NC STATE UNIVERSITY

Tacho Lycos

2024 NASA Student Launch

Critical Design Review

High-Powered Rocketry Club at NC State University
1840 Entrepreneur Drive
Raleigh, NC 27606

January 8, 2024

Common Abbreviations and Nomenclature

AGL = Above Ground Level
AIAA = American Institute of Aeronautics and Astronautics
APCP = Ammonium Perchlorate Composite Propellant
ASME = American Society of Mechanical Engineers
AV = Avionics
BEMT = Blade Element Momentum Theory
BP = Black Powder
CDR = Critical Design Review
CG = Center of Gravity
CP = Center of Pressure
ECD = Electronics, Communication, & Data
EIT = Electronics and Information Technology
FAA = Federal Aviation Administration
FEA = Finite Element Analysis
FMEA = Failure Modes and Effects Analysis
FN = Foreign National
FRR = Flight Readiness Review
HEO = Human Exploration and Operations
HPR = High-Power Rocketry
HPRC = High-Powered Rocketry Club
L3CC = Level 3 Certification Committee (NAR)
LCO = Launch Control Officer
LRR = Launch Readiness Review
MAE = Mechanical & Aerospace Engineering
MSDS = Material Safety Data Sheets
MSFC = Marshall Space Flight Center
NAR = National Association of Rocketry
NCSU = North Carolina State University
NFPA = National Fire Protection Association
PDR = Preliminary Design Review
PLAR = Post-Launch Assessment Review
PPE = Personal Protective Equipment
RF = Radio Frequency
RFP = Request for Proposal
RFS = Removable Fin System
RSO = Range Safety Officer
SAIL = STEMnauts Atmosphere Independent Lander
SL = Student Launch
SLS = Space Launch System
SME = Subject Matter Expert
SOW = Statement of Work
STEM = Science, Technology, Engineering, and Mathematics
TAP = Technical Advisory Panel (TRA)
TRA = Tripoli Rocketry Association
VTOL = Vertical Take-Off and Landing

Contents

List of Tables

List of Figures

1 Summary of CDR Report

1.1 Team Summary

1.1.1 Team Name and Mailing Address

Name: High-Powered Rocketry Club at NC State, Tacho Lycos

Mailing Address: 1840 Entrepreneur Drive, Raleigh, NC 27606

Primary Contact: Hanna McDaniel, hgmcdani@ncsu.edu, (336)553-7882

1.1.2 Mentor Information

Name	Email	Phone	TRA Certification	Flyer #
Alan Whitmore	acwhit@nc.rr.com	(919)929-5552	Level 3	05945
Jim Livingston	livingston@ec.rr.com	(910)612-5858	Level 3	02204

1.1.3 Launch Week Plans

30 club members will travel to Huntsville, AL to participate in launch week events starting on April 10th, 2024.

1.1.4 Time Spent on CDR Milestone

The team spent approximately 510 hours on the CDR milestone.

1.2 Launch Vehicle Summary

1.2.1 Target Altitude

The official target altitude is 4050 ft. above ground level.

1.2.2 Final Motor Choice

The launch vehicle will utilize an AeroTech L1940X-PS motor for propulsion to the target apogee.

1.2.3 Size and Mass of Launch Vehicle

The launch vehicle's designed dimensions include a maximum airframe diameter of 6.17 in., a total length of 105 in., and an estimated wet mass of 49.59 lb. Additionally, the dry mass of the launch vehicle without ballast is 37.89 lb. and 3.2 lb. of ballast yields a total dry mass of 41.09 lb. Furthermore, the launch vehicle includes a nose cone, a main parachute/payload bay, an avionics bay, and a drogue parachute bay/fin can. The effective lengths of each are 24 in., 39 in., 2 in., and 37 in., respectively. Having the swept fins contributes roughly 3 in. of additional length to the launch vehicle. Fully loaded, the sections weigh approximately 5.39 lb., 18.89 lb., 3.91 lb., and 21.41 lb., respectively. Finally, the burnout mass of the launch vehicle is 45.57 lb. and the landing mass of the nose cone deployment bay is 8.21 lb. while the remainder of the launch vehicle is 29.49 lb.

1.2.4 Recovery System

The final recovery system design uses an RRC3 altimeter and an Eggtimer Quasar (an altimeter and tracking device) in the avionics bay and a Big Red Bee 900 tracker in the nose cone. The drogue parachute is a Fruity Chutes 15" Classic Elliptical, the main parachute is a Fruity Chutes 96" Iris Ultra Compact, and the nose cone parachute is a Fruity Chutes 48" Classic Elliptical. At 800 ft., the main parachute will be deployed, allowing the nose cone and payload to completely separate from the rest of the launch vehicle and to stabilize before payload deployment.

1.2.5 Rail Size

The launch vehicle will require a standard 1515 launch rail that is at least 12 ft. in length.

1.3 Payload Summary

The purpose of this year's payload is to safely recover four STEMnauts in a lander without the use of parachutes or streamers. The STEMnaut Atmosphere Independent Lander, or SAIL, will consist of a contra-rotating propeller system to decrease descent velocity after releasing from the rest of the launch vehicle.

2 Changes Made Since PDR

2.1 Changes Made to Vehicle Criteria

Table 2.1: Changes Made to Vehicle Criteria

Change Description	Justification	Affected Subsystem(s)
Motor selection changed from AeroTech L1520T to AeroTech L1940X.	An increase in overall launch vehicle weight prompts need for increased thrust to satisfy NASA Requirement 2.15.	Aerodynamics
Drogue parachute changed from Fruity Chutes 18 in. Classic Elliptical to Fruity Chutes 15 in. Classic Elliptical.	This change was needed due to the change in mass of the launch vehicle and reduces expenses as the High Powered Rocketry Club already owns the 15 in. drogue parachute.	Recovery
Main parachute changed from Fruity Chutes 84 in. Iris Ultra Compact to Fruity Chutes 96 in. Iris Ultra Compact.	Due to the increase in launch vehicle weight since PDR, a larger parachute is needed to maintain a landing kinetic energy that meets the requirement of 75 ft-lbf.	Recovery

2.2 Changes Made to Payload Criteria

Table 2.2: Changes Made to Payload Criteria

Change Description	Justification	Affected Subsystem(s)
Payload deployment bay added.	Use of deployment bay ensures legs and rotor blades are not damaged by/do not cause damage to the inner surface of the airframe.	Payload Structures, Payload Systems, Recovery
Location of payload electronics changed.	Use of deployment bay concept requires release latch to be placed at the top of the deployment bay.	Payload Electronics, Payload Systems
Blade number reduced from 8 to 4.	After CFD analysis it was determined that 4 blades will generate enough thrust to slow the SAIL down. Additionally, reducing the blade count reduces the weight of the SAIL and the complexity of fabrication.	Payload Structures
Landing legs increased from 3 to 4.	Allows for easier folding/storage of the rotor blades. It also provides a more stable landing platform.	Payload Structures
Rotor blades will be printed using CF-PC instead of resin.	The rotor blade length was increased to meet performance requirements. However, the resin printer specified in PDR is unable to accommodate the new blade length.	Payload Structures
Flight computer changed from Raspberry Pi 4B to Adafruit Feather	The Adafruit Feather requires less power and is a much smaller form factor while providing the same capabilities.	Payload Electronics

2.3 Changes Made to Project Plan

Table 2.3: Changes Made to Project Plan

Change Description	Justification	Affected Subsystem(s)
Part ordering was delayed to Week 20 (See Figure 6.3).	Access to Space Grant funding was delayed.	Project Management
Full-scale and payload demonstration flight(s) added to schedule for February 24th/25th and March 23rd/24th (See Figure 6.3).	Required per NASA SL Requirement 2.19.	Project Management

3 Vehicle Criteria

3.1 Vehicle Mission Statement and Success Criteria

The mission of the launch vehicle is to safely house all payload structures, electronics, and occupants as it ascends to a declared apogee of 4050 ft. Once achieved, the launch vehicle must then follow a pre-defined recovery timeline in which each section descends under a parachute that provides an appropriate kinetic energy for the vehicle at touchdown. During this recovery timeline, the launch vehicle must also successfully release the payload after approval is given by the range safety officer.

The launch vehicle will be designed to be reusable, reliable, and safe while aligning with all NASA and team-derived vehicle requirements viewed in Section 6.3.1. If the launch vehicle accomplishes the above mission statement, it will be declared successful. Some further guidelines for vehicle success criteria are included in Table 3.1 below.

Table 3.1: Success Criteria for Launch Vehicle

Success Level	Vehicle Criteria
Success	Nominal takeoff and ascent; Reaches within $\pm$ 250 ft. of declared apogee; Follows recovery timeline; Payload ejected without damage; Recovered without any damage; Can be relaunched the same day
Partial Success	Nominal takeoff and ascent; Reaches within $\pm$ 500 ft. of declared apogee; Some minor damage upon landing that can be repaired at the field; Payload tangled during ejection but retains all functions
Partial Failure	Nominal takeoff and ascent; Reaches within $\pm$ 750 ft. of declared apogee; Damage upon landing that would prevent another launch within the same day; Payload damaged upon ejection
Failure	Catastrophe at takeoff; Nominal takeoff and ascent, but fails to get over 3000 ft. or manages to exceed 6000 ft.; Irreparable damage upon landing; Payload destroyed upon ejection

3.2 Design and Verification of Launch Vehicle

3.2.1 Launch Vehicle Design Overview

The final design of the launch vehicle is shown below in Figures 3.1 and 3.2. With this design, the launch vehicle has a maximum length of approximately 105.43 in and a maximum diameter of 6.17 in. It currently weighs 49.37 lb fully loaded and 45.35 lb after motor burnout. There are two separation points and one non-separation point. Sections that contain a separation point are held together with 4/40 nylon shear pins and non-separating sections are held together with nylon push clip rivets. The first separation point is located between the nose cone and the main parachute/payload bay while the second separation point is between the drogue parachute bay/fin can and the AV bay. Hence, the one non-separation point is located between the main parachute/payload bay and the AV bay. In Figure 3.3, the location of each separation point is shown in a CAD model of the launch vehicle. Using this configuration, the launch vehicle will separate into three sections during descent, satisfying NASA Requirement 2.4. Additionally, two 1515 Delrin rail buttons will be fixed to the drogue parachute bay/fin can to allow the launch vehicle to be launched from a standard 1515 launch rail.

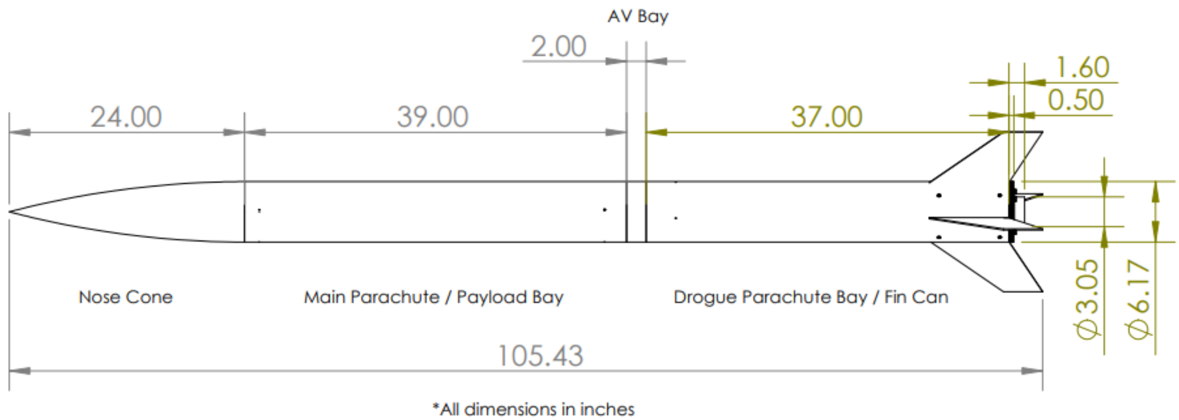

Figure 3.1: Dimensions of the final launch vehicle design.

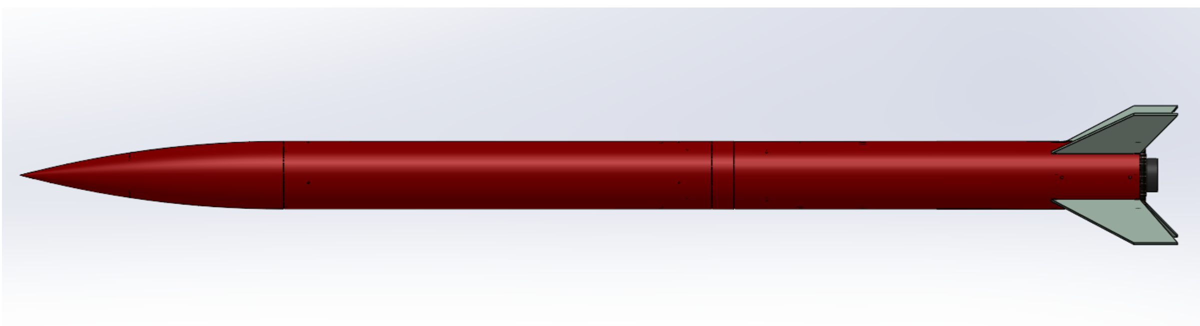

Figure 3.2: CAD model of final launch vehicle design.

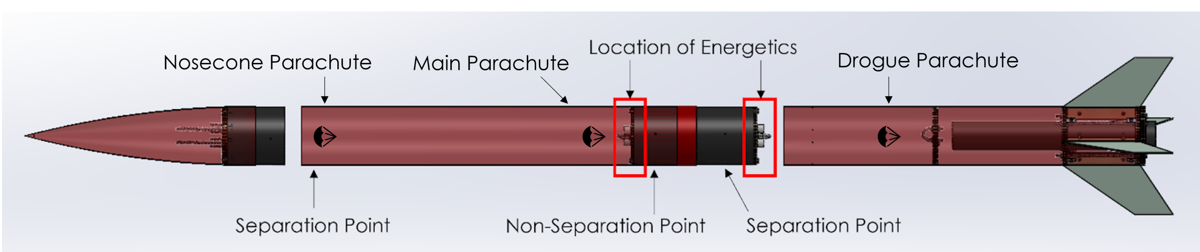

Figure 3.3: Final location of separation points and energetics for the launch vehicle.

3.2.2 Material Selection

Airframe Material

The airframe and coupler sections will be made from G12 fiberglass tubes. These filament wound tubes are made from fiberglass roving and epoxy with multiple layers and wind angles. This material is widely used in high-powered rocketry due to its high resistance to abrasion, cracking, shattering, delamination, etc. It is also water-resistant, which is important because the club's home launch field contains multiple irrigation ditches that the launch vehicle could land in. Furthermore, G12 fiberglass tubes are manufactured for use in high-powered rocketry by a large variety of suppliers.

Fin Material

The fins will be cut out of a 1/8 in. thick sheet of G10 fiberglass. G10 fiberglass is a similar material to G12 fiberglass in terms of strength but is readily produced in sheets instead of tubes. This material is commonly used for fins in high-powered rocketry in both supersonic and altitude endurance flights. Furthermore, cutting the fins out of a ready-made composite allows for the benefit of composite strength without the complexity, time, expense, and human errors involved in producing composites in-house.

Bulkhead Material

The bulkheads will be made out of 1/8 in. plies of aircraft-grade birch plywood. For each bulkhead, four of these plies will be epoxied together to achieve a 1/2 in. thickness and left to cure for 24 hours. Further details of bulkhead fabrication are laid out in Section 3.4.3. This method is used because the laser cutter available to the team can only cut through materials less than or equal to 1/4 in. Additionally, the thinner plies are cheaper and easier to obtain from suppliers.

3.2.3 Nose Cone

A 4:1 tangent ogive nose cone, made from G12 fiberglass with an anodized aluminum tip, will be used for the launch vehicle. This nose cone was selected because it offers sufficient aerodynamic performance and a lower weight than the 5:1 tangent ogive. Furthermore, these nose cones are widely available through a variety of suppliers. These suppliers also have a pre-installed 9-in. coupler section that extends 3 in. into the nose cone, leaving 6 in. of exposed coupler aft of the nose cone. This exposed coupler section will be cut down to 3 in. to reduce weight while satisfying NASA Requirement 2.4.3. Dimensions of the nose cone are shown below in Figure 3.4.

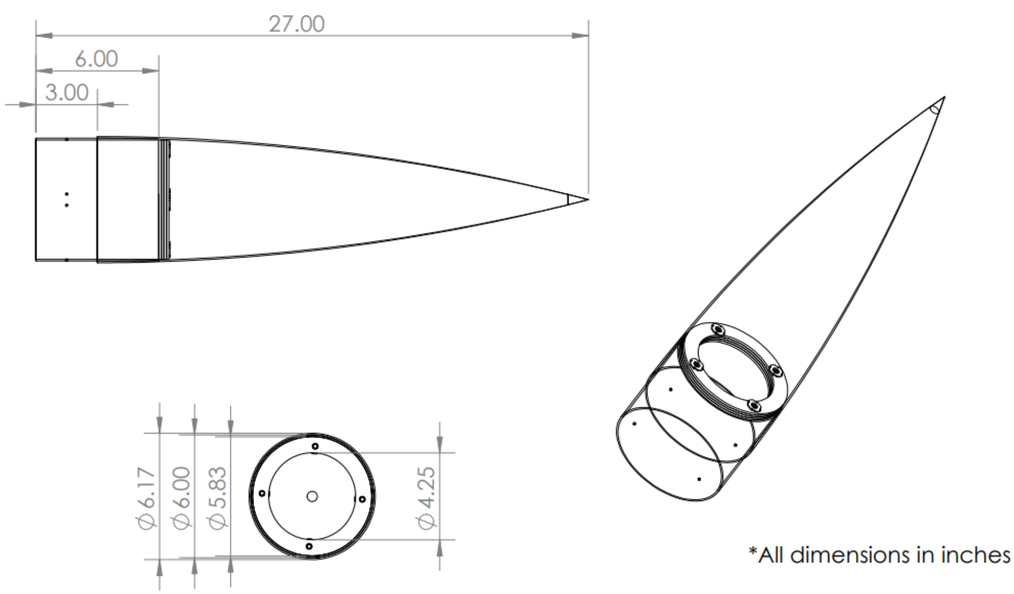

Figure 3.4: Dimensions of the launch vehicle's nose cone.

Inside the nose cone there will be a removable bulkhead and a permanent centering ring onto which the removable bulkhead will be mounted. This design was chosen to allow an electronics sled to be mounted inside the nose cone for tracking purposes. A CAD model of the nose cone with its permanent centering ring and removable bulkhead is shown below in Figure 3.5.

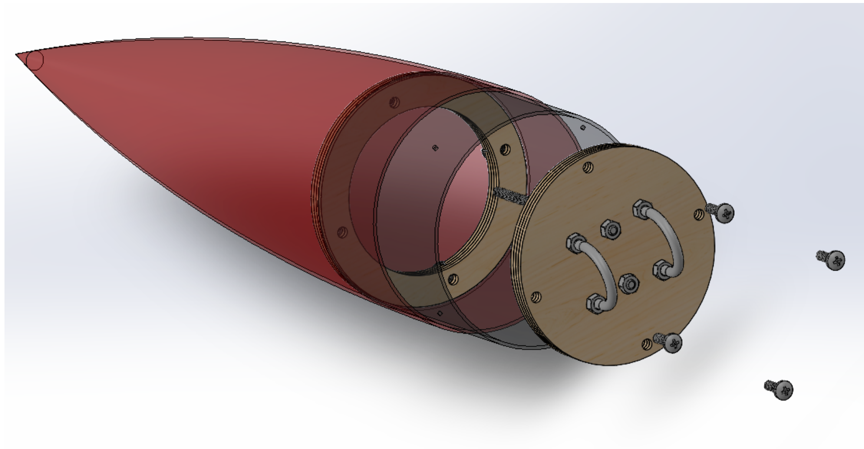

Figure 3.5: Nose cone with removable bulkhead and permanent centering ring.

The permanent centering ring will be made from four plies of 1/8 in. thick aircraft-grade birch plywood that are epoxied together. Four 1/4 in.-20 x 5/16 in. T-nuts will be added to this centering ring, allowing the removable bulkhead to be attached with four #1/4 in.-20 x 1 in. round head bolts. Using epoxy, the centering ring is permanently placed into the nose cone at the forward end of the coupler. The removable bulkhead is constructed similarly to the permanent centering ring with the addition of more hardware. This hardware includes (2) 1/4 in.-20 x 1-1/2 in. stainless steel U-bolts for recovery and (2) 1/4 in.-20 x 4 in. stainless steel threaded rods to mount the electronics sled. These two threaded rods are secured in the middle of the bulkhead to maximize space for the electronics sled. The U-bolts will be placed on either side of the threaded rods. A CAD drawing of both the permanent centering ring and the removable bulkhead is shown below in Figure 3.6.

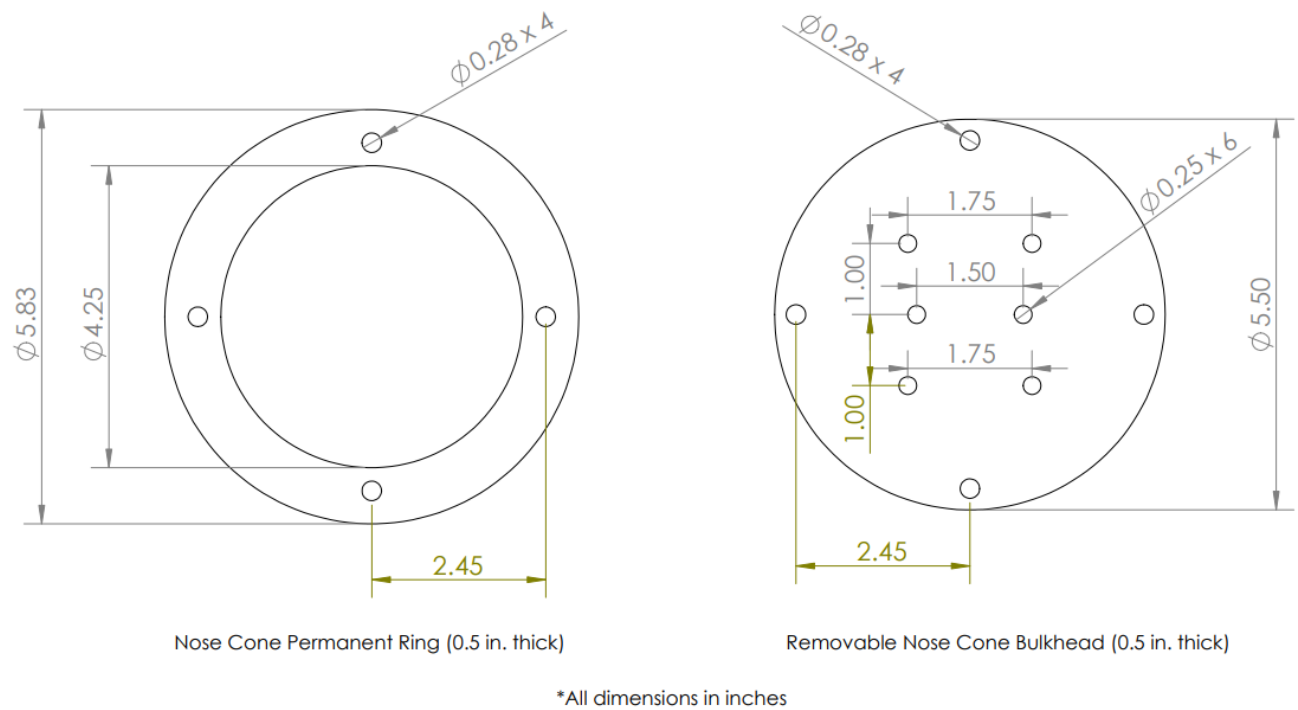

Figure 3.6: Dimensions of the nose cone centering ring and removable bulkhead.

As mentioned, the threaded rods in the middle of the removable nosecone bulkhead are used to hold an electronics sled for recovery purposes. A 1/4 in.-20 zinc-plated steel nut will be screwed onto each of the threaded rods forward and aft of the sled to hold it in place. A CAD model of this sled, along with more details of its components, is shown in Section 3.5.6.

