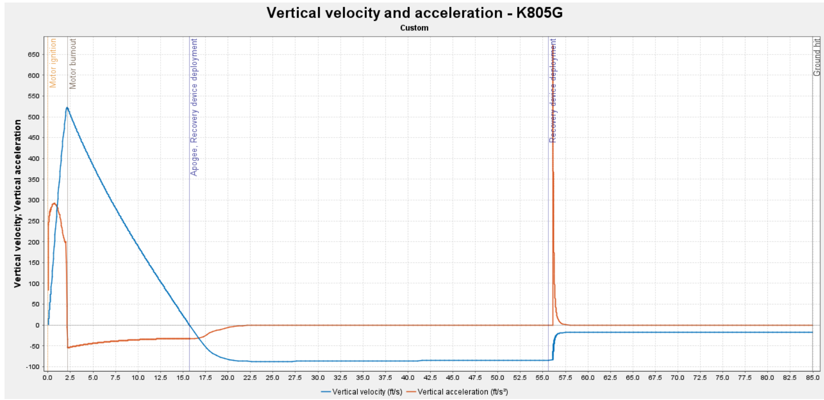


Fig. 51 - Vertical velocity and acceleration profile - K805G

Table 27 - Full-Scale Ascent Velocity

Motor	Rail exit velocity (ft/s)	Maximum velocity (ft/s)	Mach number	Time for maximum velocity (s)
K1103X	102	546	0.455	1.61
K805G	81	505	0.464	2.09

OpenRocket simulations show that the K1103X motor achieves a maximum velocity of 546 ft/s (Mach 0.455), while the K805G reaches 505 ft/s (Mach 0.464), both comfortably within the Mach 1 limit of requirement 2.22.6. The rail exit velocities of 102 ft/s for the K1103X and 81 ft/s for the K805G exceed the 52 ft/s minimum rail exit velocity as mandated by requirement 2.17 by 96.15% and 55.77% respectively.

The plots above also show the vertical acceleration of the full-scale rocket. The maximum G-force value has also been simulated and recorded.

Table 28 - Full-Scale Acceleration

Motor	Maximum acceleration (ft/s^2)	G force
K1103X	487	15.2
K805G	283	8.8

The rocket experiences significant G-forces during its ascent, especially at a maximum acceleration. For instance, when using the K1103X motor, the rocket reaches a peak G-force of 15.2 G's, driven by a maximum acceleration of 487 ft/s^2 and a gravitational acceleration of 32 ft/s^2. In contrast, with the K805G motor, the rocket faces a peak G-force of 8.8 G's, driven by a maximum acceleration of 283 ft/s^2 and a gravitational acceleration of 32 ft/s^2.

6.2 Stability

As discussed in section 4.4 Impact on Full-Scale Vehicle, the stability of the vehicle may change during the build and preparation process. To account for the drop in stability from simulation to real life, the simulated stability has been increased to avoid potential understability and enhance the vertical orientation of the vehicle.

Table 29 - Static Stability Comparison

Motor	CG location (in)	CP location (in)	Stability margin
K1103X	79.26	96.67	4.63
K805G	79.65	96.47	4.53

The simulated static stability of the full-scale with the primary and secondary motor selections are similar to within 0.1 caliber. As discussed in 4.3.3 Flight Angle, the simulated stability margin dropped by approximately 1 caliber during the design, construction, and preparation process. As our goal for stability for the full-scale rocket is approximately 3.0, this overstability margin has been pre-compensated to a higher value assuming it will drop between design and realization.

Different launch sites utilize different rail lengths. The following table shows the rail lengths that could be used during demonstration launches at various club sites and the Huntsville final launch.

Table 30 - Rail Exit Parameters - Full-Scale

Parameter	Value		
Height of front rail button from bottom of rocket	2.42 ft		
Length of launch rails	8 ft	10 ft	12 ft

The distance the front rail button travels along the rail can be calculated by:

$$D_{bottom\ to\ rail\ exit} = Length\ of\ launch\ rail - height\ of\ front\ rail\ button$$

$$D_{bottom\ to\ rail\ exit\ -\ summit\ city} = 8ft - 2.42\ ft = 5.58\ ft$$

$$D_{bottom\ to\ rail\ exit-\ TMO\ and\ Three\ oaks} = 10ft - 2.42\ ft = 7.58\ ft$$

$$D_{bottom\ to\ rail\ exit\ -\ Huntsville} = 12ft - 2.42\ ft = 9.58\ ft$$

Using OpenRocket to graph locations of CG and CP over altitude and a Python script to analyze the exact locations of CG and CP for each launch rod length.

Table 31 - Stability at Rail Exit

Launch rod length	Motor	CG location	CP location	Stability
8 ft	K1103X	77.22	96.38	4.76
	K805G	77.68	96.37	4.64
10 ft	K1103X	77.14	96.38	4.78
	K805G	77.62	96.37	4.66
12 ft	K1103X	77.08	96.38	4.79
	K805G	77.56	96.37	4.67

The stability margin at rail exit is fairly consistent in the range of 4.75 to 4.8 for the primary motor and 4.6 to 4.7 for the secondary motor. Below are graphs visualizing the full CG and CP profile for the full-scale vehicle with varying launch rod lengths.

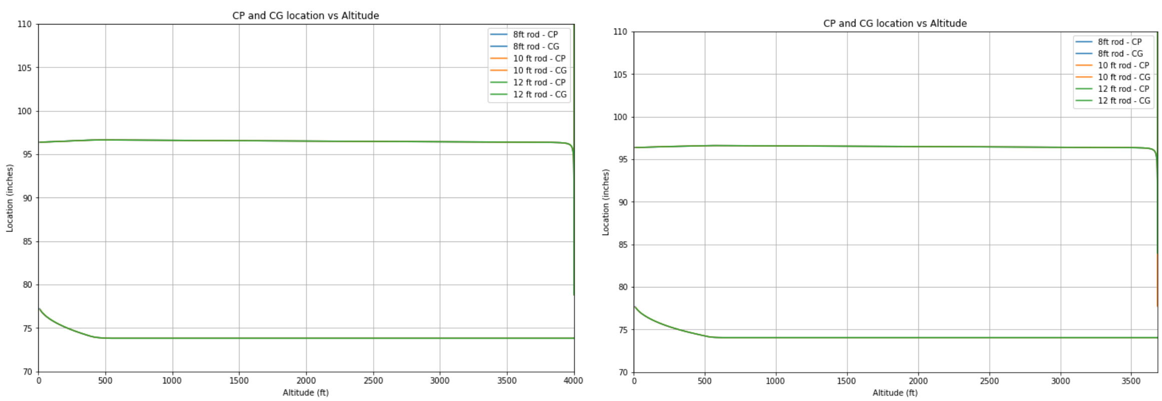


Fig. 52 - CP and CG locations with varying rail lengths - K1103X, K805G

6.3 Vertical Orientation

As mentioned in section 4.4 Impact on Full-Scale, the stability of the rocket is secondary to the vertical orientation of the rocket. Below is the mean vertical orientation in the range of 100 to 1000 ft with the worst case wind speed of 20 mph:

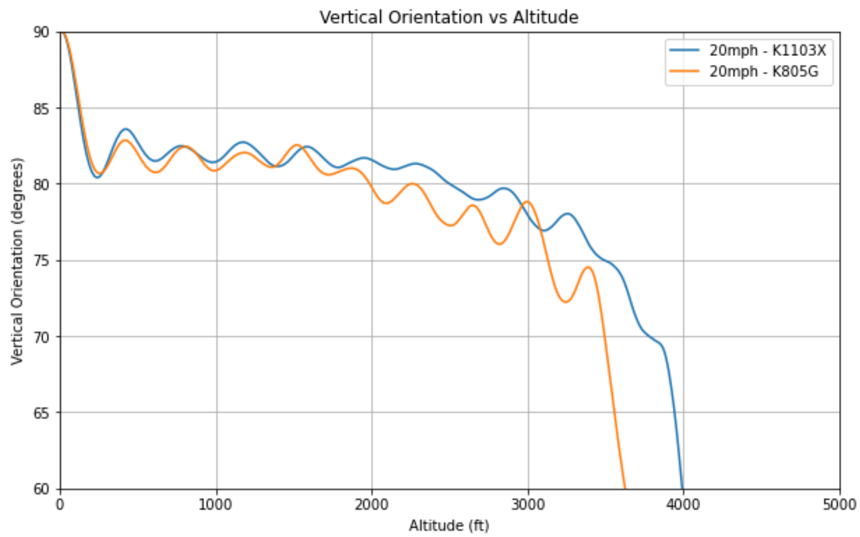


Fig. 53 - Vertical orientation full-scale

Table 32 - Vertical Orientation

Motor	Mean vertical orientation
K1103X	82.22
K805G	81.97

The mean vertical orientation of the full-scale in the worst case condition of 20 mph at the Huntsville launch is approximately 80° to 85°. The full-scale vehicle is fairly resistant to wind speeds of 20 mph with the updated fins and longer booster.

6.4 Thrust-to-Weight Ratio

The thrust-to-weight ratio (T:W) is a key parameter in rocket design as it determines whether a rocket can successfully overcome gravity and begin its ascent. Stated by requirement 2.15, the minimum T:W ratio is 5:1. The plot below shows the thrust-to-weight ratio of the rocket vs. the altitude.

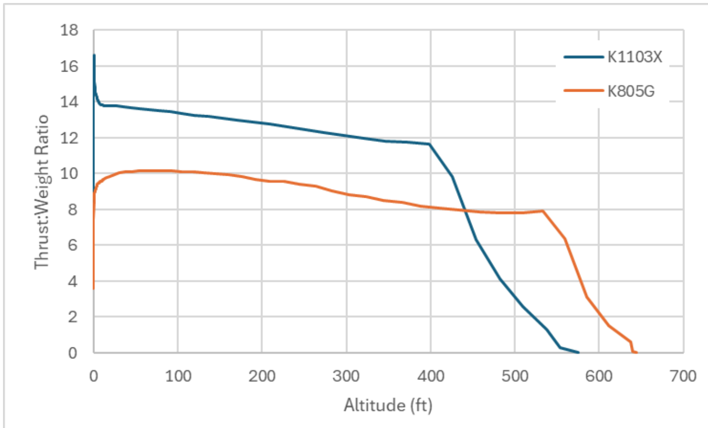


Fig. 54 - Thrust-to-weight ratio - K1103X, K805G

The thrust-to-weight ratio of both the primary and secondary motors exceeds the 5:1 ratio of requirement 2.15 at liftoff and through the early stages of flight. The K1103X achieves a maximum T:W ratio of approximately 17:1 and the K805G achieves a maximum T:W ratio of 10:1. As the motor burns near completion, both motors drop below the 5:1 ratio. In both cases, the motors provide sufficient thrust for stable flight.

6.5 Descent Characteristics

All descent simulations were conducted using the settings provided in section 6.1 Kinematics. The following section includes kinetic energy, descent velocity, descent time and total drift.

6.5.1 Kinetic Energy

The rocket's kinetic energy reaches its peak at terminal velocity during descent under the drogue chute, which for the full-scale vehicle has been simulated through OpenRocket to be 85 ft/s.

Kinetic energy can be calculated by using the following equation

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

Table 33 - Kinetic Energy Under Drogue.

Section	Mass (slugs)	Terminal velocity (ft/s)	Kinetic energy (ft-lbf)
Booster tube assembly	0.265	85	957.41
Payload tube assembly	0.284		1164.68

The terminal velocity under the main parachute has been simulated to be 18.1 ft/s. The table below shows the kinetic energy of each section under the main parachute.

Table 34 - Kinetic Energy Under Main

Section	Mass (slugs)	Terminal velocity (ft/s)	Kinetic energy (ft-lbf)
Booster tube assembly	0.265	18.1	43.41
Payload tube assembly	0.154		25.16
Nose cone assembly	0.093		16.33

The kinetic energies of each component of the full-scale vehicle satisfy the 75 ft-lbf limit stated by Requirement 3.3. The component with the highest kinetic energy on landing is the booster tube assembly with a kinetic energy of 43.41 ft-lbf.

6.5.3 Descent Time

Requirement 3.12 states that the descent time of the full-scale launch vehicle is limited to 90 seconds from apogee to touchdown. The following simulations of descent time were conducted through OpenRocket in varying wind speeds:

Table 35 - Full-Scale Descent Times for the K1103X

Wind speed (mph)	Drogue-to-main time (seconds)	Main-to-ground time (seconds)	Apogee-to-ground time (seconds)
0	43.39	30.45	73.84
5	43.14	31.23	74.37
10	43	31.47	74.47
15	43.14	31.11	74.25
20	43.1	30.26	73.36

At a wind speed of 20 mph, the total descent time for the full-scale rocket is 73.36 seconds. The full-scale vehicle remains under the drogue for an average of 43.15 seconds and 30.90

seconds under the main, making up for an average apogee to ground time of 74.06 seconds. This is below the 90 second limit set by requirement 3.12.

6.5.4 Drift

Requirement 3.11 states that the rocket must have a recovery radius of under 2,500 ft. Two methods were used to calculate the total drift that the full-scale vehicle achieves during flight. Below is the basic method of calculating the total drift of the rocket.

The basic drift calculations were performed using the method suggested for use on the flysheet. This method consists of assuming a perfect vertical flight trajectory, then multiplying the descent time by the wind speed. This produces a simplistic case where the effects of weathercocking, nosing over at apogee, variable wind speed, turbulence, and thermals.

$$\Delta x = V_{wind\ speed} * T_{avg\ apogee\ to\ ground}$$

Table 36 - Basic Drift Calculations

Wind speed (mph)	Wind speed (ft/s)	Average descent time (apogee to ground) (s)	Drift (ft)
0	0.0	73.4	0
5	7.3		538
10	14.7		1076
15	22.0		1614
20	29.3		2152

Utilizing only the distance equation, we were able to estimate the drift of the full-scale launch vehicle. The worst condition for launch, 20 mph (29.3 ft/s), causes a drift of approximately 2152 ft which stays within the requirement 3.11 which is a margin of 13.9%.

To perform a more accurate simulation for drift, OpenRocket simulations were used with a rail size of 12 ft 1515. A 90° wind vector was set in OpenRocket which simulates the worst case condition for drift. The plot below shows a visual representation of the drift.

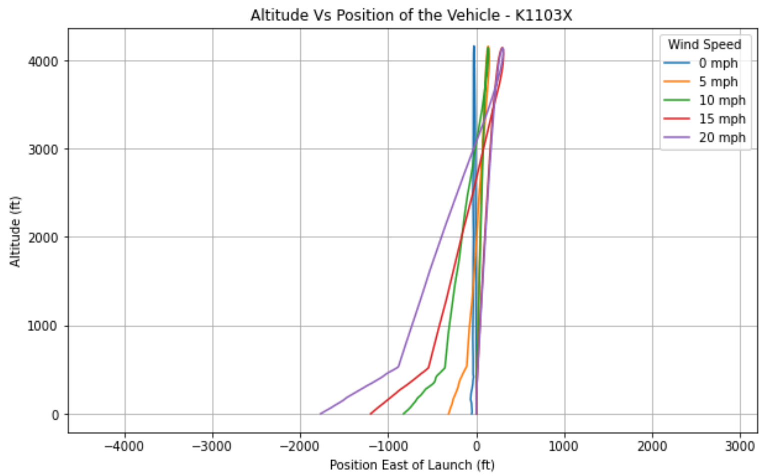


Fig. 55 - Full-scale drift plot

Table 37 - Altitude vs. Wind Speed Full-Scale

Wind speed	Drift
0 mph	53 ft
5 mph	315 ft
10 mph	826 ft
15 mph	1120 ft
20 mph	1769 ft

According to OpenRocket, our rocket even in the worst condition of 20 mph lands comfortably within the limit of 2500 ft with a 29.24% safety margin. The main difference between the more accurate analysis and the simplistic analysis is primarily due to OpenRocket including the rocket weathercocking and nosing over into the wind. These effects are not included in the simple descent time multiplied by wind speed calculations.

6.6 Summary

To consolidate the information, a table with the relevant metrics is shown below with the corresponding requirements. This is included for both primary and backup motors for full-scale vehicle

Table 38 - Summary of Performance Parameters

Metric	K1103X	K805G	Requirement
Altitude **(ft)**	4000	3684	2.1: Between 3500 and 5500 ft Apogee
Static Stability Margin at Rail Exit **(cal)**	4.63	4.53	2.13: Min 2.0 at Rail Exit
Thrust:Weight Ratio	17:1	10:1	2.14: Min 5:1
Peak Acceleration **(ft/s^2)**	487	283	No Requirement
Rail Exit Velocity **(ft/s)**	102	81	2.16: Min 52 ft/s
Peak Velocity **(ft/s)**	546	505	2.22.6: Max Mach 1 (1125 ft/s)
Capsule KE at Landing **(ft-lbf)**	16.33	16.33	3.3: Max KE at Landing of 75 ft-lbf
Coupler/Payload Tube KE at Landing **(ft-lbf)**	25.16	25.16	3.3: Max KE at Landing of 75 ft-lbf
Booster KE at Landing **(ft-lbf)**	43.41	43.41	3.3: Max KE at Landing of 75 ft-lbf
Recovery Radius at 20 mph wind **(ft)**	2152	2157	3.11: Max Radius of 2500 ft
Descent Time **(s)**	73.36	73.57	3.12: Max 90 s

7.0 Payload Criteria

For our payload, we designed and are constructing a scaled-back version of the USLI payload challenge. Instead of recording and transmitting on a 2-M radio band to the NASA base station, telemetry will be transmitted to a team receiver and interpreted locally in real-time on a laptop on-site. Similar to the college/university mission, our objective as a first-year high school team is to launch and safely recover a STEMnaut capsule holding four STEMnauts while recording telemetry data, namely max Gs, max velocity, altitude, descent rate, and parachute status.

The details of the payload description was detailed in the proposal and the Preliminary Design Review. The table below summarizes the general features of the payload.

Table 39 - Payload Summary of Specifications

Parameter	Description	Success criteria
Radio Frequency	434 MHz, Periodic transmission under FCC Part 15.231	Measured on spectrum analyzer
Radio Protocol	LoRa, ReliableDataGram	Successful reception of data packets throughout flight.
Functionality	• Power up self-test/initialization • Idle, listening mode • Active sensor reads, no transmission • Active sensor reads, periodic transmission • Sensor idle, periodic status transmissions • Program end, low power idle	Ability to remotely set active modes throughout the entire sequence from power up through rocket recovery.
Sensor Information	• Altitude • Temperature • Capsule orientation • Acceleration (3-axis)	Successful logging and transmission of data through the flight sequence.
Interpreted Results Reported	• Vehicle Status: ○ Launch detected ○ Apogee ○ Drogue descent ○ Main descent ○ Landing ○ Malfunction • Maximum velocity • Maximum acceleration during boost • Drogue parachute descent rate • Main parachute descent rate • STEMnaut Orientation at: ○ Pre-ignition ○ Boost ○ Nose Over ○ Landing	Interpreted events successfully identified by base station during flight.

7.1 Payload Design Selection

7.1.1 Control Module

For the central control module, we will use an Adafruit Feather M0 RFM96. It integrates a LoRa radio module with an Arduino IDE compatible microcontroller, reducing the need to purchase and consider the integration of any more external sensors than necessary. Furthermore, based on our electronic lead's familiarity with the platform, a large community, and abundant community resources, we chose a microcontroller with Arduino compatibility.

The RFM96 operates at 434 MHz under FCC Part 15.231 as a low power periodic transmitter. Most GPS tracking units operate in the 915 MHz band (Featherweight, SimpleGPS, and

Eggtimer). Using the 434 MHz band allows us to operate with less chance of interfering with other systems. However, this does come with a very minor range penalty. Initial estimates show that this system provides more than adequate range (P-D-2) .

7.1.2 Sensor Selection

For our sensors, we also decided to use Adafruit modules as they offer high-quality libraries that make troubleshooting and compatibility less of an issue. Furthermore, many Adafruit sensor boards use the STEMMA QT interface, consolidating connections through daisy-chaining.

To detect altitude and vertical velocity, we are using an Adafruit BMP390, which uses the newest pressure sensor chip from Bosch. To detect STEMnaut orientation, we are using an Adafruit BNO085 orientation sensor. For max acceleration, we are using an Adafruit ADXL345 triple-axis accelerometer.

7.1.3 Payload Battery Selection

A LiPo battery was selected for the payload power source. A LiPo battery provides one of the higher power to size/weight ratios, is rechargeable, and is compatible with other batteries and charging methods used within this project. The microcontroller unit has a regulator on the board and allows us to use a voltage source between 3.4 V and 9 V. This is easily satisfied by a 1S LiPo battery providing 4.1 V when fully charged, a nominal 3.7 V, and 3.5 V when discharged to 20% capacity.

Table 40 - Estimated Payload Current Requirements

Component	Current	Condition
Microcontroller/Radio	40 - 120 mA (50 mA avg)	40 mA receiving, 120 mA transmitting
BMP390	0.032 mA	
BNO085	7.5 mA	
ADXL345	0.14 mA	
Quiic OpenLog	6 - 23 mA (10 mA avg)	6 mA idle, 23 mA during writes to SD card
Total	**82.5 mA**	**Estimated**

Based on the estimated current draw of the components in the table above, a standard 1S 500 mAh will provide over 5 hours of battery life in nominal conditions, and should exceed the required three hour life in flight ready conditions (requirement 2.6, P-D-4, P-C-2). In addition, the program will have the feature to shut down the radio transmission (still receiving), the sensors, and the data logging features remotely which will save considerable power if necessary. The battery life will be tested thoroughly through test FS-P-3.

7.2 Payload CONOPS

The payload has six modes of operation. These modes are triggered either remotely by the base station, or triggered based on measured events. The description of the modes is given in the table below:

Table 41 - Payload Modes of Operation

Mode	Description	Initialization
Self-Test	• Sensor initiation • Cycle through sensors to verify valid data • Test RF communication link • Exit to Idle_1 Mode	Power Up
Idle_1	• Low power (no sensor reads, no transmissions) • Radio receiver actively listening for mode change command	Receive command for mode change
Sensor_Only	• Measure sensors every 200 ms • Log sensor data on SD card • No RF transmissions • Radio receiver actively listening for mode change command.	Receiver command for mode change.
Sensor_Transmission	• Measure sensors every 200 ms • Log sensor data on SD card • Transmit data every 1000 ms • Radio receiver actively listening for mode change command.	Receiver command for mode change.
Transmission_Only	• Transmit data every 1000 ms • Radio receiver actively listening for mode change command. • Used for summary data only. No active sensor measurements	Receiver command for mode change.
Idle_2	• Radio turned off. • No sensor reads. • Lowest power mode. • Terminal end mode (no changing modes out of this state).	• Received message to switch to this mode. • Battery voltage reaches a critically low level.

A nominal flight profile should progress through most of the available modes with the exception of Transmission_Only. This mode is primarily available in the event of a sensor failure. The ideal flow of operations is shown in the figure below. During normal operation, the sensor and radio transmissions are disabled unless remotely enabled from the base station with a radio command. This allows for reduced RF traffic congestion during the Huntsville launch as well as significant battery savings.

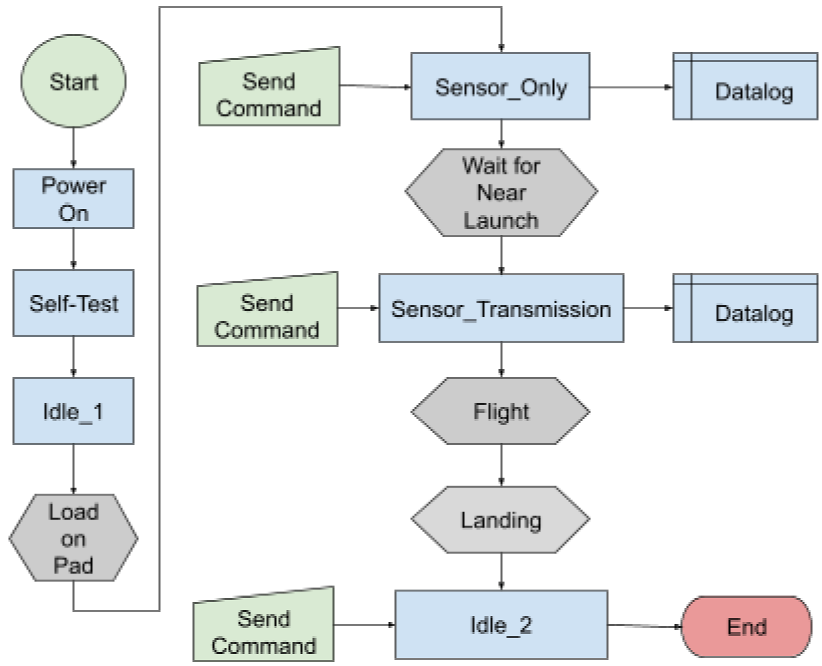


Fig. 56 - Nominal flight payload CONOPS

In the event that there is difficulty with the radio communications, the system can be configured to turn the sensor and data logging to an always on mode simply by enabling Sensor_Only mode shortly after power up. This would be the contingency if there is excessive RF interference during the launch week to allow functionality of the most mission-critical features of the system.

7.3 Mechanical Component Design

All payload components were created using Autodesk Inventor Professional and imported into Onshape for working drawings, editing, and collaboration. For modularity, ease of parts replacement, and ease of access, all parts are designed to be screwed together using #4-40 screws. Heat-set inserts are used to ensure structural integrity of mating surfaces (P-D-6). Furthermore, a variable mass component to be used for ballast is also integrated into the payload/tracker assembly.

Payload components will be 3D printed using Creality Hyper Series PLA filament. It appears, among the filaments we compared, to be the best balanced in terms of tensile strength, flexural modulus, print speed, and cost. As the failure mode for 3D printed components is typically layer adhesion, which is machine, print speed, and temperature dependent. In order to verify the structural integrity of the filament chosen and our print settings, we will carry out destructive testing (FS-P-4). This will allow us to verify our payload components comply with P-D-3 and P-D-6.

7.3.1 Component Design and Integration

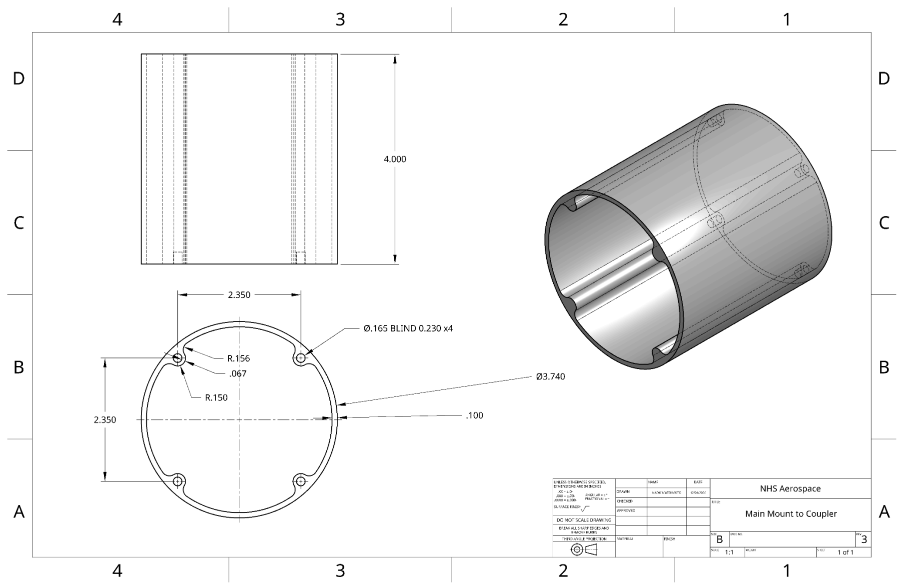


Fig. 57 - Main payload mount

The main mount will be epoxied into the nose cone coupler to act as the base for the screwed-in, modular tracker/payload assembly. To allow for addition of ballast mass, the central hole supports the addition of the ballast holder (Fig 58), to be clamped between the tracker/payload mount plate and the main mount.