3.2.4 Main and Payload Bay

The main parachute/payload bay, located below the nose cone and above the AV bay, is made from a 39 in. section of G12 fiberglass airframe. It is connected to the nose cone with 4/40 nylon shear pins and to the AV bay with nylon snap rivets. This bay will contain the nose cone parachute, the payload deployment bay, the main parachute, a deployment bag, a Nomex cloth, and Kevlar shock cords. A CAD model of the main parachute/payload bay is shown below in Figure 3.7 and dimensions of the bay are shown in Figure 3.8.

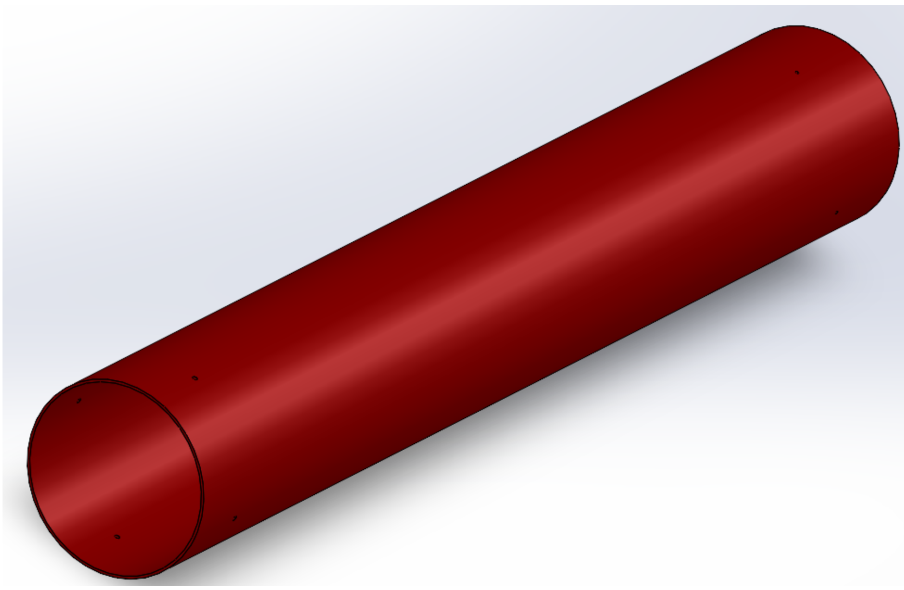

Figure 3.7: CAD model of the main parachute/payload bay.

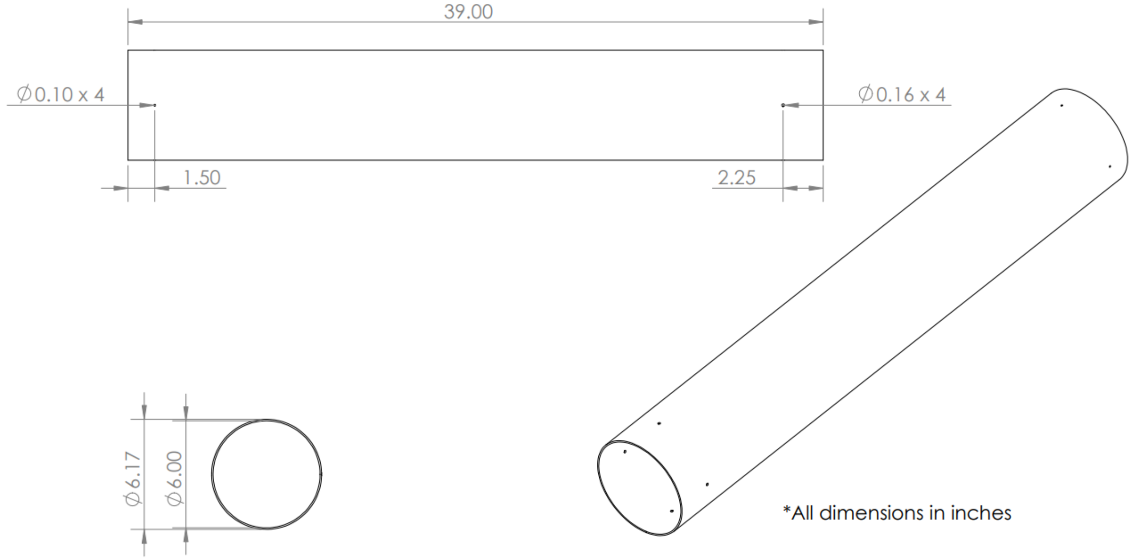

Figure 3.8: Dimensions of the main parachute/payload bay.

3.2.5 Avionics Bay

The AV bay is constructed from a 12.5 in. coupler section and a 2 in. airframe section, both made from G12 fiberglass. The 2 in. airframe section is permanently epoxied to the coupler section such that 4.5 in. of exposed coupler is left on the forward end of the AV bay and 6 in. of exposed coupler is left on the aft end of the AV bay. Such coupler lengths satisfy NASA vehicle Requirements 2.4.2 and 2.4.1, respectively. Secured with nylon push clip rivets, the forward coupler section of the AV bay sits in the aft end of the main parachute/payload bay. Additionally, the aft coupler section of the AV bay slides into the forward end of the drogue parachute bay/fin can and is secured with 4/40 nylon shear pins. Dimensions of the AV bay are viewed in Figure 3.9 below.

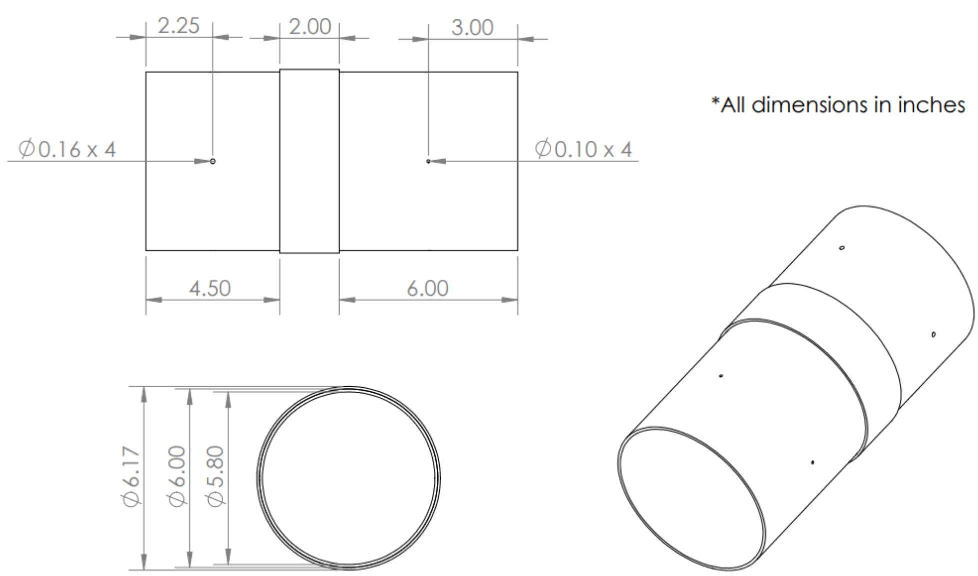

Figure 3.9: Dimensions of the AV bay.

Contained within the AV bay is an electronics sled, shown in Figure 3.51, onto which recovery electronics are mounted. This electronics sled slides onto two 1/4 in.-20 stainless steel threaded rods that extend through the AV bay and both AV bay bulkheads on either end. On the outside of each bulkhead, there will be two PVC blast caps, for primary and secondary black powder charges, and a 1/4 in.-20 x 1-1/2 in. stainless steel U-bolt to mount recovery hardware. Each blast cap will also have an associated terminal block mounted on the inside of the bulkhead to reduce the tension in the E-match wires. A CAD model of the AV bay with the attached bulkheads and threaded rods is shown below in Figure 3.10.

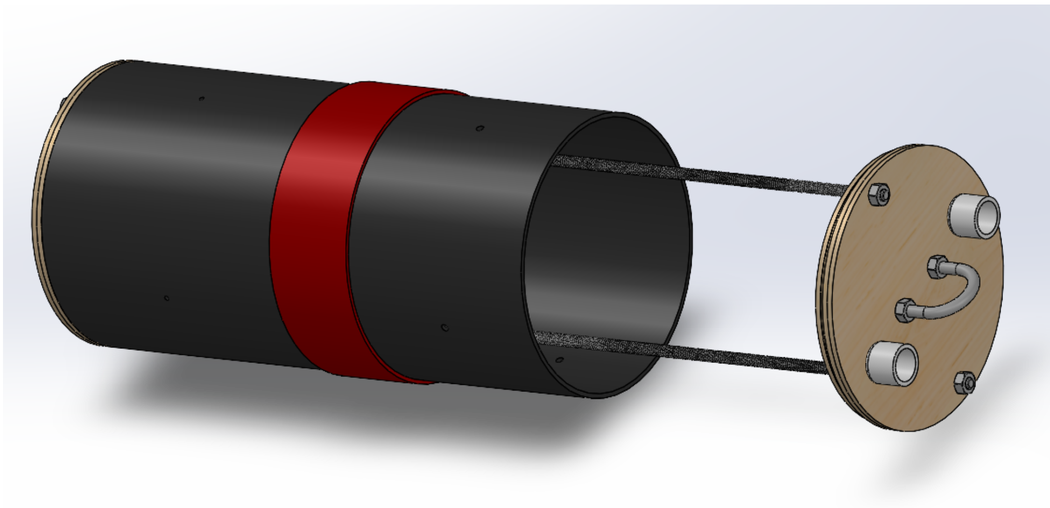

Figure 3.10: CAD model of the AV bay.

Each AV bay bulkhead will be made from four plies of aircraft-grade birch plywood that are epoxied together. The two outer plies will have the same outer diameter as the coupler section, while the remaining plies will have the same outer diameter as the inner diameter of the coupler section. This establishes a mechanical connection between the bulkheads and the AV bay in addition to the threaded rods. Once all the components are in place, a 1/4 in.-20 zinc-plated steel nut is threaded onto each end of the threaded rods and tightened until snug. A dimensioned CAD drawing of the AV bay bulkheads without hardware is shown below in Figure 3.11.

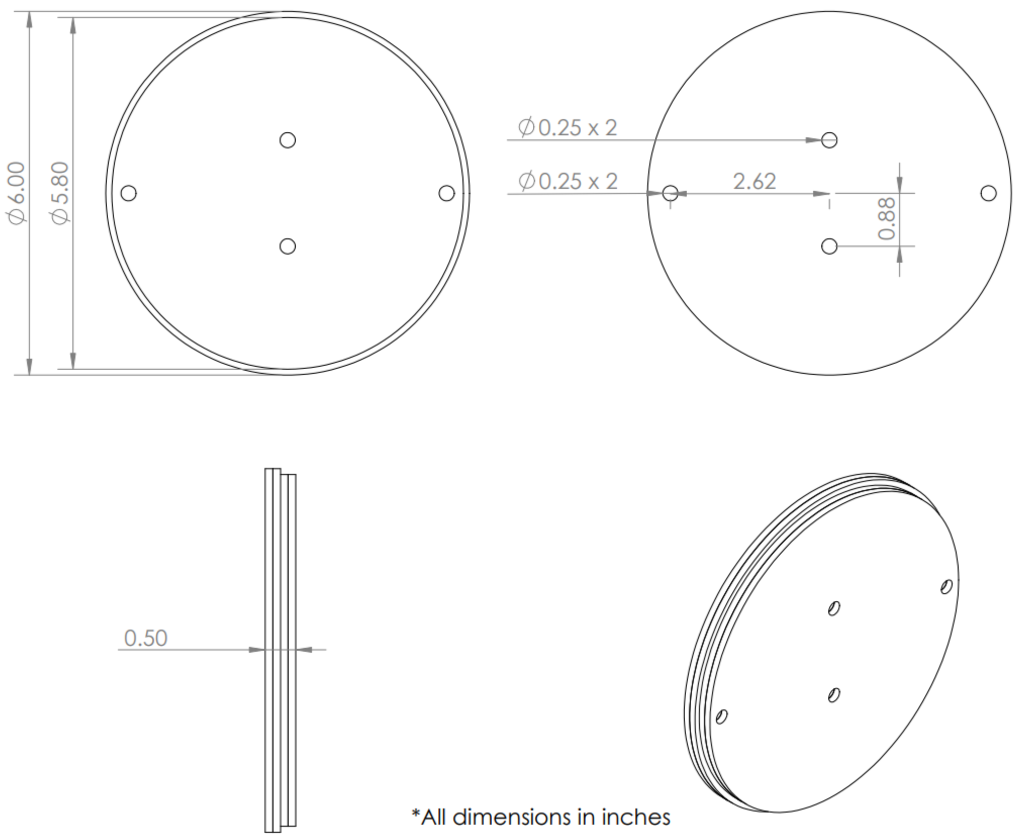

Figure 3.11: Dimensions of the AV bay bulkheads.

3.2.6 Drogue Bay and Fin Can

The drogue parachute bay/fin can is a 37 in. section of G12 fiberglass airframe which contains the drogue parachute, Nomex cloth, shock cord, fin can bulkhead, and the removable fin system. It is connected to the aft coupler section of the AV bay with 4/40 nylon shear pins. A dimensioned CAD drawing of the drogue parachute bay/fin can is shown below in Figure 3.12.

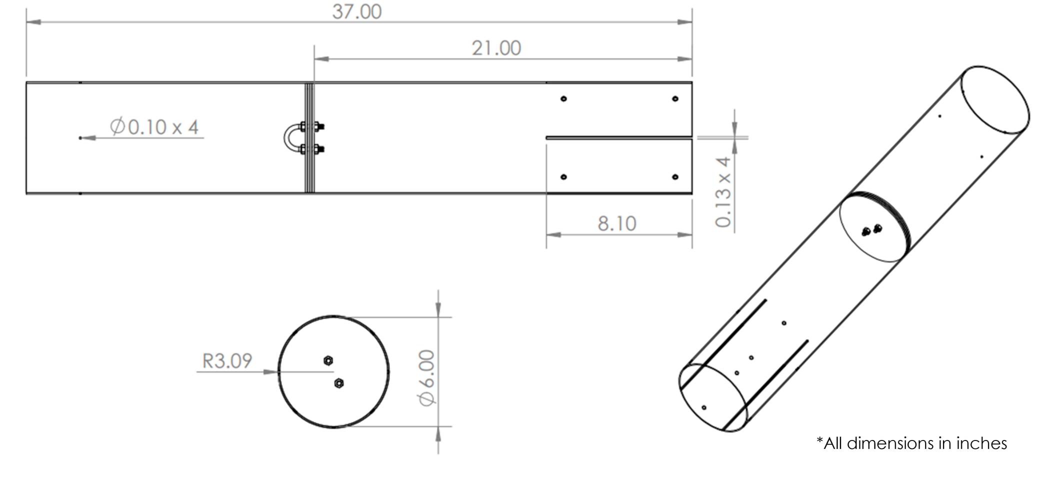

Figure 3.12: Dimensions of the drogue parachute bay/fin can.

The fin can bulkhead will be made from four plies of 1/8 in. aircraft-grade birch plywood that are epoxied together. It will contain one 1/4 in.-20 x 1-1/2 in. stainless steel U-bolt to mount recovery hardware. A CAD drawing containing the dimensions of the fin can bulkhead is shown below in Figure 3.13.

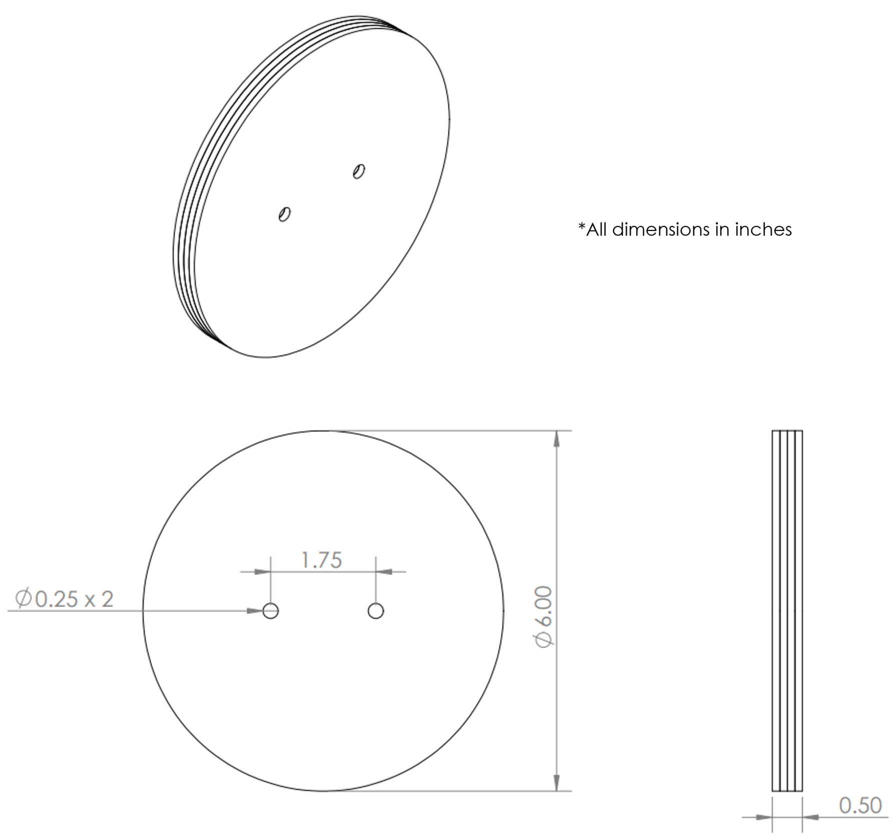

Figure 3.13: Dimensions of the fin can bulkhead.

The slots in the airframe, which can be seen in Figure 3.12, allow space for the fins attached to the removable fin system. Between each fin slot, there are two holes that will accept #8-32 zinc-plated steel machine screws which screw into the removable fin system's custom L-brackets to hold it in place. A CAD model of the drogue parachute bay/fin can with the removable fin system and motor installed is shown below in Figure 3.14.

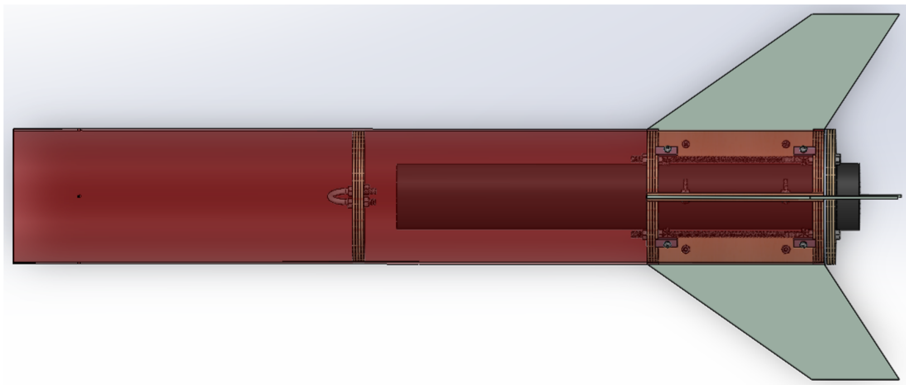

Figure 3.14: CAD model of the drogue parachute bay/fin can with removable fin system and motor installed.

3.2.7 Removable Fin System

The removable fin system design was chosen to improve the reusability of the launch vehicle. For instance, if a fin breaks from a test flight, the individual fin can easily be replaced with this design. However, if the fins were permanently epoxied into place, the entire drogue parachute bay/fin can would have to be replaced. Additionally, the removable fin system makes it easy to add any ballast to the aft end of the launch vehicle if needed for stability purposes. With a typical fixed-fin configuration, this area is normally inaccessible for ballast additions. Furthermore, the removable fin system enables inspection of all the centering rings and bulkheads in this section of airframe for any structural damage or loose hardware that needs to be addressed. Broadly, the removable fin system consists of two bulkheads, one thrust plate, one thrust bulkhead, and eight runners (two for each fin), all of which (with the exception of the thrust plate) are constructed from 1/8 in. plies of aircraft-grade birch plywood. The thrust plate is made from one 1/8 in. thick piece of 6061 aluminum alloy, which is a common material used for thrust plates in high-powered rocketry.

The two bulkheads that hold the runners in place are each made from four 1/8 in. plies of aircraft-birch plywood that are epoxied together. On each of these bulkheads, there are four custom stainless steel L-brackets which each have one #8-32 stainless steel nut welded over one of their holes. These custom L-brackets essentially hold the nut in place so that the screws attaching the removable fin system to the launch vehicle can easily be screwed in. Finally, the hole in the middle of the removable bulkheads is just wide enough to accept the motor casing for the selected motor. A CAD drawing that contains the dimensions of the removable fin system bulkheads is shown below in Figure 3.15.

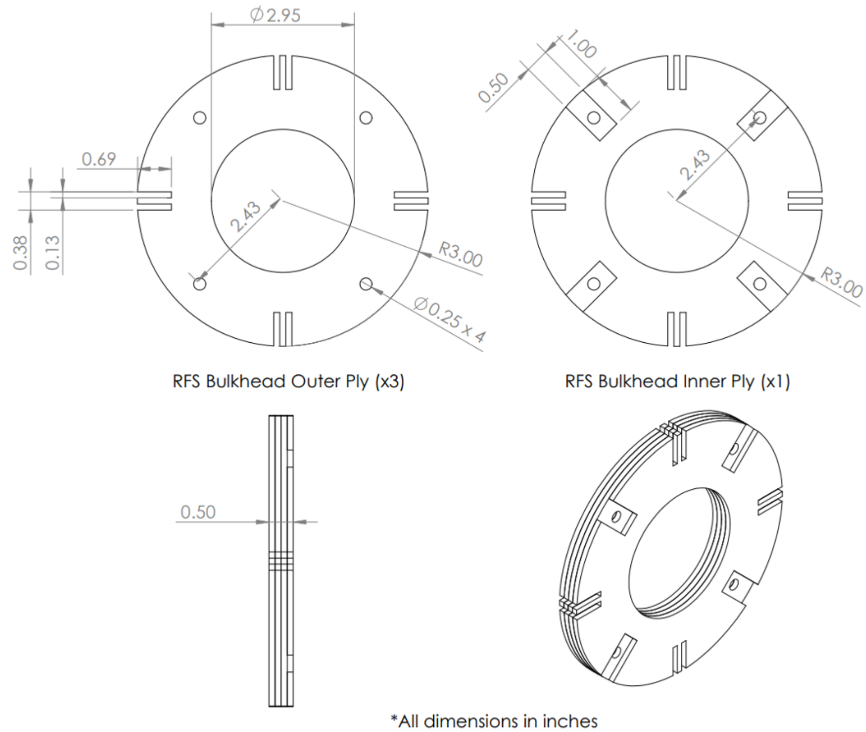

Figure 3.15: Dimensions of removable fin system bulkheads.

The two removable fin system bulkheads are held together with eight runners and four 1/4 in.-20 x 9-1/2 in. stainless steel threaded rods that extend through the entire assembly for structural rigidity. An added benefit of these threaded rods is that ballasts can be screwed onto them ensuring that they will not come loose during flight. The runners are epoxied into the slots in the removable fin system bulkheads leaving just enough space between them to accept the fin tabs. Both the runners and the fin tabs have two holes that will accept #8-32 zinc-plated steel round head machine screws and nuts to ensure that the fins will stay in place. A CAD drawing containing the dimensions of the runners and fins is shown below in Figure 3.16.