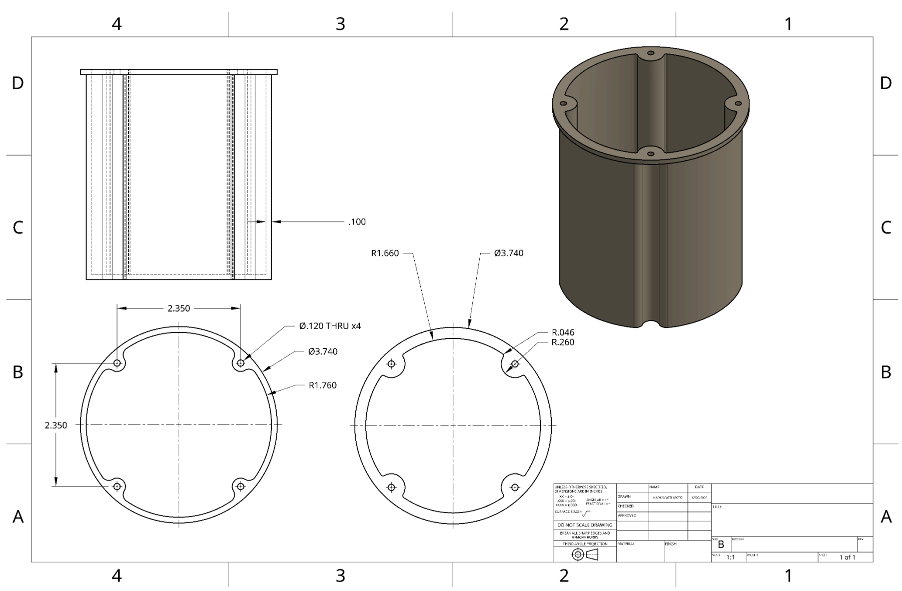


Fig. 58 - Ballast holder

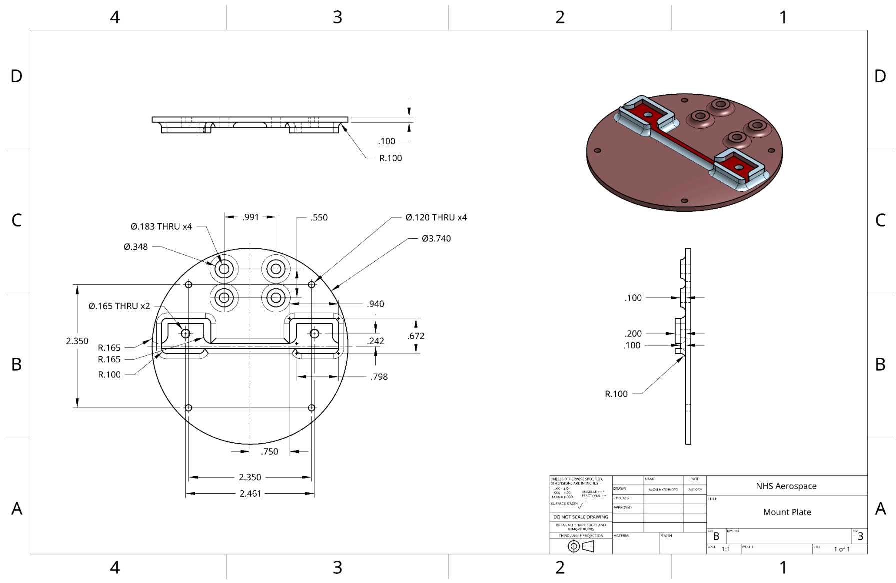


Fig. 59 - Tracker/payload mount plate

The payload and tracker will be mounted onto this main mount plate, to allow nearly full construction of the assembly before insertion into the nose cone coupler. This mount plate also clamps the ballast holder into place (see Fig. 64 for full assembly).

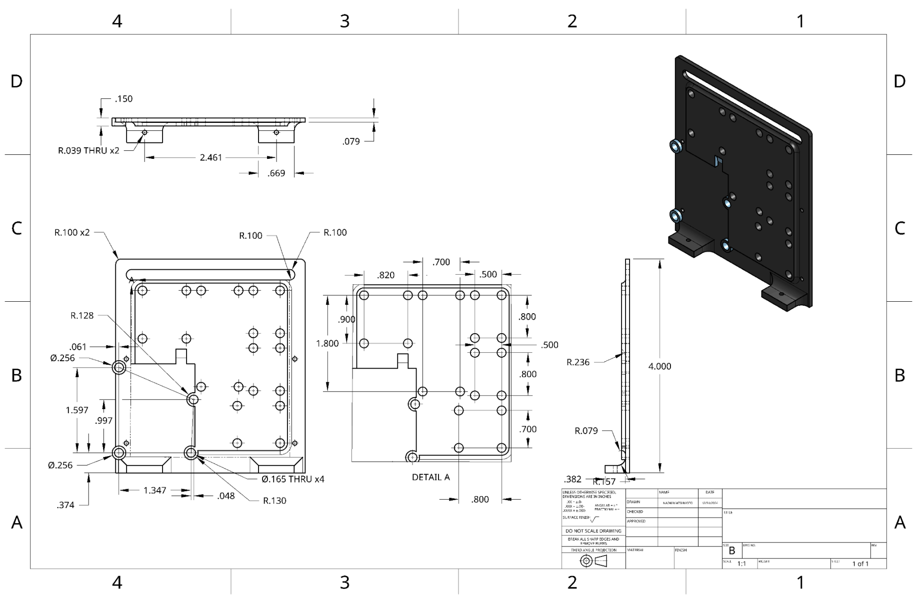


Fig. 60 - Payload electronics mount

The electronics mount plate will act as the backbone for the payload, where all electronics and the cockpit will be attached. The mount then screws into the tracker/payload mount place (Fig. 59). Holes to fit heat-set inserts are spaced to accommodate the Adafruit RFM96, sensor boards, and datalogger, as well as a mount for the cockpit. The slot at the top will be used for cable routing if needed.

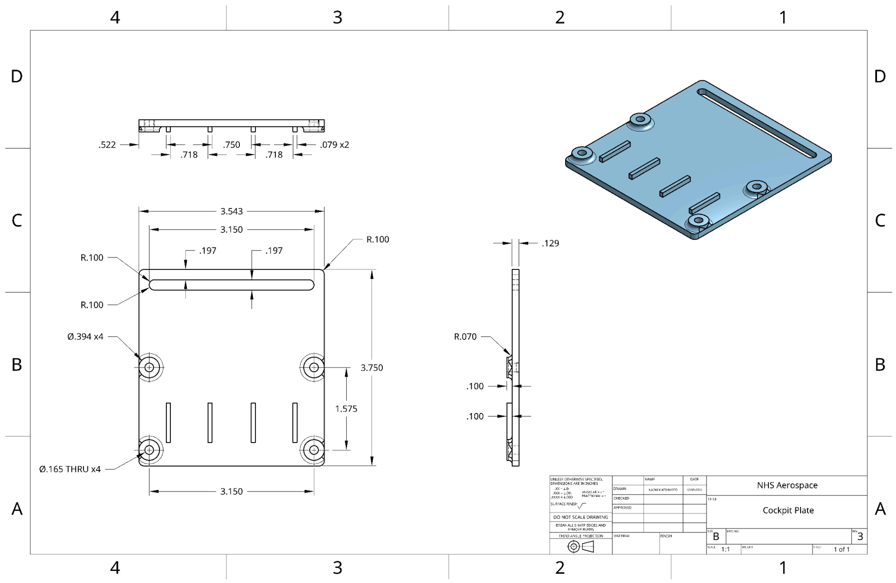


Fig. 61 - Payload cockpit mount

The cockpit will be built upon this mount plate, which will be screwed into the electronics mount. The four rectangular extrusions will be used to mount the STEMnauts into place, while the rest of the cockpit will be built freely upon the blank plate.

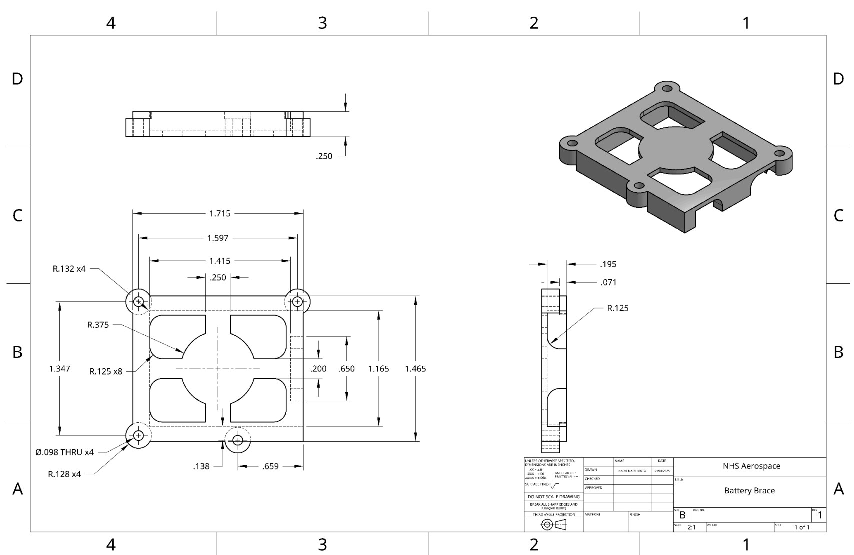


Fig. 62 - Battery brace

The battery will be held in place with this battery brace, designed to screw onto the electronics mount with four screws (see Fig. 63 - Electronics integration), with space for a flammability warning and a LiPo label.

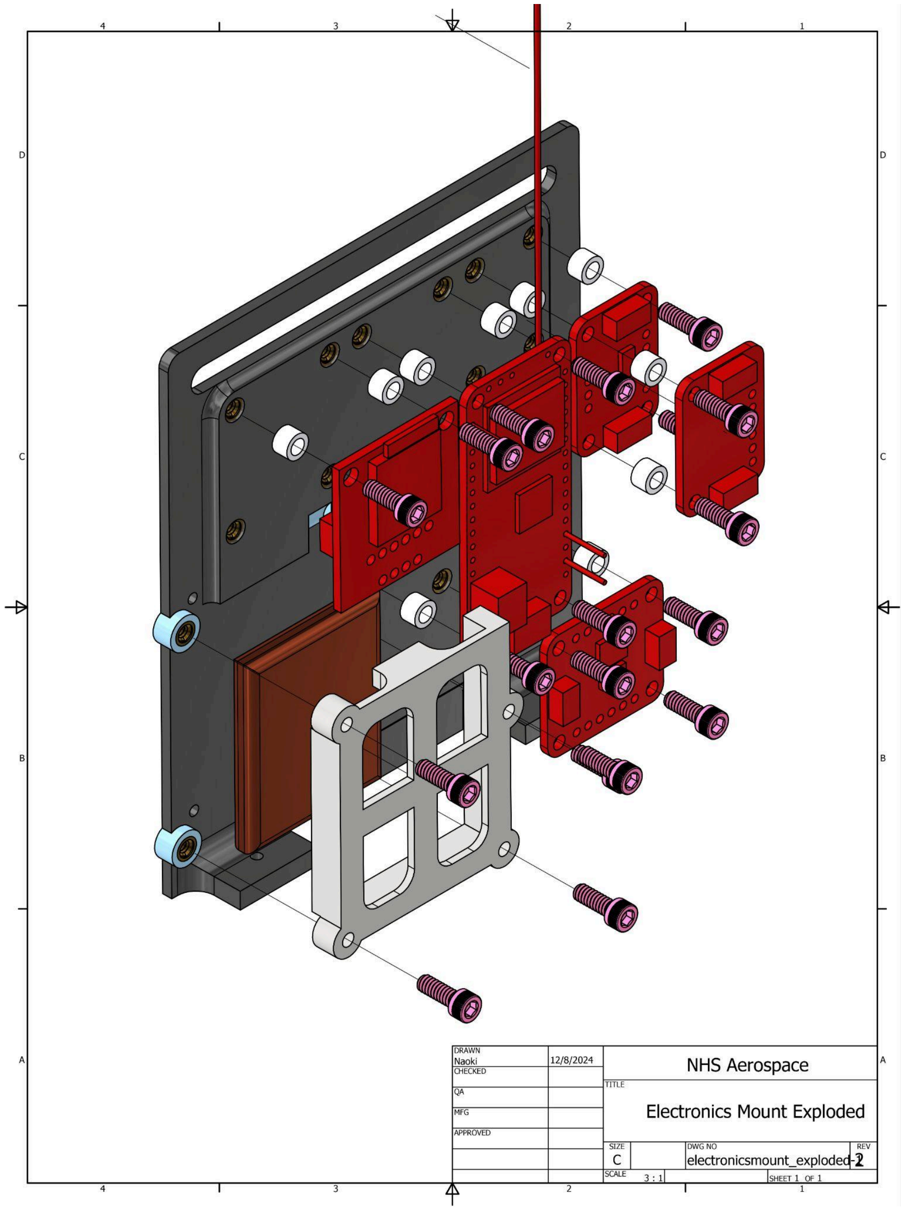


Fig. 63 - Electronics integration

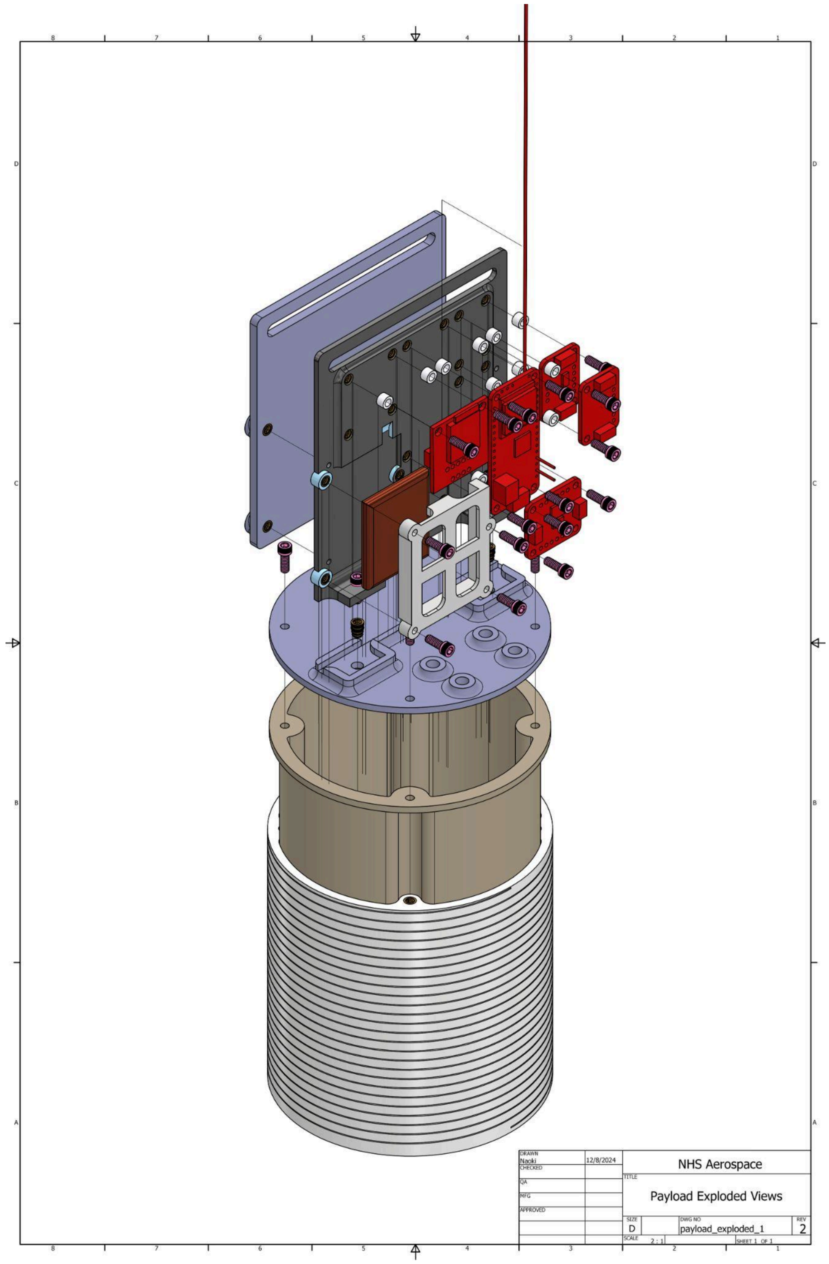


Fig. 64 - Payload assembly exploded view (antenna has been cut off for optimizing image size)

Stress analyses were performed using Autodesk Inventor. While the specific material we are using, PLA/PC, was not available in the material library, ABS/PC was determined as an appropriate substitute. Furthermore, these stress analyses are only a reference to figure out critical stress points of payload components more than to determine their failure strength. We calculated landing forces and parachute deployment forces, and simulated them on the most critical component that would be under those forces: the electronics mount. The results are summarized below:

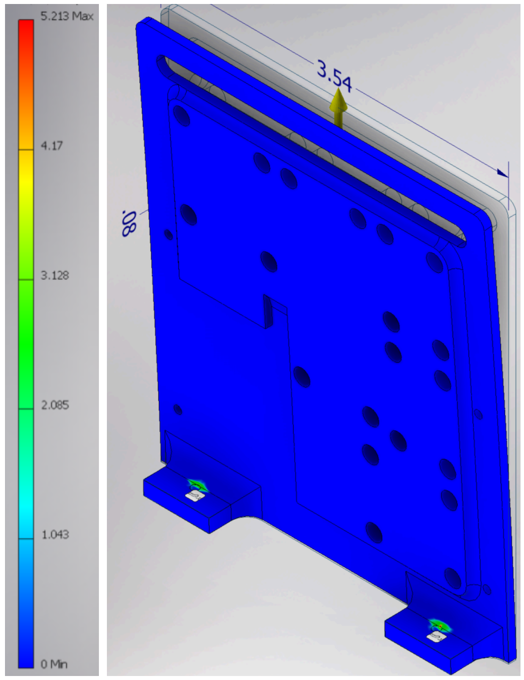


Fig. 65 - Von Mises stress calculated from finite element analysis (MPa), deployment forces

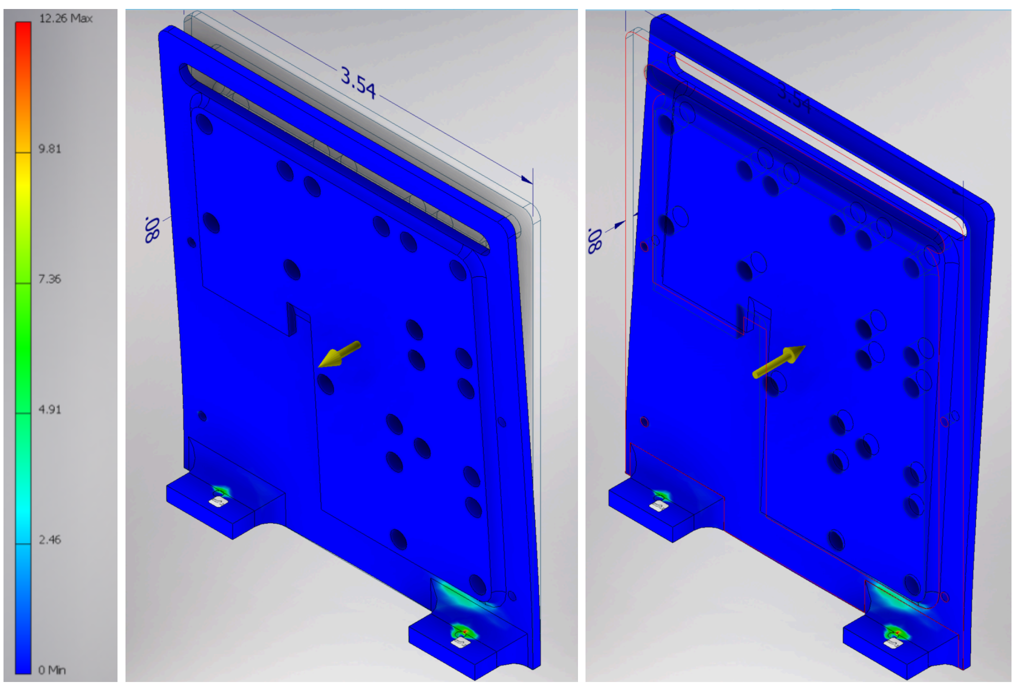


Fig. 66 - Von Mises stress calculated from finite element analysis (MPa), landing forces

The stress analysis identified areas of increased stress. Identification of these high stress areas was the goal of this analysis, and high level interpretation will not be performed. To ensure structural integrity, a drop test (FS-P-4) will be performed.

Table 42 - Payload Component Estimated Masses

Part	CAD estimated weight (lbs)
Mount	0.14
Mount plate	0.04
Electronics mount	0.06
Cockpit	0.05
Ballast holder	0.05
Battery brace	0.01

7.3.2 Airframe Integration

The main mount (Fig. 57) will be epoxied into the nose cone coupler to act as the base for the screwed-in, modular tracker/payload assembly. For ease of assembly and parts replacement, the payload and tracker will be assembled on the mount plate (Fig. 67) before being screwed into the main mount. All screw interfaces will utilize heat-set inserts to optimize strength (P-D-3, P-D-6), instead of screwing straight into 3D printed plastic. Each part has also been created to optimize contact area, allowing better load distribution under high G conditions.

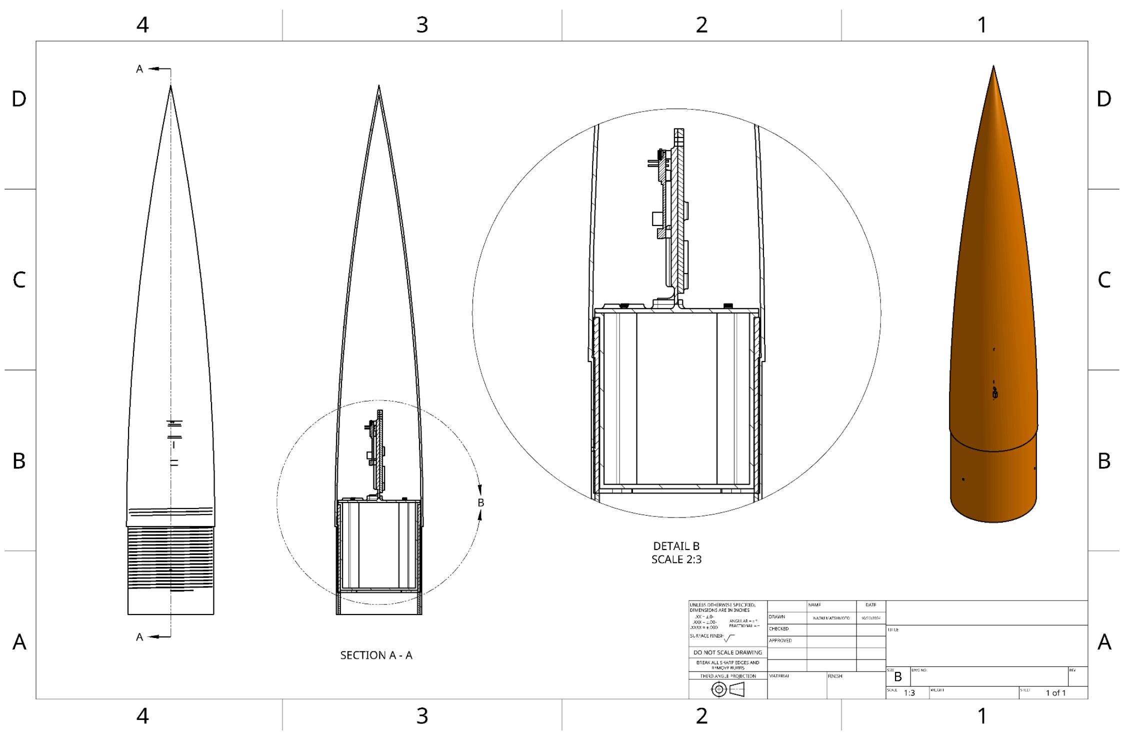


Fig. 67 - Airframe integration

7.4 Payload Electrical Design

7.4.1 Component Design

As stated in section 7.1.1 Control Module, our payload electronics will be managed by the Adafruit Feather M0 RFM96 with an integrated Arduino microcontroller. The components being managed includes the Adafruit BMP390 pressure sensor, the Adafruit BNO085 orientation sensor, the SparkFun Qwiic OpenLog datalogger, and the LiPo 1S 500 mAh battery. These components will be connected as seen in Fig. 68.

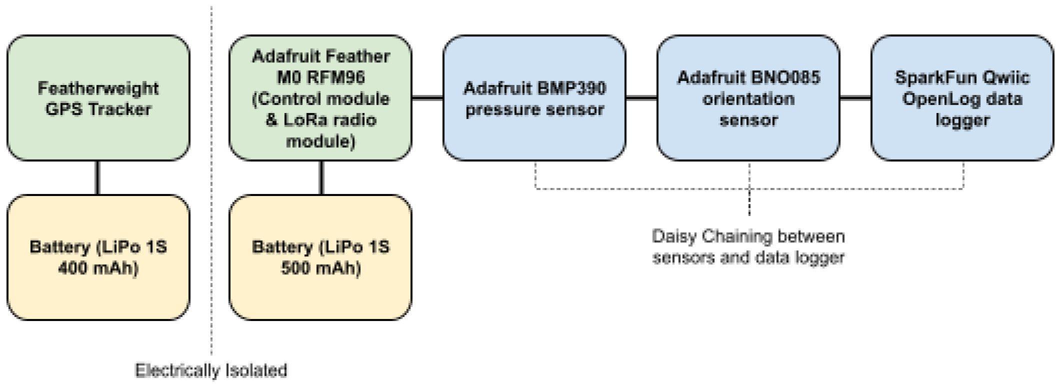


Fig. 68 - Payload electronics connection diagram

Each of our sensors will be connected to the Adafruit Feather M0 RFM96 via daisy-chaining using the Stemma-QT 4-wire cables. This allows for I2C communication between all of the sensors with a common interface. The power from the battery is connected to the 2 pin JST-PH battery port on the Adafruit Feather board.

7.4.2 Programming Logic

To measure, record, and transmit our rocket telemetry data, our software logic will follow the flowchart as documented in Fig. 69.

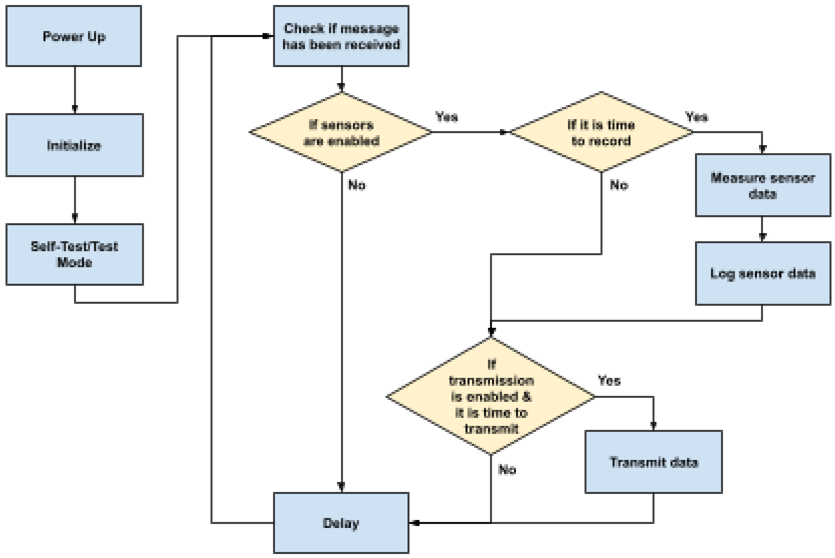


Fig. 69 - Payload programming logic flowchart

Before performing any sensor measurements or data transmissions, our control module will use its LoRa radio module (with client configuration) to check for any messages from its corresponding radio with server configuration. The client and server have unique two-byte identifiers, ensuring that they will only communicate to the IDs that they are configured to communicate with. Potential messages include enabling and disabling sensors, as well as enabling and disabling data transmission. When sensors are enabled, sensor data will be measured and logged on a set time interval (P-D-4). Data will only be transmitted if both sensors and transmission are enabled (P-D-5). Like data logging, transmissions will occur over a set interval. Once the rocket flight is complete, data measurements and transmissions can be disabled remotely (P-D-1).

8.0 Safety

8.1 Launch Preparation and Operating Procedures

8.1.1 Pre-Launch Day Drogue Recovery System Preparation

Scope: The following instructions cover the preparation of the drogue recovery system before arriving at the launch.
Members Required: Team Mentor, Safety Officer, Recovery Lead
PPE: None needed
Materials Required:

- Parachute
- Quicklink
- Kevlar harness
- Coiling tool
- Nomex Blanket

Potential Hazards:

- Partial or total airframe loss
  - Failed deployment:
    - A failed deployment could occur due to improper folding and packing which could lead to a failed recovery and structural damage or loss of the vehicle
    - A failed deployment could occur due to a loose quicklink connecting the parachute and could lead to the parachute detaching from the recovery system and lead to structural damage or loss of the vehicle.
    - A failed deployment could occur due to insufficient coverage of the parachute with the Nomex blanket during deployment, which could lead to sparks or heat damaging the parachute resulting in failure during recovery.
- Partial or total loss of recovery components
  - Parachute entanglement: Entanglement could occur due to tangled shroud lines or kevlar harness during preparation, which could lead to failed or delayed parachute deployment, resulting in a hard landing or structural damage.

Steps:

- [ ] Spread parachute out neatly, ensuring shroud lines are not tangled.
- [ ] Perform an accordion fold, making sure all shroud lines line up when fully folded. “Z fold” the shroud lines into the parachute, and roll tightly.
- [ ] “Z fold” the rolled up parachute into thirds.
- [ ] Taking care not to let it lose shape, place onto Nomex, ensuring correct orientation of Kevlar harnesses. Then, connect the parachute to quicklink and connect quicklink to loop in drogue harness (unstitched area).
- [ ] Fold top edge of Nomex over the parachute then fold the sides of Nomex in. After, roll up the parachute, taking care to ensure the Kevlar harness is coming out of the correct part of the Nomex. Then, loop the forward side of the harness through a rubber band.
- [ ] Loop bottom Kevlar harness through loop in the Nomex and secure the parachute with rubber bands. Ensure to use bright colored rubber bands to lessen the risk of forgetting to take it off.
- [ ] Measure out about 2.5 ft of the Kevlar harness (ensuring no twists) and place a coiling tool.