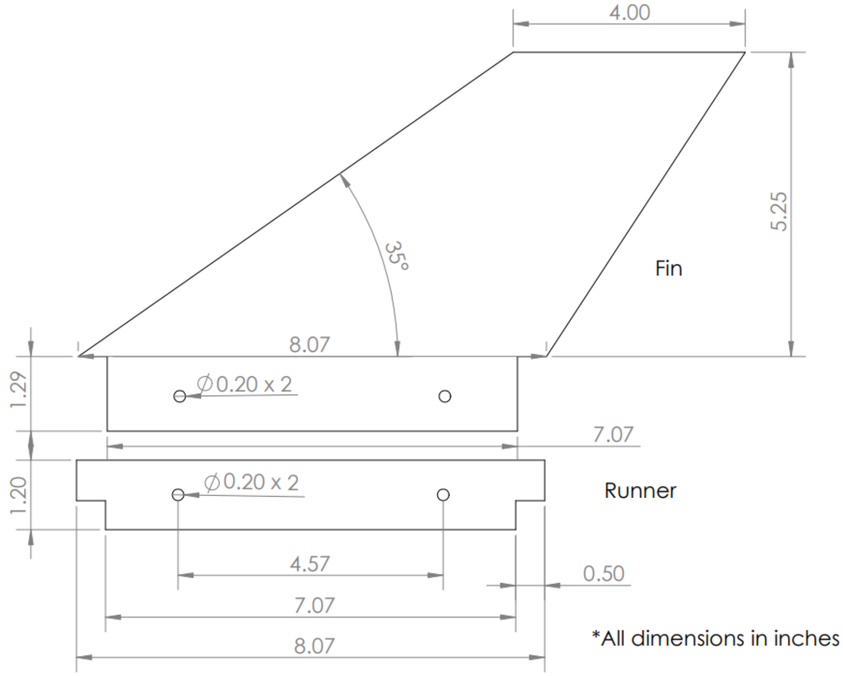

Figure 3.16: Dimensions of the runners and fins.

The aluminum thrust plate and the plies of the thrust bulkhead have the same dimensions. Both have the same outer diameter as the airframe to ensure the airframe takes most of the thrust from the motor instead of the removable fin system. Additionally, the thrust plate reduces stress concentrations on the fasteners and holes in the airframe that keep the removable fin system in place. Also, the thrust bulkhead will have a 2.95 in. (75 mm) motor retaining ring screwed in place with the included hardware for motor retention. Extending through the entire removable fin system, terminating after the thrust bulkhead, the four threaded rods are secured with 1/4 in.-20 zinc-plated steel nuts. Dimensions of the thrust plate and thrust bulkhead are shown in Figure 3.17 below.

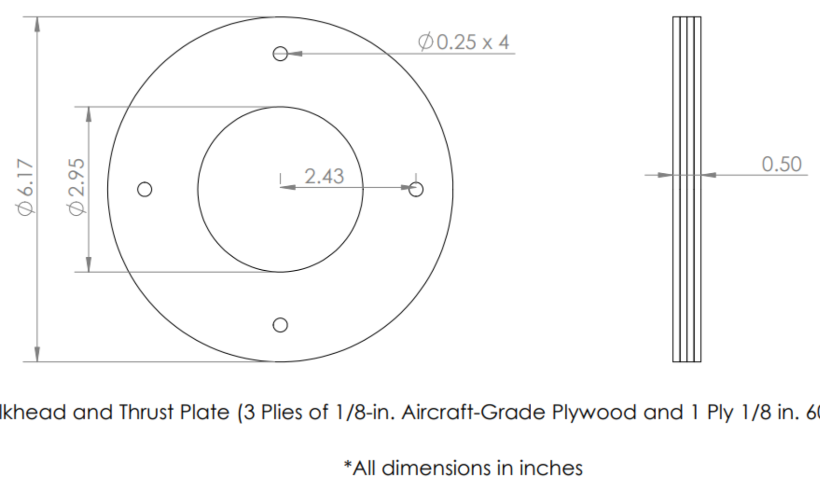

Figure 3.17: Dimensions of the thrust plate and thrust bulkhead.

In Figures 3.18 and 3.19 below are CAD models of the assembled and exploded removable fin system, respectively. Additionally, a dimensioned CAD drawing of the removable fin system assembly is shown below in Figure 3.20.

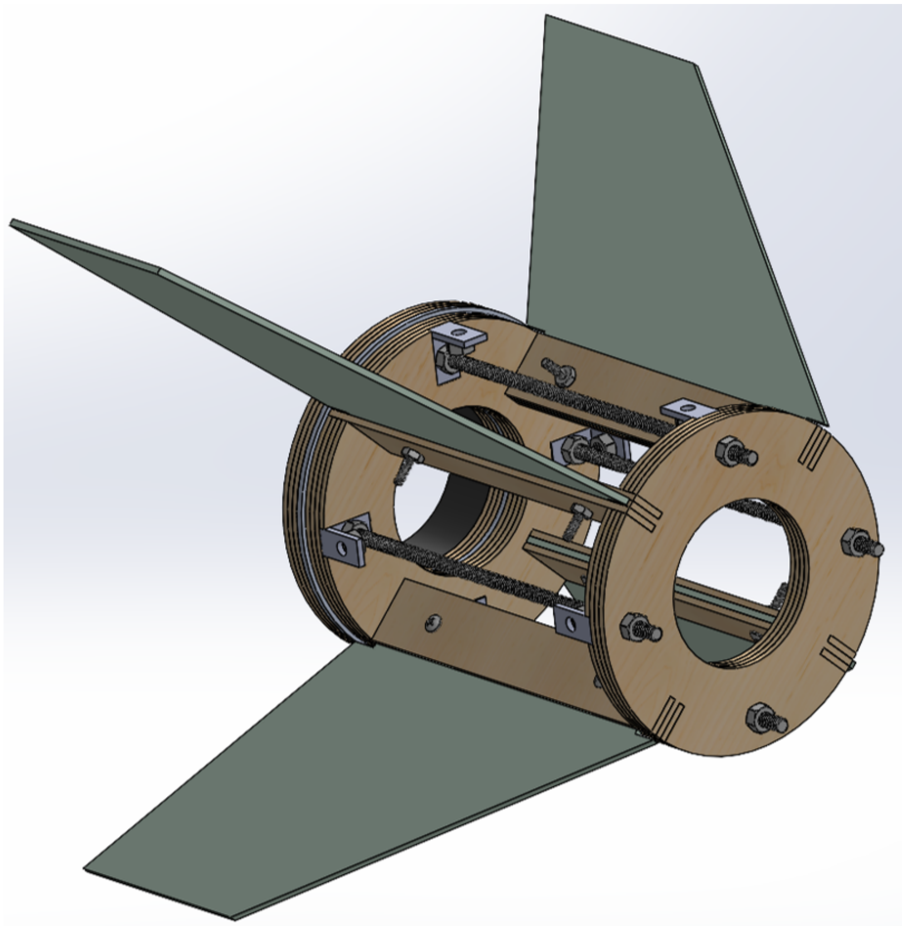

Figure 3.18: CAD model of the removable fin system.

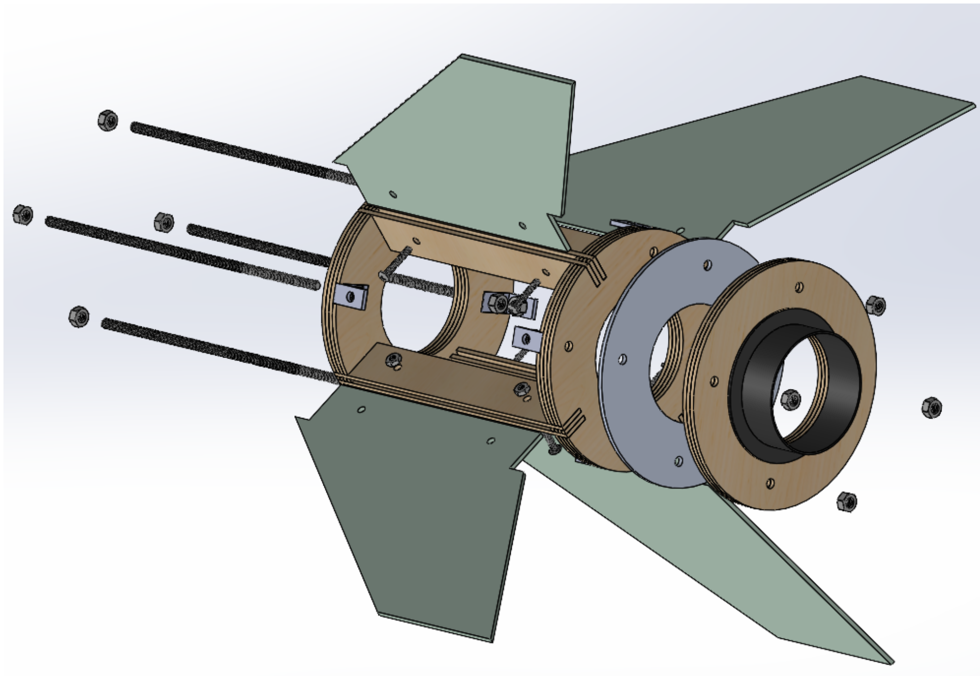

Figure 3.19: CAD model of an exploded view of the removable fin system.

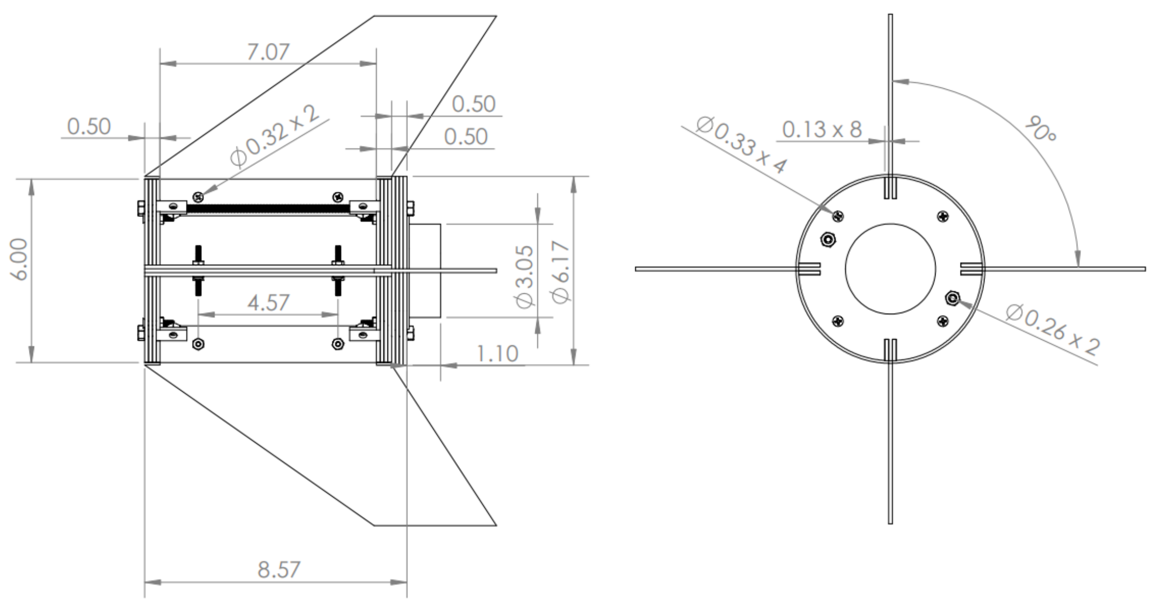

Figure 3.20: Dimensioned CAD drawing of the removable fin system.

3.2.8 Finite Element Analysis

Finite element analysis was performed on the load-bearing components of the launch vehicle using static structural testing in ANSYS Workbench. Such components include the nose cone bulkhead, AV bay bulkheads, fin can bulkhead, and the removable fin system. For this analysis, birch plywood and stainless steel were assigned to all the wooden components and metal components, respectively. The relevant properties of each (given by ANSYS) are presented in Tables 3.2 and 3.3 below. Performing this analysis verified the strength of the materials used and ensured the safety of the launch vehicle.

Table 3.2: Birch Plywood Properties

Property	Value
Density	0.0248 lb/in^3
Elastic Modulus	2.20 x 10^6 psi
Ultimate Tensile Strength	15,359 psi
Poisson's Ratio	0.37

Table 3.3: Stainless Steel Properties

Property	Value
Density	0.280 lb/in^3
Elastic Modulus	2.80 x 10^7 psi
Ultimate Tensile Strength	84,992 psi
Poisson's Ratio	0.31

Nose Cone Bulkhead FEA

The nose cone bulkhead has two U-bolts: one that must withstand the weight of the payload deployment bay and one that must withstand the shock force of the nose cone parachute. The payload deployment bay with its payload still attached weighs approximately 10.5 lb. and the shock force of the parachute is about 271.09 lb. Therefore, the total force on the bulkhead will be about 281.56 lb. (see Table 3.14). The shock force was applied to one U-bolt and the force from the payload deployment bay was placed on the other. To simulate the bulkhead inside the nose cone, fixed boundary conditions were placed on the outer edges of the permanent centering ring. The simulation results are shown below in Figure 3.21.

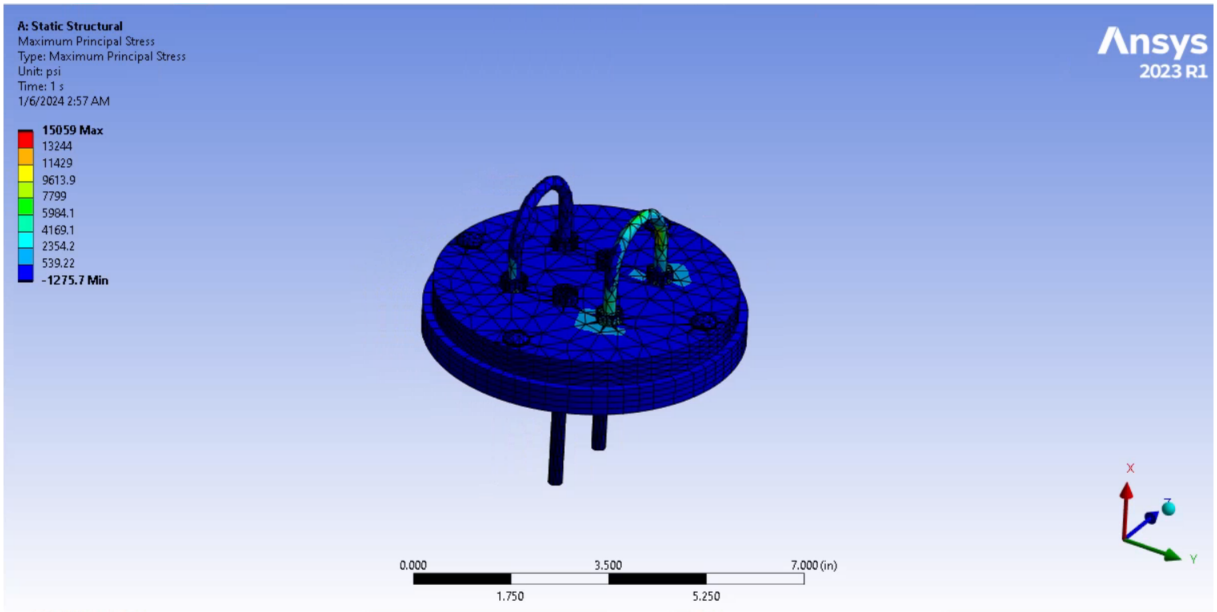

Figure 3.21: Nose cone bulkhead FEA simulation.

From the above simulation, it was found that the stress concentrations are located primarily around the U-bolt connection points. The maximum and minimum principal stresses occur on the U-bolt which experiences the shock force from the parachute. They are 15,059 and -1275.7 psi, respectively. Per Table 3.3, these stresses are well within the capabilities of stainless steel. The maximum principal stress on the removable bulkhead occurs around the U-bolt connection points and is roughly 4,169.1 psi. This yields a factor of safety of about 3.68.

AV Bay Bulkhead FEA

Each AV bay bulkhead has one U-bolt which must sustain a parachute shock force. The main parachute shock force is about 122.61 lb. (see Table 3.14). This shock force was applied to the U-bolt for the simulation. Fixed boundary conditions were placed on the ends of the threaded rods to simulate the AV bay bulkhead being pulled by them in its assembled configuration. The simulation results are shown below in Figure 3.22.

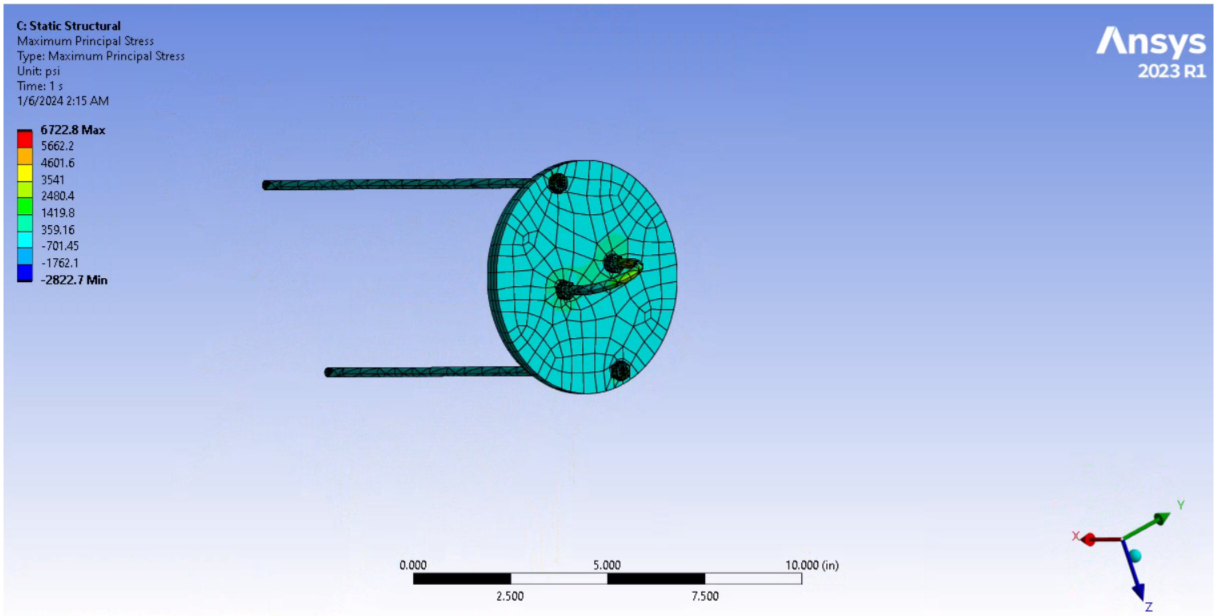

Figure 3.22: AV bay bulkhead FEA simulation.

From the above simulation, it is found that the maximum principal stresses occur on the U-bolt. Similarly, there are stress concentrations on the U-bolt attachment points. The maximum principal stress on the bulkhead is about 1419.8 psi, which yields a factor of safety of roughly 10.82.

Fin Can Bulkhead FEA

The fin can bulkhead is expected to withstand the shock force of the drogue parachute, which is about 176.09 lb. (see Table 3.14. This shock force was placed on the U-bolt in the simulation. To simulate the bulkhead being inside the fin can, fixed boundary conditions were applied to the outer edges of the bulkhead. The simulation results are shown below in Figure 3.23.

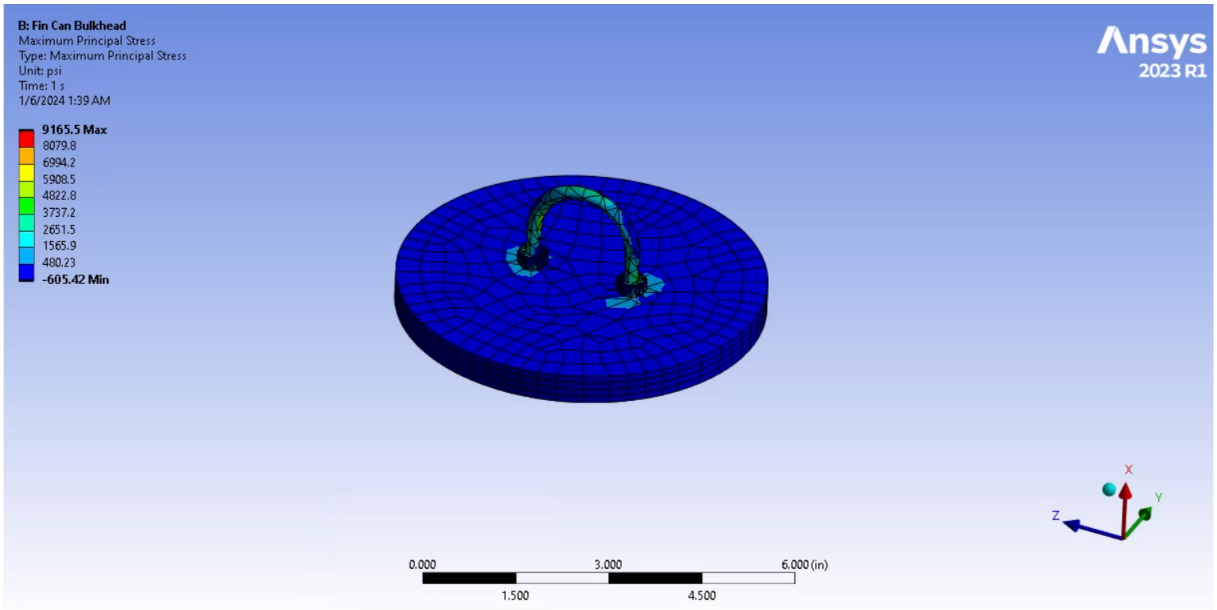

Figure 3.23: Fin can bulkhead FEA simulation.

Once again, the simulation reveals that the maximum and minimum principal stresses occur on the U-bolt. The maximum principal stress on the bulkhead occurs around the U-bolt connection points and is roughly 490.23 psi. Both the bulkhead and the U-bolt are well beyond capable of handling such stresses.

Removable Fin System FEA

Finally, the removable fin system must sustain the maximum thrust force of the motor. The maximum thrust force of the selected motor is about 521 lb. (see Table 3.6). This thrust force was applied to the flanged motor retainer in the simulation. A fixed boundary condition was applied to the face of the aluminum thrust plate since this is what pushes against the launch vehicle airframe. The simulation results are shown below in Figure 3.24.

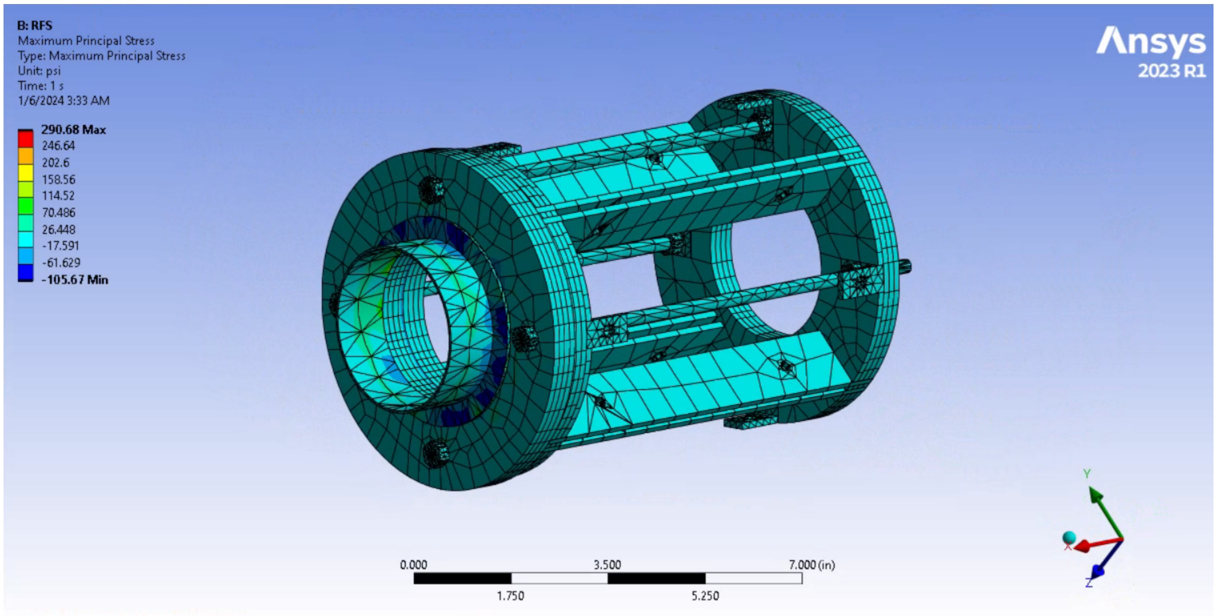

Figure 3.24: Removable fin system FEA simulation.