Then, wind the first coil until it is flush with the parachute-Nomex
- ☐ Repeat coiling in alternating directions, ensuring each coil is close enough to the previous that they will stack. Leave about 2-3 ft of harness to attach to the leader.

Troubleshooting:
- Tangled shroud lines
  - Ensure shroud lines are straight and have no knots, kinks in them prior to packing. Spread out the parachute and untangle the lines, ensuring that they are straight and aligned before folding
- Nomex coverage
  - Ensure that the parachute is folded tight and smaller than the Nomex blanket dimensions. Tightly fold each side of the Nomex blanket over the parachute
  - Ensure no nylon material is exposed after packing

8.1.2 Pre-Launch Day Main Recovery System Preparation

Scope: The following instructions cover the preparation of the main recovery system before arriving at the launch.
Members Required: Team Mentor, Safety Officer, Recovery Lead
PPE: None Needed
Materials Required:
- Parachute
- Quicklink
- Kevlar harness
- Coiling tool
- Nomex Blanket

Potential Hazards:
- Partial or total airframe loss
  - Failed deployment:
    - A failed deployment could occur due to improper folding and packing which could lead to a failed recovery and structural damage or loss of the vehicle
    - A failed deployment could occur due to a loose quicklink connecting the parachute and could lead to the parachute detaching from the recovery system and lead to structural damage or loss of the vehicle.
    - A failed deployment could occur due to insufficient coverage of the parachute with the Nomex blanket during deployment, which could lead to sparks or heat damaging the parachute resulting in failure during recovery.
- Partial or total loss of recovery components
  - Parachute entanglement: Entanglement could occur due to tangled shroud lines or Kevlar harness during preparation, which could lead to failed or delayed parachute deployment, resulting in a hard landing or structural damage.
- Severe impact from falling object
  - A ballistic recovery poses significant risk of severe injury should it land near people

Steps:
- ☐ Spread parachute out neatly, ensuring shroud lines are not tangled.

- [ ] Perform an accordion fold, making sure all shroud lines line up when fully folded. “Z fold” the shroud lines into the parachute, and roll tightly.
- [ ] “Z fold” the rolled up parachute into thirds.
- [ ] Taking care not to let it lose shape, place onto Nomex, ensuring correct orientation of Kevlar harnesses. Ensure that the parachute loop and the forward main recovery harness loop are outside of the folding area.
- [ ] Fold top edge of Nomex over the parachute then fold the sides of Nomex in. After, roll up the parachute, taking care to ensure the Kevlar harness and parachute loop coming out of the correct part of the Nomex. Attach a quicklink through both the parachute and the Kevlar harness loop
- [ ] Loop bottom Kevlar harness through loop in the Nomex and secure the parachute with rubber bands. Ensure to use bright colored rubber bands to lessen the risk of forgetting to take it off.
- [ ] Measure out about 2.5 ft of the Kevlar harness (ensuring no twists) and place a coiling tool. Then, wind the first coil until it is flush with the parachute-Nomex
- [ ] Repeat coiling in alternating directions, ensuring each coil is close enough to the previous that they will stack. Leave about 2-3 ft of harness to attach to the leader.

Troubleshooting:

- Tangled shroud lines
  - Ensure shroud lines are straight and have no knots, kinks in them prior to packing. Spread out the parachute and untangle the lines, ensuring that they are straight and aligned before folding
- Nomex coverage
  - Ensure that the parachute is folded tight and smaller than the Nomex blanket dimensions. Tightly fold each side of the Nomex blanket over the parachute
  - Ensure no nylon material is exposed after packing

8.1.3 Pre-Launch Day Avionics Bay Preparation

Scope: This portion covers the preparation of the avionics bay prior to launch day.
Members Required: Team mentor, Recovery Lead
PPE: Safety glasses
Materials Required:

- Screwdrivers (Philips head)
- Digital Multimeter
- LiPo charge level measurement box
- Avionics bay assembly
- Wire cutters
- Wire strippers
- Ejection charge screws tool (subscale only)

Potential Hazards:

- Burns or shock:
  - Handling batteries improperly could lead to short circuits or sparks, resulting in electronic shock or equipment damage
  - Exposed live wires could lead to shocks resulting in burns
- Cuts or lacerations:

    - Using sharp tools like screwdrivers, wire cutters, or strippers could lead to cuts or punctures.
- Partial or total airframe loss:
    - Deployment failure:
        - Loose screws could cause components to detach leading to deployment failure during testing or flight
        - Improper wire connections could cause a failed deployment event during testing or flight

Steps:

- [ ] Separate the avionics coupler from the rocket assembly.
- [ ] Remove the avionics bay from inside of the coupler. Then, check the batteries for damage and charge.
- [ ] Place the avionics bay inside the avionics coupler and tighten the nuts on the outside of the bulkheads.
- [ ] Place the assembled avionics bay into the stand drogue side up. The drogue side has no screws drilled into the coupler.
- [ ] Obtain the appropriate charge wells for the launch vehicle. For subscale: The main charge tube is smaller than the secondary charge tube.
- [ ] (**Mentor, Safety Glasses**) Cut E-match leads to 6” length. Strip the wires about an inch using the 22 AWG size in a wire cutter.
- [ ] (**Mentor**) Use the appropriate screwdriver to loop the stripped wire around the diameter of the screwdriver. Then, flip the loop to face left.
- [ ] (**Mentor**) Use the larger screwdriver to loop the remaining wire (resembling a spring) by starting at the end of the centrifuge tube and working your way down. Then, bend the remaining wire at a 90-degree angle.
- [ ] Remove both primary ejection charge screws using the special tool. Keep the tool upright and ensure that the screws don't fall out of the tool.
- [ ] (**Mentor**) Insert the looped centrifuge tube assembly onto the two rods. Use one of the tools to tighten one of the screws halfway. Use the other tool to tighten the other screw halfway. Then, use one screw to tighten both sides, ensuring that no copper wire is sticking outside.
- [ ] Test the resistance of the circuit by using a multimeter and setting it to 200 Ohms. Check to see that the resistance is between 1.4 to 1.9 Ohms
- [ ] Cap the ejection charge screws with a vinyl cap.
- [ ] (**Mentor**) Repeat steps 6-13 for the secondary charge. Use the larger centrifuge tube for the secondary charge.
- [ ] Flip the avionics bay with the MAIN side up. Repeat steps 6-13 for both the primary and the secondary charge.

Troubleshooting:

- Battery
    - If the battery appears damaged or fails to charge, replace the battery immediately.
    - Charge battery before using it and ensure the charge is at 100%
- Resistance out of range

- If the resistance is outside the 1.4-1.9 Ohm range, check wire connections and retest after securing them
- If the resistance is still outside the 1.4-1.9 Ohm range, replace the wires and use different ones.

- E-match issues:
    - If E-match leads are too short or damaged, recut and strip leads carefully to the correct length.
    - If wire loops are incorrectly shaped, re-loop the wires using the correct tools and verify proper orientation.
- Loose components
    - Tighten all screws and ensure that they are not loose.

8.1.4 Pre-Launch Day Payload Preparation

Scope: The following instructions cover pre-launch preparation to ensure the payload is in working order before launch.
Members Required: Payload lead, electronics lead
PPE: None required
Materials Required:

- Complete payload assembly
- Laptop
- USB cable
- 3/32” hex allen wrench

Potential Hazards:

- Burns or shock:
    - Handling LiPo batteries improperly could lead to short circuits or cell damage, resulting in electronic shock or equipment damage
    - Exposed live wires could lead to shocks resulting in burns
    - Damaged or punctured batteries will catch fire, resulting in severe burns and damage to property
- Cuts or lacerations:
    - Using sharp tools like screwdrivers or contact with a sharp edge on 3D printed parts pose a risk of minor injury

Steps:

- [ ] Check payload assembly for mechanical failures: broken or missing parts, any cosmetic or structural damage
- [ ] Turn on payload and establish connection to computer
- [ ] Verify that the payload has successfully passed mode “self-test” to ensure all sensors are working and battery is sufficiently charged
- [ ] Verify that the payload can successfully go through all successive modes (Idle_1, Sensor_Only, Sensor_Transmission, Transmission_Only, and Idle_2)
- [ ] Turn off payload

Troubleshooting:

- Battery
  - If the battery appears damaged or fails to charge, replace the battery immediately.
  - Charge battery before using it and ensure the charge is at 100%
- Electronics
  - If the payload does not pass self-test, determine its cause through the data transmitted to the laptop during that test
  - If no data are transmitted, check hardware connections for faults or short circuits
  - If cause is determined to be software based, recompile code or roll back to a version known to work to determine the root cause
- Loose components
  - Tighten all screws and ensure that they are not loose.

8.1.5 On Field Drogue Recovery System Checklist

Scope: The following instructions cover the preparation of the drogue recovery system on the field. These steps assume that the following steps have been completed before arriving to the field:

- All steps in the Pre-launch prep directions in the standard operating procedures

Required Members: Team Mentor, Safety Officer, Recovery Lead
PPE: None required
Materials required:

- Assembled drogue recovery harness
- Two quicklinks
- 2-56 Nylon shear pins (x1 2-56 for subscale, x3 2-56 for full-scale)
- Small flat head screwdriver

Potential hazards:

- Partial or total airframe loss
  - If quick links are not secured to their specific spots, it could lead to failure of the drogue recovery system, causing unsafe descent and airframe damage
  - Drag separation: if shear pins are not put in or put in improperly, this could lead to drag separation that will severely damage or destroy the airframe
- Recovery component damage or loss
  - If the parachute has not been wrapped correctly inside the Nomex blanket it could possibly lead to damage to the parachute or the destruction of the parachute in its entirety. Leading to an unsafe/ catastrophic descent which poses a potential risk to the crowd and will lead to structural damage/catastrophic damage to the rocket
- Severe impact from falling object
  - A ballistic recovery poses significant risk of severe injury should it land near people

Steps:

- [ ] Check that drogue recovery system has not disassembled
- [ ] Connect the aft end of the drogue harness to the leader with a quicklink. Fully tighten and secure the quicklink using a wrench.

- [ ] **Remove Rubber Band** holding the drogue assembly together
- [ ] Slide the drogue assembly into the booster airframe with the coil end first
- [ ] Connect the forward end of the drogue harness to the aft end of the avionics bay with a quicklink. Fully tighten and secure the quicklink using a wrench.
- [ ] Carefully feed remaining Kevlar into the airframe. Slide the avionics bay onto the booster being careful not to pinch a deployment charge wire or Kevlar.
- [ ] Line up the witness marks and secure avionics bay to the booster with a shear pin (x1 2-56 nylon shear pin for subscale, 3x 2-56 shear pin for full-scale)

Troubleshooting:
- If the drogue assembly is too tight within the airframe, unpack the burrito and repack.
- If the shear pin does not want to thread into the hole, check to make sure the opening is clear of the shear pin from prior flight and back out if necessary. If not, re-tapping may be necessary.
- If the coupler to airframe is too loose, add painters tape on the outside of the coupler as necessary. Target resistance is enough force enough to prevent side-to-side slippage of the coupler, but not more than 2-3 lbs of force to remove.

8.1.6 On-Field Main Recovery System Checklist

Scope: The following instructions cover the preparation of the main recovery system on the field. These steps assume that the following steps have been completed before arriving to the field:
- All steps in the Pre-launch prep directions in the standard operating procedures

Required Members: Team Mentor, Safety Officer, Recovery Lead, Team Lead
PPE: None required
Materials required:
- Assembled main recovery harness
- Two quicklinks
- 2-56 Nylon shear pins (x3 2-56 for subscale, x3 2-56 for full-scale)
- Small flat head screwdriver

Potential Hazards: These hazards are produced if one or more steps for prep are not completed properly.
- Partial or total airframe loss
  - If quick links are not secured to their specific spots, it could lead to failure of the drogue recovery system, causing unsafe descent and airframe damage
  - A recovery failure could lead to the loss of all payload and tracking electronics and the loss of the avionics bay making the rocket unlocatable.
- Recovery component damage or loss
  - Incorrectly assembled recovery components or incorrectly folded parachutes may lead to respective component damage or loss.

Steps:

- Check that main recovery system has not disassembled
- Connect the aft end of the main harness to the front avionics bay eye bolt by threading the recovery harness through the payload tube. Fully tighten and secure the quicklink using a wrench.
- **Remove Rubber Band** holding the main assembly together
- Slide the main assembly **halfway** into the booster airframe with the coil end first
- Connect the forward end of the main harness **and** the parachute loop to the aft end of the nose cone with a quicklink. Fully tighten and secure the quicklink using a wrench.
- Slide the remaining main assembly into the payload tube.
- Carefully feed remaining Kevlar into the airframe. Slide the avionics bay onto the aft end of the payload tube being careful not to pinch a deployment charge wire or Kevlar.
- Slide the nose cone onto the front end of the payload tube, ensuring all recovery components are inside the body tube.
- Line up the witness marks and secure avionics bay to the payload tube with a screws (3x #6 screws for subscale, 3x #8 screws for full-scale)
- Secure nose cone to the payload tube with a shear pin (x3 2-56 nylon shear pin for subscale, 3x 2-56 shear pin for full-scale)

Troubleshooting

- If the main assembly is too tight within the airframe, unpack the burrito and repack.
- If the shear pin does not want to thread into the hole, check to make sure the opening is clear of the shear pin from prior flight and back out if necessary. If not, re-tapping may be necessary.
- If screws are not threading into their respective holes, make sure that the witness mark is lined up and then slightly wiggle the screw to get it into position and thread slowly.

8.1.7 On-Field Avionics Bay Checklist

Scope: This portion covers the final on-field preparation of the avionics bay. These steps assume the following steps have been completed prior to arriving at the field:

- E-matches have been installed by the mentor
- All batteries have been charged
- Black powder charges have been pre-measured in a controlled environment

Required Members: Team Mentor, Safety Officer, Recovery Lead

PPE: Impact rated eye protection, Ear plugs

Materials Required:

- 4 E-matches (mentor provided and installed)
- Pre-measured FFFFg black powder (mentor provided)
- Small funnel
- Small quantity of wadding
- Digital multimeter
- LiPo battery level monitor

Potential hazards:

- Partial or total airframe loss
  - Improper wire connections can result in ballistic recovery leading to total airframe loss
- Personal injury (minor)
  - Premature ejection charge ignition due to static electricity which could result in burns, hearing damage or property damage

Steps:

- [ ] Open the avionics bay to allow access to the LiPo batteries. This includes disconnecting the bulkhead terminal connector on the aft end of the avionics bay.
- [ ] Check the charge of all batteries with the LiPo battery monitor.
- [ ] Re-assemble the avionics bay. Ensure that the bulkhead terminal connector is assembled prior to closing the aft bulkhead.
- [ ] Inspect E-match installation for the following:
  - [ ] No wires are broken
  - [ ] Proper strain relief
  - [ ] Wire nuts fully capture exposed wires
  - [ ] Vinyl caps installed on wire nuts
- [ ] Verify resistance of all Matches. Acceptable range is 1.4-1.9 Ohms. Record measurements below:
  - [ ] Drogue primary ______
  - [ ] Drogue secondary ______
  - [ ] Main Primary ______
  - [ ] Main Secondary ______
- [ ] Power on the altimeter to ensure conductivity of E-match connections. Power off altimeter when complete.
- [ ] ***(Eye protection, hearing protection)*** Verify the mass of the black powder charges. Record mass below:
  - [ ] Drogue primary : **0.9 g** ______
  - [ ] Drogue secondary : **1.1 g** ______
  - [ ] Main primary: **1.0 g** ______
  - [ ] Main secondary : **1.2 g** ______
- [ ] ***(Eye protection, hearing protection, performed by mentor)*** Add black powder to the appropriate charge well
- [ ] ***(Eye protection, hearing protection, performed by mentor)*** Fill the remaining volume of the charge well with wadding and compact. Close charge well.

Troubleshooting:

- If battery level is below 70%, either charge battery on site, replace with charged cell, or scrub launch.
- If the resistance of the E-match is outside of the acceptable range, have the mentor replace E-match.

- If the conductivity test fails on the drogue charge, remove the aft bulkhead and ensure that the terminal connector was connected correctly.
- If pre-measured black powder quantities are outside of +/- 0.05 g tolerance, either adjust on site or simply use a different vial of pre-measured black powder.
- If any black powder is lost due to spillage or wind, dump the black powder and use a fresh vial of pre-measured black powder.

8.1.8 On-Field Electronics Preparation (Tracker+Payload)

Scope: The following instructions cover the preparation of the nose cone assembly on the field during launch day. These steps assume that the following have been performed pre launch day:

- All batteries have been charged
- All tracking and payload electronics are functional.

Members Required: Team mentor, Team lead Safety lead, Recovery lead, Payload lead
PPE: None required
Materials Required:

- Allen wrenches (3/32” and 5/64”)
- Multimeter
- Ballast mass
  Complete payload assembly
- Laptop
- Phone with Featherweight UI installed and linked to ground station

Potential hazards:

- Burns or shock:
  - Handling LiPo batteries improperly could lead to short circuits or cell damage, resulting in electronic shock or equipment damage
  - Exposed live wires could lead to shocks resulting in burns, or cause a short circuit, potentially resulting in a LiPo fire
  - Damaged or punctured batteries will catch fire, resulting in severe burns and damage to property
- Cuts or lacerations:
  - Using sharp tools like screwdrivers or contact with a sharp edge on 3D printed parts pose a risk of minor injury
- Critical electrical component damage
  - Improperly secured payload and/or tracker could become loose or break during flight, leading to damage of said components. A tracker failure will pose a significant challenge in locating the airframe for safe recovery

Steps:

- [ ] Turn on Featherweight tracker module
- [ ] Turn on Featherweight ground station module
- [ ] Verify adequate satellite coverage through the Featherweight UI App.
- [ ] Turn on payload electronics if present

- [ ] Establish payload communication with laptop
- [ ] Verify payload has passed self-test
- [ ] Include any ballast or representative mass if present
- [ ] Mount the tracker onto the 3D printed mount with the 4-40 screws
- [ ] Mount payload onto 3D printed mount plate
- [ ] Insert bulkhead/tracker assembly into the nose cone and line up the set screws with the holes in the nose cone shoulder
- [ ] Back out the set screws to retain the bulkhead. Make sure the set screws are flush with the nose cone surface

Troubleshooting

- If the Featherweight tracker does not turn on, check power supply, inspect for any damage, or utilize another tracker.
- If the Featherweight tracker mount is loose or misaligned, check alignment and tighten securely
- If payload electronics do not turn on, verify the power source, test individual components using a multimeter
- If the Featherweight tracker does not connect to satellites, restart the tracker and wait for adequate coverage before flight.

8.1.9 On-Field Motor Preparation

Scope: The following instructions cover the motor insertion
Required Members: Team Mentor, Safety Officer, Recovery Lead, Rocket prep lead
PPE: Impact rated eye protection, Ear plugs
Materials required:

- Booster tube
- COTS motor retainer
- Motors
    - [ ] Subscale
        - [ ] Primary I300T
        - [ ] Secondary I161W
    - [ ] Full-scale
        - [ ] Primary: K1103X
        - [ ] Secondary: K805G

Potential Hazards:

- Partial or total airframe loss
    - An improperly assembled motor will lead to a CATO, which will potentially total the booster and motor assembly
    - Premature motor ignition poses significant risk of airframe damage due to uncontrolled flight
- Major burns/cuts and lacerations
    - A premature motor ignition poses significant risk of personal injury, including blunt force trauma, third degree burns, and hearing loss

- Minor injury (cuts, scrapes)
    - Sharp tools such as X-acto knives pose a risk of minor injury (mentor only)

Steps:

- [ ] ***(Eye protection, hearing protection, performed by mentor)*** Observe the mentor while the motor is being constructed and ensure all steps are followed
- [ ] ***(Eye protection, hearing protection, performed by mentor)*** Observe the mentor insert the assembled motor inside the motor mount
- [ ] Ensure that the motor has been secured with a COTS motor retainer cap
- [ ] Cut a slot which is big enough for the igniters to pass through, into the red cap provided in the motor package
- [ ] Let the mentor insert the red cap loosely to the aft end of the motor nozzle

Troubleshooting

- If the motor closures do not fully close, there is a possibility that the motor liner provided by the manufacturer is too long. If this happens, up to a ⅛" gap is acceptable. Put all of the gap on the aft closure end (Aerotech statement on The Rocketry Forum by Gary Rosenfield).
- If there are any extra pieces during the motor assembly, disassemble the motor, inventory all components, and start over.

8.1.10 Setup on Launch Pad Checklist

Scope: The following instructions cover the setup on the launch pad.
Members Required: Mentor, Safety officer, Recovery lead
PPE: Safety goggles
Materials Required:

- Phillips screwdriver
- Prepped rocket
- Ignitor

Potential Hazards:

- Airframe loss
    - Improper loading of the launch vehicle could lead to structural damage to the airframe rendering it unfit for launch
- Failed deployment / ballistic recovery
    - Not turning on recovery equipment could lead to a failed deployment and could lead to a ballistic recovery

Steps:

- [ ] Lower the launch rail till it is horizontal
- [ ] Load the rocket by threading the aft rail button into the launch rail slot and then proceed by threading the forward rail button on the rail
- [ ] Slide the rocket to the bottom of the launch rail
- [ ] Raise the launch rail till it is vertical
- [ ] Adjust rail angle as needed.
- [ ] Verify that the Featherweight tracker is functional and connected to satellites
- [ ] Turn on Altimeter switches using the phillips screwdriver and tighten the screw switches.

- [ ] **Arm primary altimeter (192.168.4.1)**
- [ ] Wait for confirmation beep (fast pulsing)
- [ ] **Arm secondary altimeter (192.168.4.1)**
- [ ] Wait for confirmation beep (fast pulsing)

- [ ] Take a group photo at the pad prior loading the ignitor into the rocket.

Troubleshooting:

- If our group is unable to take a group picture at the launch pad, comply with the decisions of the RSO. Do not take a picture.
- If the tracker stops communicating, reboot the program and try to connect. Repeat if needed. The program possibly malfunctioned. Alternatively, disassemble the rocket, rearrange the tracker, and possibly scrape off metallic paint, which can block radio signals.
- If altimeters do not arm, move the commanding device closer to the rocket, reboot the program, and try again. Repeat if needed. If attempts to arm altimeters continue to fail, remove the rocket, disassemble it, inspect, and correct found faults.

8.1.11 Igniter Installation

Scope: The following instructions cover the installation of the igniter into the motor at the launchpad.
Members Required: Mentor, Safety officer, Recovery team lead
PPE: Ear plugs, Safety glasses
Materials Required:

- Ignitor
- Red cap
- Fully loaded rocket

Potential Hazards:

- Partial or total airframe loss
  - Motor failure: a live ignitor could lead to premature ignition of the motor and could lead to unpredictable flight which may damage or total the airframe
  - Incorrect ignitor installation could lead to an improper or failed motor ignition and a failed launch attempt
- Personal injury
  - Premature motor ignition can lead to third degree burns, hearing loss, and potentially blunt-force trauma

Steps

- [ ] Lift the rocket up and ensure that it is held by a person
- [ ] Thread the ignitor through the slot cut into the red cap
- [ ] Thread the ignitor into the nozzle till it touches the top of the motor casing.
- [ ] Back out the ignitor about 0.5 in and firmly press the red cap against the nozzle.
- [ ] Lower the rocket back onto the pad and ensure that the excess ignitor wires are secured.
- [ ] Test the alligator clips for power
- [ ] Separate the ignitor wires and tightly coil the wires around the alligator clip.
- [ ] Ensure that the alligator clips are not touching any metal and the ignitor is still inside the motor.

- [ ] Press and hold the continuity button for 2 seconds and make sure a solid audible tone is heard

Troubleshooting:
- If clips are already energized before connecting to igniter, call launch pad LCO to troubleshoot further. Do not connect to the igniter.
- If the igniter slides out from motor, let mentor reassemble the igniter by reinserting and taping it in place.
- If the igniter fails the continuity test, indicating a bad igniter, let mentor disassemble the igniter and replace with a new one.

8.1.12 Launch Procedure

Scope: The following instructions cover the instructions for team members during the launch procedure
Members Required: All team members
PPE: None needed
Materials Required:
- Timing equipment
- Complete payload assembly
- Photography/ videography equipment

Potential Hazards:
- Physical injury/ death
  - In the event of an improper launch or a CATO, standing near to the vehicle during launch could result in severe physical injury or even death.
- Burns/ Hearing loss
  - Standing too close to the launch site could lead to severe burns and hearing loss.

Steps:
- [ ] Team lead and safety officer are responsible for grouping all team members prior to launch.
- [ ] All team members are to stand behind the RSO table during launch
- [ ] Two team members are responsible for timing the launch from launch to touch down.
- [ ] Dedicated videographers and photographers are responsible for recording the launch
- [ ] Dedicated spotters are responsible for keeping track of the rocket at all times when possible
- [ ] The dedicated tracker is responsible for calling out the altitude and position data from the featherweight GPS app during launch.
- [ ] The payload team is responsible for keeping track of payload operations during flight.

Troubleshooting:
- If the igniter fails, wait for LCO to clear range, ask for permission to retrieve rocket, and let mentor replace faulty igniter with a new one.
- If the event of a CATO:
  - Obtain permission to enter the range
  - Verify that all electronics are disarmed by turning off altimeters.
  - (**Mentor**) Carefully remove all unfired energetics.

- (**Mentor**) Depending on the extent of the CATO, remove the motor, collect all fuel grains, collect all jettisoned pieces.
- (**Mentor**) Photograph and document as much detail of the CATO as possible.
- (**Mentor**) Contact manufacturer and file MESS report.

8.1.13 Post Flight Retrieval and Inspection

Scope: The following instructions cover the post flight retrieval and inspection procedures
Members Required: Mentor, Safety Officer, Recovery lead
PPE: Safety glasses, Ear plugs
Materials Required:

- Wrench for opening quicklinks
- Small phillips head screwdriver

Potential Hazards:

- Burns and hearing damage
  - If ejection charges do not deploy and go off after landing, this can lead to burns and hearing damage

Steps:

- [ ] After confirmation of landing, transmit command to put payload into mode "Idle_2" to prevent excessive radio transmission and enter a low-power state
- [ ] Confirm that the RSO has called for an open range
- [ ] Locate the vehicle using the GPS device and note the distance and direction
- [ ] Approach the vehicle
- [ ] Thoroughly record the landing configuration of the launch vehicle ensuring each component has been photographed in its original configuration
- [ ] Disarm both altimeters by loosening the screw switches
- [ ] Disconnect main recovery system quicklinks
- [ ] Disconnect the parachute and the Nomex blanket from the recovery system.
- [ ] Loosely fold the parachute and the Nomex blanket
- [ ] Coil the main Kevlar harness
- [ ] Disconnect the drogue recovery system from the avionics bay
- [ ] Disconnect the drogue parachute and the Nomex blanket from the recovery system
- [ ] Loosely coil the drogue recovery harness and put it inside the booster tube.
- [ ] Assemble the rocket
- [ ] Take rocket back to the prep table
- [ ] Let the mentor remove the motor
- [ ] Disconnect the drogue Kevlar harness from the motor casing
- [ ] Place all recovery hardware in zip lock bags
- [ ] Remove nose cone from the rocket and turn off all payload electronics
- [ ] Remove SD card from datalogger and store in secure container
- [ ] Turn off the featherweight tracker
- [ ] Re-assemble the rocket and inspect for any physical damages.

Troubleshooting:

- If one or more deployment charges failed to fire, disarm altimeter and disassemble rocket. Salvage and empty black powder charges and observe if there were any damaged, abnormal, broken or misplaced parts. Check software and circuit board for any bugs, glitches, or components susceptible to faulty operation. Replace or fix parts accordingly.
- If recovery sequence failed and resulted in a ballistic descent, attempt to recover as many parts as possible from landing and wreckage. Check for any damaged, abnormal, broken, or misplaced parts that may have contributed to failed descent, including harnesses, quick links, Nomex blankets, and parachutes. Turn off altimeters to prevent safety risks from black powder. Check black powder charges to see if they triggered properly. Attempt to salvage data from altimeter and GPS to determine exact time and location of error(s). Take many pictures to document as much evidence as possible. In the event of a ballistic recovery, a significant portion of the rocket is likely in the ground, requiring it to be dug out.

8.2 Personnel Risks

Hazard	Cause	Effect	Likelihood (before)	Severity (before)	Mitigation	Likelihood (after)	Severity (after)	Verification
Direct contact with edges of fiberglass	Handling fiberglass	Skin irritation, minor cuts, and possible infection	5	1	• Eliminate sharp edges by taping when possible. • Wear protective gloves and clothing. • Have a first aid kit available at all times should an incident arise.	1	1	• Verify presence of SOP for fiberglass handling (Inspect). • Inspect fiberglass edges prior to working with it. • Inspect first aid kit is present and stocked prior to each build session.
Exposure to airborne particulates	Sanding fiberglass	Possible respiratory complications like coughing, wheezing, and soreness in the nose and throat. Long-term effects include complications such as dermatitis	5	3	• Wet sand when possible to eliminate dust becoming airborne. • Work in areas with adequate ventilation including air filtration. • Wear a respirator or a dust mask • Dispose of all extra dust formed into a closed-off container to prevent it from being airborne	1	1	• Verify presence of SOP for fiberglass handling (inspect) • Inspect respirator and filter condition before each build session
	Mixing epoxy using additives	Respiratory complications, silicosis	5	1	• Minimize the possibility of additives becoming airborne by keeping additives confined. • Wear a particulate mask/respirator to prevent inhalation.	3	1	• Verify presence of SOP for epoxy use • Check respirator filters at the start of all build sessions.
	Sanding body filler, primer,	Respiratory irritation and complications.	5	1	• Wet sand when possible to reduce the amount of dust generated and regularly clean the workspace and equipment to prevent the	1	1	• Verify presence of SOP for sanding paint layers • Inspect first aid kit is present and fully

	paint, or clear coat layers.				accumulation of hazardous materials • Wear a respirator at all times while working with surface fillers and primers • Work in a well-ventilated area or outside			stocked prior to each build session
	Applying filler, spray paint, or clearcoat where paint has been been oversprated (particulate)	Eye and respiratory irritation, and long-term detrimental effects to the cardiovascular systems.	5	1	• Minimize overspray and regularly maintain and clean equipment. • Wear a respirator at all times while working with paint and a clear coat. • Work in a well-ventilated area or outside	3	1	• Verify presence of SOP for drill press use. • All machining to be worked in pairs. • Verify first aid kit is present and stocked prior to each build session.
Exposure to toxic fumes	Cleaning fiberglass with solvents	Headaches, nausea, unconsciousn ess, skin irritation, permanent eye damage.	5	2	• Work in a well-ventilated area or work outside. • Wear gloves and a respirator at all times while handling solvents	2	1	• Verify presence of SOP for fiberglass handling • Check respirator filters at the start of all build sessions
	Working with epoxy resins	Respiratory injury, allergic reactions, and possible asphyxiation.	5	2	• Use the least hazardous type of epoxy that performs the desired functions • Minimize quantity of epoxy in use at a given time. • Wear a respirator at all times and work in a well-ventilated area.	3	1	• Verify presence of SOP for epoxy use • Inspect the conditions of the air purifier and verify that the fan is turn on • Inspect conditions of respirator filters before each build session
	Using solvent based surface fillers such as Bondo.	Eye and respiratory irritation, detrimental effects on the nervous system, and reproductive harm.	5	1	• Reduce risk by using an appropriate amount of Bondo and other solvent-dissolved surface fillers • Wear a respirator at all times. • Work in a well-ventilated area.	2	1	• Verify presence of SOP for drill press use • All machining to be worked in pairs. • Verify first aid kit is present and stocked prior to each build session.

	Applying aerosolized primer, paint, or clearcoat	Eye and respiratory irritation, long-term detrimental effects to the nervous, cardiovascular, and reproductive systems.	5	1	• Prevent exposure by using less toxic, Low Volatile Organic compounds paint and clear coats when possible • Work in a well-ventilated area or outside • Wear a respirator at all times while working with paint and clear coat. • Wear safety glasses.	3	1	• Verify presence of SOP for aerosol paints • Check for an air purifier. • Check respirator filters at the start of all build sessions.
	Heating flux (soldering)	Inflammation of the nose, eye, throat, and long-term effects like asthma and dermatitis.	5	1	• Eliminate risk by working in a well-ventilated area or under a fume extraction system to prevent inhalation of fumes. • Reduce the effects of exposure by avoiding prolonged exposure and using a flux with low volatility or less harmful substances. • Store solder in a sealed container and away from direct contact to reduce the risk of accidental exposure or spillage	2	1	• Verify the presence of the SOP of a soldering iron • All soldering is done under supervision..
	HF release from mishandling of lithium batteries	Lung damage.	1	4	• Eliminate the risk of exposure to HF gas by handling batteries according to manufacturer instructions and avoid any actions that could lead to leakage or overheating. • Use proper containment and disposal methods for damaged or defective batteries to prevent the release of hazardous gasses • Reduce the effects of exposure by working in a well-ventilated area. If the battery leaks or emits gas, evacuate the area immediately and utilize chemical-resistant gloves and goggles at all times • Regularly inspect the lithium batteries for damage and store them in a cool, dry place away from flammable materials.	1	1	• Verify presence of SOP for battery handling • Verify first aid kit is present and stocked prior to each build session.

Direct skin contact with toxic chemical	Working with epoxy	Development of irritation and allergic contact dermatitis.	5	1	• Maintain safe working distance when working with epoxies, and use appropriately sized applicators when possible. • Wear nitrile gloves while working with epoxy. • If epoxy gets on the skin, immediately clean the contact area with isopropyl alcohol.	2	1	• Verify presence of SOP for epoxy use. • Maintain stock levels of isopropyl alcohol for cleaning epoxy
	Altering epoxy using additives	Skin irritation	5	1	• Wear protective gloves • Wear protective clothing/apron	2	1	• Verify presence of SOP for epoxy use. • Check for an air purifier. • Check respirator filters at the start of all build sessions.
	Using solvent based surface fillers such as Bondo.	Skin and eye irritation,, detrimental effects on the nervous system, and reproductive harm.	5	1	• Reduce risk by using an appropriate amount of Bondo and other solvent-dissolved surface fillers • Wear protective nitrile gloves • Wear protective clothing and eye protection.	2	1	• Verify the presence of an SOP for a drill press • Inspect the conditions of the first aid kit and ensure that it is fully stocked prior to each build session
	Applying spray filler, paint, or clearcoat.	Skin and eye irritation, and long-term detrimental effects to the nervous, cardiovascular, and reproductive systems.	5	1	• Prevent exposure by using less toxic, Low Volatile Organic compounds paint and clear coats when possible • Wear nitrile gloves. • Wear protective clothing and eye protection.	2	1	• Verify presence of SOP for aerosol paints • Inspect the condition of respirator filters prior to build sessions.
	Skin contact with solder and flux	Skin rashes and long-term effects like dermatitis.	5	1	• Wear gloves to avoid direct skin contact with flux. • Reduce the effects of exposure by avoiding prolonged exposure and using a flux with low volatility or less harmful substances. • Store solder in a sealed container and away from direct contact to reduce the risk of accidental exposure or spillage	2	1	• Verify presence of SOP for soldering.

	HF contact from mishandling of lithium batteries	Skin burns, damage to calcified organs.	1	4	• Eliminate the risk of exposure to HF gas by handling batteries according to manufacturer instructions and avoid any actions that could lead to leakage or overheating. • Use proper containment and disposal methods for damaged or defective batteries to prevent the release of hazardous gasses • Reduce the effects of exposure by working in a well-ventilated area. If the battery leaks or emits gas, evacuate the area immediately and utilize chemical-resistant gloves and goggles at all times • Regularly inspect the lithium batteries for damage and store them in a cool, dry place away from flammable materials.	1	1	• Verify presence of SOP for battery handling • Verify first aid kit is present and stocked prior to each build session.
Loss of breathable oxygen	Working with epoxy resins	Possible asphyxiation.	1	5	• Use the least hazardous type of epoxy that performs the desired functions • Use only small quantities of resin at a time. • Work in large room or outdoor space.	1	1	• Verify the presence of the SOP for epoxy resins • Inspect the conditions of the air purifier and verify that the fan is turned on. • Inspect conditions of the respirator filter before each build session.
Exposure to highly flammable gasses	Use of aerosolized paint and clearcoat	High risk of ignition from a spark or heat source causing first/second/third degree burns and injury	5	4	• Eliminate risk by avoiding the use of aerosolized paint and clearcoat near open flames, sparks, or any heat sources • Work outside, in a well-ventilated area, or use ventilation systems that safely disperse flammable gasses. • Prevent build-up of flammable gasses by storing aerosolized paint and clearcoat cans in cool, well-ventilated areas and follow all guidelines for handling and disposal	5	1	• Verify presence of SOP for aerosol paints • Verify first aid kit is present and stocked prior to each build session.
Exposure to high temperatures	Thermal runaway exothermic reactions from epoxy curing	Burns, the container melting, and possible exposure of skin and/or	3	1	• Mix the appropriate amount of epoxy when in use. • Apply epoxy in thin layers, especially in large cavities, and ensure the working area is well-ventilated • To prevent heat buildup, transfer epoxy from the mixing container to a wide shallow	3	1	• Verify presence of SOP for epoxy use. • Check for the air purifier and fan turned on. • Check respirator filters at the start of all build sessions.

		wounds to hot, uncured epoxy.			container to increase surface area.			
	Soldering electrical components	First/second/third-degree burns	5	4	• Eliminate risk by using a soldering iron with temperature control and holding the soldering rod by the insulated handle at all times • Work in a well-ventilated area and wear heat-resistant gloves, wear proper PPE at all times • Prevent accidents by keeping the soldering iron in a designated stand and make sure to turn it off and wait for the soldering iron to cool before changing tips.	5	1	• Verify the presence of an SOP for a soldering iron • Inspect the first aid kit and verify that it is present and fully stocked prior to each build session
	Handling the hot end of a 3D printer	First/second/third-degree burns	2	2	• Avoid touching the hot end of a 3D printer • Ensure that the 3D printer is turned off and unplugged before approaching and use heat-resistant gloves or wait a sufficient amount of time before lifting hot components	2	1	• Verify the presence of an SOP for 3D printers • Inspect the first aid kit and verify that it is present and fully stocked prior to each build session
	Premature motor ignition	First/second/third-degree burns	1	4	• Motor components are stored unassembled in ESD-safe packaging. • The motor is only assembled immediately before launch. • Igniter leads are shorted until ready to hook up to ignition leads. • Check all electronic equipment including the electronic igniters. • Verify igniter leads are un-energized before connecting to the igniter.	1	3	• Verify presence of launch checklists • Ensure motors and all explosives are only handled by the mentor • Verify that the motor packaging is safely sealed prior to handling (by mentor) • Standard NAR/Tripoli protocol is to be followed by waiting at least 60 seconds before approaching the launch vehicle. • In the case of a misfire, wait to approach the rocket for clear range and only under the permission of LCO.
	Premature black powder ignition	First/second/third-degree burns	1	4	• Only allow authorized personnel to handle any flammable or potentially explosive materials and ensure safety protocols are followed. • Safe distance of 20 ft while conducting ground tests. • Wear protective PPE.	1	1	• Verify presence of SOP for ground testing

Contact with a sharp, spinning edge	Use of a drill press	Cuts, hair removal, and abrasion, loss of extremities	1	4	• Eliminate risk by securing the workpiece with clamps or a vise before starting the machine, and make sure that the drill bit is functioning as intended. • Reduce risk by utilizing protective barriers or guards on the drill press, wearing appropriate PPE • Prevent accidents by keeping hands, loose clothing, and long hair away from drill bits, and turn off the drill press before making any adjustments.	1	1	• Verify presence of SOP for ground testing • All machining to be worked in pairs. • Verify first aid kit is present and stocked prior to each build session.
Contact with a sharp, spinning edge	Use of a router table	Cuts and abrasion, loss of extremities	1	5	• Use jigs and push-blocks to feed material with hands away from the cutter. • Work in pairs with one observer checking for hand positions.	1	1	• Verify presence of SOP for router table use
Exposure to intense sound	Use of a router table	Hearing loss	5	2	• Maintain a safe distance from the machinery when in operation. • Use sound-dampening materials to reduce sound produced and wear proper hearing protection while operating such machines.	5	1	• Verify the presence of an SOP for a router table
Exposure to intense sound	Use of a dual-action polisher	Hearing loss	5	1	• Wear appropriate ear protection while working with a dual-action polisher • Maintain a firm grip on the polisher and use it at the recommended speed settings. • Keep all lose clothing, and hair away from the dual action polisher at all times	5	1	• Verify the presence of an SOP for a dual-action polisher • Inspect the first aid kit and verify that it is present and fully stocked prior to each build session
Exposure to intense sound	Premature motor ignition	Hearing loss	1	2	• Motor components are stored unassembled in ESD-safe packaging. • The motor is only assembled immediately before launch. • Igniter leads are shorted until ready to hook up to ignition leads. • Check all electronic equipment including the electronic igniters. • Verify igniter leads are un-energized before connecting to the igniter.	1	1	• Ensure presence of launch checklists

	Premature ignition during ground test	Hearing loss	1	4	• Only allow authorized personnel to handle any flammable or potentially explosive materials and ensure safety protocols are followed. • Safe distance of 20 ft while conducting ground tests. • Wear protective PPE.	1	1	• Verify presence of SOP for ground testing
	Static electricity ignition of black powder	Hearing loss	1	4	• Only allow authorized personnel to handle any flammable or potentially explosive materials and ensure safety protocols are followed. • Use twisted pairs for leads to E-matches to prevent magnetic field coupling from other electronic devices.	1	1	• Verify the presence of an SOP for black powder handling. • Ensure that we are working in properly grounded environment to ensure static discharge does not happen
Exposure to fast-moving mechanical components	Working with a 3D printer	Impact injury and trauma	1	1	• Ensure that all moving components are properly enclosed or guarded. Avoid reaching in or attempting to adjust the printer when in operation • Maintain a safe distance and ensure that the printer is equipped with emergency stop buttons.	1	1	• Verify presence of SOP for 3D printer use • Inspect the first aid kit and verify that it is present and fully stocked prior to each build session
	Use of a vinyl cutter	Physical injury, minor cuts	1	1	• Eliminate risk from sharp moving blades by ensuring that the machine’s safety guards are functional and in the proper place. • Maintain a safe working distance while the machine is in operation • Always turn off and unplug the machine when making adjustments or removing vinyl.	1	1	• Verify the presence of an SOP for a vinyl cutter • Inspect the first aid kit and verify that it is present and fully stocked prior to each build session
Contact with the sharp edge of a blade	Use of hobby knives, utility knives, and scissors	Cuts and infection	5	2	• Eliminate risk by using safety features like retractable blades or blade guards, ensure the tools are in good condition, and avoid using excessive force • Use cutting tools on stable, non-slip surfaces and wear protective gloves designed to resist cuts and avoid distractions. • Store knives and scissors in a safe container and cover the blades when not in use.	2	1	• Verify first aid kit is present and stocked prior to each build session.
Exposure to fast-moving polishing wheel	Use of a dual-action polisher	Clothes and hair being caught and	5	1	• Maintain a firm grip on the polisher and use it at the recommended speed settings. • Keep all lose clothing, and hair away from the	3	1	• Verify presence of SOP for dual action polisher use

		polishing compounds entering the eyes, causing physical injury.			dual action polisher at all times			• All machining to be worked in pairs. • Inspect the first aid kit and verify that it is present and fully stocked prior to each build session
Exposure to metal shrapnel	Trimming or cutting electrical components	Eye injury, skin injury	3	1	• Eliminate risk by using the appropriate tools such as precision cutters and wearing protective safety goggles at all times • Perform cutting operations in a controlled environment where debris can be contained and cleaned up • Prevent the generation of metal shrapnel by securing the electrical components before trimming to minimize the risk of accidental debris.	1	1	• Verify the presence of an SOP for a wire cutter • Inspect the first aid kit and verify that it is present and fully stocked prior to each build session
Severe Impact from Falling Objects	Parachute deployment failure	Severe impact injury	2	5	• Redundant altimeters and ejection charges • Ground testing • Angle launch vehicle away from personnel/spectators. • Enable failsafe mode on the flight computer to deploy the main if it detects no drogue separation.	1	1	• Verify presence of launch checklists • Inspect the first aid kit and verify that it is present and fully stocked prior to each build session
	Parachute tangle of failure to inflate	Severe impact injury	2	4	• Angle launch vehicle away from personnel/spectators. • Ensure shroud lines are not obstructed. • Verify that the Nomex material does not interfere with parachute deployment • Rehearse rocket preparation before conducting a launch and make sure that team members are well-versed in recovery processes.	1	4	• Verify presence of launch and pre-launch checklist
	Failure of rocket components to stay tethered.	Severe impact injury	1	5	• Design for adequate recovery load margin • Ensure all connection points are secured and functional without damage • Follow a checklist to minimize mistakes	1	5	• Verify presence of launch and pre-launch checklists
	Trajectory change from	Severe impact injury	1	5	• Design for adequate stability • Follow NAR safe distance requirements	1	5	• Verify the presence of launch day checklists

	excessive weathercocking or instability				• Angle launch rods away from spectators. • Do not launch in excessive wind conditions			• Follow all LSO and RSO instructions
	Fin failure in flight	Severe impact injury	1	3	• Use best practices for assembly (clean epoxy surfaces, adequate filletting, material selection, etc.). • Design fin structures to push the fin flutter velocity above operating range plus margin. • Perform margin analysis to avoid fin flutter velocities.	1	3	• Conduct an analysis for fin flutter ensuring that the fin flutter velocity is higher than the maximum velocity achieved by the vehicle.

8.3 Failure Modes and Analysis

8.3.1 Vehicle Structure FMEA

Failure mode	Cause	Effect	Likelihood (before)	Severity (before)	Mitigation	Likelihood (after)	Severity (after)	Verification
Premature motor ignition	Electrostatic discharge	Premature or unprompted launch of rocket, motor ignition before being put in rocket, and/or loss of a potential launch	1	4	• Motor components are stored unassembled in ESD-safe packaging. • The motor is only assembled immediately before launch. • Igniter leads are shorted until ready to hook up to ignition leads.	1	4	• Verify presence of launch checklists
	Faulty wiring or connectors				• Follow NAR requirement of arming altimeter with the rocket vertical, prior to insertion of igniter. • Check all electronic equipment including the electronic igniters. • Verify igniter leads are un-energized before connecting to the igniter.	1	1	• Verify presence of launch and pre-launch checklists
	Delayed ignition after				• Standard NAR/Tripoli protocol is to be followed by waiting at least 60 seconds before	1	1	• Verify presence of launch checklists

	initial ignition attempt.				approaching the launch vehicle. ● Wait to approach the rocket for clear range and only under the permission of LCO.			
Trajectory change	Winds or drift due to early parachute deployment	Impact incident resulting in severe airframe stress and/or failure	1	5	● Identify trajectory and stand clear of the landing path. ● Use a GPS tracker for recovery ● Follow Standard NAR protocols.	1	5	● Verify presence of launch checklists
Structural failure in air.	Fin failure	Impact incident resulting in severe airframe stress and/or failure	1	5	● Use best practices for assembly (clean epoxy surfaces, adequate filletting, material selection, etc.). ● Perform margin analysis to avoid fin flutter velocities.	1	5	● Verify fin flutter analysis in simulation ● Ensure SOP for epoxy use and fiberglass preparation was followed
Motor failure	Motor overpressurization	Loss of airframe and/or booster assembly through metal shrapnel, rapid unscheduled disassembly of the airframe resulting in airframe loss	1	5	● Make sure that the motor has been assembled according to the manufacturer's descriptions.	1	5	● Mentor to inspect fuel grains for cracks prior to assembly. ● Verify presence of launch checklists ● Inspect the motor for any physical damages and ensure that it has been assembled using the manufacturers description
	Motor under pressurization	Inconsistent or failure of flight, resulting in unscheduled airframe stress or failure	1	3	● Select a motor with a history of proven starts ● Select an easily ignitable, low-oxidation propellant ● Check the simulation of motor internal pressures to ensure the motor design is pressurizing adequately. ● Ensure the igniter and pressurization cap are correctly installed per motor instructions and verify that the igniter is secured	1	3	● Verify presence of launch checklists ● Inspect the motor for any physical damages and ensure that it has been assembled using the manufacturers description

8.3.2 Recovery FMEA

Failure mode	Cause	Effect	Likelihood (before)	Severity (before)	Mitigation	Likelihood (after)	Severity (after)	Verification
Black powder ignition	Static electricity ignition	Unprompted ejection of a parachute during launch, resulting in failure of recovery equipment	1	5	• Only allow authorized personnel to handle any flammable or potentially explosive materials and ensure safety protocols are followed. • Use twisted pairs for leads to E-matches to prevent magnetic field coupling from other electronic devices.	1	5	• Verify presence of pre-launch checklist
Black powder non-ignition	Failed electronic deployment, miscalculated ejection charges	Main and/or drogue parachute ejection failure	1	5	• Redundant altimeters and ejection charges • Ground testing • Angle launch vehicle away from personnel/spectators. • Enable failsafe mode on the flight computer to deploy the main if it detects no drogue separation.	1	1	• Verify the presence of the pre-launch checklist • Ensure mentor and/or appropriately certified personnel is overseeing pre-launch procedures
Parachutes do not open after ejection	Improper folding of the parachute, tangled parachute, improper preparation	Main and/or drogue parachute ejection failure	1	3	• Ensure shroud lines are not obstructed. • Verify that the Nomex material does not interfere with parachute deployment • Rehearse rocket preparation before conducting a launch and make sure that team members are well-versed in recovery processes.	1	3	• Verify presence of pre-launch checklist • Ensure mentor and/or appropriately certified personnel is overseeing pre-launch
No separation events after planned ejection altitudes	Electronics turned off/not working, miscalculated ejection charges.	Main and/or drogue parachute ejection failure	1	5	• Ground test and make sure the black powder charges are sufficient enough to separate the rocket. • Verify no binding in the couplers. • Perform E-match conductivity checks and inspect all wiring. • Use a checklist with independent confirmation to ensure the altimeter is armed and all necessary steps are performed.	1	5	• Verify the ground test SOP. • Ensure mentor and/or appropriately certified personnel is overseeing pre-launch procedures

Ripped parachutes due to drag separation	Failure to anticipate aerodynamic forces	High G incident resulting in failure of recovery equipment	1	5	• Shear pin calculations are done correctly • Checklist to prevent forgetting installation of shear pins.	1	5	• A ground test SOP will be followed • Ensure mentor and/or appropriately certified personnel is overseeing pre-launch procedures
Recovery chain is open	Missing quicklinks, loose U-bolts, breakage of recovery chain	Pieces of the rocket falling untethered and possibly ballistic	2	5	• Verify installation of all U-bolts prior to launch. • Inspect harnesses for damage prior to launch • Verify installation of U-bolts. • Practice rigging the recovery system.	1	5	• Verify the presence of the recovery preparation checklist • Perform final check of the entire recovery chain prior to launch installation.

8.3.3 Payload FMEA

Failure mode	Cause	Effect	Likelihood (before)	Severity (before)	Mitigation	Likelihood (after)	Severity (after)	Verification
Failure of mechanical components	Improper construction, improper load distribution design	Payload experiment failure	1	4	• Follow best practices for mechanical design • Load testing in CAD, use of oversized load-bearing surfaces and heat-set inserts	1	4	• Verify presence of SOP for epoxy use • Verify payload integrity through FS-P-4
Failure/improper operation of electronic components	Improper electronics construction (soldering, circuit design), coding errors	Payload experiment failure	2	4	• Verify electronics operation prior to system and airframe integration	2	4	• Test the integrity of the payload design by using test FS-P-4 • Test the functionality of the electronics through FS-P-1
Airframe integration failure	Improper construction, improper load distribution design	Payload dislodged from nose cone; payload experiment failure	1	3	• Drop tests prior to payload flight testing • Load testing in CAD	1	3	• Verify presence of SOP for epoxy use • Verify payload integrity through FS-P-4

Runs out of battery	Lack of testing, uneducated/ unresearched battery selection, charging forgotten before use	Payload experiment failure	2	4	• Ensure proper battery selection in PDR • Calculate estimated battery life in battery selection	2	4	• Ensure a SOP is created for pre-launch payload preparation • Conduct tests to verify battery life
Inaccurate clocking/ logging	Coding errors	Payload experiment failure, payload accuracy jeopardized, data analysis requiring significant correction	2	3	• Multiple verifications of any written code by peers and/or mentor • Electronics tests prior to system and airframe integration	2	3	• Refer back to payload electronics flowchart to ensure it is followed, verify prior to critical construction and integration steps

8.4 Environmental Risks

Environmental risk	Cause	Effect	Likelihood (before)	Severity (before)	Mitigation	Likelihood (after)	Severity (after)	Verification
Unsecured hazardous chemicals	LiPo battery rupture or explosion.	Harm to wildlife	1	4	• Purchase from a credible source. Test capabilities of the battery in a real life setting.	1	4	• Verify the presence of an SOP for handling batteries • Conduct ground testing to ensure failure during the mission does not happen
Waste from rocket build	Microparticles from sanding, materialistic waste	Pollutes environment	5	1	• Wet sand when possible • Use disposable materials only as necessary or if it is optimal to build efficiency	5	1	• Verify the presence of an SOP for sanding materials • Verify the presence of an SOP for proper waste disposal • The team will be briefed on proper disposal of hazardous waste from build sessions
Expulsion of greenhouse gasses into the atmosphere	Transportation via a combustion engine powered vehicle.	Pollutes environment	5	1	• Optimize transportation by carpooling when realistic	5	1	• Communicate with team about possible transportation methods prior to travel
Launch vehicle lands outside the designated launch area	Drift, trajectory change	Rocket lands where wildlife or fauna could be harmed	1	1	• Check weather before launch, perform drift calculations, make sure rocket lands in a 2,500 ft radius.	1	1	• Verify the presence of launch SOP • The team will comply with any RSO decisions at the launchsite
Structural failure	Improper construction	Critical structural failure	1	3	• Ensure all components are structurally sound • Use best practices for assembly (clean epoxy surfaces, adequate filletting, material selection, etc.)	1	3	• Ensure the team follows proper construction steps as defined in the proposal.
	Mid-flight CATO, fin flutter	Rocket debris scattered across the launch site,	1	3	• Ensure fin flutter does not occur • Use a motor with proven reliability	1	3	• Analyze fin flutter velocity before construction of the vehicle and ensure that the maximum velocity does not exceed the fin flutter velocity • Inspect fins prior to launch

		harming wildlife and contaminating crop soil.						• Ensure that the team will purchase a motor with a known, high reliability, from a reliable vendor
General waste	Using a 3D printer	Non-biodegradable waste contributes to pollution	3	1	• Optimize prints • Optimize as much as possible in software prior to printing	1	1	• Verify the presence of an SOP for 3D printer use to ensure that parts print properly. • Verify the presence of an SOP for waste disposal.
	General irresponsibility when managing waste; failure to properly dispose of waste	Unnecessary litter, potential release of hazardous waste into the environment	3	3	• Properly label and dispose of hazardous waste • Ensure team properly disposes of general waste • Clean all surfaces, characterize waste.	2	3	• Verify the presence of an SOP for waste disposal • The team will be briefed on proper disposal of hazardous waste from build sessions

8.5 Project Risks

Project risk	Cause	Effect	Likelihood (before)	Severity (before)	Mitigation	Likelihood (after)	Severity (after)	Verification
Funds exhausted before project completion	Lack of fundraising, unanticipated costs, poor planning	Funds not available to make required purchases	4	5	• Improve project planning and cost estimation. • Perform additional fundraising activities. • Agree to self-fund unfunded travel costs.	3	1	• Inspect funds and verify that the project has enough funds to continue. • Demonstrate clear communication by communicating budget status to the team.
Deadlines missed	Major NASA milestone report - PDR, CDR, FFR, PLAR	Cannot proceed to next milestone or disqualified	2	5	• Improve project planning and time estimation. • Delegate tasks to spread resources across the project.	1	5	• Demonstrate communication by consistently updating the Gannt chart and ensuring each team member is informed about major deadlines
	Subscale	Cannot launch	1	5	• Plan project with enough time to allow several	1	5	• Demonstrate communication by consistently

	and/or full-scale vehicle launch test deadlines missed	the rocket.			potential launch dates			updating the Gantt chart and ensuring each team member is informed about major deadlines
	Some members are overcommitted to other activities.	Cannot complete critical project steps	5	3	• Delegate tasks with redundant assignments to spread tasks.	2	2	• Demonstrate communication by consistently updating the Gannt chart and ensuring each team member is informed about major deadlines • Demonstrate communication by checking availability of all members
	Some team members do not complete tasks	Cannot complete critical project steps	5	5	• Delegate tasks with redundant assignments • Provide open access to educator and mentor for additional technical support	5	2	• Ensure communication in and across each team section. • Ensure that team members are aware of expected tasks and deadlines.
	Weather delays launch	Cannot launch rocket	5	5	• Plan multiple potential launch dates	5	2	• Ensure that team members are aware of all potential launch dates in advance.
Resources not available for build.	Shipments fail to arrive in a timely manner or are damaged.	Cannot complete assembly or launch test flights.	4	5	• Plan acquisition of long lead-time items. • Order components assuming delays when possible. • Pre-order rocket motors.	2	5	• Verify that all materials have been ordered in advance and account for potential delays..