From the simulation, the maximum principal stresses occur on the motor retainer itself. The runners and the threaded rods do an excellent job of evenly distributing the stress throughout the rest of the assembly. The maximum stress found on any given component of the remainder of the assembly is roughly 26.448 psi. Therefore, there is no concern for the failure of this system or its components.

3.2.9 Fins

The launch vehicle will utilize four fins placed symmetrically across the X and Y axis of the airframe to maintain stability during flight. Due to the launch vehicle's symmetric profile and lack of a required external identifying geometry to denote the axis, the definition of the X and Y axes lies within the CAD model of the launch vehicle. This method was chosen as opposed to a tri-fin design to decrease the stresses associated with certain landing configurations while maintaining the stability required to fulfill NASA Vehicle Requirement 2.14. A depiction of the launch vehicle CAD axes has been provided.

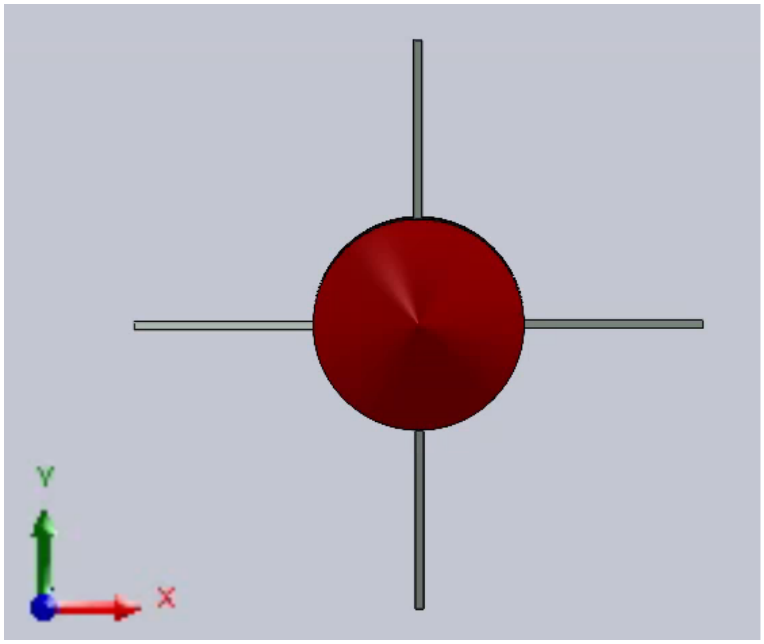

Figure 3.25: Launch Vehicle Coordinate System.

The fins will be swept aft to a measured angle of 55 degrees relative to the launch vehicle's XY Plane. This sweep will shift the center of pressure of the launch vehicle further aft increasing the stability margin of the launch vehicle without increasing the total area of the fin profile. CFD simulations conducted on the swept and symmetric fin profile yielded a 24.3% decrease in the drag force generated along the leading edge with a far smoother turbulence profile aft of the trailing edge of the fins. CFD results of the pressure distribution across the fin profile at the maximum launch vehicle velocity have been provided. Further discussion of the CFD results is provided in the PDR document [18]. Overall the fins will utilize an 8 in. root chord, a 4 in. tip chord, have a span of 5.25 inches, and a swept length from the leading edge of the root chord to the leading edge of the tip chord of 7.5 in. A fully dimensioned profile of the fins has been provided in Figure 3.16

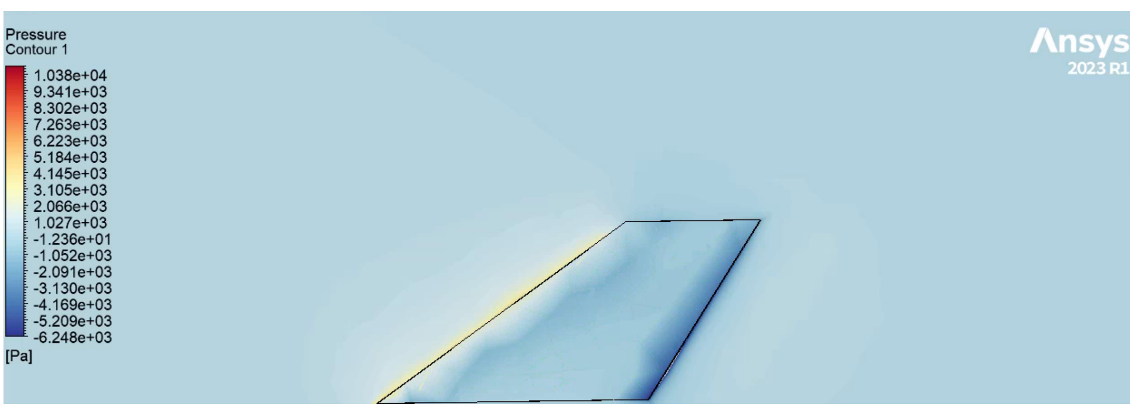

Figure 3.26: CFD derived swept fin pressure profile.

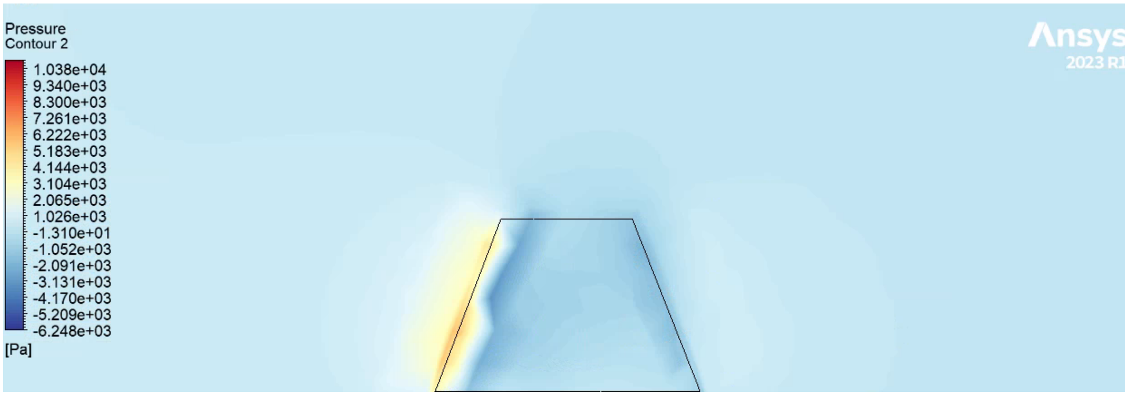

Figure 3.27: CFD derived symmetric fin pressure profile.

The fins will be manufactured from a single sheet of 0.125-in. G10 fiberglass for its superior strength and ability to resist the bending loads associated with flight. Additionally, the edges of the fins exposed to the airflow will be chamfered to reduce the total bluff frontal area. This will further reduce the drag profile of the fin and decrease the trailing edge flow separation by providing a transitional area for the flow to gradually reduce in pressure as the fluid void is filled aft of the fin.

3.2.10 Motor Mounting and Retention Methods

A 2.95 in. (75 mm) diameter AeroPack flanged motor retainer will be used for motor retention. It will be fixed to the thrust bulkhead with the included hardware. Once the motor casing is inserted through the thrust bulkhead and the two removable fin system bulkheads, the retaining ring can be screwed onto the retainer to keep the motor casing in place. An image of the flanged motor retainer and retaining ring is shown below in Figure 3.28.

Figure 3.28: AeroPack 75mm motor retainer and hardware [16]

3.2.11 Rail Button Placement

The rail button placement is essential for the mitigation of oscillatory motion as the launch vehicle leaves the launch rail. While the wind speed for the day of launch is unknown, the determination of the minimum attitude angle for various wind speeds will ensure that the launch vehicle remains with its velocity vector in the correct orientation. To optimize the rail button placement, RocketPy simulations were conducted using a loop iterator to vary the location of the upper and rail buttons across the airframe of the launch vehicle. The ”lateral-attitude-angle” method within RocketPy was then used to extract the direction of the velocity vector with respect to the Z axis of the launch vehicle. This method was then taken at maximum to determine the maximum angle that the launch vehicle pitches or yaws during ascent. This value is likely to occur just after liftoff when the control authority of the fins is minimized due to a limited launch vehicle velocity. This process was then repeated until a clear trend emerged.

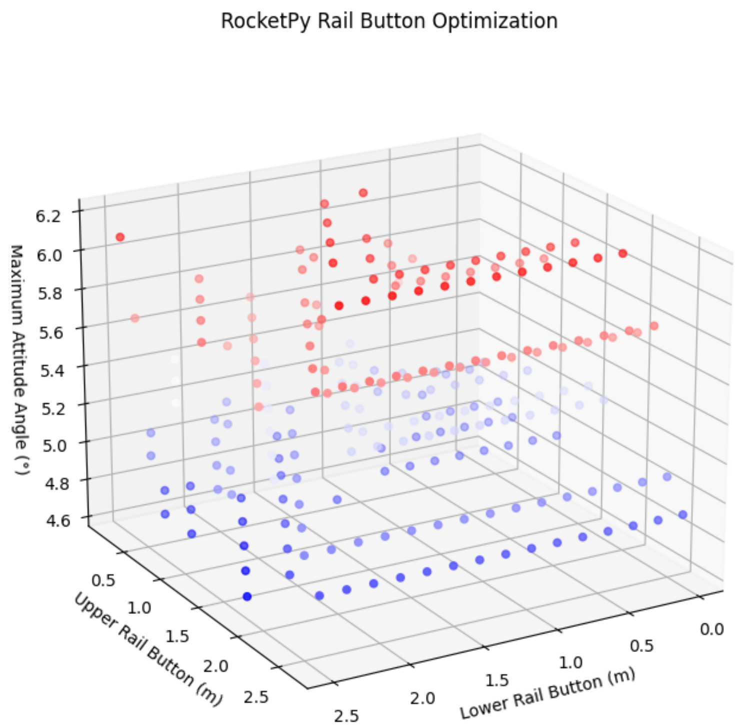

Figure 3.29: Rail button optimization at 20 mph constant wind speed.

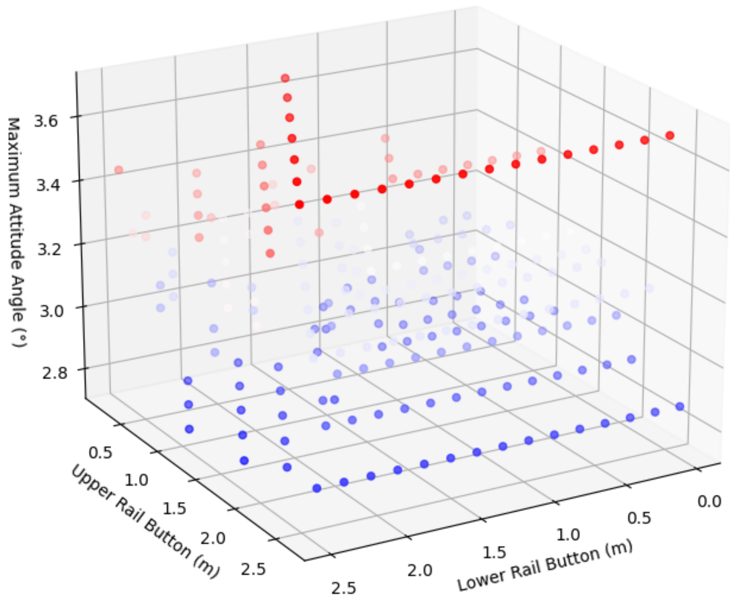

Figure 3.30: Rail button optimization at 10 mph constant wind speed.

From Figure 3.29 and 3.30, the optimal rail button placement to minimize material angle optimization occurs with the upper rail button placed approximately 1.5 meters from the nose of the launch vehicle, and the lower rail button placed at a maximum from the nose of the launch vehicle. Based on the data from section 3.6.4, the upper rail button's optimal placement appears to align with the center of gravity of the launch vehicle as the gravitational forces act through this point of the vehicle, requiring the most support during liftoff. The lower rail button remaining in contact with the rail for the longest duration ensures that the aft section of the vehicle remains parallel with the launch rail during liftoff.

3.2.12 Vehicle Mass Breakdown

Table 3.4: Launch Vehicle Weight Estimates

Section	Weight (lb)
Nose Cone	5.39
Main Parachute/Payload Bay	18.89
AV Bay	3.91
Drogue Parachute Bay/Fin Can	21.41
Total	49.59

Table 3.5: Launch Vehicle Section Weight Estimates

Nose Cone	
Component Name	Weight (lb)
Airframe and Coupler	3.81
Centering Ring	0.140
Removable Bulkhead	0.264
Electronics Sled	0.178
Shock Cord	0.259
U-Bolts	0.438
Misc. Hardware	0.301
Total	5.39
Main Parachute/Payload Bay	
Component Name	Weight (lb)
Airframe	4.94
Main Shock Cord	0.842
Main Parachute	1.01
Main Parachute Nomex	0.064
Payload Parachute	0.200
Payload Parachute Nomex	0.064
Deployment Bag	0.258
Quick Links	0.820
Deployment Bay/Mechanism	2.82
SAIL	7.88
Total	18.89
AV Bay	
Component Name	Weight (lb)
Airframe and Coupler	1.48
Bulkheads	0.617
Blast Caps	0.156
Electronics Sled	0.945
U-Bolts	0.438
Misc. Hardware	0.274
Total	3.91
Drogue Parachute Bay / Fin Can	
Component Name	Weight (lb)
Airframe	4.68
Fin Can Bulkhead	0.321
Fin Can U-Bolt	0.219
Thrust Bulkhead	0.195
Thrust Plate	0.279
Drogue Parachute	0.132
Drogue Parachute Nomex	0.035
Shock Cord	0.583
Quick Links	0.492
Fins	1.47
RFS Bulkheads and Runners	0.665
Ballast	3.2
Misc. Hardware	0.641
Loaded Motor	8.50
Total	21.41

3.2.13 Motor Selection

The AeroTech RMS-75/3840 reloadable motor casing has previously supported the team's full-scale launches for multiple competition cycles and its flight-proven reliability has justified its usage on this year's launch vehicle. Previously, the team selected the AeroTech L1520-T motor for the launch vehicle, but as the launch vehicle mass matured to CDR level, the total impulse requirement to reach the target apogee fell outside of the range of the L1520T. Therefore, a motor with a larger specific impulse that utilizes the AeroTech RMS-75/3840 was selected.

The AeroTech L1940X thrust profile is most desirable for the launch vehicle due to its trailing thrust magnitude and high thrust peak at the beginning of the launch vehicle's ascent. High thrust at the beginning of the launch vehicle ascent allows for the velocity of the launch vehicle to increase rapidly, providing high-velocity air to flow past the fins, increasing the stabilizing control authority of the fins early into the flight. Additionally, the trailing thrust profile decreases the total dynamic pressure on the launch vehicle due to the acceleration decreasing as the velocity reaches a maximum value. From the manufacture specifications, the X in the motor name denotes the use of high ISP propellants which are desirable for this increase in required motor performance. The larger motor also requires a greater density of propellant to produce the desired impulse. This increase in propellant density will shift the center of gravity of the launch vehicle further aft, preserving the stability margin induced by the larger payload mass since PDR.

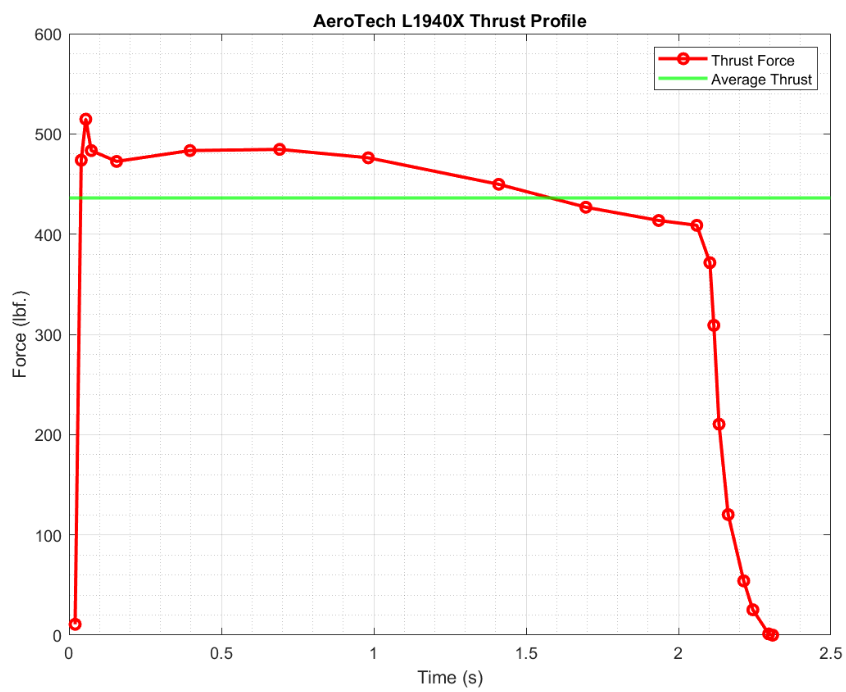

Figure 3.31: AeroTech L1940X Thrust Profile.

From figure 3.31, the initial peak performance of the motor is apparent. The bimodal profile of a relative flat thrust profile followed by a high slope decrease in performance during the final third of a second of performance is also observed with its desirable effects shown above. In Table 3.6, motor characteristics derived from the manufacturer's specifications have been provided.

Table 3.6: Selected Motor for 2024 Launch Vehicle.

Motor	Propellant Mass (slug)	Total Mass (slug)	Total Impulse (lb•sec)	Average Thrust (lb)	Maximum Thrust (lb)	Burn Time (sec)	Casing	Length (in)
L1940X	0.1250	0.2642	973.24	435.97	521.21	2.2	RMS-75/3840	22.04

To determine the thrust-to-weight ratio of the launch vehicle during ascent, RocketPy variable export was used to divide the thrust profile of the rocket by the mass of the rocket as a function of time. This estimation is better than hand calculations since the inner and outer diameters of the grain profile are used in the determination of the mass flow exit of the nozzle as a function of the increased burning surface area of the motor's internal structure. To verify this calculation, a linear mass flow rate was used by determining the slope between the initial and final mass of the launch vehicle across the burn time of the motor. For Equation 1, T represents the thrust of the motor over time, M_i represents the initial mass of the launch vehicle, and $\dot{m}$ represents the mass flow rate leaving the motor.

$$TWR(t) = \frac{T(t)}{M_i - \dot{m}(t)} \tag{1}$$

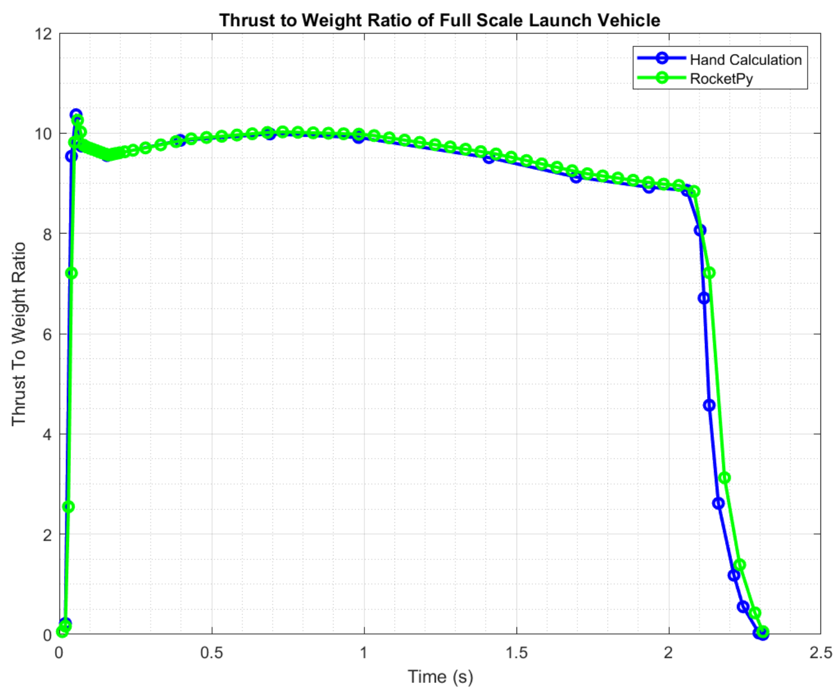

Figure 3.32: Full scale launch vehicle thrust to weight ratio.

From Equation 1 visualized in 3.32, the maximum thrust-to-weight ratio of the launch vehicle occurs at liftoff with a value of 10.26, and the average thrust-to-weight ratio during the power-on section of the flight is 8.64.

3.3 Subscale Flight Results

3.3.1 Flight Predictions

The flight predictions for the subscale launch vehicle centered around the verification of the drag coefficient model derived in ANSYS Fluent, along with the RocketPy methodology used in the determination of apogee. With this, the predicted launch vehicle stability was 2.30 with an apogee of 1,444 ft. AGL.

To determine this apogee, the NOAA Global Forecast System (GFS) forecast model method was used within RocketPy to pull forecasted wind speed data for the specific date, time, and coordinate location of the launch field. Plots of this data used in the apogee estimation have been provided in Figure 3.33.

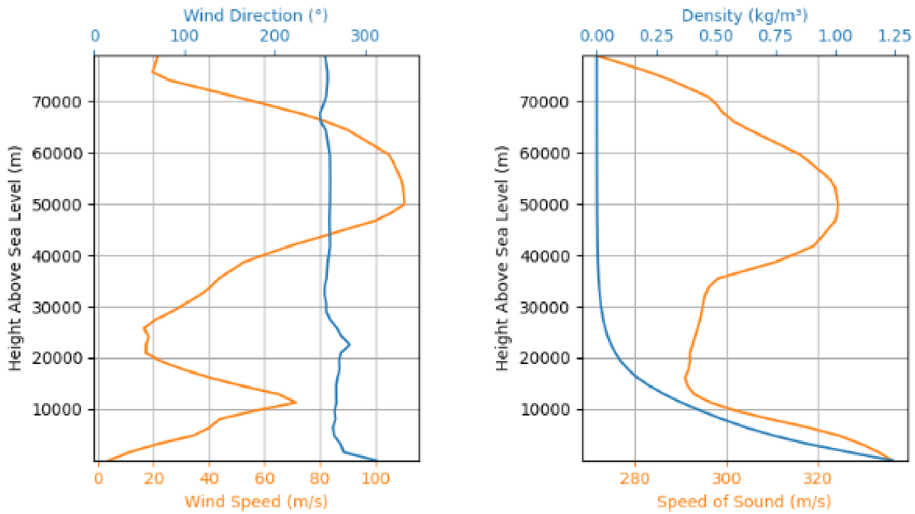

Figure 3.33: Subscale GFS atmospheric model from the day of launch.

This data was then used as the input to the flight method of RocketPy's 6 DOF model to determine the launch vehicle's apogee. Specific consideration was taken to determine the AGL apogee as RocketPy's default apogee is measured from sea level. Results of this simulation are shown in Section 3.3.4

3.3.2 Flight Results

The stability of the launch vehicle was verified on the launch field to be 2.31 with a mass difference of 0.2 lb from the model. This verified that the RocketPy model would be able to isolate the drag coefficient to be the single source of difference between the OpenRocket model and the full-scale model. Additionally, the apogee was verified on the launch field after field recovery to be 1,439 ft. AGL. This difference of 5 ft. or 0.346% demonstrated that the CFD-derived drag profile could be used as a source of truth for the launch vehicle behavior. Furthermore, this shows the day-of-launch ballast system could be used to modify the launch vehicle's apogee to a high fidelity when simulated in RocketPy. The launch field verified apogee has been provided below.

2:47

QUASAR_A0271D 1.02a

Flight Summary

Flight No.: 31
Flight Status: Landed

Apogee:.........1439
Time to Apogee.....10.05

Figure 3.34: Launch field verified subscale apogee.

Flight Data

The altimeter altitude and velocity plots have been provided in Figures 3.35 and 3.36 below.

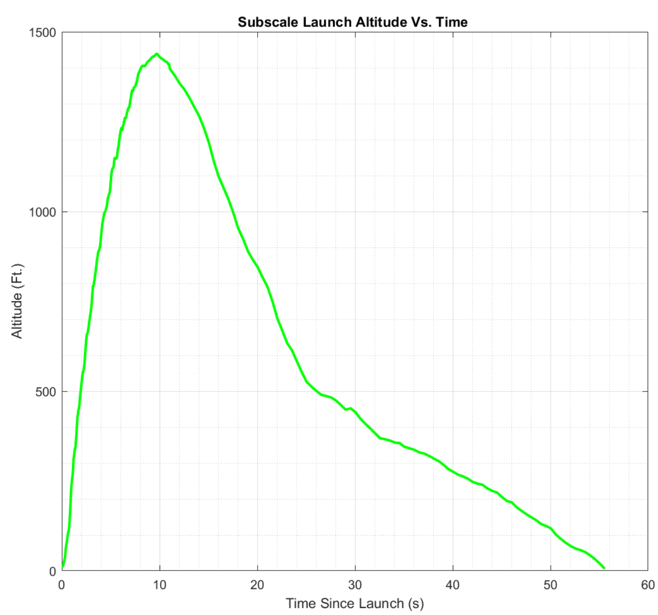

Figure 3.35: Subscale altitude profile from the altimeter.

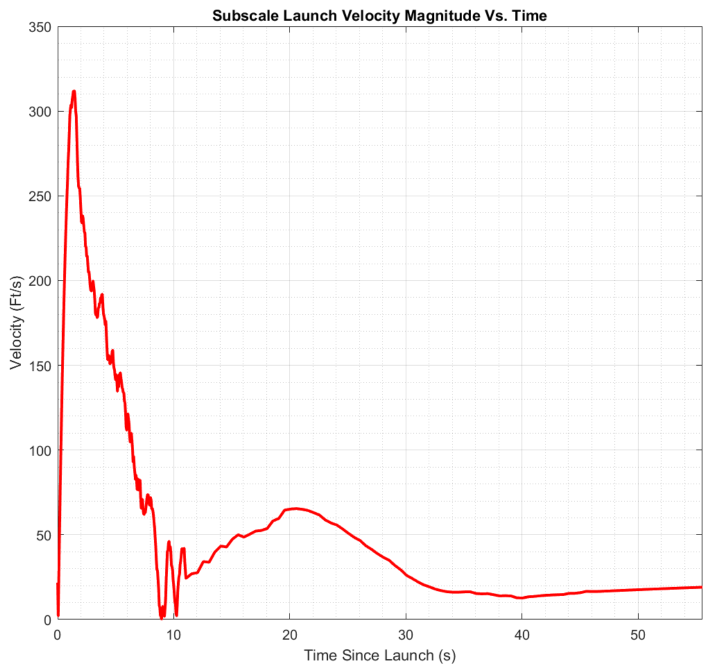

Figure 3.36: Subscale velocity profile from the altimeter.

Recovery Results

The recovery system worked exactly as intended. At apogee, the drogue parachute was deployed successfully. At 800 ft. AGL, the nose cone separated pulling the payload out and, most importantly, removing the deployment bag off the main parachute for the launch vehicle. The main parachute successfully deployed, and the vehicle landed safely. No damage to the launch vehicle was incurred upon landing. In Figures 3.37, 3.38, and 3.39 below, the landing configuration for the fin can, main parachute/payload bay, and nose cone is shown, respectively. As seen, no shock cords or parachutes were tangled up on deployment, during descent, or landing. Due to these factors, the recovery system was considered a success for the subscale launch vehicle.

Figure 3.37: Fin Can Landing Configuration for the Launch Vehicle

Figure 3.38: Main Parachute/Payload Bay Landing Configuration

Figure 3.39: Nose Cone Landing Configuration

It is important to note that the image of the nose cone landing configuration is a recreation, as pictures were not taken of the nose cone after landing on launch day. The nose cone landing configuration was replicated based on eye-witness accounts on a later date. There was no damage to the nose cone or any of the recovery components under that section. Note that the fin can and payload bay landing configurations were captured directly following the subscale launch. As shown in Figures 3.37 and 3.38, the shock cords did not tangle during deployment, descent, or landing. The deployment bag was cleanly removed from the main parachute, and the payload mass simulator did not tangle or detach from the nose cone.

The subscale launch vehicle drifted approximately 633.35 ft with roughly 12 mph winds at the time of launch, according to a weather archive for Bayboro, NC. Using the overestimation approach for drift distance used in Section 3.6.7, the subscale launch vehicle was overestimated to drift 946.7 ft. This means it is a good overestimation that will be used for the full-scale launch vehicle as well, ensuring the launch vehicle or any independent components will not exceed 2,500 ft from the launch pad.

3.3.3 Scaling Factors

A scaling factor of 2/3 was implemented for all driving dimensions of the full-scale launch vehicle to generate the subscale and satisfy NASA Vehicle Requirement 2.18.5. This factor was rigidly upheld to ensure that the aerodynamic coefficients validation of the subscale would match the full-scale. The fin root, tip, and span were scaled by this factor along with the nose cone and body tube. Commercially available 4 in. diameter body tube allowed for streamlined construction of the launch vehicle without requiring modification to COTS parts. To accurately represent the influence of the full-scale payload on the center of mass of the launch vehicle, the mass used to represent the payload was taken as a fraction of the dry mass of the launch vehicle. This was chosen over a 2/3 scale factor since the mass of the ballast is heavily dependent on the volume of the payload as opposed to a single characteristic length. Performing this analysis yielded a payload mass simulation of 2.11 pounds placed in a location where the payload would be attached to the nose cone bulkhead. A comparison of the subscale and full-scale parameters has been provided in Table 3.7.

Table 3.7: Scaling Factors between the subscale and full-scale launch vehicle.

Parameter	Full Scale Value	Subscale Value	As Built Scaling Factor	As Designed Scaling Factor
Length (in.)	105	70.4	66.9%	66.0%
Diameter (in.)	6.2	4.0	65.2%	66.0%
CP (in.)	77.9	51.3	65.8%	66.0%
CG (in.)	60.8	41.9	68.6%	66.0%
Stability (cal)	2.31	2.77	-	-
Fin Root Chord (in.)	8	5.25	65.6%	66.0%
Fin Tip Chord (in.)	4	2.65	66.2%	66.0%
Fin Span (in.)	5.25	3.5	66.6%	66.0%
Payload Mass (lb.)	8	2.11	26.4%	$66\%^3$ = 28.74%

3.3.4 Flight Analysis

The comparison between the simulation and flown altimeter data are very closely related throughout the altitude profile, with the peak altitude from the altimeter being slightly less than the RocketPy predicted value. The velocity profile also follows the expected trend throughout the ascent. There is some variability in the altimeter data during the point of main deployment, registering a lower than expected apogee, but this can be attributed to a longer than expected time for the main parachute to unfold. Additionally, the slope of the altitude plot also appears to be more shallow on the altimeter data than the expected results indicating that the drag coefficient listed on the manufacturer specifications of 1.55 may be less than the actual drag coefficient of the parachute. Furthermore, the altimeter velocity and altitude were post-processed using the MATLAB signal processing toolbox to remove noise using a Savitzky-Golay filter.

Simulation Comparison

The simulated altitude and velocity profiles, Figures 3.40 and 3.41, of the subscale launch vehicle have been provided for comparison between the actual and expected results.

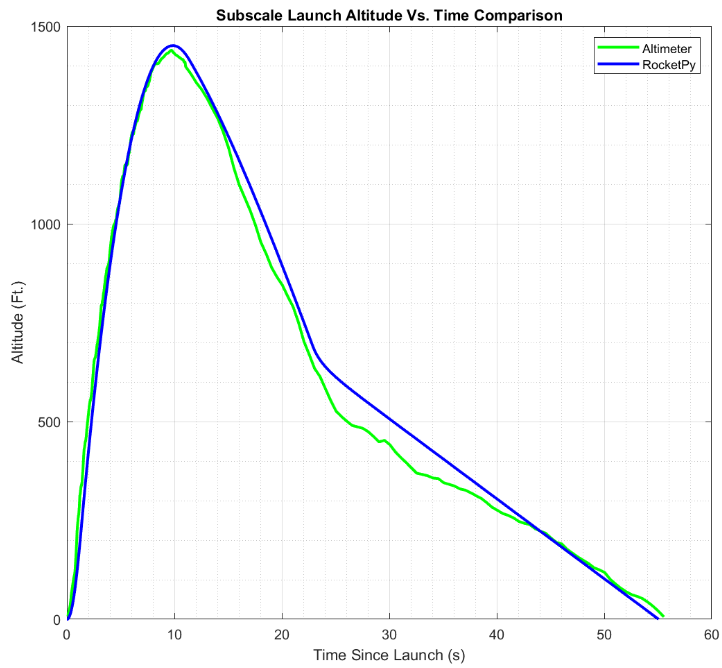

Figure 3.40: Altitude Comparison between the actual and expected profile.

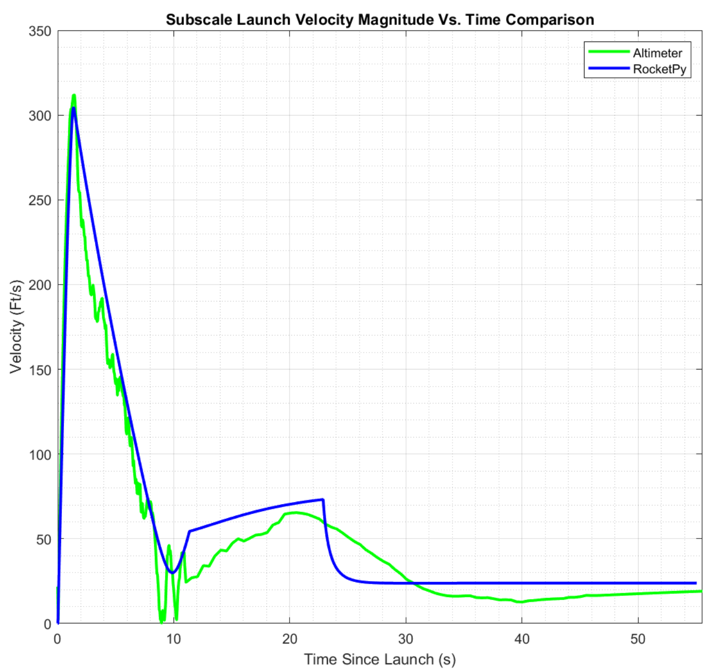

Figure 3.41: Velocity Comparison between the actual and expected profile.

Drag Coefficient Estimation

Based on the data provided, the drag coefficient can be estimated for the launch vehicle. This will be used to validate the ANSYS fluent derived C_d value for the launch vehicle. By using the equations below, the drag coefficient can be found for the coast phase of the flight.

$$F_d = -mg - ma \quad (2)$$

$$C_d = \frac{2F_d}{\rho v^2 A} \quad (3)$$

Where F_d is the drag force, a is the deceleration of the launch vehicle measured by taking the derivative of the velocity profile, m is the mass of the launch vehicle once all of the propellant mass has been expelled through the nozzle, ρ is the density of the air, v is the velocity of the launch vehicle, and A is the frontal area of the launch vehicle comprised of the body tube area and fin perpendicular area which was found to be 82 cm^3. From this analysis, the drag coefficient of the launch vehicle was found to be 0.52. This value fits very closely with the ANSYS fluent-derived value of 0.54. OpenRocket estimates the drag coefficient to be 0.45, thus explaining why the apogee calculated in OpenRocket was an overestimate of the actual value. Overall, the validity of the drag profile has been confirmed using data collected from the subscale flight.

3.3.5 Impact on Full-Scale Design

Based on the knowledge gained from the subscale flight, the main target of revision will be the addition of a larger structure to support ballast additions. This is due to the required ballast to offset the deviation from a nominal center of gravity caused by the mass of the payload which is located close to the nose cone of the rocket. As the mass analysis converged in OpenRocket to the as-build configuration, the amount of ballast that the removable fin system can support approached a maximum. By adding additional threaded rods to the internal structure of the full-scale removable fin system, this issue will be remediated by allowing more space for extra ballast. Furthermore, this revision allows for a significant ballast capacity margin, alleviating concerns about where to secure ballast to the aft section of the launch vehicle.

3.4 Vehicle Manufacturing

3.4.1 Airframe and Coupler Cutting

Given that the airframe and coupler sections will be made out of G12 fiberglass, it is important to be in a well-ventilated area with the proper tools and safety equipment when cutting the tubes to length. As such, all sections made of G12 fiberglass will be cut in NC State's Senior Design Lab by professional personnel. After cutting, each section will need to be sanded to avoid sharp edges and fiberglass splinters. Such sanding will be done with sandpaper while wearing Nitrile gloves, safety glasses, and a respirator.

3.4.2 Bonding Airframe and Coupler Sections

Any airframe sections that need to be permanently bonded to coupler sections will be epoxied together using the following steps. Note that nitrile gloves, safety glasses, and a respirator must be worn for this procedure.

1. Wipe down the contact areas on both the airframe and coupler sections with isopropyl alcohol.
2. Lightly sand the contact areas with 100-grit sandpaper.
3. Wipe down the sanded contact areas with isopropyl alcohol.

4. Mix an appropriate amount of West System's 105 Epoxy Resin and 206 Slow Hardener using the correct mixing ratio of 1:1.
5. Apply a thin coat of the resin/hardener mixture to the contact areas.
6. Place the sections together.
7. Wipe up any of the excess resin/hardener mixture with a paper towel.
8. Place the section assembly on its side to dry so that gravity does not cause the sections to slide while drying.
9. Leave the section assembly to dry for 24 hours.

3.4.3 Bulkhead Fabrication

All bulkheads will be designed in SolidWorks where technical drawings can be made to send to one of NC State's ULS laser cutters. After the parts have been laser cut from a sheet of 1/8 in. thick aircraft-grade birch plywood, the bulkheads can be constructed using the following steps. Note that nitrile gloves must be worn for this procedure.

1. Sand the contact areas on each of the plies with 100-grit sandpaper.
2. Cut 1 in. wooden dowels to fit in the alignment holes in the bulkhead plies.
3. Cut an appropriately sized piece of peel ply that can be wrapped around the assembled bulkhead.
4. Place the piece of peel ply on the counter with the vacuum and surround it with a layer of yellow sealant tape.
5. Cut a piece of breather material that will fit within the confines of the yellow sealant tape border.
6. Cut a piece of polyurethane material that fits just outside of the yellow sealant tape border.
7. Place the bottom ply of the bulkhead onto the peel ply.
8. Mix an appropriate amount of West System's 105 Epoxy Resin and 206 Slow Hardener using the correct mixture ratio of 1:1.
9. Apply a thin coat of the resin/hardener mixture to the top face of the bulkhead ply.
10. Insert the wooden dowels into the alignment holes.
11. Apply a thin coat of the resin/hardener mixture to both faces of the next two bulkhead plies and stack them on top of the bottom bulkhead ply making sure to use the wooden dowels to keep the plies aligned.
12. Apply a thin coat of the resin/hardener mixture to the bottom face of the last ply and stack it on top of the other plies as in the previous step.
13. Cut off any of the extra material from the wooden dowels so that they are flush with the top of the bulkhead.
14. Place a drop of the resin/hardener mixture into each alignment hole occupied by the wooden dowels to make sure they do not come loose.
15. Using a paper towel, wipe up any of the excess resin/hardener mixture.
16. Wrap the peel ply around the bulkhead and place the breather material over the top.
17. Place the vacuum tube inside the confines of the yellow sealant tape border and use more yellow sealant tape to help keep it in place and prevent air leaks.
18. Place the polyurethane material over the yellow sealant tape border and press firmly around the border to ensure there are no air leaks.
19. Turn on the vacuum and inspect for air leaks.

20. If there are air leaks, use the yellow sealant tape to plug them until a vacuum is formed.
21. If there are no air leaks, leave the assembly to cure for 24 hours.

Nose Cone Removable Bulkhead

The removable nose cone bulkhead and centering ring will be manufactured using the same steps listed in 3.4.3. After the centering ring is fabricated, four T-nuts will be hammered into the pre-cut holes. The steps outlined in 3.4.2 will be followed to install the centering ring permanently into the nose cone. After the permanent centering ring has been installed, all the necessary hardware can be attached to the removable bulkhead and then screwed in place.

3.4.4 Main and Payload Bay Fabrication

The main parachute/payload bay will first be cut to length using the procedures outlined in 3.4.1. After the section has been cut to length and sanded, holes will be drilled using an electric hand drill to accept 4/40 nylon shear pins and nylon push clip rivets. Safety glasses and a respirator must be worn during this procedure.

3.4.5 Avionics Bay Fabrication

The AV bay airframe and coupler sections will be cut to length using the procedures outlined in 3.4.1. The two sections will then be permanently joined together using the steps in 3.4.2. Once the sections have cured, holes will be drilled with an electric hand drill on each exposed coupler section to accept 4/40 nylon shear pins, nylon push clip rivets, and a pull-pin switch. Pressure port holes will also be drilled according to the altimeters' manufacturer's recommendation along the switchband to ensure that the altimeters can take accurate pressure measurements. Safety glasses and a respirator must be worn during such drilling.

The bulkheads for the AV bay will be constructed using the steps outlined in 3.4.3. Afterward, the U-bolts, blast caps, and terminal blocks can then be attached to the bulkheads. Additionally, the stainless steel threaded rods are cut to length using a metal cutting bit on a Dremel tool and then added to one of the bulkheads using the zinc-plated steel nuts. Note that safety glasses must be worn when cutting with the Dremel tool. Finally, the electronics sled can be slid onto the threaded rods and secured by placing the other bulkhead onto the ends of the threaded rods and tightening it down using zinc-plated steel nuts.

3.4.6 Drogue Bay and Fin Can Fabrication

The drogue parachute bay/fin can will be cut to length using the procedures outlined in 3.4.1. Such procedures will also be used to cut the slots for the fins. Additionally, an electric hand drill will be used to drill holes to accept 4/40 nylon shear pins and #8-32 machine screws. Note that safety glasses and a respirator must be worn while drilling into fiberglass.

3.4.7 Removable Fin System Fabrication

The removable fin system bulkheads and the thrust bulkhead will be fabricated using the steps outlined in 3.4.3. Once the removable fin system bulkheads are constructed, the slots for the runners, and the tabs on the runners, will be sanded with 100-grit sandpaper. After mixing an appropriate amount of West System's 105 Resin and 206 Slow Hardener, a thin layer of the mixture will be applied to the runner slots and runner tabs. The two removable fin system bulkheads and the eight runners will then be left to dry for 24 hours. Figure 3.42 illustrates how the removable fin system should look at this point.

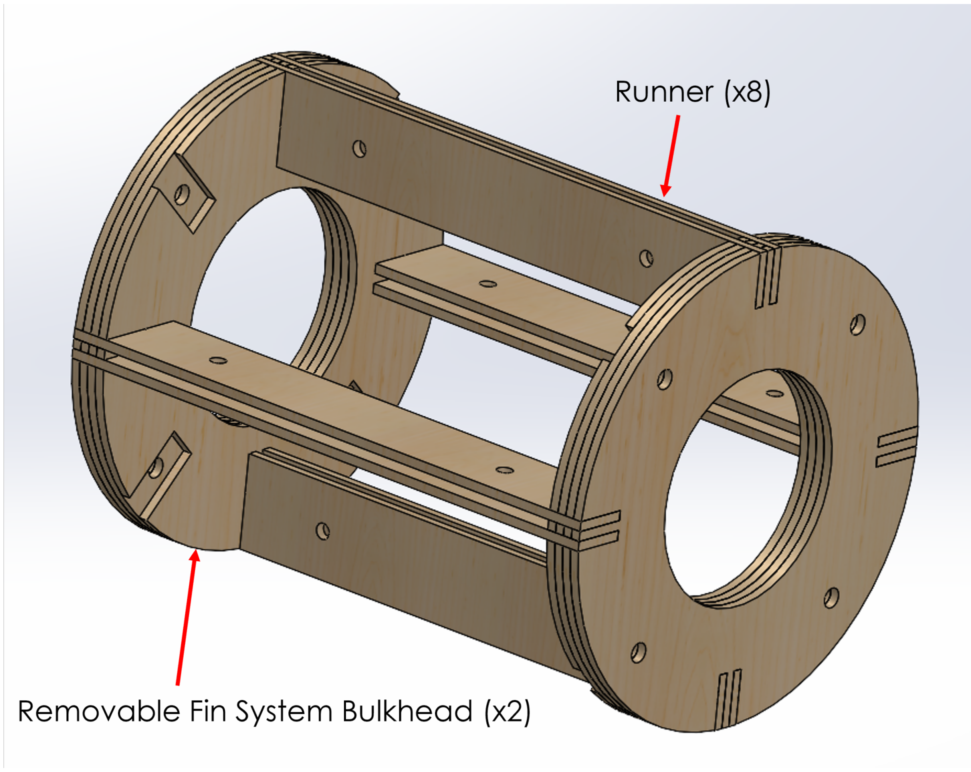

Figure 3.42: Runners inserted into the removable fin system bulkheads.

Each removable fin system bulkhead will have four stainless steel L-brackets, each with a #8-32 stainless steel nut welded over one of its holes. Such welding will take place by professional personnel in NC State's Senior Design Lab. Each custom L-bracket must be inserted into its slot onto its bulkhead such that the face containing the stainless steel nut points towards the concentric axis of the removable fin system assembly. These L-brackets are held in place by the (4) 1/4 in.-20 x 9-1/2 in. stainless steel threaded rods that extend through the entire assembly and (8) 1/4 in.-20 zinc-plated steel nuts (4 per bulkhead or 2 per threaded rod). Figure 3.43 illustrates how the removable fin system should look after inserting the L-brackets, threaded rods, and hardware.

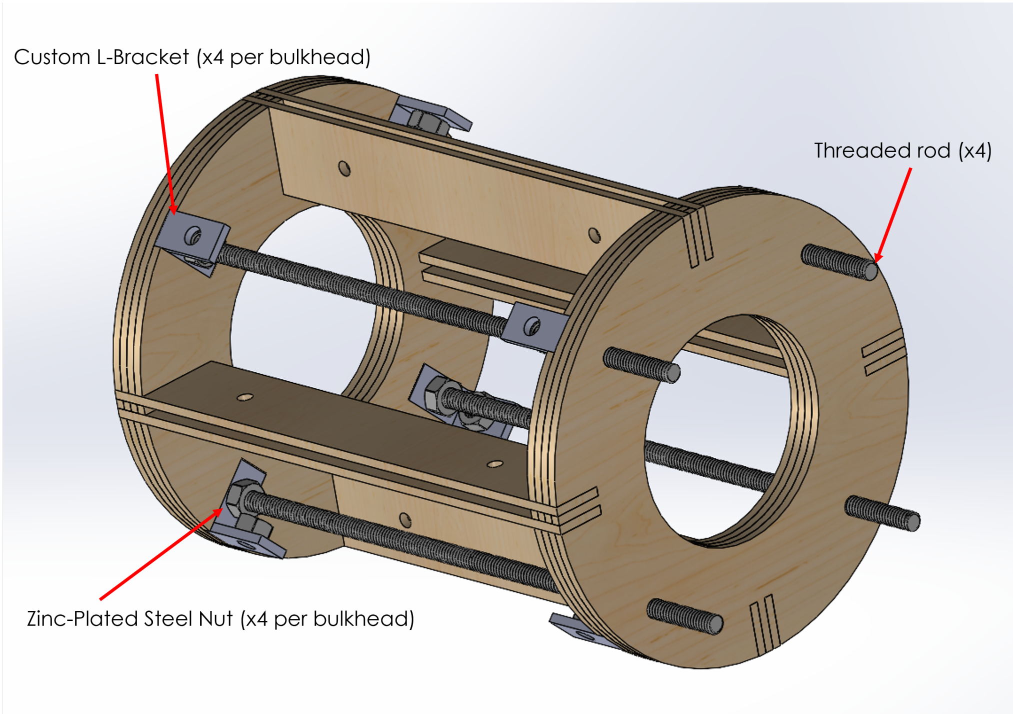

Figure 3.43: Custom L-brackets, threaded rods, and hardware added to removable fin system assembly.

A 6061 aluminum alloy thrust plate will slide onto the threaded rods on the aft end of the assembly. This thrust plate will be designed in SolidWorks and sent to NC State's Senior Design Lab where the part can be machined out of a single sheet of the material using a water jet.