9.0 Project Plan

9.1 Team Derived Verification Plan

Table 43 - Team Derived Verification Test Plan

Verification	Component	Description	Verification result
SS-R-1	Subscale Primary Altimeter	**Demonstration** of functionality of subscale primary flight computer. Required for successful recovery. ● Altimeter placed in a transparent lid vacuum chamber with incandescent Christmas lights attached on deployment channels. ● Air is pumped out of the chamber in a controlled manner to simulate launch. ● At a pressure of -15 inches, air is very slowly let into the chamber to simulate descent. ● Illumination of the Christmas lights is observed to make sure they match expected deployment events. ● Altimeter data is inspected against expected results.	● Demonstration performed 11/24/2024. ● All events occurred as expected. ● Altimeter datalog is consistent with known good reference altimeters.
SS-R-2	Subscale Backup Altimeter	**Demonstration** of functionality of subscale backup flight computer. Required for successful recovery ● Altimeter placed in a transparent lid vacuum chamber with incandescent Christmas lights attached on deployment channels. ● Air is pumped out of the chamber in a controlled manner to simulate launch. ● At a pressure of -15 inches, air is very slowly let into the chamber to simulate descent. ● Illumination of the Christmas lights is observed to make sure they match expected deployment events. ● Altimeter data is inspected against expected results.	● Demonstration performed 11/24/2024. ● All events occurred as expected. ● Altimeter datalog is consistent with known good reference altimeters.
SS-R-3	Subscale Primary Deployment Charges	**Demonstration** of deployment charges. Required to verify safe separation. ● Prepared the entire airframe for launch minus motor propellant. ● Place the altimeter in deployment test mode and select the appropriate channel to test. ● Inspect for adequate separation. ● Repeat as needed, either increasing or decreasing the quantity of black powder. ● Repeat for both deployment events.	● Demonstration performed 11/24/2024. ● Initial calculations of black powder were slightly low with either inadequate or no separation. ● Altimeter datalog is consistent with known good reference altimeters. ● Final values were: ○ 0.9 g for the drogue deployment ○ 1.0 g for the main deployment
SS-R-4	Subscale Primary Deployment Charges	**Demonstration** of deployment charges. Required to verify safe separation. ● Prepared the entire airframe for launch minus motor propellant. ● Place the altimeter in deployment test mode and select the appropriate channel to test. ● Inspect for adequate separation.	● Demonstration performed 11/24/2024. ● Values were simply run at +20% of the primary test results. ● Both deployment values fired adequately. ● Final values were:

		• Repeat as needed, either increasing or decreasing the quantity of black powder. • Repeat for both deployment events.	○ 1.1 g for the drogue deployment ○ 1.2 g for the main deployment
SS-R-5	Cd test of subscale drogue parachute	**Analysis** was performed on descent characteristics of the drogue. From this, we learned the CD of the subscale parachute, which extrapolates to full-scale performance • Flight data of rates of descent were corrected for temperature and timing events. • Using the same launch conditions from subscale flight, the Cd was adjusted in OpenRocket until the simulated rate of descent matched the flight data.	• Data from 12/7/2024 subscale launch was analyzed. • OpenRocket simulation values of Cd = 1.50 - 1.55 matched the rate of descent to within measurement error.
SS-R-6	Cd test of subscale drogue parachute	**Analysis** was performed on descent characteristics of the main. From this, we learned the CD of the subscale parachute, which extrapolates to full-scale performance. • Flight data of rates of descent were corrected for temperature and timing events. • Using the same launch conditions from subscale flight, the Cd was adjusted in OpenRocket until the simulated rate of descent matched the flight data.	• Data from 12/7/2024 subscale launch was analyzed. • OpenRocket simulation values of Cd = 1.55 - 1.60 matched the rate of descent to within measurement error.
SS-A-1	Launch preparation rehearsal	**Demonstration** - Practice rigging subscale rocket in preparation for flight. Provided adequate preparation training for the whole team and help regularize safety for all members • Subset of the team practice rigging the subsale project for launch. • Full recovery chain preparation in a controlled environment.	• Demonstration performed on 12/6/2024. • Attended by Team Lead, Safety Officer, and representative from recovery. • Time to prepare was approximately 50 min.
SS-A-2	Subscale flight demonstration	**Demonstration** of subscale flight. Critical for estimating the full-scale vehicle performance. • Fly a 50% scale airframe with material set, construction methods, and aerodynamic conditions as close to representative of the full-scale as reasonably possible. • Demonstrate proficiency in preparation and recovery. • Provide first introduction to high power flying for many of the team members. • Practice analysis and documentation of the flight.	• Subscale flight performed at Tripoli Mid-Ohio (TRA Prefecture #31) on 12/7/2024 at approximately 11:30 AM. • Slight deviation from vertical flight, but otherwise very nominal flight and recovery. • Detailed demonstration results, analysis, and lessons learned are in CDR 4.0 Subscale (Rooni Jr) Flight Results • Modifications to the full-scale vehicle have been justified in section 4.4 Impact on Full-Scale
FS-R-1	Full-scale Primary Altimeter	**Demonstration** of functionality of subscale primary flight computer. From this we learned the functionality of the altimeter • Altimeter placed in a transparent lid vacuum chamber with incandescent Christmas lights attached on deployment channels. • Air is pumped out of the chamber in a controlled manner to simulate launch. • At a pressure of -15 inches, air is very slowly let into the chamber to simulate descent. • Illumination of the Christmas lights is observed to make sure they match expected deployment events. • Altimeter data is inspected against expected results.	• Demonstration performed 12/22/2024. • All events occurred as expected. • Altimeter datalog is consistent with a known good reference altimeter.

FS-R-2	Full-scale Backup Altimeter	**Demonstration** of functionality of subscale backup flight computer. From this we learned the functionality of the altimeter ● Altimeter placed in a transparent lid vacuum chamber with incandescent Christmas lights attached on deployment channels. ● Air is pumped out of the chamber in a controlled manner to simulate launch. ● At a pressure of -15 inches, air is very slowly let into the chamber to simulate descent. ● Illumination of the Christmas lights is observed to make sure they match expected deployment events. ● Altimeter data is inspected against expected results.	● Demonstration performed 12/22/24. ● All events occurred as expected. ● Altimeter datalog is consistent with a known good reference altimeter.
FS-R-3	Full-Scale Primary Deployment Charges	**Demonstration** of deployment charges. Needed to figure out the amount of black powder needed for a successful separation ● Prepared the entire airframe for launch minus motor propellant. ● Place the altimeter in deployment test mode and select the appropriate channel to test. ● Inspect for adequate separation. ● Repeat as needed, either increasing or decreasing the quantity of black powder. ● Repeat for both deployment events.	***To be performed once full-scale is assembled and prior to vehicle demonstration flight.***
FS-R-4	Full-Scale Backup Deployment Charges	**Demonstration** of deployment charges. Needed to figure out the amount of black powder needed for a successful separation ● Prepared the entire airframe for launch minus motor propellant. ● Place the altimeter in deployment test mode and select the appropriate channel to test. ● Inspect for adequate separation. ● Repeat as needed, either increasing or decreasing the quantity of black powder. ● Repeat for both deployment events.	***To be performed once full-scale is assembled and prior to vehicle demonstration flight.***
FS-R-5	Cd test of full-scale parachutes	**Analysis** - From this we learned the estimated performance of the parachutes ● Apply Cd values from subscale flight to full-scale simulations to obtain initial design values for full-scale vehicle demonstration flight. ● Analyze full-scale demonstration flight data and back-simulate to obtain accurate Cd values for parachutes used.	● Subscale flight data obtained on 12/7/2024 and flight data has been analyzed in CDR. ● Full-scale flight demonstration ***to be performed. Estimated date is early February, 2025.***
FS-R-6	Test idle on time of Altimeter 1	**Test** - Vital in choosing the correct size of batteries for the full-scale altimeter. ● Fully charge altimeter battery. ● Turn on the altimeter while connected to the battery level measurement box. ● Use a representative idle time prior to arming and arm altimeter. ● Measure battery voltage vs. time. ● Using measured data, calculate time to reach 20% charge.	● ***Test not performed yet.***
FS-R-7	Test idle on time of Altimeter 2	**Test** - Vital in choosing the correct size of batteries for the full-scale altimeter ● Fully charge altimeter battery. ● Turn on the altimeter while connected to the battery level measurement box. ● Use a representative idle time prior to arming and arm altimeter.	● ***Test not performed yet.***

		• Measure battery voltage vs. time. • Using measured data, calculate time to reach 20% charge.	
FS-P-1	Functionality test of payload (pre-integration)	**Test** - Vital for project planning and early debugging before full integration. • Prior to integration, test functionality of payload. • Verify two way communication between base station and payload. • Measure reported orientation vs. measured orientation. • Measure pressure sensor against reference altimeter.	• ***Test not performed yet. Requires payload initial programming completed.***
FS-P-2	Range test of payload (pre-integration)	**Test** - Used to test the maximum range of the payload and test if it is capable of transmitting data in the 2500 ft maximum radius. • Set up base station and payload in vertical orientation. • Measure RSSI, signal-to-noise, and status of packet reception vs. distance. • Repeat for the payload in horizontal orientation.	• ***Test not performed yet. Requires payload initial programming completed.***
FS-P-3	Payload battery life verification	**Test** - Vital in choosing the correct size of batteries for the full-scale altimeter. • Fully charge payload battery. • Turn on payload • Use a representative idle time before turning on active measurement and transmission. • Measure battery voltage vs. time. • Using measured data, calculate time to reach 20% charge.	• ***Test not performed yet. Requires payload initial programming completed.***
FS-P-4	Impact test of mechanical assembly	Drop test from 10 ft for safety margin **Test -** Test to measure the structural integrity of the payload design • Turn payload on with control module, datalogger, and accelerometer attached • Secure payload into test housing • Drop payload from increasing heights starting at 2 ft, in 2 ft increments until 10 ft (10 ft is calculated to appropriately approximate nominal landing forces) • Measure impact forces vs. height using accelerometer in payload • Using measured data, confirm that 10 ft appropriately simulates landing forces • Verify no components are critically damaged and the payload is still fully capable of executing all functions	• ***Test not performed yet. Requires payload mechanical initial assembly***
FS-P-5	Depressurization test	**Demonstration** - Vital to see the functionality of the payload in the event of depressurization that could occur in flight. • Place payload in a bell jar in an active measurement/transmit configuration. • Pump air out from the bell jar in a simulated launch scenario. • Verify functionality.	• ***Test not performed yet. Requires payload initial programming completed.***
FS-A-1	Launch preparation rehearsal	**Demonstration** - Practice rigging full-scale rocket in preparation for flight. Important to streamline the launch preparation process for the entire team. • Subset of the team practice rigging the full-scale project for launch. • Full recovery chain preparation in a controlled environment.	• ***Test not performed yet. Requires full-scale airframe recovery.***
FS-A-2	Full-scale vehicle demonstration flight	**Demonstration** of full-scale flight. Important to test the functionality of the full-scale vehicle. • Fly the full-scale airframe with representative mass of the payload.	• ***Test not performed yet. Requires full-scale airframe recovery.***

		• Demonstrate proficiency in preparation and recovery. • Provide first introduction to high power flying for many of the team members. • Practice analysis and documentation of the flight.	
FS-S-1	Launch preparation rehearsal	**Demonstration** - Practice rigging full-scale rocket in preparation for flight. Important to streamline the launch preparation process for the entire team. • Subset of the team practice rigging the full sale project for launch. • Full recovery chain preparation in a controlled environment. • Full-scale payload preparation in a controlled environment.	• ***Test not performed yet. Requires full-scale airframe, recovery, and payload.***
FS-S-2	Full-scale payload demonstration flight	**Demonstration** of full-scale flight. Important to test the functionality of the full-scale vehicle and the fully integrated payload. • Fly the full-scale airframe with representative mass of the payload. • Demonstrate proficiency in preparation and recovery. • Provide first introduction to high power flying for many of the team members. • Practice analysis and documentation of the flight. • Practice analysis and documentation of the payload.	• ***Test not performed yet. Requires full-scale airframe, recovery, and payload.***

9.2 Requirements Compliance

9.2.1 Derived Requirements

Table 44 - NHS Aerospace Launch Vehicle Derived Requirements

Req	Description	Justification	Verification
LV-C-1	All launch vehicle airframe components should be designed to withstand multiple flights and rigorous testing	Reusability is key to both the success and budget of the mission. Durability across multiple flights helps validate the design and reduces the need for frequent replacement and repairs	**Demonstration** - Students have built Jr L1 airframes from similar material sets with high degree of reusability. Airframe will launch a minimum of three times to demonstrate material selection.
LV-C-2	All airframe components will be water and moisture resistance	Most launch flights have environments which could cause water damage to the launch vehicle and could compromise the structural integrity of the rocket.	**Demonstration** - All airframe components will be washed, dried, and inspected.
LV-C-3	All launch vehicle components shall be designed with a safety factor of more than 15% from the minimum	A 15% safety factor ensures that all components can withstand unforeseen loads or stresses during flight. Improving overall reliability and reducing the risk of failure during the mission	**Analysis -** As of CDR, we are unsure of how to verify a safety margin of 15%
LV-C-4	The launch vehicle design should be able to withstand fin flutter velocities > 1125 ft/s	Ensuring that the vehicle's maximum speed does not exceed Mach 1 or (1125 ft/s), to comply with both Nasa's requirements and preserve the integrity of the rocket.	**Analysis** - Fin flutter analysis was performed and presented in PDR.
LV-C-5	All dimensions from the OpenRocket design should be accurately reflected in the ordered components, with a maximum tolerance of ± 0.1 inch.	The dimensions of the rockets are an important component for the accuracy and success of the mission	**Inspection** - Fiberglass components were measured and within tolerance.
LV-C-6	All masses from the OpenRocket design should be accurately reflected in the components with a tolerance of 0.1 oz.	Accurate mass distribution is critical for stability and achieving the desired CG.	**Inspection** - All fiberglass components were weighed upon receipt. OpenRocket component values were updated.
LV-C-7	Coupler and nose cone will be constructed of materials that do no strongly attenuate RF signals.	Reliable transmissions of RF signals from telemetry, tracking, payload and recovery is critical for mission success.	**Test** - RF attenuation will be measured of electronics inside the nose cone vs. outside the nose cone. ***Not completed.***

LV-C-8	Interior body tube diameter greater than 3.8"	Minimum outer diameter of payload is 3.8”. This must fit within the airframe inner diameter.	**Inspection** - The interior body tube has been measured and exceeds 3.8”.
LV-C-9	Aft fin taper >45°	Prevent fin damage for nominal landing (<45 ° booster tilt on landing).	**Inspection** - The aft fin taper was measured and is greater than 45°
LV-C-10	Coupler length > 2x (body tube dia) + (switch band length)	Ambiguous requirement 2.4.1 and 2.4.2 for coupler that satisfies both. Selecting more stringent of the two plus adding requirement of accommodating switch band.	**Inspection** - Design prints show adequate coupler length exceeding derived requirement.
LV-M-1	Largest motor to be used is in the 54/1706 case	Motor case is borrowed from a mentor. Mentor does not own 54/2560 cases.	**Inspection** - Selected motor is K1103X, which fits in 54/1706 case.
LV-A-1	Components in contact with the motor mount require high-temp-epoxy.	Conventional epoxy weakens with temperature. Outside of the motor case can reach 200 C.	**Inspection** - ***To be completed.*** Fins, centering rings, and motor retainer to be epoxied to motor mount with JB Weld or ProLine-4500.
LV-D-1	Static Stability < 4.0	Required to meet vertical orientation (LVF-2) in presence of 20 mph crosswind.	**Analysis** - OpenRocket simulations to confirm stability margin.
LV-D-2	Dry weight (including payload) < 19.8 lbs	Using Aerotech 54/1706 case, largest motor, assume negligible Cd, 19.8 lbs dry weight is the heaviest that can be lifted to 4000 ft.	**Inspection** - The total dry weight of the full-scale vehicle will be measured.
LV-D-3	Target altitude between 3800 ft and 5200 ft	Target the mid range of requirement 2.1 with enough margin to deal with unexpected design challenges.	**Analysis** - OpenRocket simulations to confirm apogee
LV-D-4	Vertical Flight Orientation > 80° through motor burnout	Have less than 100 ft of altitude variation due to weathercocking	**Analysis** - OpenRocket simulations to confirm vertical flight orientation.
LV-D-5	All parts of the launch vehicles should not exceed the limit of $2500	Reduce waste and make sure that all components bought are used properly. Minimize fund usage.	**Inspection** - Accounting from costs show the launch vehicle is under budget.

Table 45 - NHS Aerospace Recovery Derived Requirements

Req	Description	Justification	Verification
R-C-1	All simulated recovery components should match physical measurements to within 0.1 oz	Mass is important for KE and force calculations on the recovery systems and will affect the overall flight of the	**Inspection** - All recovery component masses will be measured and incorporated into the OpenRocket model to

		rocket.	within 0.1 oz. ***Not completed.***
R-C-2	Recovery load strength to have a minimum 100:1 safety margin from nominal deployment forces.	Safety margin suggested by mentor.	**Analysis** - Recovery load analysis was performed on specified components.
R-C-3	Non-protected components in the recovery chain will be made of Kevlar or other flame resistant material.	Exposed recovery components such as the recovery harness cannot be adequately protected from black powder ejection charges.	**Inspection** - Exposed recovery components are all fabricated from either Kevlar or 304/316 stainless steel.
R-D-1	Apogee to landing time <80 seconds	Meet requirement 3.12 plus 10 s margin to account for uncontrollable environmental effects such as thermals and barometric pressure changes.	**Analysis** - OpenRocket simulations performed to verify apogee to landing time meets requirements.
R-D-2	Main deployment altitude > 600 ft	Meet requirement 3.1.1 plus 100 ft (1-2s) for main to deploy and inflate.	**Inspection** - Rocket preparation checklists set main primary deployment at 650 ft. **Demonstration** - Vehicle and payload demonstration flights will verify deployment charge settings.
R-D-3	Secondary deployment charge should fire >= 500 ft.	Meet requirement 3.1.1 assuming primary charge fails.	**Inspection** - Rocket preparation checklists set main backup deployment at 500 ft. **Demonstration** - Vehicle and payload demonstration flights will verify deployment charge settings.
R-D-4	Heat sensitive recovery components should have sufficient thermal protection	Requirement 3.1 requires a parachute be used to control descent from 500 ft to ground. Parachutes are typically made from nylon, which is heat sensitive and requires thermal protection from deployment charges	**Inspection** - All heat sensitive recovery components will have sufficient Nomex material to protect against heat.
R-D-5	Kevlar should have abrasion protection when in contact with fiberglass edges during the recovery stage.	Fiberglass edges are highly abrasive. Safety and re-usability.	**Inspection** - All Kevlar that will contact fiberglass edges will have heat shrink or electrical tape wrapped to protect it from damage
R-D-6	The recovery leader needs to be removable from the full-scale assembly	The recovery leader could be subject to wear, tear and abrasion which could compromise the effectiveness of the components. The leader needs to be removable for regular inspection.	**Inspection -** The recovery leader has been connected to the motor mount for easy removability and can be inspected after each flight.
R-D-7	The backup ejection charges will be +20% of the primary charges.	If the primary charges fail, an adequate safety margin is required to ensure airframe separation.	**Inspection** - We will verify that the avionics prep checklist was followed when loading deployment charges (done by mentor, verified by safety officer)

R-D-8	Altimeter failsafe mode will be enabled.	Should the drogue primary and back charges fail, we need to ensure that the rocket does not come down ballistic, even if this means violating 3.11 and 3.12.	**Inspection** - We will verify that the failsafe mode is enabled through the alitmeter's web interface.
R-T-1	Altimeters should pass the FS-R-1,2 tests	Require simulated depressurization and pressurization test as well as functionality of the deployment charge switches prior to use.	**Inspection** - the FS-R-1, 2 tests have been successfully completed and both altimeters are ready for flight.

Table 46 - NHS Aerospace Payload Derived Requirements

Req	Description	Justification	Verification
P-D-1	The radio will be able to be turned on and off remotely	Should interference with other systems occur while loaded on the pad or after launch, we need to prevent our system from interfering with other systems.	**Demonstration** - The self test will be initiated and the functionality of the payload will be demonstrated by turning it on and off.
P-D-2	Maximum transmission range on the ground must be greater than 2500 ft.	Payload transmissions need to be possible to the maximum possible altitude of the flight.	**Test** - FS-P-2 will be followed to verify payload range adequacy
P-D-3	Payload to support pressurization/depressurization from 11 psi to 14 psi	The launch vehicle will go to a maximum of 5500 ft.	**Test** - The payload will be tested during the FS-S-2 to see if it is able to survive pressurization/depressurization from 11 psi to 14 psi
P-D-4	A failsafe for failed radio transmission, data logging, shall be added to the payload	If RF transmission fails, it is required to have a log of relevant flight data.	**Demonstration** - We will verify that flight data is recorded to an SD card on the rocket.
P-D-5	Radio transmission must automatically disable after 5 failed transmission attempts	This would ensure that if the radio signal were lost after launch, the radio signal would not interfere with other rocket transmissions	**Test** - FS-P-1 will be performed previous to airframe integration to verify all functionality of the payload
P-D-6	Structural components will be designed to handle >10x estimated shock loads.	FS-P-3	**Analysis -** As of CDR, we are unsure of how to verify a safety margin of >10x
P-C-1	Free space transmission range must be greater than 5500 ft in altitude	Payload transmissions need to be greater than the maximum landing radius for ground level transmissions.	**Test** - FS-P-2 will be followed to characterize the received signal strength over distance
P-C-2	The battery must last longer than 3 hours when inside the rocket, outside with a temperature range 80F.	Requirement 2.6 states that the rocket must have 3 hours of standby life. This adds clarification to the battery life.	**Test** - FS-P-3 will be performed to verify payload battery life adequacy

P-T-1	Provide a functional testing plan for all electronic components prior to each launch	Ensures all components work before each launch and are able to transmit accurate data.	**Demonstration**- All electronic components will be tested for functionality before each flight
P-A-1	All dimensions from the CAD model should accurately reflect in iterations with a tolerance of 0.1 inch	Keeping a tolerance of 0.1 inch will ensure that the payload can fit inside the launch vehicle.	**Inspection** - All printed components will be measured to see whether they are within a tolerance of 0.1 inch.
P-A-2	All wires making hard contact require strain relief	Without proper strain relief, wires could break during handling or launch, inhibiting data collection and transmission	**Inspection** - Avionics bay and payload bay will be reviewed and inspected for the presence of strain relief.
P-A-3	STEMnauts shall be securely fastened to the cockpit area and should not shift beyond 0.5 in under nominal deployment loads.	Unrestrained STEMnauts present a hazard to other payload components during flight	**Test** - FS-P-4 will be performed to verify STEMnauts will remain in place under nominal deployment loads

9.2.2 NASA SLI Requirements

Table 47 - General Requirements

Requirement	Compliance	Verification	Report reference
1.1 Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Student team members shall only be a part of one team in any capacity. Teams will submit new work. Excessive use of past work will merit penalties	Students are doing all of the work under the guidance of an adult educator and mentor. No energetics have been used, but will rely on the mentor to perform all of the purchase, storage, and preparation of all energetics.	**Demonstration** - The students have shown through PDR presentation and subscale that they have been doing 100% of the project minus the required items of handling propellant and energetics.	
1.2 The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations	Project plan is created and a working document. This plan will be continuously updated as the project progresses.	**Inspection -** The team has shown the project plan through each milestone report	9.0 Project Plan
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: 1.3.1. Students actively engaged in the project throughout the entire year. 1.3.2. One mentor (see requirement 1.13). 1.3.3. No more than two adult educators	The adult educator has registered the team through the NASA Gateway system. Team roster preparation is in process. Team will have one TRA mentor and one adult educator.	**Inspection** - The team has submitted the roster on 12/10/2024 on NASA Gateway	
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. A template of the STEM Engagement Activity Report can be found on pages 86 – 89.	We completed three activities with 4 different classes under the same general course, being Intro to Engineering and Design. Our activity was building straw rockets from the NASA Educator Guide and in total, we have completed Education Direct Engagement STEM activities with 120 students.	**Demonstration** As of the CDR, we have reached out to 246 out of 250 students, maintaining all safety compliances.	

	We have completed three activities so far, one of which being at the high school itself under the course "Intro to Engineering and Design", and the other two being at a middle school, Meads Mill Middle School. At the highschool, used the NASA Educator Guide activity of building straw rockets, reaching out to roughly 120 students. At the middle school, we completed an activity regarding propulsion systems with different propellants, and another activity with the objective to build a glider totalling to 126 students. All in all, we have completed Education Direct Engagement STEM activities with 246 students.		
1.5. The team shall establish and maintain a social media presence to inform the public about team activities.	We have created social media platforms as follows Twitter: @NHSAerospace Facebook: @Northville High School Aerospace Club Instagram: @OfficialNHSAeropace Website: https://nhsaerospace.github.io We have been updating the platforms with fun facts about rocketry and regular updates about the team's progress across the project.	**Demonstration** - The following accounts have been created and maintained to demonstrate our social media presence. Student Launch accounts have been tagged in most posts.	
1.6. Teams shall email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of PDR, CDR, or FRR milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No PDR, CDR, or FRR milestone documents will be accepted beyond the 72-hour	All deliverables have, and will continue to be submitted in a timely manner, meeting or exceeding deadlines.	**Inspection** - At the time of drafting the CDR, all deliverables to date have been submitted prior to the required deadline.	

window. Teams that fail to submit the PDR, CDR, or FRR milestone documents will be eliminated from the project			
1.7. Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) shall be provided action items needed to be completed following their review and shall be required to address action items in a delta review session. After the delta session, the NASA management panel shall meet to determine the teams' status in the program and the team shall be notified shortly thereafter	The PDR met all requirements of the milestone review. For future milestone reviews, every effort will be made to adequately respond to all assigned actions promptly as a result of a review.	N/A	
1.8. All deliverables shall be in PDF format.	All documents, with exception of the team roster, have and will continue to be submitted as pdf.	**Inspection** - All documents to date have been delivered in correct format.	
1.9. In every report, teams shall provide a table of contents including major sections and their respective subsections	Table of contents will be included on all reports.	**Inspection** - PDR and CDR have table of contents	Table of Contents
1.10. In every report, the team shall include the page number at the bottom of the page.	Page numbers are included on the bottom of pages for all documents.	**Inspection** - Page numbers on the bottom of all document pages.	
1.11. The team shall provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to: a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	Video conference equipment to be provided by the school district.	**Demonstration** - The school district has provided suitable video conference equipment for PDR review.	
1.12. All teams attending Launch Week shall be required to use the launch pads provided by Student Launch's launch services provider. No custom pads shall 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 wind conditions.	Team will use NAR/NASA supplied launch equipment. As the rocket is greater than 20 lbs, we plan to use a 1515 rail.	**Demonstration** - *To be done*. Team will use NAR/NASA provided launch equipment. **Inspection** - All designs are currently designed for 12-foot 1515 rails.	1.0 Team Summary Page

1.13. 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, through the National Association of Rocketry (NAR) or Tripoli Rocketry 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	A mentor has been identified and accepted the role. The mentor is TRA L3/NAR L2 and has flown more than the required K and higher impulse flights with electronic recovery. The mentor will attend and assist with ground testing, subscale, vehicle demonstration, payload demonstration, and final flight in Huntsville.	**Inspection** - Team mentor has been specified on Team Summary Page	1.0 Team Summary Page
1.14. Teams will track and report the number of hours spent working on each milestone.	The number of hours for each milestone are being tracked.	**Inspection -** Hours reported on Team Summary Page.	1.0 Team Summary Page

Table 48 - Vehicle Requirements

Requirement	Compliance	Verification	Report reference
2.1 The vehicle shall deliver the payload to an apogee altitude between 3,500 and 5,500 ft above ground level (AGL). Teams flying below 3,000 ft or above 6,000 ft on their competition launch will not be eligible for the Altitude Award.	The overall design and motor selection targeted approximately 4500 ft as the midpoint of the range and detailed simulations show consistent modeling to support this. Actual performance will be demonstrated with the full-scale demonstration flights.	**Analysis** - Simulations were performed in OpenRocket to verify performance **Demonstration** - Once full-scale demonstration flights are complete, this will switch to demonstration. ***Not yet completed.***	3.2 Final Design Seleciton 6.1 Kinematics
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.	Altitude is declared at CDR	**Inspection** - The target altitude is declared on the cover page of the CDR.	1.0 Team Summary Page