The motor retainer and its included hardware will be attached to the thrust bulkhead before sliding it onto the (4) 1/4 in.-20 x 9-1/2 in. stainless steel threaded rods, sandwiching the thrust plate with the aft removable fin system bulkhead. At this point, a 1/4 in.-20 zinc-plated steel nut can be threaded onto both ends of each of the threaded rods and tightened until snug, holding everything in place. Figure 3.44 illustrates what the removable fin system should look like at this point.

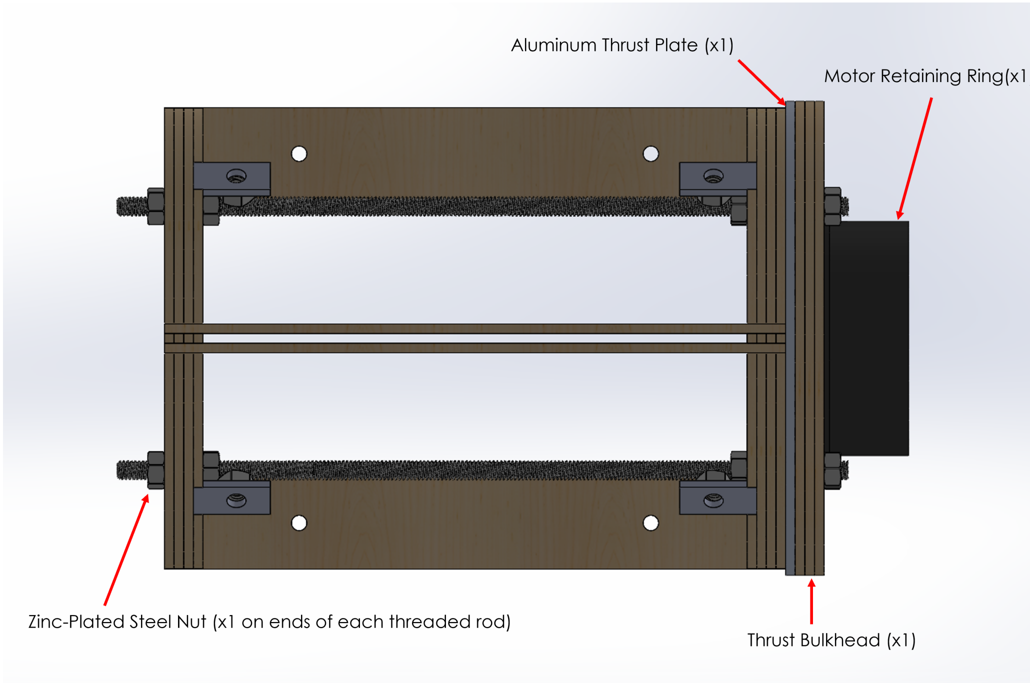

Figure 3.44: Thrust plate, thrust bulkhead, and motor retaining ring attached to removable fin system assembly.

Finally, each of the fiberglass fins can be inserted into their respective fin slots (the space between the runners) and secured in place with (2) #8-32 zinc-plated steel screws and nuts. Figure 3.45 illustrates the removable fin system with its fins installed, completing the construction of the removable fin system.

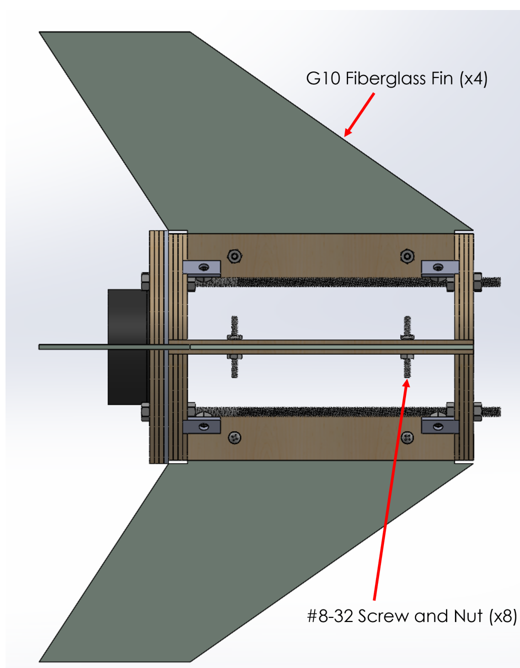

Figure 3.45: Fins and fin hardware attached to removable fin system assembly.

3.4.8 Fin Fabrication

The fins will be cut out of a single sheet of G10 fiberglass using a Dremel tool with a metal cutting bit. This process will take place in NC State's Senior Design Lab which has a well-ventilated room for cutting and sanding composites. Nitrile gloves, a respirator, and safety glasses will be worn during the entire fin fabrication process. After the fins are cut out of the fiberglass sheet, they will be beveled using a belt sander in the same facility. Afterward, holes will be drilled in the fin tabs using an electric hand drill. Finally, the fins will be thoroughly cleaned with isopropyl alcohol before handling.

3.5 Recovery Subsystem

3.5.1 Recovery Design Overview

The recovery subsystem ensures that the launch vehicle will have a controlled descent and will land safely in a reusable condition. This includes the use of a recovery harness and parachute system, an avionics system, and a tracking system. The majority of the electronics used for the recovery of the launch vehicle are mounted on an AV sled that is located in the AV bay of the launch vehicle, with the exception of a tracker in the separating nose cone. Section 3.5.6 contains a more detailed description of this AV sled.

As a quick overview, the primary altimeter shall be an RRC3 sport altimeter, and the secondary altimeter shall be an Eggtimer Quasar. The RRC3 will be powered by a standard 9V battery, while the Quasar will be powered by a 2S/ 7.4 LiPo battery. These altimeters are responsible for launch vehicle separation through the use of a black powder ejection system. On the forward and aft bulkheads of the AV bay rests two PVC blast cast caps used to store black powder (see Figure 3.10). Each altimeter will have two wires feeding to a terminal block on the inside of the bulkheads, with an e-match also connected to the terminal block that will feed through the bulkhead and rest in a blast cap. There is a U-bolt on each bulkhead that is used to link the Kevlar shock cord via a stainless steel quick-link that will keep the separated sections together and hold the parachutes.

There will be two GPS tracking devices onboard the launch vehicle, one for the launch vehicle itself, and one for the nose cone since it is separating independently. The launch vehicle tracker shall be an Eggtimer Quasar, which also functions as the secondary altimeter, and the nose cone tracker will be a Big Red Bee 900. Additionally, the launch vehicle tracker will be powered on during AV bay assembly and connected to the Eggfinder handheld LCD receiver, while the nose cone tracker will be powered on during nose cone assembly and will connect to its handheld receiver. Both of the receivers for each tracker will be in the possession of the Recovery Lead during and post-flight.

Upon launch day assembly, the altimeters will not be armed while they are connected to live black powder charges. Given that they must be armed for the continuity check, this check will be conducted before the wires are connected to the terminal blocks. These steps prevent the risk of accidental detonation of the black powder. Additionally, the altimeters must be armed once the AV bay is being assembled for a short period since the pull-pin switch must be pulled out while everything is being slid into place. Upon completion, the pull-pin switch will be inserted through the exterior of the rocket, disarming the altimeters. These altimeters will then remain disarmed until the launch vehicle is on the launch pad before the motor igniter is inserted.

Upon successful launch of the vehicle, once the primary altimeter detects apogee, a signal will be sent to the primary drogue ejection charge. One second after apogee, the secondary altimeter will send a signal to the secondary drogue ejection charge, separating the rocket if the first charge did not. With successful drogue separation, the 15 in. drogue parachute will deploy, and the launch vehicle will descend under the drogue to 800 ft. Once the primary altimeter senses the launch vehicle is at 800 ft., a signal is sent to the primary main ejection charge, separating the nose cone from the launch vehicle. Additionally, once the secondary altimeter detects a height of 700 ft., a signal is sent to the main secondary ejection charge, separating the nose cone if the first charge did not. Connected to the nose cone is its parachute, the deployment bay for the payload, and the deployment bag that covers the main parachute used for the rest of the launch vehicle. After successful nose cone separation, the 96 in. main parachute for the launch vehicle will deploy. The nose cone will then descend with a 48 in. parachute with the payload attached until approximately 450 ft., where the payload is dropped via a latch, discussed in Section 4.4. The drogue and nosecone parachutes will be protected from ejection charges with a Nomex cloth, and the main parachute will be protected by the deployment bag. An illustration that conveys the deployment timeline of the recovery system is shown below in Figure 3.46.

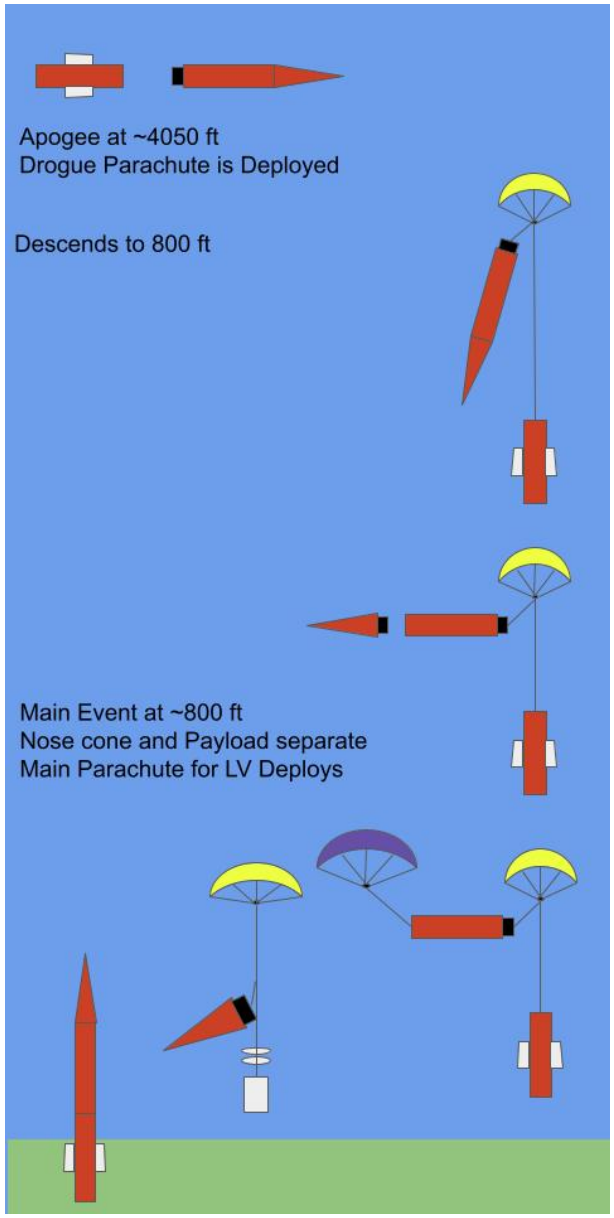

Figure 3.46: Deployment timeline of the launch vehicle.

The drogue event separation point is aft of the AV bay and forward of the drogue parachute bay/fin can. These sections of the rocket are held together by 4-40 nylon shear pins. Detonation of the drogue ejection charges during flight will break these pins, allowing the sections to separate. Additionally, the main event separation point is aft of the nose cone and forward of the main parachute bay/ payload bay. These sections are also held together by 4-40 nylon shear pins that are built to break upon detonation of the main charges. Furthermore, the nose cone will separate and descend untethered to the rest of the launch vehicle independently with a 48 in. parachute, the main parachute's deployment bag, and the payload. The mass of the ejection charges is calculated, shown in Section 3.6.8, to ensure the pressure created from the detonation is large enough to shear the pins, and therefore separate the rocket. Lastly, before each launch, an ejection test will be conducted to ensure that the masses of these charges will separate the launch vehicle.

Upon successful launch vehicle recovery, the handheld receivers will be used to locate the nose cone and the launch vehicle. The apogee detected by both altimeters will be recorded and then disarmed by inserting the pull-pin switch.

3.5.2 Altimeters

There will be two altimeters onboard the launch vehicle for the competition launch. The primary altimeter will be the RRC3 ”sport” altimeter, and the secondary will be an Eggtimer Quasar that also functions as a tracker. These altimeters control the recovery events at apogee and main deployment altitude of 800 ft. The secondary altimeter operates on a one-second delay after apogee for the secondary drogue charge and sends the secondary main charge at 700 ft. (a 100 ft. delay). This is because the Quasar does not have a time delay feature for the main deployment, only an altitude specification in increments of 100 ft. Additionally, the primary altimeter will be connected to one primary drogue ejection charge and one primary main ejection charge, with the secondary altimeter being connected to one secondary drogue ejection charge and one secondary main ejection charge. However, the RRC3 primary altimeter will report the competition altitude.

Due to its high precision, ease of programming, historic reliability in the High Powered Rocketry Club, and the possession of one already, the RRC3 was chosen to be the primary altimeter. This device boasts a 1 ft. altitude logging resolution, a 20/s sampling rate, and can be programmed from the MissleDacs software on a computer [38]. An image of this altimeter is shown below in Figure 3.47.

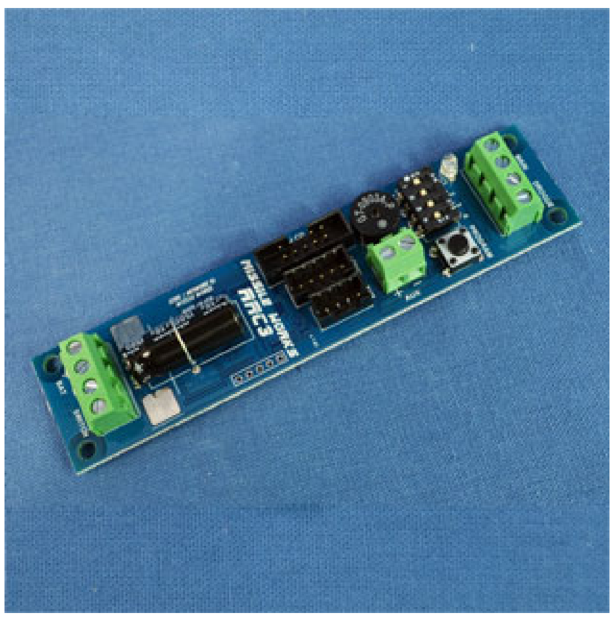

Figure 3.47: RRC3 Sport altimeter by Missile Works [38].

Though the Eggtimer Quasar has not been used as an altimeter in the club’s history, its precision and ease of use are great characteristics to use it as a secondary altimeter. It can be programmed and armed from a smartphone, and flight data can be pulled from the phone as well. The main appeal to this device is its dual functionality as a tracker [25]. Additionally, this was used as the NCSU 2022-2023 NASA SLI competition launch vehicle tracker and has been proven to be reliable. Therefore, due to its GPS tracking capabilities, and altimeter functionality, the Eggtimer Quasar was chosen to be the secondary altimeter. Shown below in Figure 3.48 is an image of the Eggtimer Quasar.

Figure 3.48: Quasar altimeter/tracker by Eggfinder.

It is important to note that the primary altimeter will be powered by a standard 9V battery, and the Quasar will be powered by a 2S/ 7.4V LiPo battery. Additionally, both altimeters will be tested several times before every launch in a pressure chamber to ensure it is operating correctly. This testing procedure is explicated in depth in Section 6.1.4.

3.5.3 Altimeter Arming Method

All avionics in the AV bay shall be armed and disarmed by a pull-pin switch. These were chosen due to previous success within the club, its ease of use, and they effectiveness for the subscale launch vehicle. When the pin is inserted in the switches, the circuit from the batteries to the altimeters is open, preventing them from being armed. Upon removal of the pin, the devices will be powered and armed. During the AV bay assembly on launch day, the pull-pin must be removed when inserting the sled into the bay, thus the altimeters will be on momentarily. To prevent accidental activation of the charges, there will be no connection to the black powder charges until the pin is re-inserted through the exterior of the rocket. The pins will then remain inserted until the launch vehicle is in the correct orientation on the launch pad. Presented in Figure 3.49 is an image of the pull-pin switch kit that will be used on the launch vehicle [33].

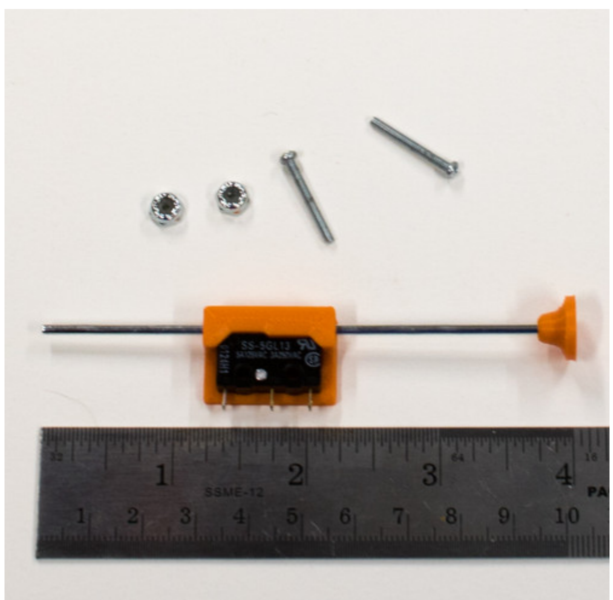

Figure 3.49: Pull-pin switch by Lab Rat Rocketry [33].

3.5.4 Tracking Devices

As mentioned in the altimeter section, the launch vehicle tracker will be the Eggtimer Quasar, which also functions as the secondary altimeter. This transmits a signal on the 70 cm band, has a 250 mW transmitter power, and has a transmitter frequency of 420.250 MHz, thus the receiver must be operated by someone with a HAM radio license to comply with FCC regulations [25]. This device transmits to the Eggfinder LCD handheld receiver, which will display the GPS coordinates of the tracker. Upon successful recovery, the Quasar will transmit its location after five seconds of no movement from the launch vehicle. An image of this launch vehicle tracker is shown in Figure 3.48.

Due to the nose cone separating as an individual section, not tethered to the launch vehicle, it will need a separate tracker. The nose cone tracker shall be the Big Red Bee 900. It has a transmitter power of 250 mW and a transmitter frequency of 900 MHz, meaning no HAM license is required to operate this tracker [22]. This was chosen due to its ease of use, simplicity, and small form factor since it will be in the nose cone. Additionally, it is paired with a handheld receiver that will display the GPS coordinates of the tracker. Figure 3.50 below shows an image of the nose cone tracker.

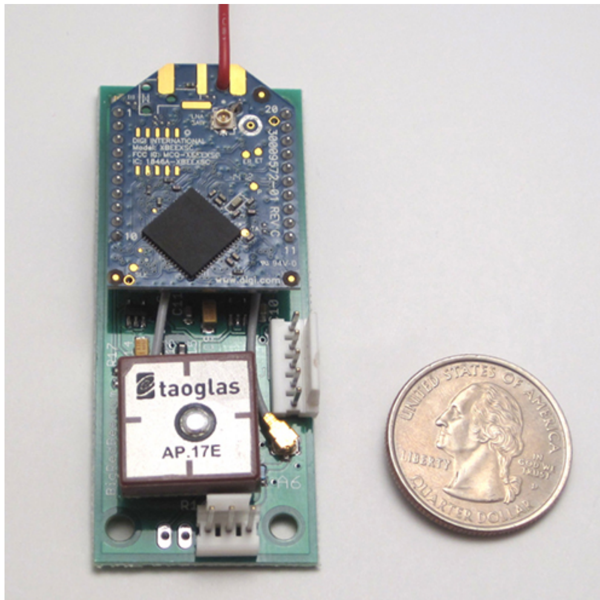

Figure 3.50: Big Red Bee 900 tracker by BigRedBee.

These tracking devices satisfy NASA Requirement 3.13, both having a range exceeding 6 miles and a transmitter power of less than 250 mW. Each tracker will be tested several times before each launch to ensure they are operating correctly.

3.5.5 Avionics Sled Design

The AV sled will hold the launch vehicle avionics, their batteries, and the pull-pin switches. It was designed in SolidWorks and will be fabricated with a 3D printer using PETG filament. The rectangular mounting surface will have an area of 8 by 5.725 in. Additionally, all avionics will be mounted on 4-40 nylon standoff screws attached to the sled. These screws will be attached to threaded inserts placed into the surface with a soldering iron tip. Furthermore, battery compartments for both altimeters are located on the bottom surface, the smaller one for the 9V primary altimeter battery, and the bigger one for the 2S/ 7.4 LiPo for the secondary altimeter/tracker. For mounting, the hollow tubes serve as rails for the threaded rods that run through the AV bay, securing the sled on the rods using 1/4 in. nuts. Lastly, the small holes in the design are for the pull-pin mechanical arming switches that will be bolted onto the sled. Presented in Figures 3.51 and 3.53 is a model of the final AV sled design.

The top surface of the AV sled, Figure 3.51, will hold both the RRC3 primary altimeter and the Quasar secondary altimeter and launch vehicle tracker. These avionics will be mounted onto this surface through the use of nylon standoffs. Threaded inserts meant for a 3D-printed filament will be inserted into the top surface after holes for the avionics have been drilled. Afterward, the threaded standoffs will be screwed into the inserts firmly. Once secured, the avionics will be mounted onto the standoffs, and additional screws will be added to secure the avionics to the standoffs. This mounting configuration is capable of staying secure during the sustained

G's experienced upon launch. An example of this mounting configuration is shown in Figure 3.52, as it was successfully used on the subscale launch vehicle for this competition year.

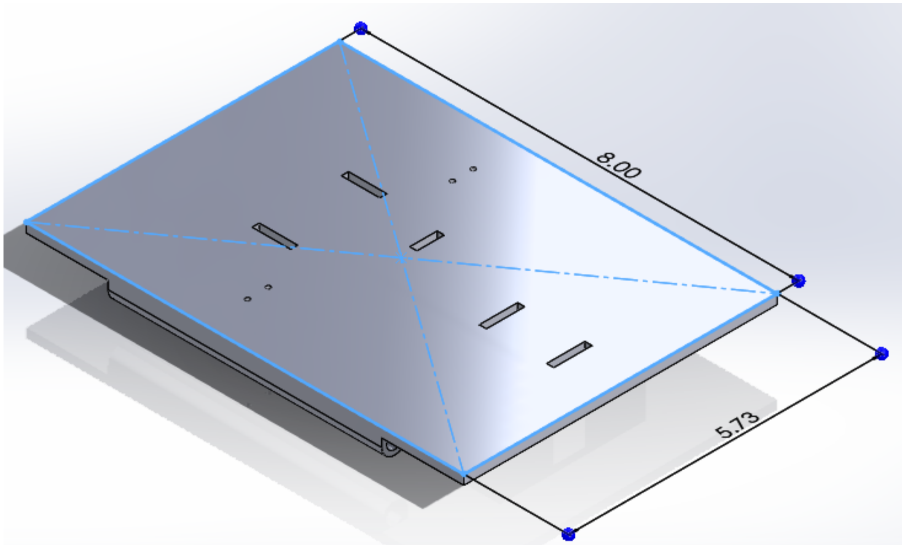

Figure 3.51: Top surface of full-scale avionics sled.

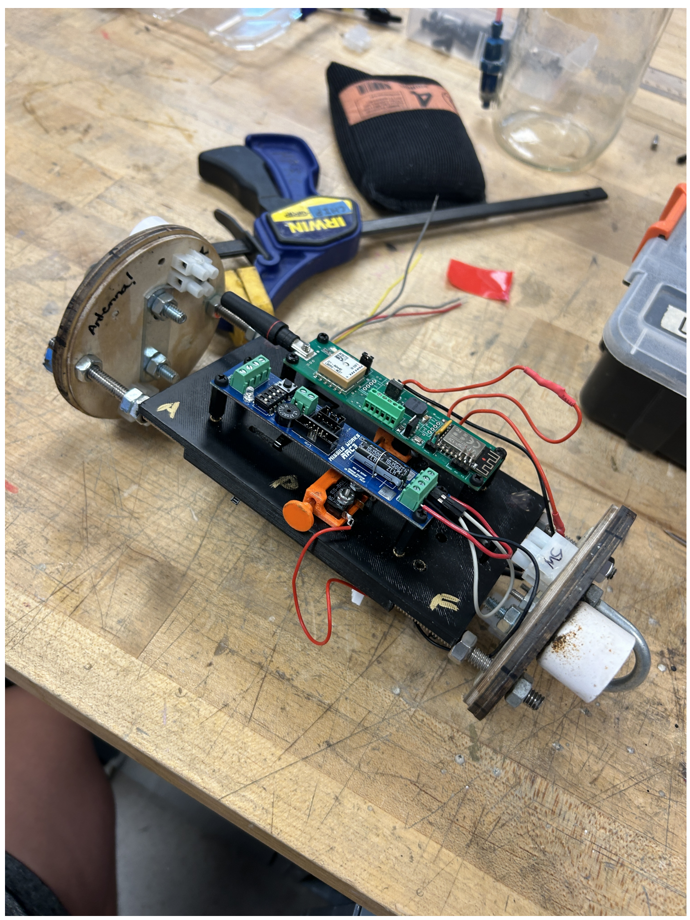

Figure 3.52: Top surface of subscale avionics sled.