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.	The material set and overall design of the launch vehicle has been performed with reusability in mind	**Inspection** - Material selection criteria was used to determine the best option for components.	3.3 Finished Component Specifications
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. 2.4.1. Coupler/airframe shoulders which 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.) 2.4.2. Coupler/airframe shoulders which 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.) 2.4.3. Nose cone shoulders which are located at in-flight separation points shall be at least ½ body diameter in length.	The vehicle has 3 independent sections, all tethered together. One end of the coupler has an in-flight separation, and one end is a non-in-flight separation point. Both 2.4.1 and 2.4.2 apply. The current coupler exceeds required length for both applicable rules. The shoulder extends well beyond the required ½ body tube minimum.	**Inspection** - Prints for the complete airframe were generated with only three independent sections and sufficient coupler shoulder extensions	3.3.3 Avionics Coupler. 3.3.5 Nose Cone 3.2 Final Design Selection
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.	While this cannot be addressed at this time, there are dry-run preparation rehearsals in the project testing plan prior to each launch.	**Demonstration** - Team verification FS-A-1 will provide practice preparation for the full-scale. This will be timed to demonstrate preparation time. To be completed prior to Payload Demonstration Flight. ***Not yet completed.***	9.1 Team Derived Verification Plan FS-A-1
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.	Battery sizing has been calculated to provide adequate on time In addition, tests are defined in the test plan to verify on time before functional test	**Test** - The battery capacity vs. time will be measured for the altimeters and payload under elevated temperature to verify idle and operating time and margin. This test will be performed prior to Payload Demonstration Flight. ***Not yet completed.***	5.6.2 Avionics Battery Selection 5.7 Rocket Tracking and Telemetry 7.1.3 Payload Battery Selection 9.1 Team Derived Verification Plan
2.7 The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system. The	All motors selected are TRA certified motors supplied with igniters that	**Inspection** - The selected motors are TRA certified	1.0 Team Summary Page

firing system will be provided by the NASA-designated launch services provider	are specified to function with 12 V launch controllers. However, we have no control over how effective the current sourcing capabilities are of the supplied launch controllers. Additional igniters will be available should a misfire occur.	motors. The datasheets and certification data were inspected and confirmed to use standard 12 V launch control systems. Motor is declared on the Team Summary Page.	
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 services provider)	No additional ground support will be required to initiate launch.	**Demonstration** - The launch vehicle will be flown for Vehicle Demonstration Flight and Payload Demonstration Flight with no external circuitry or ground support. ***Not yet completed.***	
2.9 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 (TRA), and/or the Canadian Association of Rocketry (CAR). 2.9.1. Final motor choice shall be declared by the Preliminary Design Review (PDR) milestone. 2.9.2. 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. The only exception is teams switching to their secondary motor choice, provided the primary motor choice is unavailable due to a motor shortage	The motors selected as the primary and alternate for both subscale and full-scale flights are TRA certified, commercially available motors. The subscale motors are in possession of the mentor. The primary full-scale motors have been on order for 10 weeks. We anticipate delivery in the next 4-6 weeks with plenty of time prior to the required time for the full-scale launch.	**Inspection** - The declared motor is listed on the Team Summary Page. Motor is listed on the NAR/TRA list of certified motors. **Demonstration** - The subscale airframe was flown on an I161W. This motor is listed on the NAR/TRA list of certified motors.	1.0 Team Summary Page
2.10 The launch vehicle shall be limited to a single motor propulsion system.	Both subscale and full-scale use single motor (no clusters or staging).	**Inspection** - The design and motor declaration are for a single motor.	1.0 Team Summary Page 3.2 Final Design Selection
2.11 The total impulse provided by a High School or Middle School launch vehicle shall not exceed 2,560 Newton-seconds (K-class).	The total impulse of the full-scale selected motors is less than 2560 N-s	**Inspection** - The selected motor has a total impulse of 1789 N-s per TRA certification	1.0 Team Summary Page
2.12 Pressure vessels on the vehicle must be approved by the RSO and shall meet the following criteria: 2.12.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating	Not applicable. There are no intentional pressure vessels used.	**Inspection** - There are no intentional pressure vessels on the launch vehicle.	3.2 Final Design Selection

Pressure) will be 4:1 with supporting design documentation included in all milestone reviews. 2.12.2. 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. 2.12.3. 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			
2.13 The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	The current design has a static stability of approximately 3 at rail exit, exceeding the required value of 2.0	**Analysis** - Detailed OpenRocket simulations were performed to determine stability at rail exit.	6.2 Stability
2.14 The launch vehicle shall have a minimum thrust-to-weight ratio of 5.0 : 1.0.	The motors selected easily exceed the minimum thrust-to-weight ratio of 5:1.	**Analysis** - Detailed OpenRocket simulations were performed to determine thrust-to-weight ratio during boost.	6.4 Thust-to-Weight Ratio
2.15 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) causes minimal aerodynamic effect on the rocket's stability	There are no structural protuberances currently. May add a commercially available rocket camera shroud in the future. That will be made clear at CDR.	**Inspection** - Design was inspected and there are no structural protuberances forward of the center of gravity at motor burnout present.	3.2 Final Design Selection
2.16 The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	The design of the full-scale and subscale exceed 52 ft/s at rail exit. The modeled exit velocity for the full-scale is 102 ft/s. These numbers will be verified with altimeter data from launches.	**Analysis** - The rail exit velocity was analyzed in OpenRocket for launch conditions.	6.1.2 Velocity
2.17 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 proposal award and the CDR submission	A 50% subscale has been launched and successfully recovered. The aerodynamics and center of mass are as close to a 50% scaling as the full-scale as possible within the	**Demonstration** - The subscale was successfully flown on 12/7/2024 at Tripoli Mid-Ohio (Prefecture 31).	4.1 Subscale Design and Assembly 4.2 Subscale Flight Conditions and Observations 4.3 Subscale Flight Analysis

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). 2.17.1. The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale will not be used as the subscale model. 2.17.2. The subscale model shall carry an altimeter capable of recording the model's apogee altitude. 2.17.3. The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project. 2.17.4. Proof of a successful flight shall be supplied in the CDR report. 2.17.4.1. Altimeter flight profile graph(s) OR a quality video showing successful launch and recovery events 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. 2.17.4.2. Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the CDR report. This includes, but is not limited to: nose cone, recovery system, airframe, and booster. 2.17.5. 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	constraints that were available. The stability was designed to be as close as reasonably possible between the full-scale and the subscale The propulsion has been selected to roughly replicate the acceleration and rail velocity that the full-scale will experience	Proof of successful flight is shown with: • Photographs of launch • Photographs of landed airframe in good, reusable condition • Altimeter and GPS data from the flight. • Detailed flight analysis agreeing with simulation. **Inspection** - The subscale was a 50% scale version of the PDR intent full-scale airframe. **Analysis** - Barometric pressure conversion and time shifting analysis to align GPS and altimeters. Data compared to simulated data to show this flight demonstration was valid and agreed with modeling. Data was then applied to full-scale airframe plan.	4.4 Impact on Full-Scale Vehicle
2.18.1. Vehicle Demonstration Flight—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 as 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.) The following criteria	Vehicle Demonstration Flight will be scheduled for Feb time frame. Motors are currently on order. Airframe components are waiting for results of subscale and feedback from PDR/CDR.	**Demonstration** - *Scheduled for Feb 2025.* ***Not yet completed.***	

shall be met during the full-scale demonstration flight: 2.18.1.1. The vehicle and recovery system shall have functioned as designed. 2.18.1.2. The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year's project. 2.18.1.3. The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply: 2.18.1.3.1. If the payload is not flown, mass simulators shall be used to simulate the payload mass. 2.18.1.3.2. The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass. 2.18.1.4. 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. 2.18.1.5. 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. 2.18.1.6. 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. 2.18.1.7. 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). 2.18.1.8. Proof of a successful flight shall be supplied in the FRR report. 2.18.1.8.1. 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. 2.18.1.8.2. 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: nose cone, recovery system, airframe, and booster. 2.18.1.8.3. Raw altimeter data in.csv or.xlsx format. 2.18.1.9. 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 deadline			
2.18.2 Payload Demonstration Flight—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 (if applicable) as designed. The following criteria shall be met during the Payload Demonstration Flight: 2.18.2.1. 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. 2.18.2.2. The payload flown shall be the final, active version. 2.18.2.3. 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. 2.18.2.4. Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED	Payload Demonstration Flight has not occurred.	**Demonstration** - *Scheduled for March 2025.* ***Not yet completed.***	

2.19 An FRR Addendum shall be required for any team completing a Payload Demonstration Flight or NASArequired Vehicle Demonstration Re-flight after the submission of the FRR Report. 2.19.1. Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline shall not be permitted to fly a final competition launch. 2.19.2. Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload during launch week. Permission shall not be granted if the RSO or the Review Panel have any safety concerns	FRR has not occurred.	N/A - ***Not yet completed.***	
2.20 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	Team contact information will be added to the airframe after paint. Information will be added with permanent adhesive vinyl.	**Inspection** - ***Not yet completed.*** *Will be added after the airframe is painted.*	
2.21 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.	LiPo batteries will comply with regulation. 3D printed housings will secure batteries and leave ample room for marking.	**Inspection** - LiPo batteries are secured in their housings. ***Not yet completed.*** *Labeling will be applied prior to any launch.*	5.6.3 Avionics Sled Design 7.3 Mechanical Component Design
2.22.1. The launch vehicle shall not utilize forward firing motors. 2.22.2. The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.) 2.22.3. The launch vehicle shall not utilize hybrid motors. 2.22.4. The launch vehicle shall not utilize a cluster of motors. 2.22.5. The launch vehicle shall not utilize friction fitting for motors. 2.22.6. The launch vehicle shall not exceed Mach 1 at any point during flight. 2.22.7. 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.	We are not planning on using any forward firing motors, motors with titanium sponge based propellant, hybrid motors, or clusters. Motor will be retained with an aluminum screw cap retainer (see section The launch vehicle will stay below Mach 1 (current simulations are at Mach 0.54. The current plans for ballast weight will be below 10% of vehicle mass. All transmitters are well under 250	**Inspection** - The motor utilizes Aerotech Propellant-X which does not contain titanium sponge. The motor is secured with an aluminum screw cap retainer. All transmitters meet power requirements and FCC part 15 compliance. **Analysis** - The velocity of the launch vehicle has been analyzed in OpenRocket under a wide variety of launch conditions.	1.0 Team Summary Page 3.3.2 Motor Mount, Centering Ring, and Motor Retention 6.1.2 Velocity 5.6.1 Altimeter Selection 5.7 Rocket Tracking and Telemetry 7.1.1 Control Module

on the pad may contain a maximum of 4 lbs. of ballast). 2.22.8. Transmissions from on-board transmitters, which are active at any point prior to landing, shall not exceed 250 mW of power (per transmitter.) 2.22.9. Transmitters shall not create excessive interference. Teams shall utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams 2.22.10. Excessive and/or dense metal shall not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses	mW and comply with FCC part 15. Transmitters will abide by frequency allocation. In addition, we plan to use LoRaWAN network with unique addressing. The payload transmitter uses unique addressing, acknowledgements, and reliable handshake protocols. The launch vehicle does not contain excess metal other than hardware in the recovery chain and minor nuts/bolts.		

Table 49 - Recovery System Requirements

Requirement	Compliance	Verification	Report reference
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. 3.1.1. The main parachute shall be deployed no lower than 500 ft. 3.1.2. The apogee event shall contain a delay of no more than 2 seconds. 3.1.3. Motor ejection is not a permissible form of primary or secondary deployment.	Drogue Primary = Apogee Drogue Backup = Apogee + 1.5 s Main Primary = 650 ft Main Backup = 500 ft	**Inspection** - Recovery CONOPS details recovery plan. **Demonstration** - *Will demonstrate on Vehicle Demonstration Flight, currently scheduled for Feb 2025.* ***Not yet completed.***	5.2 Recovery CONOPS
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.	Ground testing will be performed prior to launch for both subscale and full-scale	**Demonstration** - Subscale - Done (11/23/24) Full-scale - *To be done prior to vehicle demonstration flight. Estimated Jan 2025* ***Not yet completed.***	4.1 Subscale Design and Assembly 9.1 Team Derived Verification Plan

3.3 Each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf at landing.	The kinetic energy is simulated to be much less than 75 ft-lbf at landing	**Analysis** - An analysis was performed based on OpenRocket simulations and estimated airframe masses.	6.5.1 Kinetic Energy
3.4 The recovery system shall contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	The recovery system design has full parallel, redundant systems of commercially available flight computers	**Inspection** - Block diagrams show completely independent, parallel systems. **Demonstration** - Each parallel system is shown to function with the other system disabled.	5.6 Avionics Design
3.5 Each altimeter shall have a dedicated power supply, and all recovery electronics shall be powered by commercially available batteries.	Each altimeter has its own power switch and commercially available battery	**Inspection** - Block diagram and battery selection shows dedicated power from commercially available batteries.	5.6.2 Battery Selection 5.6.3 Avionics System Assembly
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	The current design plans to use two screw switches, accessible from the exterior of the airframe with a screwdriver	**Inspection** - Block diagram shows an independent screw switch for each deployment channel.	5.6.3 Avionics System Assembly
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).	The screw switch is locked in an on position by torquing the screw	**Inspection** - Screw switch shows locking position when activated. **Demonstration** - Subscale flew with identical switches to those used in full-scale. Switches stayed in locked position during flight forces.	5.6.3 Avionics System Assembly 4.2 Subscale Flight Conditions and Observations
3.8 The recovery system, GPS and altimeters, and electrical circuits shall be completely independent of any payload electrical circuits.	Recovery, GPS, and payload are each on their own independent power supply.	**Inspection** - Recovery electronics are physically in a different section of the rocket with no electrical connection. Payload and GPS share the same physical compartment, but are electrically isolated.	5.6.3 Avionics System Assembly 7.4.1 Component Design
3.9 Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment	3x 2-56 and 3x 4-40 nylon shear pins will be used for the booster-to-coupler and payload tube to nose cone, respectively.	**Inspection** - Design specification details use of shear pins.	5.8 Shear Pins.

3.10 Bent eye bolts shall not be permitted in the recovery subsystem.	All recovery harness hard point attachments use ¼-20 U-bolts or forged eye bolts. No bent eye bolts are used in the entire recovery chain	**Inspection** - Inspection of the recovery chain shows no bent eye bolts.	5.3.3 Recovery Hardware Selection 5.4 Recovery Attachment
3.11 The recovery area shall be limited to a 2,500 ft. radius from the launch pads.	The current recovery radius is less than 2500 ft at 20 MPH wind speed, calculated two different methods	**Analysis** - OpenRocket simulations were performed to model recovery radius under worst case flight conditions.	6.5.4 Drift
3.12 Descent time of the launch vehicle shall be limited to 90 seconds (apogee to touch down).	The descent time from apogee to touchdown is currently modeled at 80 s	**Analysis** - OpenRocket simulations were performed to determine descent time.	6.5.3 Descent Time
3.13 An electronic 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. 3.13.1. Any rocket section or payload component, which lands untethered to the launch vehicle, shall contain an active electronic tracking device. 3.13.2. The electronic tracking device(s) shall be fully functional during the official competition launch.	All parts of the launch vehicle will be tethered. There will be a single GPS tracker and telemetry unit in the nose cone. The selected tracker device is a Featherweight GPS tracker	**Inspection** - As shown in Recovery CONOPS, the entire vehicle is tethered together. The GPS unit is included in this tethered assembly in the nose of the airframe. **Demonstration** - The subscale used an identical recovery configuration. The entire airframe was tethered with the tracking module in the nose.	5.7 Rocket Tracking and Telemetry 5.2 Recovery CONOPS 7.3.1 Component Design and Integration 4.2 Subscale Flight Conditions and Observations
3.14 The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing). 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 and/or magnetic wave producing device. 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. 3.14.3. The recovery system electronics shall be shielded from all on-board devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The recovery system is housed in a separate avionics bay (the main coupler) and is isolated from the payload and tracking system (nose cone). While the altimeters are WiFi based, they have been thoroughly tested with 802.11 with unique ID's and arming codes. All leads to E-matches are tightly twisted reducing any possible flux coupling. The payload and tracking unit radios are low power and in an isolated chamber. There are no large magnetic field	**Inspection** - The recovery electronics are in a separate, isolated bay from other transmitters. Airframe design shows no other large sources of magnetic fields.	3.2 Final Design Selection 7.3.1 Component Design and Integration

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 electronics	generators such as solenoids, generators, or Tesla coils present on the rocket.		

Table 50 - Payload Experiment Requirements

Requirement	**Compliance**	**Verification**	**Report Reference**
4.1 High School/Middle School Division— Teams may design their own science or engineering experiment or may choose to complete the College/University Division mission stated below. Data from the science or engineering experiment will be collected, analyzed, and reported by the team following the scientific method.	Data will be datalogged as well as sent via LoRa radio to a base station.	**Inspection** - Payload design is presented in the CDR. **Demonstration** - ***Not yet completed:*** Payload will be demonstrated on the bench as well as during the payload demonstration flight.	7.0 Payload Criteria
4.2 ULSI - Not applicable	N/A	N/A	
4.3 ULSI - Not applicable	N/A	N/A	
4.4 General Payload Requirements: 4.4.1. 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. 4.4.2. Teams shall abide by all FAA and NAR rules and regulations. 4.4.3. 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. 4.4.4. 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. 4.4.5. 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). 4.4.6. Any UAS weighing more than. 55 lbs. shall be	Black powder will only be used for deployment charges (handled by the mentor). The team will follow all applicable rules and regulations including, but not limited to BATF, FAA, NFPA, FCC, and local ordinances. In addition, the team will follow the NAR safety code as well as the Tripoli Unified Safety Code for all launches and preparation for launches. No experiments will be jettisoned from our airframe, and no UAV/UAS devices will be used.	**Inspection** - The design of the payload does not contain any energetics or other materials that would violate FAA/NAR/TRA regulations or safety requirements. The design of the payload does not jettison.	7.0 Payload Criteria

registered with the FAA and the registration number marked on the vehicle			

Table 51 - Safety Requirements

Requirement	Compliance	Verification	Report reference
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.	The team will begin writing a launch and safety checklist. The completion of the list will gate the subscale demonstration launch and show continuous improvement through every launch up until LRR.	**Inspection** - Draft safety checklists are included in the CDR. The FRR has not occurred. ***Not yet completed.*** **Demonstration** - Draft safety checklists were used during the subscale flight.	8.1 Launch Preparation and Operating Procedures
5.2 Each team shall identify a student safety officer who will be responsible for all items in Section 5.3	Naoki Matsumoto has been identified as our team's student safety officer.	**Inspection** - Safety officer was named in submitted PDR and roles are defined in the appendix. **Demonstration** - The safety officer has been present and assumed his role at all club events.	Appendix H - Role of Student Team 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	The role of the safety officer was defined in the proposal and copied into the PDR. The role includes all points under requirement 5.3.	**Inspection** - The role of the safety officer is shown in the appendix.	Appendix H - Role of Student Team Safety Officer

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.	At all launches, the team will follow the rules and guidance of the club and RSO. The RSO's decision on all matters is final and absolute.	**Demonstration** - During the subscale launch, all TRA and Tripoli Mid-Ohio rules were followed and all flight intentions communicated to prefect/RSO. ***Not yet completed***: Vehicle demonstration flight, payload demonstration flight, SLI flight.	4.2 Subscale Flight Conditions and Observations
5.5 Teams shall abide by all rules set forth by the FAA.	All flights will be conducted at NAR/TRA club fields with established FAA waivers. The waiver will be verified by the student team safety officer.	**Demonstration** - Flights have only occurred at sanctioned launches where FAA waiver has been confirmed by the safety officer.	4.2 Subscale Flight Conditions and Observations

Table 52 - Final Flight Requirements

Requirement	**Compliance**	**Verification**	**Report reference**
6.1 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. 6.1.2. Teams 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. 6.1.4. The scoring altimeter shall be presented to the NASA scoring official upon recovery. The scoring altimeter shall be one of the altimeters used for recovery events. 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	The team understands and will abide by the requirements for the NASA Launch Complex. The team mentor may have a commitment on the last day of the event. An alternative mentor, Richard Sharp, has been selected and agreed to serve as team mentor for this day. The team is familiar with this mentor and have flown with him before. This has been approved by John Eckhart.	**Inspection** - A team code of conduct for NASA Launch Week will be drafted and signed by team members. ***Not yet completed***. **Demonstration** - Adherence to NASA 6.1 will be demonstrated during Launch Week ***Not yet completed.***	
6.2 Commercial Spaceport Launch Site - Not Applicable	N/A	N/A	

9.3 Budget

A complete table of total expenditures is in Appendix G.

Table 53 - Total Breakdown of Budget

Balance summary	Budget (2024-2025)	Actuals	Variance
Income	**6,640.37**	**5,835.37**	**805.00**
Revenue (1000)	6,640.370	5,835.37	805.000
Sponsors (1100)	**1,510.00**	**1,510.00**	**0.00**
Membership fees (1200)	**1235.00**	**930.00**	**305.00**
Fundraising (1300)	**0.00**	**0.00**	**0.00**
Other (1400)	**2895.37**	**2895.37**	**01**
Expenses	**5,439.61**	**1,009.51**	**4,430.10**
Build (2000)	1,469.16	856.63	612.53
Rocket (2100)	**1,335.21**	**837.85**	**497.36**
Full-scale (2101)	1,119.11	634.28	484.83
Subscale (2102)	216.10	203.58	12.53
Miscellaneous (2200)	**133.40**	**70.82**	**62.58**
Consumables (2201)	62.58	0.00	62.58
Personal Protection Equipment (2202)	70.82	70.82	0.00
Stem Engagement (3000)	0.00	0	0
Supplies (3001)	0.00	0	0.00
Outreach: Supplies	0.00	0	0.00
Management (4000)	3,971.00	100.84	3,870.16
Travel (4101)	2,641.00	0.00	2,641.00
Other (4201)	1,330.00	100.84	1,229.16
Administration: Shipping	200.00	100.84	99.16
Administration: Launch Fees	30.00	0.00	30.00
Administration: Contingency	1,100.00	0.00	1,100.00
Net difference (surplus or deficit)	**1,200.76**	**4,825.86**	**-3,625.10**

9.3.1 Bill of Materials (BOM)

The BOM is categorized into full-scale and subscale line item budgets including individual components, quantity of units, and material vendors. Each BOM also includes the final gross cost for each rocket.

Table 54 - Full-Scale Bill of Materials

Full Scale Bill of Materials							
System	**Component**	**Vendor**	**Qty**	**Unit Cost**	**Shipping**	**Details**	**Team Cost**
Booster	54 mm Screw On Motor Retainer	Mach1Rocketry	1	$31.00	$80.00	15% vendor discount	$26.35
	54 mm FWFG Motor Mount, price per inch	Mach1Rocketry	18	$1.50	$0.00	15% vendor discount	$22.95
	54 mm to 98 mm G10 Fiberglass Centering Rings	Mach1Rocketry	3	$6.75	$0.00	15% vendor discount	$17.21
	3/16" G10 Fiberglass Custom Fin Set	Mach1Rocketry	1	$30.00	$0.00	15% vendor discount - design changed	$30.00
	U-bolt, Stainless, 1/4-20, 1-1/4" (8896T94)	McMaster-Carr	0	$5.47	$0.00		$0.00
	1515 Rail Buttons	Railbuttons	2	$0.75	$0.00	Donated by Mentor	$0.00
	PEM nuts, Stainless, #10-24 (96439A450)	McMaster-Carr	2	$0.50	$0.00	Donated by Mentor, rounding error	$0.00
	98 mm FWFG Body Tube, Price per foot.	Mach1Rocketry	5	$30.00	$0.00	15% vendor discount	$127.50
	Custom Fin Slotting	Mach1Rocketry	3	$2.00	$0.00	15% vendor discount	$5.10
Nose Assembly	98 mm Nose Cone, FWFG, 5:1 cone, coupler, bulkhead	Mach1Rocketry	1	$90.00	$0.00	15% vendor discount	$76.50
	#8-32 Stainless PEM Nuts (96439A360)	McMaster-Carr	3	$0.37	$0.00	Donated by Mentor, rounding error	$0.00
	#8-32 Stainless Truss Head Screws	McMaster-Carr	3	$0.07	$0.00	Donated by Mentor, rounding error	$0.00
	U-bolt, Stainless, 1/4-20, 1-1/4" (8896T117)	McMaster-Carr	2	$5.16	$0.00		$10.32
	Featherweight GPS Tracker Module	Featherweight	1	$165.00	$0.00	Loaned by Mentor	$0.00

Avionics Bay	98 mm FWFG Coupler, 12" length	Mach1Rocketry	12	$3.00	$0.00	15% vendor discount	$30.60
	98 mm G10 Stepped Bulkhead	Mach1Rocketry	2	$14.00	$0.00	15% vendor discount	$23.80
	98 mm FWFG Switch Band, 1" length	Mach1Rocketry	1	$3.50	$0.00	Design changed, new parts on order	$3.50
	Threaded Rod, 1/4-20, Stainless, 13" (98804A107)	McMaster-Carr	2	$4.66	$0.00		$9.32
	Nylon Lock Nut, 1/4-20, Stainless (91831A029)	McMaster-Carr	2	$0.13	$0.00	Donated by Mentor, rounding error	$0.00
	Knurled Nut, 1/4-20 (92741A160)	McMaster-Carr	2	$1.00	$0.00	Donated by Mentor	$0.00
	Eggtimer Quantum	Eggtimer Rocketry	2	$40.00	$0.00	Loaned by Mentor	$0.00
	Perfectflite Stratologger CF	Perfectflite	0	$64.95	$0.00	Loaned by Mentor	$0.00
	Screw Switch	Missileworks	2	$3.00	$0.00	Loaned by Mentor	$0.00
	#8-32 Stainless PEM Nuts (96439A360)	McMaster-Carr	3	$0.37	$0.00	Loaned by Mentor	$0.00
	U-bolt, Stainless, 1/4-20, 1-1/4" (8896T117)	McMaster-Carr	2	$5.16	$0.00		$10.32
	2S 450 mAh LiPo Battery	Amazon	2	$10.00	$0.00	Loaned by Mentor	$0.00
	1/4" Stainless Split Lock Washer (92145A029)	McMaster-Carr	10	$0.04	$0.00	Donated by Mentor	$0.00
	1/4" Stainless Washer (92141A029)	McMaster-Carr	6	$0.06	$0.00	Donated by Mentor	$0.00
	1/4-20 Stainless Nut (91845A029)	McMaster-Carr	6	$0.05	$0.00	Donated by Mentor	$0.00
	#6-32 Stainless PEM Nuts (96439A230)	McMaster-Carr	8	$0.23	$0.00	Donated by Mentor	$0.00
	#4-40 Stainless PEM Nuts (96439A140)	McMaster-Carr	8	$0.22	$0.00	Donated by Mentor	$0.00
	#6-32 Stainless Screws (Look up P/N)	McMaster-Carr	8		$0.00	Donated by Mentor	$0.00
	#4-40 Stainless Screws (Look up P/N)	McMaster-Carr	8		$0.00	Donated by Mentor	$0.00
	#6 Stainless Washer (92141A008)	McMaster-Carr	16	$0.02	$0.00	Donated by Mentor	$0.00
	#6-32 Stainless Nut (91841A007)	McMaster-Carr	16	$0.04	$0.00	Donated by Mentor	$0.00
	Ring Terminal Connector for #6 Post (298-10424-ND)	Digi-Key	4	$0.23	$0.00	Donated by Mentor	$0.00
	#6 Brass Knurled Nut (92741A110)	McMaster-Carr	4	$0.41	$0.00	Donated by Mentor	$0.00
	Altimeter Sled	Custom	1		$0.00	3D Printed	$0.00
	Switch Holder Sled	Custom	1		$0.00	3D Printed	$0.00
	Battery Sled	Custom	1		$0.00	3D Printed	$0.00
	Battery Brace	Custom	1		$0.00	3D Printed	$0.00
	#4-40 Brass Heat Set Inserts (93365A122)	McMaster-Carr	14	$0.18	$0.00	Donated by Mentor	$0.00
	#4-40 Stainless Screws (Look up P/N)	McMaster-Carr	8		$0.00	Donated by Mentor	$0.00
	#4-40 Stainless Screws (Look up P/N)	McMaster-Carr	4		$0.00	Donated by Mentor	$0.00
	#4-40 Stainless Screws (Look up P/N)	McMaster-Carr	4		$0.00	Donated by Mentor	$0.00
	5 gram Charge Well	Custom	2		$0.00	3D Printed	$0.00
	6 gram Charge Well	Custom	2		$0.00	3D Printed	$0.00

Experimental Payload	STEMMA QT / Qwiic JST SH 4-Pin Cable - 50mm Long	Adafruit	5	$0.95	$0.00		$4.75
	STEMMA QT / Qwiic JST SH 4-pin to Male Headers Cable	Adafruit	1	$0.95	$0.00		$0.95
	Adafruit Feather M0 RFM96 LoRa Radio	Adafruit	3	$34.95	$21.43		$104.85
	Adafruit 9-DOF Orientation IMU Fusion Breakout	Adafruit	1	$24.95	$0.00		$24.95
	ADXL345 - Triple-Axis Accelerometer	Adafruit	1	$17.50	$0.00		$17.50
	BMP390 Barometric Sensor Board	Adafruit	1	$10.95	$0.00		$10.95
	LiPo 1S 450 mAh Battery	Adafruit	1	$7.95	$0.00	Loaned from Mentor	
	#4-40 Brass Heat Set Inserts (93365A122)	McMaster-Carr		$0.18	$0.00	Donated by Mentor	
	Payload Mount	Custom	1		$0.00	3D Printed	
	Ballast Holder	Custom	1		$0.00	3D Printed	
	Tracker/Payload Mount Plate	Custom	1		$0.00	3D Printed	
	Payload Electronics Mount	Custom	1		$0.00	3D Printed	
	Payload Cockpit Mount	Custom	1		$0.00	3D Printed	
	Stemnauts	Custom	4		$0.00	TBD	
	#4-40 Brass Heat Set Inserts (93365A122)	McMaster-Carr	22	$0.18	$0.00	Donated by Mentor	
	#4-40 Stainless Screws (Look up P/N)	McMaster-Carr	14		$0.00	Donated by Mentor	
	#4-40 Stainless Screws (Look up P/N)	McMaster-Carr	2		$0.00	Donated by Mentor	
	#4-40 Stainless Screws (Look up P/N)	McMaster-Carr	4		$0.00	Donated by Mentor	
	#4 x 1/8" Nylon Spacers (94636A702)	McMaster-Carr	14	$0.15	$0.00	Donated by Mentor	