Due to space constraints on the subscale launch vehicle, the pull-pin switch mechanical arming devices were added below the avionics. However, due to the increase in space in the full-scale AV Bay, they will be in front of the avionics that are mounted in parallel. These are located 3.25 in. from the forward side of the sled, meaning they will line up with the AV band on the exterior of the rocket, allowing for exterior arming. The battery compartments will retain their design and size but will be in a different location along the length of the sled. Once again, the smaller compartment is for a 9V battery that will power the RRC3 primary altimeter, and the larger compartment is for a 2S/7.4V LiPo battery that will power the Quasar secondary altimeter and launch vehicle tracker. Lastly, the holes in these compartments are for zip ties that will secure the batteries in place during launch day. Shown in Figure **??** below is the bottom surface of the designed AV sled.

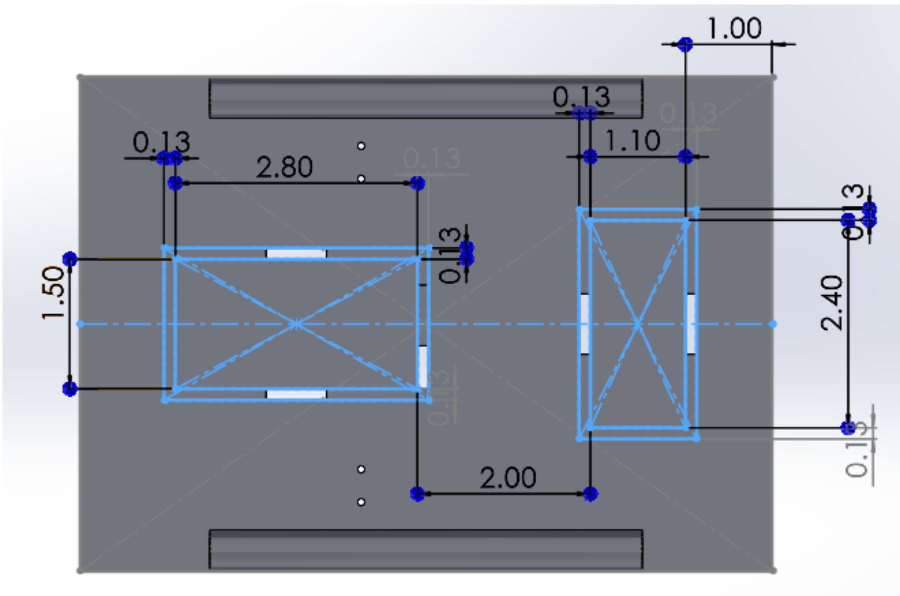

Figure 3.53: Bottom surface of full-scale avionics sled.

PETG filament was chosen as the material for the sled because it is strong enough to withstand the forces the launch vehicle experiences during flight. Additionally, 3D printing was chosen as the fabrication method due to its ease of use, reliability, and ease of access to NC State's 3D printers. The electrical flow diagram for all avionics on the AV sled is presented in Figure 3.54. This ensures there is redundancy in the system, and that the vehicle will separate. Additionally, all wires will be marked with tape with a label such as "MP" for the main primary charge, or "DS" for the drogue secondary charge for clarity and simplicity during AV bay assembly.

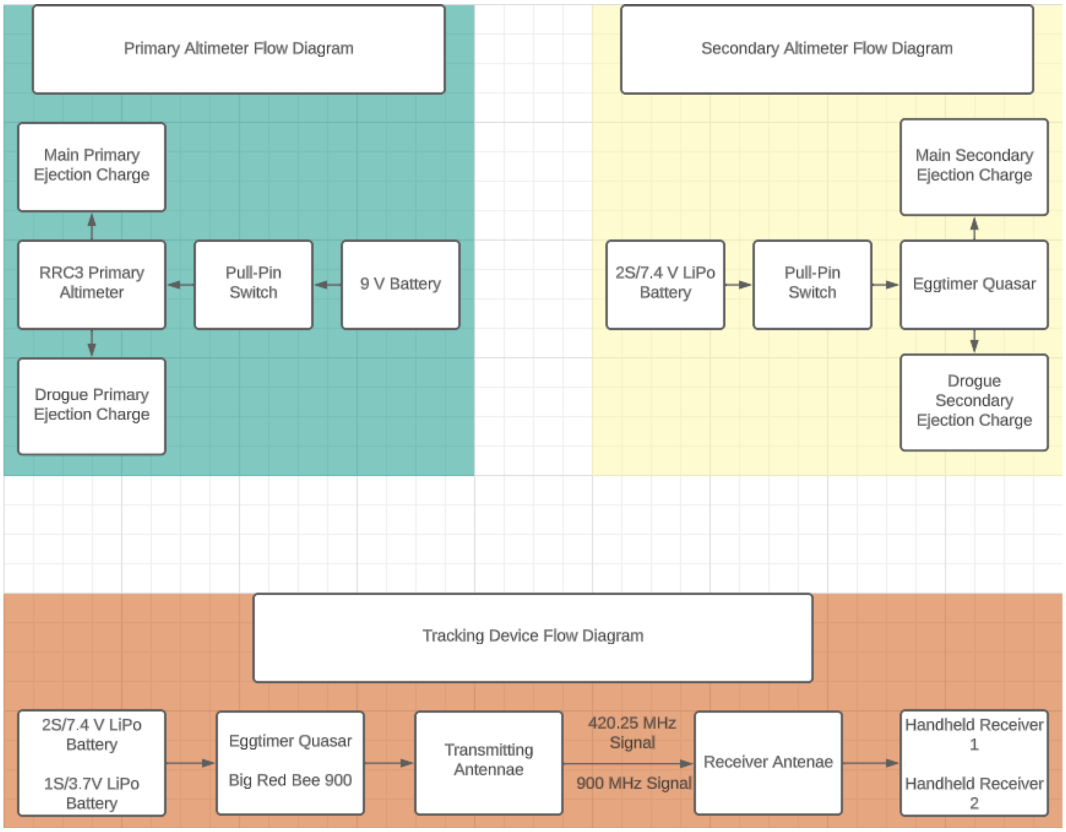

Figure 3.54: Avionics flow diagram.

The blue diagram represents the wiring diagram for the RRC3 primary altimeter which will report the competition altitude, while the yellow diagram represents the wiring diagram for the Quasar secondary altimeter. Each altimeter has pairs of terminal screws for their respective batteries and two e-matches. For the primary altimeter, one wire is connected from the terminal screw on the device to a terminal block on the inside of the aft AV Bay bulkhead. On the other side of the terminal block is an e-match that will feed through the bulkhead and will lay on the inside of the ”primary drogue” blast cap which will be triggered at apogee. Additionally, the other e-match wire for the primary altimeter will go into the terminal block on the inside of the forward AV Bay bulkhead. From there, the e-match will feed through the bulkhead and rest in the ”main primary” blast cap which will be triggered at 800 ft. This process is repeated for the secondary altimeter with their respective secondary blast caps and will trigger at their respective delays of one second after apogee and 700 ft. Finally, the orange diagram conveys the flow diagram for the launch vehicle tracker, the top row, and the nose cone tracker, the bottom row. It is important to note that all LiPo batteries will be charged and tested before each flight, and a fresh 9V battery will be used to ensure there is enough power to ignite the e-matches and record data.

3.5.6 Nose Cone Sled Design

Due to the nose cone separating as an independent section upon the main deployment ejection charge, there needs to be a GPS tracking device in it to comply with NASA Requirement 3.13. This will be done by using a nose cone sled that will hold the nose cone tracker and its battery. This sled is similar to the AV sled in that it will sit on 1/4 in. threaded rods that run through the middle of the nose cone bulkhead seen in Section 3.2.3. Furthermore, like the AV sled, this sled was modeled in SolidWorks and will be 3D printed using PETG filament. The tracker will be mounted through 4-40 nylon standoff screws, and threaded inserts for 3D printed material as discussed in Section 3.5.6. The 1s 3.7V LiPo will be attached through zip ties in drilled holes, similar to the holes in the battery compartments in the AV sled section. Lastly, the nose cone sled shall be secured firmly in place on the threaded rod using 1/4 in. nuts. Shown in Figures 3.55 and 3.56 is the design of the nose cone sled.

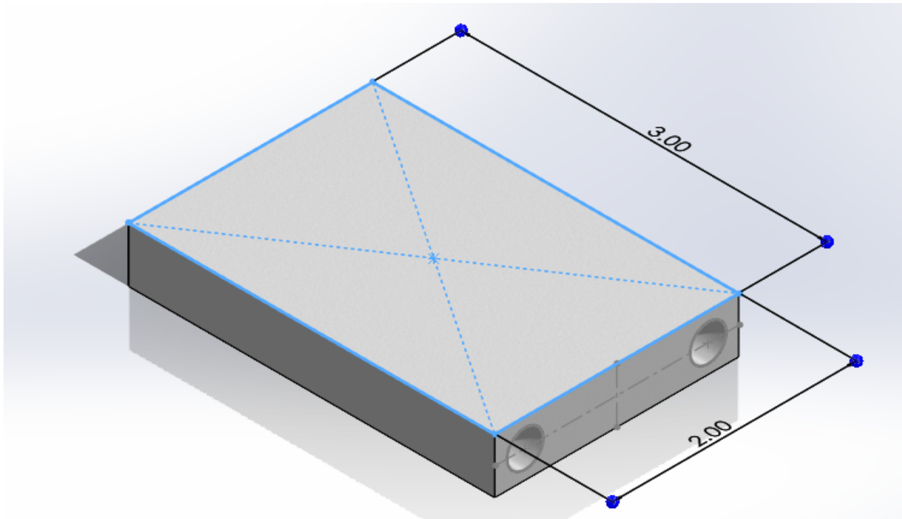

Figure 3.55: Full-Scale nose cone sled.

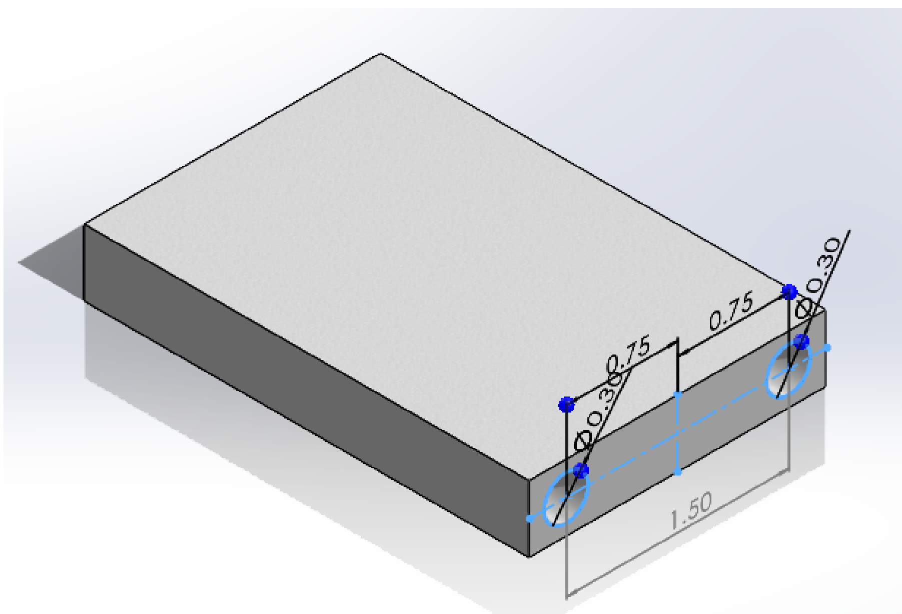

Figure 3.56: Full-Scale nose cone sled.

3.5.7 Parachute Selections

Deployed at apogee via an ejection charge, the drogue parachute for the launch vehicle shall be a Fruity Chutes 15 in. classic elliptical parachute. With a burnout mass of 1.41 slugs, the launch vehicle will descend under this drogue parachute at a rate of 110.13 ft/s until an altitude of 800 ft. The drogue descent velocity, along with main and nose cone descent velocities were calculated using the descent velocity under a parachute equation in Section 3.6.5. Once the launch vehicle reaches 800 ft., the nose cone separates, pulling the payload out of the launch vehicle and the deployment bag off of the main parachute for the launch vehicle. The main parachute for the launch vehicle shall be a Fruity Chutes 96 in. Iris Ultra Compact. Once the main parachute is deployed, the launch vehicle, with a new mass of .92 slugs, will fall at a rate of 15.38 ft/s until it lands. At this point, the launch vehicle will no longer contain the nose cone or payload deployment bay, hence the smaller mass. Under this main parachute, the maximum drift distance is 2391.81 ft., the maximum kinetic energy is 63.89 ft-lbs, and the descent time of the launch vehicle is calculated to be 81.54 seconds. These parameters are calculated using the equations in Sections 3.6.5, 3.6.6, and 3.6.7. Therefore, this parachute is the only alternative that meets the wind drift distance, kinetic energy, and descent time requirements for the launch vehicle, and these specifics are shown in detail in Section 3.6.

The nose cone parachute shall be a Fruity Chutes 48 in. classic elliptical parachute. With a mass of .493 slugs, the nosecone will descend at a rate of 27.16 ft/s while the payload is attached. Once the payload is released at approximately 450 ft., the nose cone, with a mass of .167 slugs, will descend at a rate of 15.83 ft/s. Under this parachute, the landing kinetic energy for the nose cone is 20.97 ft-lbs, the maximum drift distance from the launch pad is 2077.72 ft., and the descent time after main separation is 41.32 seconds. The descent time of the launch vehicle from apogee to main deployment altitude is 29.51 seconds, thus the total descent time of the nose cone from apogee to landing will be 70.83 seconds. Once again, these parameters are calculated using the equations in Sections 3.6.5, 3.6.6, and 3.6.7. Therefore, this parachute meets the wind drift distance, kinetic energy, and descent time requirements for the nose cone, and these specifics are shown in detail in Section 3.6.

3.5.8 Shock Cord and Points of Attachment

The shock cords used for the launch vehicle will be 5/8 in. thick Kevlar webbed shock cords. These were chosen over nylon shock cords due to their greater strength and historic use in the club. Shown below in Figure 3.57 is a diagram of the shock cord configuration and lengths used for the recovery system.

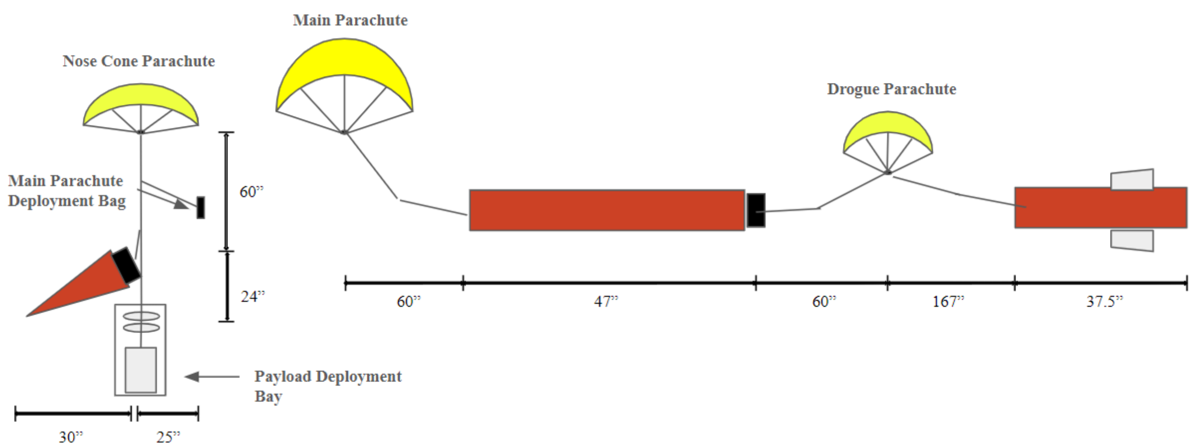

Figure 3.57: Shock cord and parachute placement diagram.

The parachutes are attached to the shock cord via stainless steel quick links that attach to bowline knots in the shock cord. Additionally, the shock cord is attached to the bulkheads of the launch vehicle through these quick links going through bowline knots on the cord and U-bolts on the bulkheads. The bowline knot for the drogue parachute will be 60 in. aft of the AV Bay bulkhead, where the drogue parachute and a protective Nomex cloth will be connected with a quick link. Given that the fin can will be descending lower than the rest of the launch vehicle under the drogue parachute, the length of the shock cord between the drogue parachute and the fin can is very large to allow a 5 ft. gap of separation between the falling separating sections. This avoids collision between the sections and prevents damage to the launch vehicle. The main parachute will be located on a bowline knot at the end of the 100.5 in. long shock cord, where the main parachute will be protected by a deployment bag that gets removed by the nose cone. Also, the deployment bag that covers the main parachute while it is packed in the main parachute/payload bay is attached to a 25 in. shock cord that is connected to a loop halfway along the nose cone parachute shock cord via a quick link. Additionally, the nose cone parachute is tied to a bowline knot 60 in. from the U-bolt of the nose cone bulkhead, where the nose cone parachute and a protective Nomex cloth will be connected with a quick link. Lastly, the U-bolt on top of the payload deployment bay will be tethered to the nose cone U-bolt via a 24 in. shock cord, where connections are made using quick links as well. The payload will be housed in the deployment bay, and its release is explicated in Section 4.4. As a result, once the main deployment ejection charge ignites, the nose cone separates independently, first pulling out the nose cone parachute which will deploy, then pulling out the payload deployment bay, and lastly, the now independent nose cone will remove the deployment bag off the main parachute since the bag is attached to the nose cone via shock cord. This shock cord length configuration allows for separation in this correct order, as it was tested successfully for the subscale launch. Upon complete successful separation, the main parachute for the launch vehicle will deploy since the deployment bag will be removed, and the nose cone and payload will descend under its own parachute. Due to the complexity of this recovery configuration for the nose cone parachute, payload deployment bay, and main parachute, a packing illustration is shown in Figure 3.58 below for clarity.

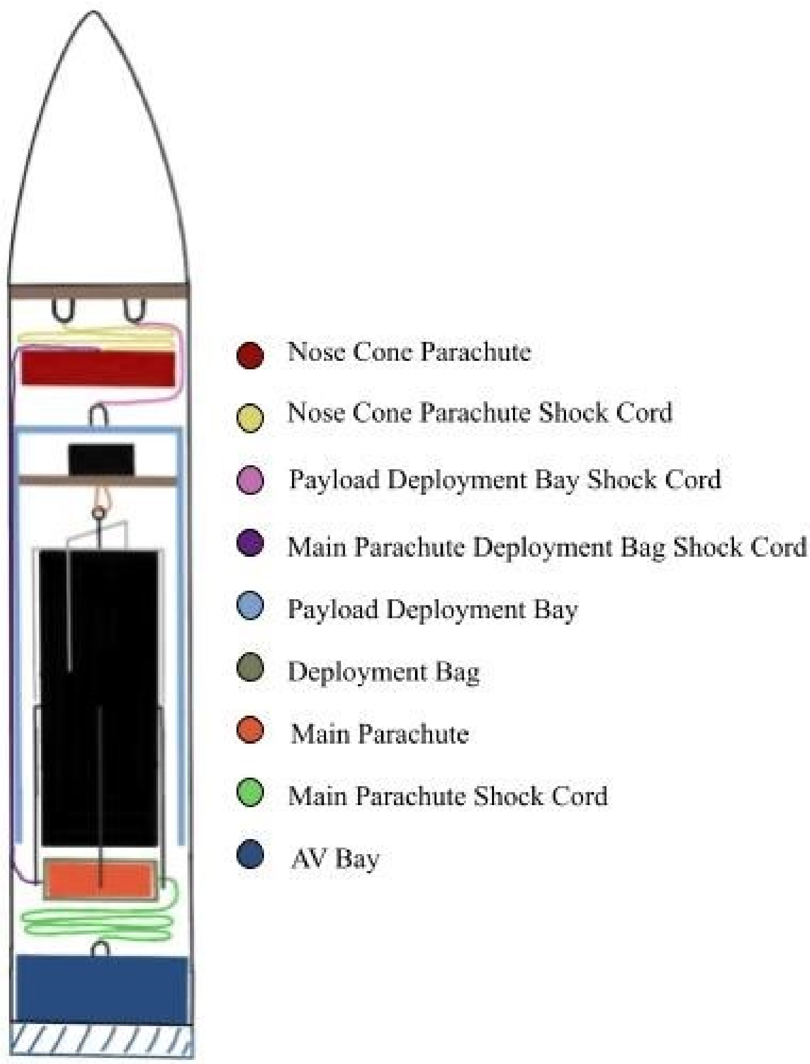

Figure 3.58: Main parachute bay packing diagram.

3.6 Mission Performance Predictions

3.6.1 Launch Day Target Apogee

The officially declared target apogee is 4050 ft. AGL. Simulations and hand calculations verify that launch conditions according to the 2024 Student Launch Handbook specifications with accurate drag profile and wind forecast will reach this target apogee with a high degree of confidence.

3.6.2 Updated Flight Profile Simulations

Based on the updated launch vehicle mass and selected motor, the RocketPy analysis used to generate the highest fidelity results was reconfigured. The process of reconfiguration involved the updating of the launch vehicle's center of gravity derived from the OpenRocket mass distribution, along with the recalculation of the launch vehicle's moment of inertia. Special consideration was used to specify the exact coordination of the launch location, such as high-fidelity elevation and wind forecasting, generated using the NOAA Global Forecast Model (GFS). RocketPy contains specific API methods for retrieving various forecast methods, and as models for the launch forecast become relevant, the RocketPy model can be regenerated. For this analysis, a 12 ft. rail length was used, along with a 5° rail cant, following NASA Requirement 1.12. From the current model, the predicted apogee was found to be 4048.67 ft., occurring at 16.05 seconds into the flight.

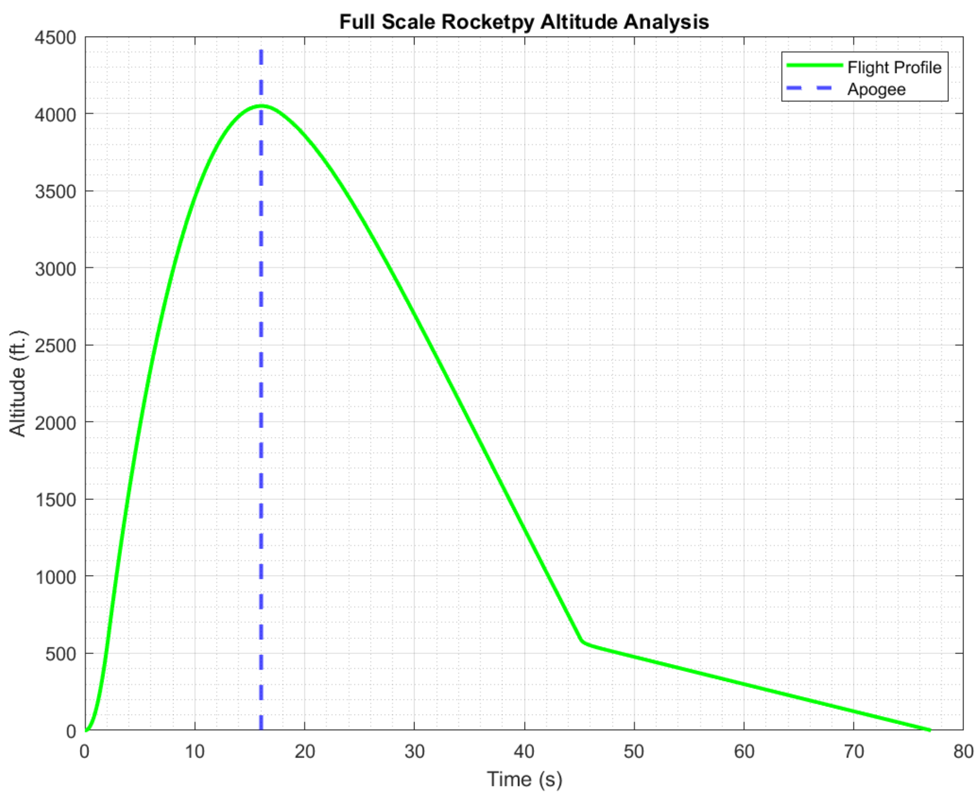

Figure 3.59: Calculated flight profile of the full-scale launch vehicle.