Rocket Payload Assembly	98 mm FWFG Body Tube, Price per foot.	Mach1Rocketry	4	$30.00	$0.00	15% vendor discount	$102.00
	#8-32 Stainless Truss Head Screws	McMaster-Carr	3	$0.07	$0.00	Donated by Mentor	$0.00
Recovery	Quicklinks, Stainless, 5/16". (8947T27)	McMaster-Carr	5	$5.00	$0.00	Loan from Mentor	$0.00
	Quicklink, Stainless, 1/4"	McMaster-Carr	1	$2.00	$0.00	Loan from Mentor	$0.00
	Drogue Harness, 3/8" Tubular Kevlar, Stitched Loop, 30 ft	Custom	1	$46.00	$0.00	Loan from Mentor	$0.00
	Main Harness, 3/8" Tubular Kevlar, Stitched Loop, 25 ft	Custom	1	$33.00	$0.00	Loan from Mentor	$0.00
	Drogue Parachute, 18” elliptical	Custom	1	$79.23	$0.00	Loan from Mentor	$0.00
	Main Parachute, 78” elliptical	Custom	1	$200.00	$0.00	Loan from Mentor	$0.00
	Drogue Nomex Blanket	Custom	1	$9.00	$0.00	Donated by Mentor	$0.00
	Main Nomex Blanket	Custom	1	$19.00	$0.00	Donated by Mentor	$0.00
Energetics	Aerotech K1103X-P Reload Kit	buyrocketmotors	3	$183.99	$35.00	20% vendor discount, + HAZMAT fee	$441.58
	Aerotech 54/1706 Motor Case	Wildman Hobbies	1	$186.29	$0.00	Loan from Mentor	$0.00
	Goex ffffG Black Powder, per gram	Chris' Rocket Supplies	100	$0.07	$0.00	Donated from Mentor, rounding error	$0.00
	Firewire Electronic Match	MJG Technologies	20	$0.71	$0.00	Donated from Mentor	$0.00
						Team Cost Total:	**$1,101.00**

Table 55 - Subscale Bill of Materials

Sub-Scale Bill of Materials							
System	**Component**	**Vendor**	**Qty**	**Unit Cost**	**Shipping**	**Details**	**Team Cost**
Booster	38 mm Screw On Motor Retainer	Mach1Rocketry	1	$27.00	$0.00	15% vendor discount	$22.95
	38 mm FWFG Motor Mount, price per inch	Mach1Rocketry	12	$1.25	$0.00	15% vendor discount	$12.75
	38 mm to 54 mm G10 Fiberglass Centering Rings	Mach1Rocketry	2	$4.50	$0.00	15% vendor discount	$7.65
	3/32" G10 Fiberglass Custom Fin Set	Mach1Rocketry	1	$20.00	$25.00	15% vendor discount	$20.00
	1010 Rail Buttons	Railbuttons.com	2	$0.75	$0.00	Donated by Mentor	$0.00
	PEM nuts, Stainless, #10-24 (96439A450)	McMaster-Carr	2	$0.50	$0.00	Donated by Mentor, rounding error	$0.00
	54 mm FWFG Body Tube, 27"	Mach1Rocketry	2	$16.00	$0.00	15% vendor discount	$27.20
	Custom Fin Slotting	Mach1Rocketry	3	$2.00	$0.00	15% vendor discount	$5.10
Nose Assembly	54 mm Nose Cone, FWFG, 5:1 cone, coupler, bulkhead	Mach1Rocketry	1	$63.50	$0.00	15% Discount	$63.50
	Forged Eye Bolt, M4, Stainless	Amazon	1	$1.14	$0.00	Donated by Mentor	$0.00
	Featherweight GPS Tracker Module	Featherweight	1	$165.00	$0.00	Loaned by Mentor	$0.00
	3D Printed Tracker Mount	Custom	1		$0.00	Donated by Mentor	$0.00
	4-40 3/8" Stainless Screws	McMaster-Carr	4	$0.06	$0.00	Donated by Mentor, rounding error	$0.00
Avionics Bay	54 mm FWFG Coupler, 7" length	Mach1Rocketry	7	$2.00	$0.00	15% vendor discount	$11.90
	54 mm G10 Stepped Bulkhead	Mach1Rocketry	2	$9.50	$0.00	15% vendor discount	$16.15
	54 mm FWFG Switch Band, 1" length	Mach1Rocketry	1	$2.00	$0.00	15% vendor discount	$1.70
	Threaded Rod, M4, Stainless, 8" Length (90024A222)	McMaster-Carr	1	$3.37	$0.00	Donated by Member	$0.00
	Nylon Lock Nut, M4, Stainless (93625A150)	McMaster-Carr	2	$0.08	$0.00	Donated by Mentor	$0.00
	Knurled Nut, M4, Stainless	Amazon	2	$0.92	$0.00	Donated by Mentor	$0.00
	Eggtimer Quantum	Eggtimer Rocketry	2	$40.00	$0.00	Loaned by Mentor	$0.00
	Screw Switch	Missileworks	2	$3.00	$0.00	Loaned by Mentor	$0.00
	#6-32 Stainless PEM Nuts (96439A230)	McMaster-Carr	3	$0.23	$0.00	Donated by Mentor	$0.00
	Forged Eye Bolt, M4, Stainless	Amazon	2	$1.14	$0.00	Donated by Mentor, rounding error	$0.00

Payload Assembly	54 mm FWFG Body Tube, 19"	Mach1Rocketry	2	$16.00	$0.00	15% vendor discount	$27.20
	#6-32 Stainless Truss Head Screws	McMaster-Carr	3	$0.07	$0.00	Donated by Mentor, rounding error	$0.00
Recovery	Quicklink, Stainless, 1/4"	Amazon	4	$2.40	$0.00	Loan from Mentor	$0.00
	Quicklink, Stainless, M3	Amazon	1	$0.64	$0.00	Loan from Mentor	$0.00
	Drogue Harness, 1/4" Tubular Kevlar, Stitched Loop, 20 ft	Custom	1		$0.00	Loan from Mentor	$0.00
	Main Harness, 1/4" Tubular Kevlar, Stitched Loop, 15 ft	Custom	1		$0.00	Loan from Mentor	$0.00
	Drogue Parachute (15" 0.707 Elliptical)	Custom	1	$59.26	$0.00	Loan from Mentor	$0.00
	Main Parachute (32" 0.707 Elliptical)	Custom	1	$105.18	$0.00	Loan from Mentor	$0.00
	Drogue Nomex Blanket	Custom	1		$0.00	Loan from Mentor	$0.00
	Main Nomex Blanket	Custom	1		$0.00	Loan from Mentor	$0.00
Energetics	Aerotech I Reload Kit	Wildman Hobbies	1	$65.00	$0.00	Donated from Mentor	$0.00
	Aerotech 38/XXX Motor Case	Wildman Hobbies	1		$0.00	Loan from Mentor	$0.00
	Goex ffffG Black Powder, per gram	Chris' Rocket Supplies	15	$0.07	$0.00	Donated from Mentor, rounding error	$0.00
	Firewire Electronic Match	MJG Technologies	8	$0.71	$0.00	Donated from Mentor	$0.00
						Team Cost Total:	**$216.10**

Table 56- Personal Protective Equipment - Bill of Materials (BOM)

Item	Source	Quantity	Price	Total
Nitrile Gloves (400 Pack)	Costco	1	$27.99	$27.99
Leather Work Gloves	Walmart	2	$2.97	$5.94
Safety Glasses Z87.1	Walmart	9	$2.24	$20.16
N95 Respirator Mask	Home Depot	4	$1.97	$7.88
Ear Plug (3-Pack)	Walmart	3	$4.97	$14.91
		Total		$76.88

Table 57- Consumables - Bill of Materials (BOM)

SLI Sub-Scale and Full-Scale Consumables					
Component	**Vendor**	**Qty**	**Unit Cost**	**Status**	**Team Cost**
Proline 4500Q (pint) *	Wildman Hobbies	1	$39.00	Donated by Mentor	$0.00
JB Weld (10 oz) *	Amazon	1	$17.98	Donated by Mentor	$0.00
West System 105/206 (32 oz) *	Amazon	1	$105.86	Donated by Mentor	$0.00
West System 404, High Density Filler *	Amazon	1	$51.26	Donated by Mentor	$0.00
West System 406, Colloidal Silica *	Amazon	1	$19.21	Donated by Mentor	$0.00
Dupli-Color Filler Primer	JB Tools	1	$7.74		$7.74
Dupli-Color Sandable Primer	JB Tools	2	$6.81		$13.62
Dupli-Color Base Coat Paint	JB Tools	3	$6.87		$20.61
Dupli-Color High Temperature Gloss Clear Coat	JB Tools	3	$6.87		$20.61
			Total:		**$62.58**

9.3.2 STEM Engagement

(STEM) The team's STEM Engagement activities' materials are subsidized by the school district. No current expenses are required, though we have included the gross expense for valuing purposes. A breakdown of expenses is located in Appendix G.

9.4 Funding

9.4.1 Funding Pathways

During the project timeline, the team will strive towards several approaches to generate funding for the necessary expenditures.

Team Fund: As of CDR, the team has approximately $6,000 allocated for buying airframe components and funding the club's sustainability plans for future members. This fund includes funding from sponsorships, membership fees, and the team savings from previous years. This funding has increased from PDR as the team acquired additional sponsorships.

Grants: Our team has received a Northville Education Foundation grant covering our airframe expenses. This grant is a restricted fund and can only be utilized for full-scale and subscale build materials. We did not receive a travel grant, so each team member is required to fund their own trip to Launch Week.

Sponsorships: Approach local businesses or branches to request grants to fund the project. In return, the team promotes the companies on our website, social media, team events, and on the rockets themselves. Currently, our team is supported by Microchip, Ganesh Moorthy, Lauren Carr, and Evigia Systems.

Fundraising Events: Organize bake sales and coordinate with local businesses (ie. Chipotle or Panera) to raise money for travel.

9.4.2 Allocation of Funds

Project Materials: Materials and components needed to successfully build the two rockets and the payload, including all component materials, consumables, tools, PPE, motors, and electronics. Currently, 20% of our funding is allocated towards project materials.

Travel Expenses: The budget currently accounts for our educator's travel expenses, as well as a set subsidy for team members, to participate in the Launch Week. We intend to fund a total of $1,800 across all members for travel costs to ensure greater participation at Huntsville, AL. The budget for travel, however, has been reduced since our PDR Report to create a contingency fund.

Contingency Fund: The team intends to allocate $1,100 to our contingency fund to cover unexpected incidentals that may arise during the competition. The fund is sufficient in providing parts for another full-scale rocket in case of failure.

9.5 Timeline

In order to break down the project and have deadlines for important milestones, the team created a GANTT chart to ensure all work that needs to be completed is getting completed. The GANTT chart includes all important NASA deliverables and team deadlines. This will be used in conjunction with a work assignment spreadsheet to delegate appropriate tasks to appropriate people.

As we complete the CDR milestone, we will complete payload design and subscale flight to ensure the completion of the project within the required due dates. Full-scale build is starting as the CDR milestone completes, and the vehicle demonstration flight is planned with a primary launch date of 2/1, with backup dates spanning till the week of 3/16. The payload demonstration flight will take place after the vehicle demonstration flight, with the same team-set deadline of the week of 3/16.

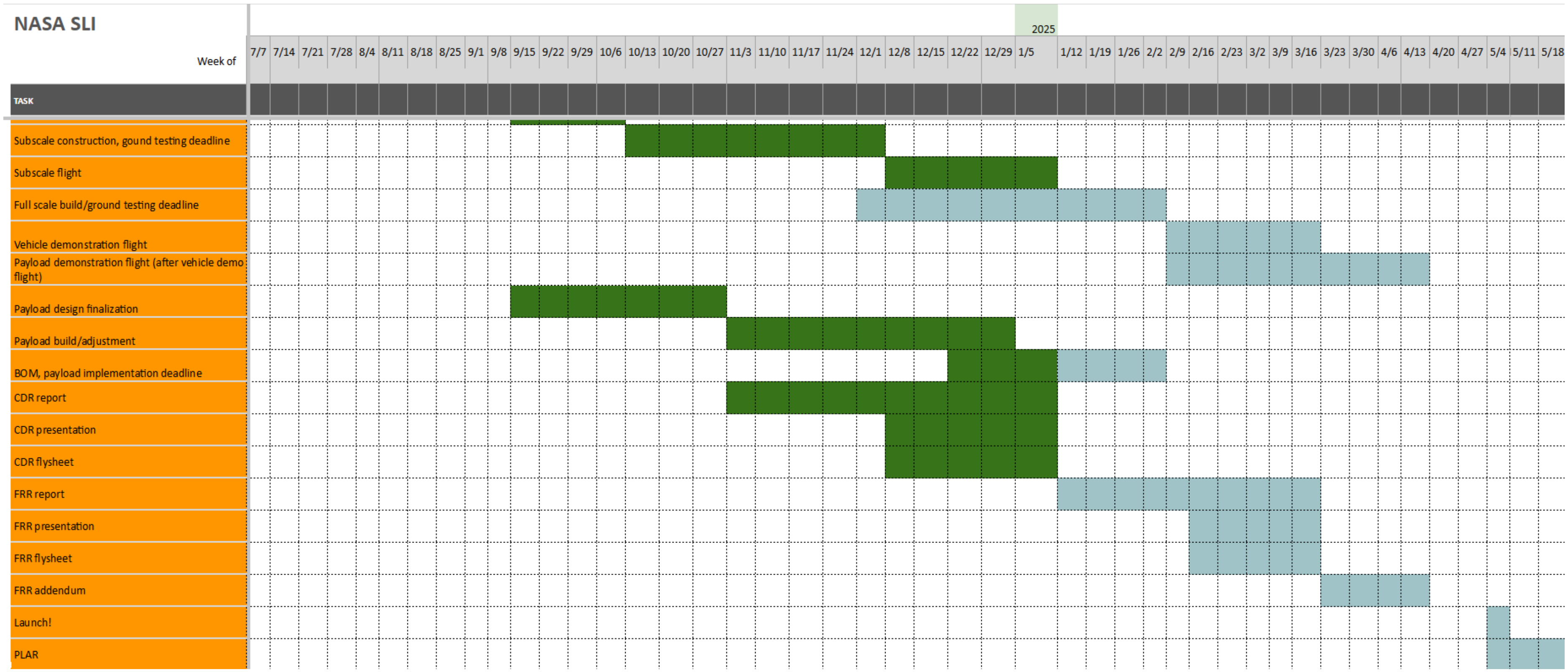


Fig. 70 - Gantt chart - timeline

Appendix A - Full-Scale Deployment Charge Hand Calculations

The nose cone will be coupled together using three 4-40 nylon shear pins, and the booster coupled using three 2-56 shear pins. Assuming the maximum value of tolerance and only the shear strength of the shear pins, the nose cone will require 163.53 lbs of force to separate and the booster 101.64 lbs. To ensure separation, we will add 20%: 196.24 lbs, and 121.97 lbs, respectively.

On our 4 in the airframe, $A \approx 4\pi$ in^2, using F=PA, the pressure needed to separate the nose from the payload tube is 15.62 psi and the coupler from the booster is 9.71 psi. Converting that to atmospheres and substituting into PV=nRT, we get for the nose cone:

$$1.06V = n(0.08206)T$$

And for the booster:

$$0.66V = n(0.08206)T$$

We are solving for *n*, moles of gas, thus:

$n_{nose} = \frac{1.06V}{0.08206T}$ and $n_{booster} = \frac{0.66V}{0.08206T}$

The volume of our payload section is approximately 7.93 L and the volume of our booster is 6.62 L. Depending on its composition, black powder burns at ~1200°-1350° Celsius. Taking a middle of 1250° C for T, we get the payload:

$$n_{nose} = \frac{1.06(7.93)}{(0.08206)(1523.15)}$$

And for the booster:

$$n_{booster} = \frac{0.66(6.62)}{(0.08206)(1523.15)}$$

These calculations give us the moles of gas needed to create our specified pressure:

$n_{nose} = 0.0673\, moles$ and $n_{booster} = 0.0350\, moles.$

A simplified chemical equation for the combustion of black powder is:

$2KNO_3 + 3C + S \rightarrow K_2S_{(s)} + 3CO_{2\,(g)} + N_{2\,(g)}$. †

Using stoichiometry, we can calculate the mass of black powder needed; the ratio of moles of gas to moles of reactants is 5:6:

For the nose cone:
5:6=0.0673:x
x=(0.101 moles black powder)*45.0 g/mol = 4.55 g

For the booster:
5:6=0.0350:y
y=(0.0524 moles black powder)*45.0 g/mol = 2.36 g

†: The reaction for the combustion of black powder is complex with many products, and said products change based on the reaction environment. However, this seems to be an accepted simplification of the reaction, which should be good enough for our uses.

Appendix B - Spreadsheet Deployment Charge Calculations

Table 58 - Full-Scale Main Parachute Black Powder Calculations

Black powder: drogue		
Rocket	SLI full-scale	
Body tube diameter	4	in
Body tube length	39	in
Ground level altitude	250	ft
Max altitude	4500	ft
Force to overcome friction	3	lbs
Screw size	4-40	
Number of screws	3	
Black powder weight	3.30	g
Calculated values		
Ground level pressure	14.56	psi
Max altitude pressure	12.46	psi
Ejection charge pressure	13.03	psi

Table 59 - Full-Scale Drogue Parachute Black Powder Calculations

Black powder: main		
Rocket	SLI full-scale	
Body tube diameter	4	in
Body tube length	39	in
Ground level altitude	250	ft
Max altitude	4500	ft
Force to overcome friction	3	lbs
Screw size	2-56	
Number of screws	3	
Black powder weight	2.05	g
Calculated values		
Ground level pressure	14.56	psi
Max altitude pressure	12.46	psi
Ejection charge pressure	8.10	psi
Force on nose cone at max altitude	26.46	lbs
Min shear strength of screws	92.94	lbs
Max shear strength of screws	104.65	lbs
Ejection charge force at ground level	104.82	lbs
Ejection charge net force at max altitude	131.28	lbs
Good combination?	TRUE	

Table 60 - Subscale Main Parachute Black Powder Calculations

Black powder: drogue		
Rocket	SLI subscale	
Body tube diameter	2	in
Body tube length	19	in
Ground level altitude	250	ft
Max altitude	2550	ft
Force to overcome friction	3	lbs
Screw size	2-56	
Number of screws	3	
Black powder weight	1	g
Calculated values		
Ground level pressure	14.56	psi
Max altitude pressure	13.39	psi
Ejection charge pressure	32.45	psi
Force on nose cone at max altitude	3.69	lbs
Min shear strength of screws	92.94	lbs
Max shear strength of screws	104.65	lbs
Ejection charge force at ground level	104.95	lbs
Ejection charge net force at max altitude	108.63	lbs
Good combination?	TRUE	

Table 61 - Subscale Drogue Parachute Black Powder Calculations

Black powder: main		
Rocket	SLI Subscale	
Body tube diameter	2	in
Body tube length	19	in
Ground level altitude	250	ft
Max altitude	2550	ft
Force to overcome friction	3	lbs
Screw size	2-56	
Number of screws	1	
Black powder weight	0.35	g
Calculated values		
Ground level pressure	46.56	psi
Max altitude pressure	13.39	psi
Ejection charge pressure	11.36	psi
Force on nose cone at max altitude	3.68	lbs
Min shear strength of screws	30.98	lbs
Max shear strength of screws	36.88	lbs
Ejection charge force at ground level	38.68	lbs
Ejection charge net force at max altitude	42.37	lbs
Good combination?	TRUE	

Appendix C - Full-Scale Avionics Bay Design

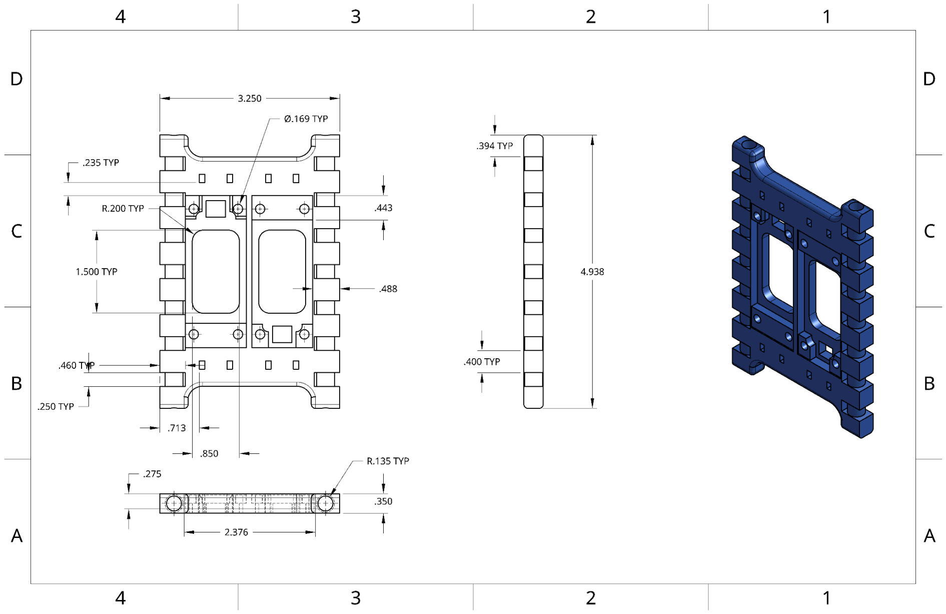


Fig 71 - Altimeter sled drawing

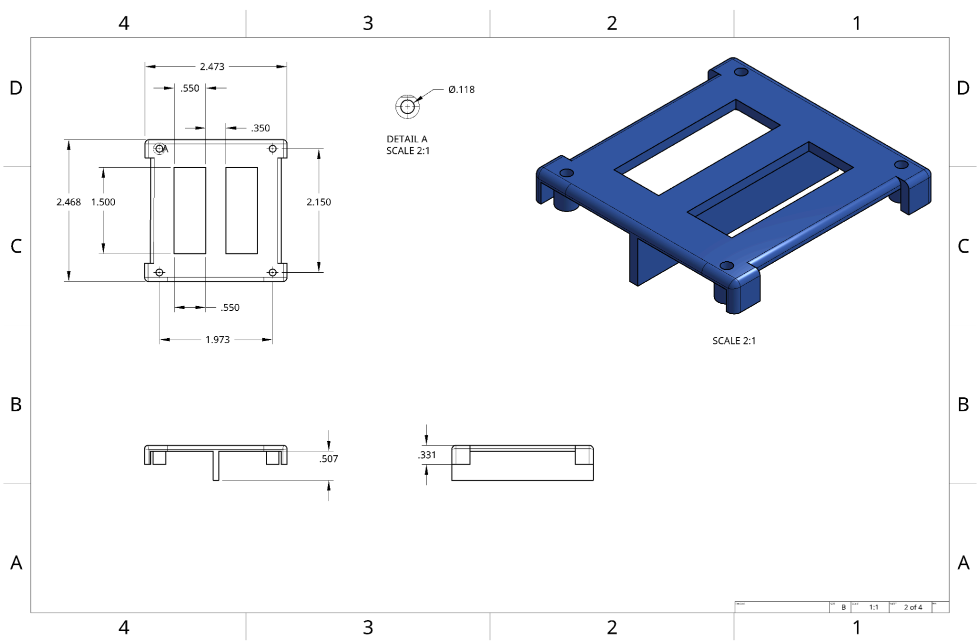


Fig. 72 - Battery brace drawing

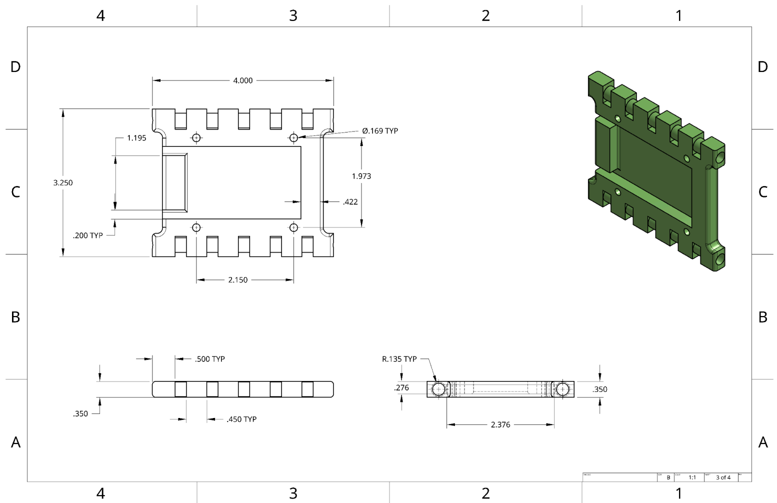


Fig. 73 - Battery sled drawing

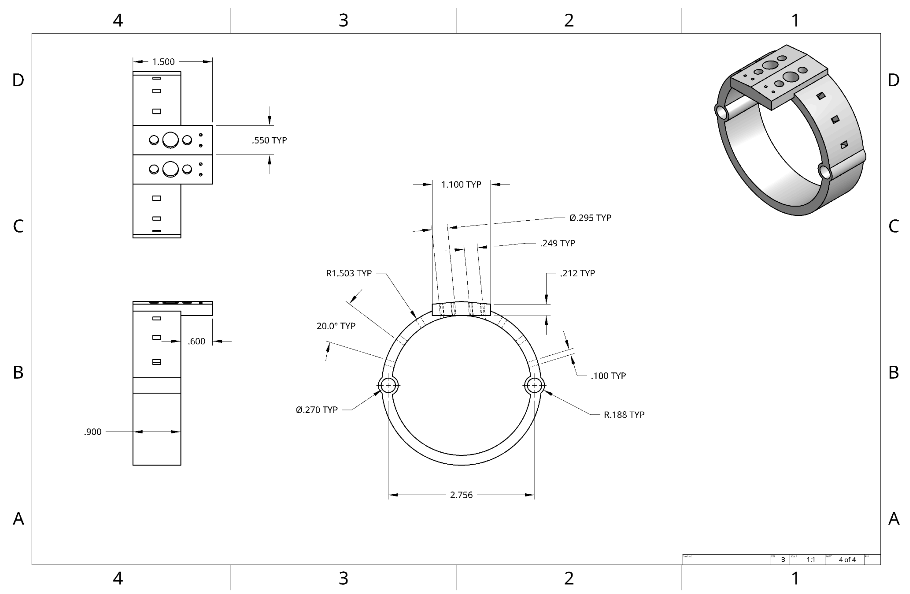


Fig. 74 - Power Switch drawing

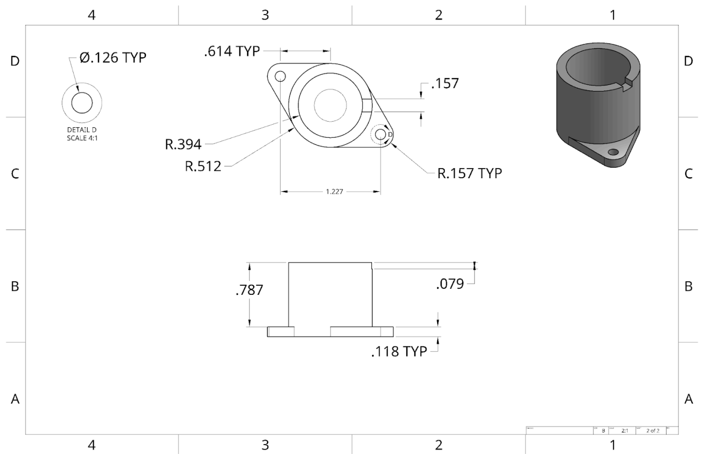


Fig. 75 - Ejection charge well drawing

Appendix D - Propulsion

For our full-scale rocket, we will use an Aerotech K1103X (primary) or an Aerotech K805G motor (secondary). Vehicle Requirements 2.14, 2.13, and 2.16 require a minimum thrust-to-weight ratio of 5.0:1.0, a minimum static stability margin of 2.0 caliber at the rail exit, and a 52 ft/s rail exit velocity. Several K-impulse motors were compared in our proposal, but limited to motors that fit in the Aerotech 54/1706 case or smaller (LV-M-1). After further analysis, we deemed the K1103X as the best choice for the primary motor selection and the K805G as the secondary choice. Technical information we based our choice upon is organized in the following table:

Table 62 - Motor details

Variables	Motor details	
Motor name	K1103X	K805G
Total impulse (Ns)	1789	1762
Thrust-to-weight ratio	17:1	9:1
Rail exit velocity (ft/s)	102	81
Rail exit stability (caliber)	4.42	4.31
Comments:	Easy to ignite, large flame, low amount of smoke.	Green flame, difficult to ignite

We concluded that the K1103X would be the best selection for our purposes. Upon simulation in OpenRocket, this motor allowed us to reliably reach our target altitude of 4000 ft and met all of the minimum requirements for thrust-to-weight ratio, stability, and rail exit velocity; however, it requires the fuel grains to be glued to the liner, which will be done by the mentor.

As the relevant vehicle requirements were met, we are considering the K805G as our second option. Its overall numbers are slightly less than the K1103X; however, they still meet all requirements by NASA. The K1103X was chosen as first choice over the K805G due to the K805G's difficulty to ignite and its toxic barium chloride exhaust. Other motors considered in the proposal did not meet stability requirements or had unjustifiably high rail exit velocities.

Appendix E - Subscale Deployment Charge Hand Calculations

Shear Pins: Nose cone, three 2-56s; booster, one 2-56

Nose (drogue):

Body tube size: 13.5*pi
101.64 lbs
121.968 (20% margin)
Pressure: p=f/a 121.968/pi = 38.82 psi=2.64 atm
pv=nrt
2.64(0.69)=n(0.08206)(1523.15)
n= 0.015 mol blk powder/6*5 *45 g = 0.55 g

Booster (main):

Body tube size: 14*pi = 0.72L
33.88 lbs
40.656 (20% margin)
Pressure: f=pa 40.656/pi = 12.94 psi = 0.88 atm
pv=nrt
0.88(0.72)=n(0.08206)(1523.15)
n= 0.0051 mol blk powder/6*5*45 g = 0.19 g

Appendix F - Subscale CAD and Component Specification

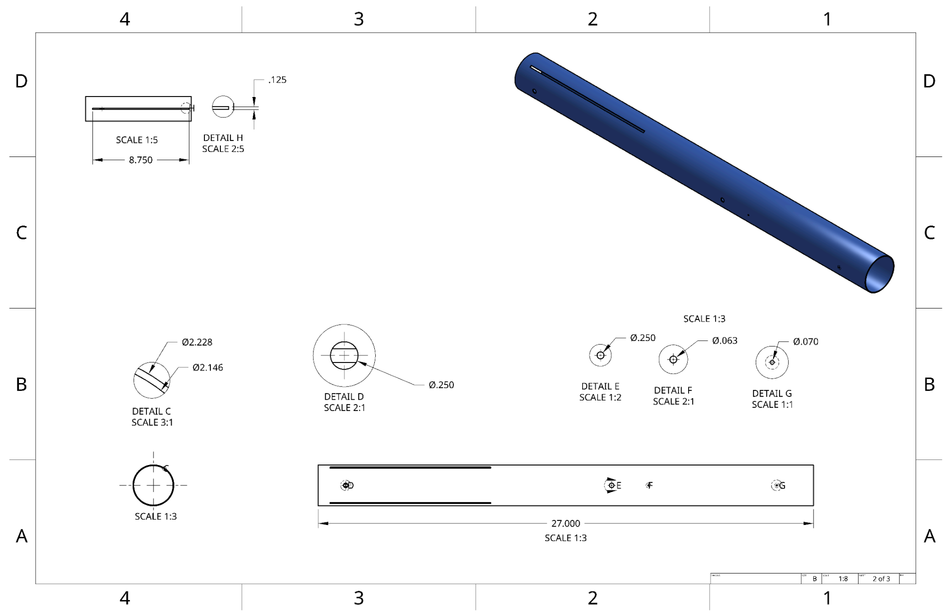


Fig. 76 - Subscale booster tube drawing

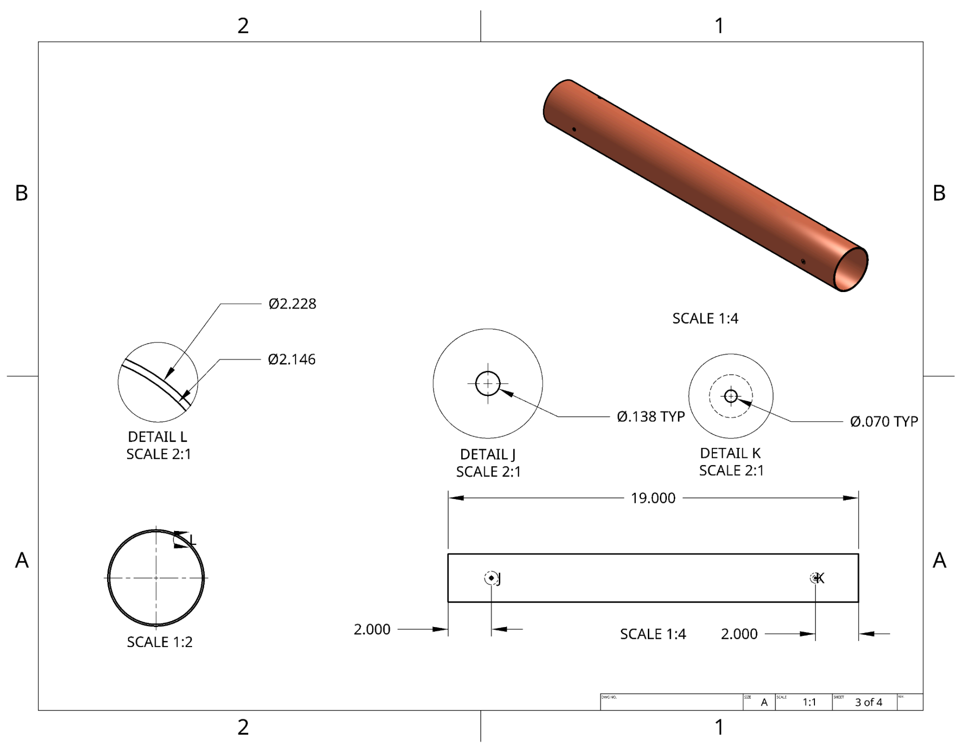


Fig. 77 - Subscale payload tube drawing

Table 63 - Body Tube Parameters

Booster tube		Payload tube	
Parameter	**Value**	**Parameter**	**Value**
Material	FW fiberglass	Material	FW fiberglass
Length	27 in	Length	19 in
Outer diameter	2.228 in	Outer diameter	2.228 in
Inner diameter	2.146 in	Inner diameter	2.146 in
Number of slots	3		
Fin slot length	8.85 in		
Fin slot width	0.125 in		

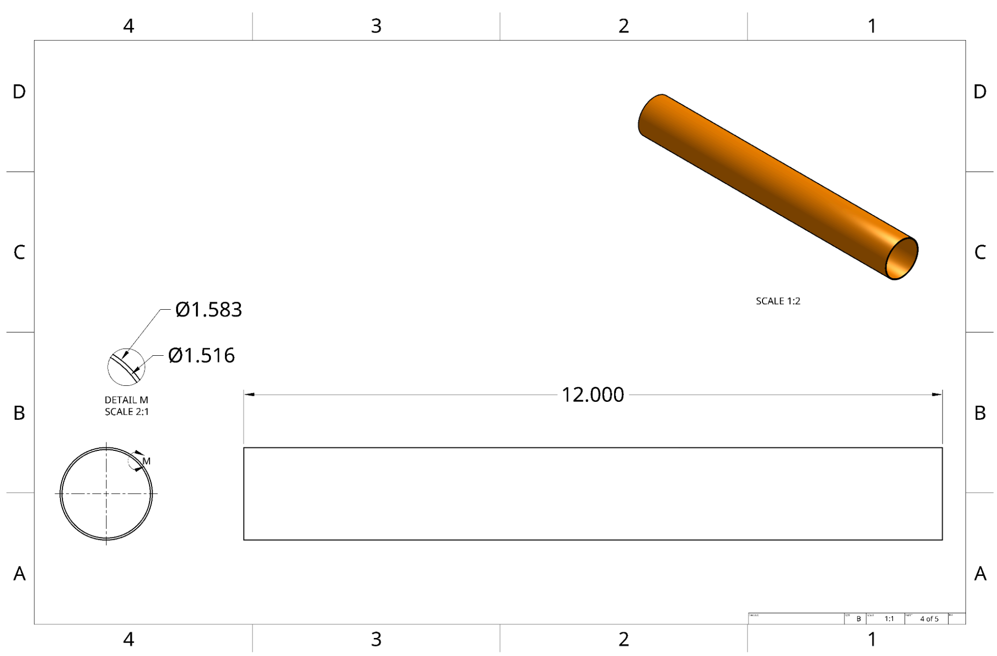


Fig. 78 - Motor mount tube

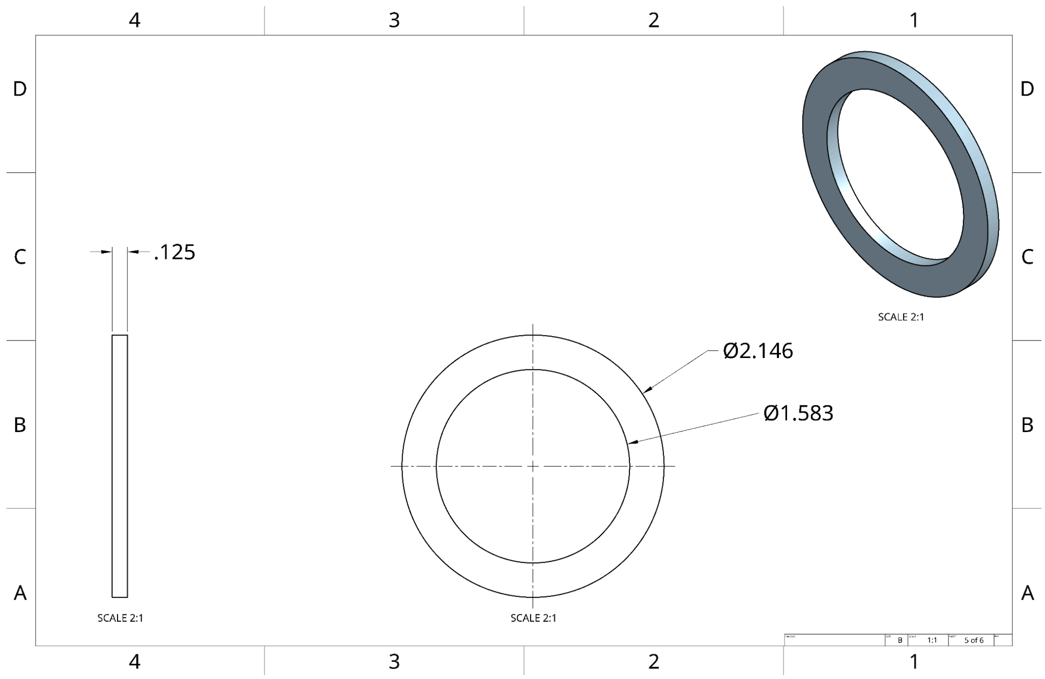


Fig. 79 - Forward centering ring

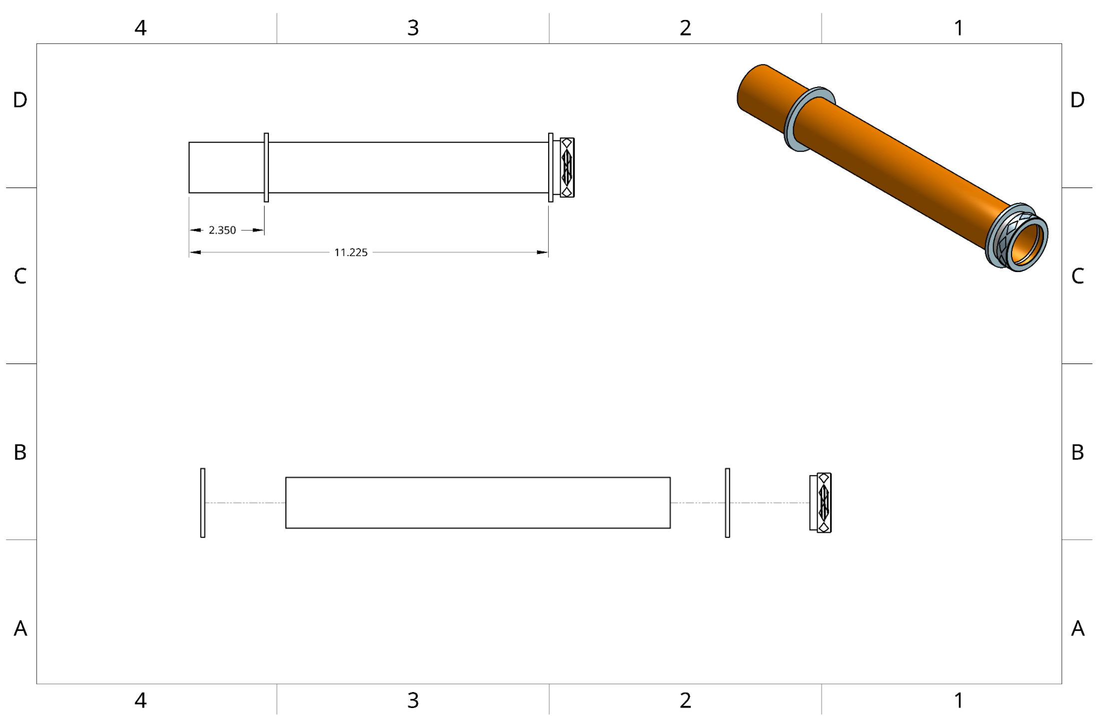


Fig. 80 - Motor mount assembly drawing

Table 64 - Motor Mount and Centering Ring Parameters

Parameter	Value
Motor mount material	FW fiberglass
Motor count length	12 in
Motor mount outer diameter	1.583 in
Motor mount inner diameter	1.516 in
Centering ring outer diameter	2.146 in
Centering ring iner diameter	1.583 in
Centering ring thickness	0.125 in

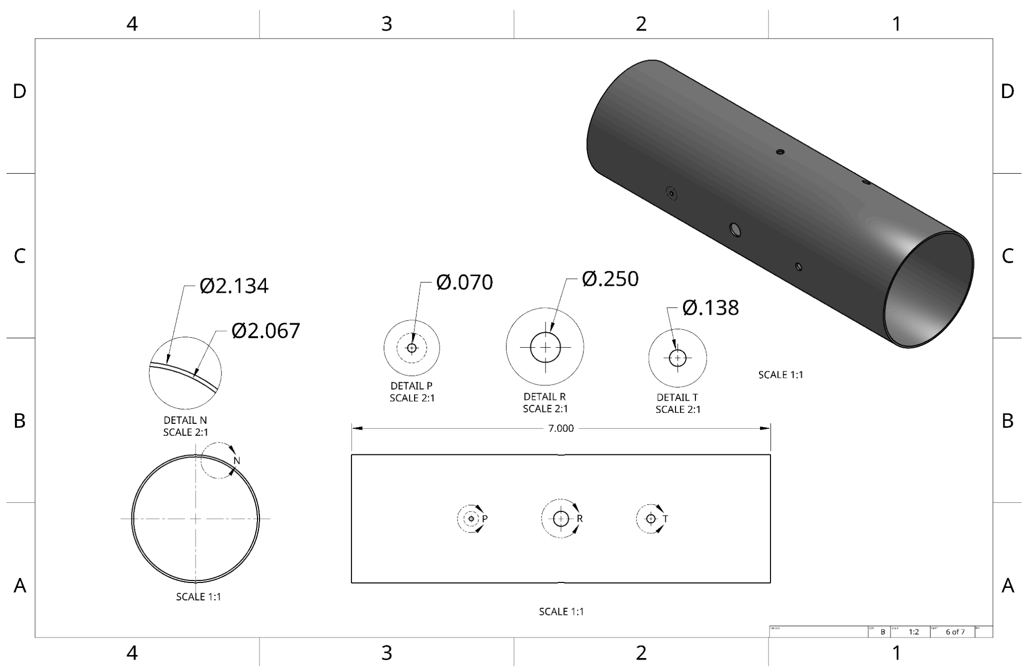


Fig. 81 - Subscale avionics coupler

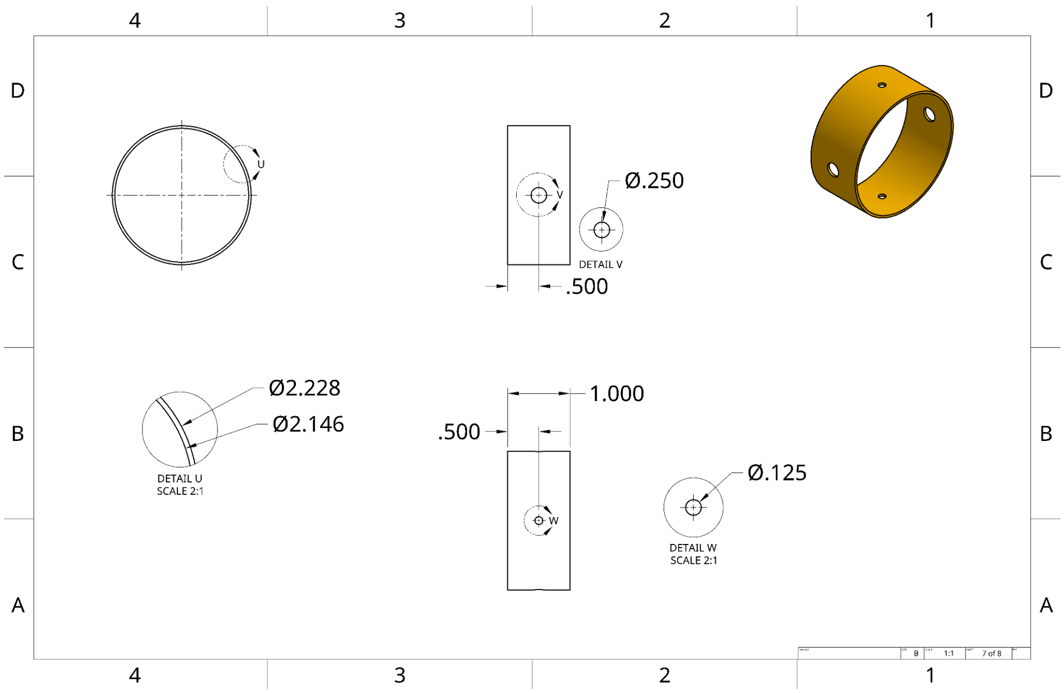


Fig. 82 - Coupler sleeve drawing

Table 65 - Subscale Coupler/Avionics Bay Parameters

Coupler			Switch band	
Parameter	**Value**		**Parameter**	**Value**
Material	FW fiberglass		Material	FW fiberglass
Length	7 in		Length	1 in
Outer diameter	2.134 in		Outer diameter	2.228 in
Inner diameter	2.146 in		Inner diameter	2.146 in

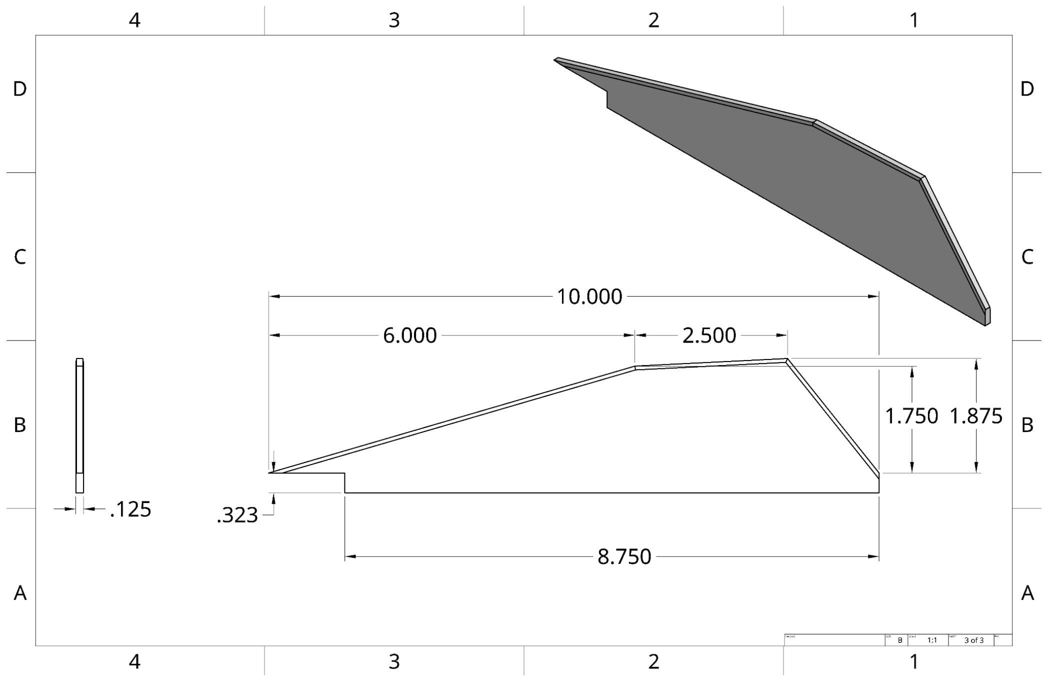


Fig. 83 - Subscale fin design

Table 66 - Fin Parameters

Parameter	Value
Material	G10 fiberglass
Length	10.255 in
Max height	2.125 in
Thickness	0.125 in
Bevel angle	11.25°
Bevel distance	0.45 in
Fin tab length	8.75 in
Fin tab width	0.323 in

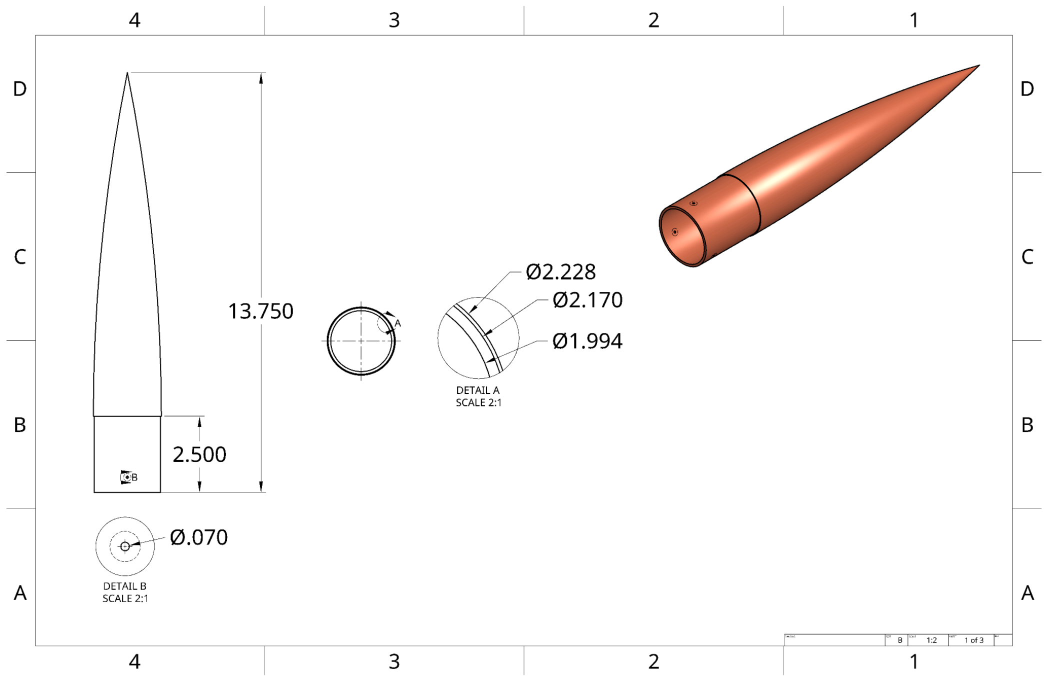


Fig. 84 - Nose cone drawing

Table 67 - Nose Cone Dimensions

Parameter	Size
Length	11.25 in
Outer diameter	2.228 in
Nose cone shoulder length	2.5 in
Nose cone shoulder outer diameter	2.17 in
Nose cone shoulder inner diameter	1.994 in

Appendix G - Budget

Table 68 - Total breakdown of budget

Balance summary	Budget (2024-2025)		Actuals	Variance
Income	**6,640.37**		**5,835.37**	**805.000**
Revenue (1000)	6,640.370		5,835.37	805.000
Sponsors (1100)	**1,510.00**		**1,510.00**	**0.00**
Administration: Microchip	1,000.00		1,000.00	0.00
Administration: Ganesh Moorthy	500.00		0.00	500.000
Administration: Andrew Brown	10.00		10.00	0.00
Administration: Lauren Carr	400.00		400.00	0.00
Administration: Evigia	600.00		600.00	0.00
Membership fees (1200)	**1235.00**		**930.00**	**305.00**
Administration: Income	1235.00		930.00	305.00
Fundraising (1300)	**0.00**		**0.00**	**0.00**
Administration: Income	0.00		0.00	0.00
Other (1400)	**2895.37**		**2895.37**	**01**
Administration: Previous surplus	1,369.91		1,369.91	0.00
Administration: NEF Grant	1,525.46		1,525.46	0.00
Expenses	**5,439.61**		**1,009.51**	**4,430.10**
Build (2000)	**1,335.21**		856.63	612.53
Rocket (2100)	**1,329.70**		**837.85**	**497.36**
Fullscale (2101)	1,119.11		634.28	484.83
Build: Booster	240.05		224.61	15.44
Build: Nose Assembly	87.44		76.50	10.94
Build: Avionics Bay	83.87		159.38	-75.51

Build: Experimental Payload	163.95		173.79	-9.84
Build: Payload	102.22		0.00	102.22
Build: Recovery	0.00		0.00	0.00
Build: Energetics	441.58		0.00	441.58
Subscale (2102)	216.10		203.58	12.53
Build: Booster	95.65		92.65	3.00
Build: Nose Assembly	63.50		53.98	9.53
Build: Avionics Bay	29.75		29.75	0.00
Build: Payload	27.20		27.20	0.00
Build: Recovery	0.00		0.00	0.00
Build: Energetics	0.00		0.00	0.00
Miscellaneous (2200)	**133.40**		**70.82**	**62.58**
Consumables (2201)	62.58		0.00	62.58
Build: Consumables	62.58		0.00	62.58
Personal Protection Equipment (2202)	70.82		70.82	0.00
Administration: PPE	70.82		70.82	0.00
Stem Engagement (3000)	0.00		0	0
Supplies (3001)	0.00		0	0.00
Outreach: Supplies	0.00		0	0.00
Management (4000)	3,971.00		100.84	3,870.16
Travel (4101)	2,641.00		0.00	2,641.00
Administration: Mentor Travel	841.00		0.00	841.00
Administration: Member Travel	1,800.00		0.00	1,800.00
Other (4201)	1,330.00		100.84	1,229.16
Administration: Shipping	200.00		100.84	99.16
Administration: Launch Fees	30.00		0.00	30.00

Administration: Contingency	1,100.00		0.00	1,100.00
Net difference (surplus or deficit)	**1,200.76**		**4,825.86**	**-3,625.10**

Appendix H - Role of Student Team Safety Officer

The safety officer is responsible for ensuring the safety of the team for the entire duration of the project. The role of safety officer has been appointed by the club, and the team members have direct contact through WhatsApp as well as group meetings. Responsibilities of the safety officer include:

1) Mitigation of potential hazards:
    a) Responsible for implementing protocols that help mitigate potential hazards.
    b) Maintaining the safety documentation for the team.
2) Attend every potentially hazardous step to ensure proper precautions are taken to mitigate risks. These responsibilities include:
    a) Making sure proper procedures are followed during build opportunities including all PPE equipment.
    b) Supervised launch vehicle and payload assembly and enforced proper procedures during all testing and launching days.
    c) Ground testing. NAR/TRA qualified mentors should be present for additional supervision and handling of all potentially explosive. flammable substances.
    d) Launch days
        i) Subscale launch testing: Ensure all safety measures are taken before/during/after launch and ensure all redundancy measures have been checked and are functional.
        ii) Full-scale launch testing: Ensure all safety measures are taken before/during/after launch and ensure all redundancy measures have been checked and are functional. Ensure the payload does not cause any structural strain on the rocket.
    e) Supervision of team on launch days
        i) Ensure the team follows all safety protocols for pre/post-launch
        ii) Ensure all redundancy equipment is operational
        iii) NAR/TRA certified mentor should be present and supervising the team in any step involving potential chemical/physical hazards
    f) Supervision of recovery activities
        i) Maintaining contact with the electronic recovery equipment in the rocket to track the trajectory and alert the team about any changes.
        ii) Enforce recovery safety protocols
        iii) Verify that all deployment charges are spent and electronics are disarmed before handling the rocket.
        iv) Supervise the disposal of spent propellant.
3) Hazard mitigation in STEM engagement
    a) Adult supervision while helping educate students.
    b) All members need to be accounted for at all times

Appendix I - Abbreviations of Team Derived Requirements

Table 69 - Abbreviations for Verification Number

Airframe			System	
Abbreviation	Meaning		Abbreviation	Meaning
SS	Launch Vehicle		A	Airframe
FS	Recovery		R	Recovery
			P	Payload
			S	Full System

Table 70 - Abbreviations for Derived Requirements

System			Subsystem	
Abbreviation	Meaning		Abbreviation	Meaning
LV	Launch Vehicle		C	Component
R	Recovery		M	Motor
P	Payload		A	Assembly
			T	Test
			F	Flight
			D	Design