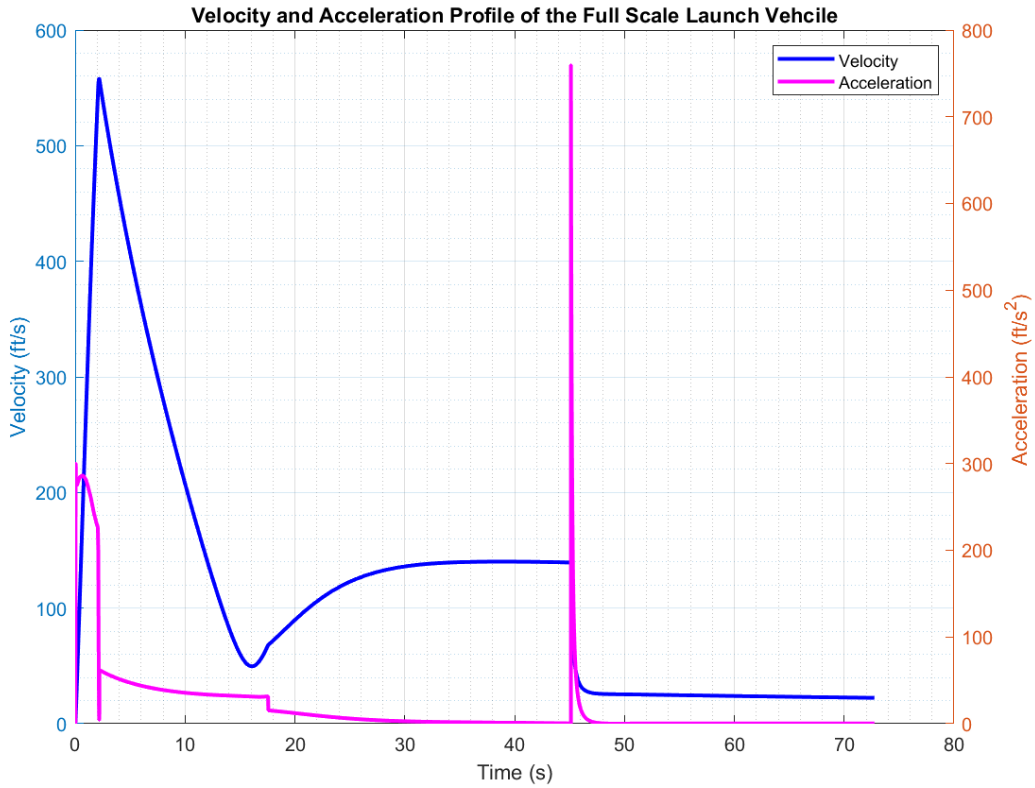

Figure 3.60: Calculated velocity and acceleration profile of the full-scale launch vehicle.

From Figure 3.60, the maximum velocity achieved is 555.24 ft/s which equates to a Mach number of 0.51, satisfying NASA Vehicle Requirement 2.22.6. The launch vehicle archives a maximum acceleration during liftoff of $299.26 ft/s^2$ satisfying LVD 8. The decent velocity under the drogue and main parachute is shown to be a constant 140 ft/s, and 17 ft/s, respectively. Due to the low velocity at apogee deployment, the shock acceleration experienced by the launch vehicle due to drogue deployment is minimal. However, the decent rate under a drogue parachute produces a large spike in acceleration, approximately 2.5 times larger than the maximum acceleration of the launch vehicle during ascent. From the exported data from RocketPy, a sample flight profile can be plotted in Google Earth using the supplied KML file.

Figure 3.61: 3D flight profile plotted using Google Earth.

3.6.3 Altitude Verification

To verify that the apogee value produced by RocketPy is within a margin of expected values, the Fehskens-Malewicki equations can be used. The background regarding these equations was discussed in detail in the PDR document.

The drag force unit velocity squared can be expressed by the constant k:

$$k = \frac{1}{2}\rho C_d A \quad (4)$$

The empirical factor q, which is a relationship between the thrust, drag, and gravity, can be expressed as:

$$q = \sqrt{\frac{T - Mg}{k}} \quad (5)$$

The empirical factor x, which relates the drag and q per unit mass, can be expressed as:

$$x = \frac{2kq}{M} \quad (6)$$

The maximum velocity of the launch vehicle can then be derived by using Equations 5 and 6:

$$v_{max} = q\frac{1 - e^{-xt}}{1 + e^{-xt}} \quad (7)$$

The altitude of motor burnout, where the force of drag and gravity become the primary forces acting on the launch vehicle, can be determined by:

$$Z_{burnout} = -\frac{M}{2k} \ln\left(\frac{T - Mg - kv_{max}^2}{T - Mg}\right) \tag{8}$$

The total coast distance of the launch vehicle after burnout can be determined by:

$$Z_{coast} = \frac{m \ln\left(\frac{mg+kv^2}{mg}\right)}{2k} \tag{9}$$

Finally, to determine the apogee of the launch vehicle, the coast distance and height of burnout can be summed:

$$Z_{apogee} = Z_{burnout} + Z_{coast} \tag{10}$$

With these equations, the constants and resulting values can viewed in Table 3.8.

Table 3.8: Apogee Calculation Constants and Results

Constant	Variable Name	Value	Units
M	Power On Average Mass	1.354	$slug$
m	Power Off Average Mass	1.286	$slug$
g	Gravitational Acceleration	32.174	ft/s^2
t	Motor Burn Time	2.6	s
T	Average Thrust	312.48	lbf
ρ	Air Density	0.002377	$slug/ft^3$
A	Launch Vehicle Frontal Area	0.2076	ft^2
C_d	Drag Coefficent	0.54	N/A
Equation	**Result**		**Units**
k	0.0001332		$slug/ft$
q	1420.687		ft^2/s^2
x	0.2795		ft/s^2
v_{max}	546.355		ft/s
$Z_{burnout}$	813.227		ft
Z_{coast}	3250.67		ft
Z_{apogee}	4063.89		ft

From the analytical calculation, the apogee of the launch vehicle is within 15 ft. of the numerical simulation-derived value, a 0.369% difference. The high similarity among the values instills confidence in the accuracy of the numerical simulations.

3.6.4 Stability Margin Simulation

The center of pressure of the launch vehicle is the location for which all aerodynamic forces act on the launch vehicle without the addition of a corrective moment. This location is a function of the aerodynamic surfaces of the launch vehicle, such as the nose cone and fins. As the rocket leaves the launch rail, an oscillatory motion is induced due to the distance between the rail buttons and the external forces of the launch vehicle. As the launch vehicle increases in speed, the control authority of the fins increases to a point where the motion has damped into a constant launch vehicle angle of attack. The center of gravity also changes during the flight of the launch vehicle as propellant mass leaves the motor, causing the center of gravity to shift further forward. The location of the center of gravity is easily determined analytically and experimentally, but the center of pressure calculation involves CFD simulations to yield high-fidelity results.

For this analysis, a ballast of 3.2 pounds has been used. Based on the most current simulation data presented, to reach a desired apogee of 4050 ft, a maximum ballast of 3.2 pounds is required. While this ballast functions as an apogee target modifier, the location of this ballast plays a roll in the stability of the launch vehicle. Due to the high concentration of mass at the top of the launch vehicle, the ballast will be placed within the removable fin system to decrease the stability of the launch vehicle by shifting the center of gravity aft. Depending on simulation data, ballast in the form of metal may be removed from this location in order to compensate for wind speeds present on the launch field. Ballast may also be secured to the avionics bay in order to increase or decrease the mass of the launch vehicle by up to 0.25 lb without altering the center of gravity as per LVD 10.

Rocket simulation softwares have developed algorithms that can determine an estimate for the center of pressure to a high enough accuracy for most applications, but the determination of the center of pressure varies between software. Figure 3.62 shows an example launch vehicle using OpenRocket with the center of gravity being shown in blue and the center of pressure being shown in red.

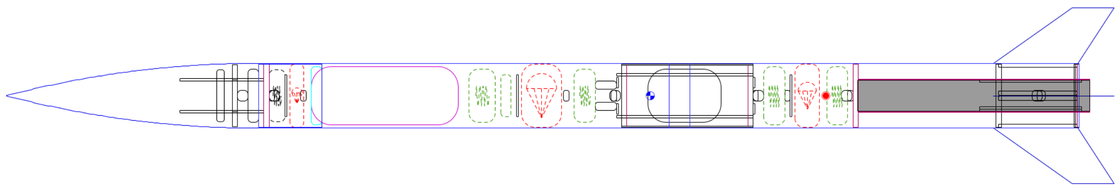

Figure 3.62: Center of gravity and center of pressure labeled on the full-scale launch vehicle.

To capture the change in center of gravity and center of pressure throughout the flight profile, OpenRocket launch data has been exported and plotted. From the data, it can be seen that the center of pressure increases as the launch vehicle velocity increases. The center of gravity also decreases linearly as mass is ejected from the launch vehicle. The stability margin remains positive throughout the accent, with a maximum value of 3.306. Per NASA Requirement 2.13, the stability at the rail exit must be greater than 2.0. Multiple software simulations were used to verify this as shown in Table 3.9.

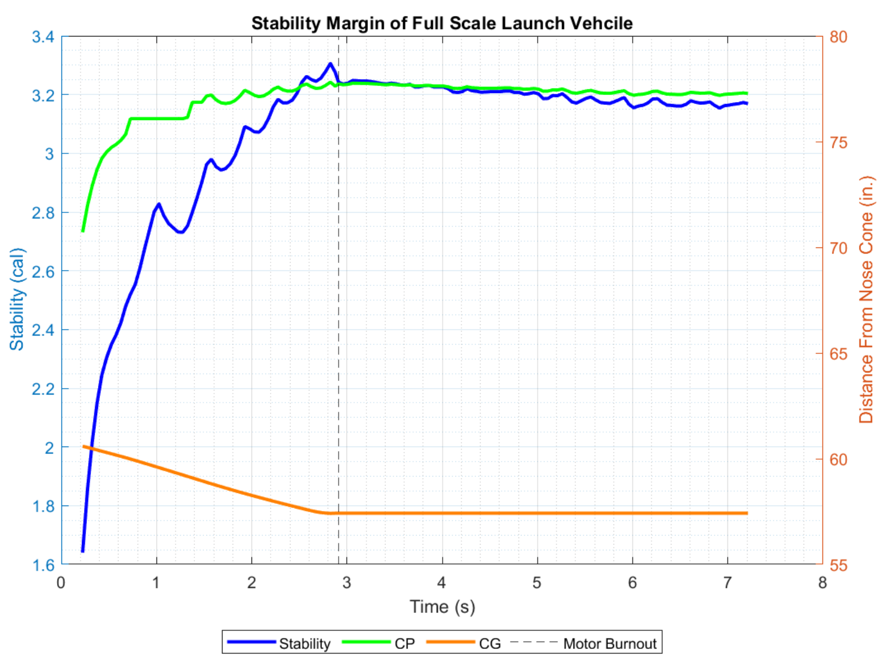

Figure 3.63: Stability margin throughout the ascent of the launch vehicle.

Table 3.9: Stability Margin at Rail Exit

Software	Stability Margin	Center of Gravity (in.)	Center of Pressure (in.)
OpenRocket	2.70	61.23	77.90
RocketPy	2.66	61.23	77.65
RasAeroII	2.65	61.23	77.59

From Table 3.9, the calculated stability margins are all within 0.05 calipers of each other, resulting in a high confidence in the fidelity of the stability margin calculation for verification of NASA Requirement 2.14.

Barrowman Verification

Barrowman's equations can be used to anchor the software-determined stability with analytical calculations by incorporating the nose cone and fin stability estimation equations shown below. These values are used to determine an estimate for the center of pressure that is used in Equation 15 to determine the stability margin in a similar fashion to Table 3.9.

$$X_N = 0.466 L_N \tag{11}$$

$$(C_{N_f}) = 1 + \frac{R}{S+R}\left[\frac{4N(\frac{S}{d})^2}{1+\sqrt{1+(\frac{2L_F}{C_R+C_T})^2}}\right] \tag{12}$$

$$X_f = X_B + \frac{X_R(C_R+2C_T)}{3(C_R+C_T)} + \frac{1}{6}\left[(C_R+C_T - \frac{C_R C_T}{C_R+C_T}\right] \tag{13}$$

$$X_{CP} = \frac{C_N X_N + C_F X_F}{C_N + C_F} \tag{14}$$

$$SM = \frac{X_{CP} - X_{CG}}{2R} \tag{15}$$

The constants used in this equation, along with the results of each equation, are provided in Table 3.10.

Table 3.10: Stability Margin Constants and Results

Constant	Variable Name	Value	Units
$(C_N)_N$	Nose Cone Coefficient	2	N/A
X_N	Nose Cone Length Factor	11.184	in.
R	Body Radius	3.085	in.
S	Fin Span	5.25	in.
N	Number of Fins	4	N/A
d	Base of Nose Diameter	6.17	in.
L_F	Fin Midchord Line Length	7.60	in.
C_R	Fin Root Chord Length	8	in.
C_T	Fin Tip Chord Length	4	in.
X_B	Nose to Root Chord LE length	93.5	in.
X_R	Tail to Root Chord LE length	7.5	in.
Equation	Result		Units
$(C_N)_f$	6.83		N/A

Table 3.10: Stability Margin Constants and Results

Constant	Variable Name	Value	Units
X_f	98.388		in.
X_{CP}	78.62		in.
SM	2.81		Calibers

From this analysis, the stability margin calculated is within 0.11 calipers of the software-derived values. This validates the performance of the analysis software and ensures that the stability margin determined by OpenRocket fits the expected values. Overall, the stability margin satisfies NASA Requirements 2.13, LVD 5, and LVD 6.

3.6.5 Kinetic Energy at Landing

Through the use of Newtonian Mechanics, the kinetic energy for the launch vehicle upon landing can be calculated using Equation 16. Let KE represent the kinetic energy, m represent the mass of the launch vehicle or independent section, and V represent its velocity.

$$KE = \frac{1}{2}mV^2 \tag{16}$$

Per NASA Requirement 3.3, the maximum impact energy allowed for each body section is 75 ft-lbf. Additional points can be attained for being below 65 ft-lbf. Using the equation listed above, the impact velocity necessary to meet the kinetic energy requirement for each section of the launch vehicle under main parachute descent is shown in Table 3.11.

Table 3.11: Required Velocity for Kinetic Energy Requirement

Section	Section of Mass	Descent Velocity Necessary to be Awarded Points	Descent Velocity Necessary to be Awarded Bonus Points
Nose Cone	.167 slugs	29.97 ft/s	27.90 ft/s
Main Parachute/ Payload Bay and Avionics Bay	.376 slugs	19.97 ft/s	18.59 ft/s
Drogue Bay/ Fin Can	.540 slugs	16.67 ft/s	15.52 ft/s

Mentioned in Section 3.5.7, the main parachute selected is the 96 in. Iris Ultra Compact by Fruity Chutes. The descent velocity for the launch vehicle and nose cone without the payload attached can be found using Equation 17 below. Let m be the burnout mass of the launch vehicle, g be Earth's gravitational acceleration constant, S be the parachute's area, C_D the drag coefficient of the parachute, ρ the density of the air, and V_D the descent velocity of the launch vehicle.

$$v_d = \sqrt{\frac{2gm}{SC_D\rho}} \tag{17}$$

Using the equation above, the descent velocity of each section can be used to calculate their kinetic energy upon landing. These values are presented in Table 3.12 below.

Table 3.12: Landing Kinetic Energy for Each Section

Section	Section of Mass	Velocity Under Main Parachute	Impact Energy
Nose Cone	.167 slugs	15.83 ft/s	20.97 ft-lb
Main Parachute/ Payload Bay and Avionics Bay	.376 slugs	15.38 ft/s	44.47 ft-lb
Drogue Bay/ Fin Can	.540 slugs	15.38 ft/s	63.89 ft-lb

Mentioned in Section 3.5.7, and seen in the table above, the descent velocity calculated for the launch vehicle with the 94 in. Iris Ultra Compact parachute is 15.38 ft/s. Additionally, the descent velocity of the nose cone without the payload will be 15.83 ft/s. It can be seen from Table 3.12 that the kinetic energy requirement for each section hitting the ground is satisfied. The velocities provided were calculated using Equation 17, where the AV bay, main parachute/payload bay, and fin can have the same descent rate since they are tethered together under the main parachute.

3.6.6 Expected Descent Time

The total descent time for the launch vehicle is broken up into two sections, the descent time under drogue, and the descent time under main parachute. Calculated using 17, and stated in Section 3.5.7, the descent velocity of the launch vehicle under drogue and main parachutes is used to find the descent time. Additionally, the descent time is a factor of the apogee height and the main deployment altitude. Total descent time is found using Equation 18 below.

$$t = \frac{h_a - h_m}{v_d} + \frac{h_m}{v_m} \tag{18}$$

Let t represent the total descent time for the launch vehicle, h_a is the apogee altitude, h_m is the main deployment altitude, v_d is the descent velocity of the vehicle under drogue parachute, and v_m is the descent velocity of the launch vehicle under main parachute. The total descent time for the launch vehicle was calculated to be 81.54 seconds, which meets NASA Requirement 3.12.

Additionally, the nose cone descent time can be found using Equation 19 and both the descent velocity of the nose cone with the payload attached to the payload deployment bay at an altitude of 450 ft., and the descent velocity of the nose cone when the payload is not attached to the deployment bay at landing. These parameters are referenced in Section 3.5.7.

$$t_n = t_d + \frac{h_m - h_p}{v_p} + \frac{h_p}{v_n} \tag{19}$$

Where t_n is the total descent time of the nose cone, t_d is the descent time of the launch vehicle under drogue, h_m is the height the main parachute is deployed (800 ft.), h_p is the height the payload is deployed (450 ft.), v_p is the descent velocity of the nose cone and payload under the nose cone parachute, and v_n is the descent velocity of the nose cone without the payload attached. The total descent time of the nose cone from apogee to landing is 70.83 seconds, which meets NASA Requirement 3.12.

3.6.7 Expected Wind Drift Distance

When determining the expected drift distance, a large overestimation is used to ensure the launch vehicle will not drift more than 2,500 ft. from the launch pad. This consists of assuming that the drift velocity of the launch vehicle is equal to the wind speed, where this drift velocity is completely horizontal. Another assumption is that the launch vehicle will only travel vertically to apogee, the launch vehicle immediately descends under the drogue parachute's terminal velocity upon drogue separation, and the launch vehicle immediately falls under the main parachute's terminal velocity upon main separation. Therefore, it is assumed that from apogee to landing, the launch vehicle and separated nose cone will descend in one direction at a constant horizontal drift speed equivalent to the wind speed. It is important to state that the actual drift speed is a function of the drag from the parachute, the descent velocity, and other factors meaning it is not equivalent to the wind speed in reality. It is desirable to overshoot this estimation to eliminate the risk of even getting close to the maximum 2,500 ft. drift distance. Using the following equation, the drift distance of the launch vehicle can be calculated for different wind speed conditions. Let v_w be the wind speed, t be the estimated descent time, and D is the expected drift. As mentioned in Section 3.6.6, the total descent time for the launch vehicle is approximately 81.54 seconds, and the descent time for the nose cone from the main deployment altitude is 41.32 seconds.

$$D = v_w t \tag{20}$$

Using this equation, the total wind drift for the launch vehicle can be calculated using the wind drift under the drogue parachute and adding the wind drift from the main parachute. For the nose cone, the total wind drift is found using the wind drift for the launch vehicle under drogue, and adding the wind drift of the nose cone under its parachute. Presented below in Table 3.13 are the wind drift distances calculated for various wind speeds.

Table 3.13: Wind Drift Distances for Varying Wind Speeds

Wind Velocity	Launch Vehicle Drift Distance	Nose Cone Drift Distance
0 mph	0 ft	0 ft
5 mph	597.95 ft	519.42 ft
10 mph	1,195.90 ft	1,038.86 ft
15 mph	1,793.85 ft	1,558.30 ft
20 mph	2,391.81 ft	2,077.72 ft

From looking at the table, the overestimated maximum drift distance under a 20 mph wind will be 2,309.63 ft., which is under the 2,500 ft. requirement set by NASA.

3.6.8 Ejection Charge Sizing

When determining the mass of the black powder charge, the varying factor is the empty volume in the section that is separating. This empty volume is found by taking the volume of the compartment and subtracting the volume of the shock cord, parachute, and any other recovery/payload components in the section. The other factor to be found is the pressure that will separate the section by breaking the shear pins. Once the empty volume and the pressure are calculated, the ideal gas law equation can be used to determine the mass needed for black powder. The ideal gas law is shown in Equation 21 below.

$$PV = mRT \tag{21}$$

Let P represent the pressure needed to separate the section, V represents the empty volume of the section, m is the mass of the black powder, R is the gas constant of black powder combustion products, and T is the temperature of black powder during combustion. This temperature is known to be 3,307 degrees Rankine, the gas constant is 22.16 ft-lb, and the calculated pressure needed to shear the pins is 20 psi. Note that each 4-40 nylon shear pin is rated for 2.5 psi, thus a pressure of 10 psi is necessary to shear 4 pins holding the separating sections together. However, a factor of safety of 2 is used on the necessary pressure to shear the pins to account for any incomplete combustion of black powder during the ejection charge, and the skin friction between the separating section and coupler tubes.

The recovery system includes a secondary black powder charge to ensure redundancy for launch vehicle separation. Each secondary charge will be 0.5 grams more than the primary charge for that section, ensuring separation in case of primary charge failure while not being large enough to cause damage. Shown below in Table 3.14 are the calculated ejection charge sizes.

Table 3.14: Ejection Charge Sizing for Each Separating Section

Point of Separation	Primary Charge Mass	Secondary Charge Mass
Nose Cone and Main Parachute/ Payload Bay	4.5 grams	5.0 grams
Avionics Bay and Drogue Bay/ Fin Can	2.5 grams	3.0 grams

The ejection charge itself shall be 777-grade FFF black powder, its very fine grains allowing for faster combustion. Faster combustion is preferred since it allows for a clean separation and leaves less unburnt black powder scattered in the separated section.

To comply with NASA Requirement 3.2, a ground ejection test will be performed for both primary charges before launch. A successful ejection test demonstrates that the launch vehicle will be able to separate and the ejection charges are sized appropriately. If the launch vehicle fails to separate during the ejection test, an additional 0.2 grams will be added to the primary charge, and the test will be repeated. This process, outlined in Section 6, will continue until safe, successful separation is ensured.

3.6.9 Parachute Opening Shock Calculations

One of the largest loads the launch vehicle experiences is the shock force experienced when the main parachute deploys. The shock force is a function of the time it takes the parachute to open, the change in velocity of the launch vehicle from drogue descent to main descent, and the mass of the launch vehicle. To calculate the shock force, the time it takes the parachute to open needs to be calculated first. This is found using the equation below, where r is the radius of the parachute opening, v is the drogue descent velocity, and t is the time it takes the parachute to open.

$$t = \frac{8r}{v} \tag{22}$$

Found in a study by W. Ludtke on how to calculate opening shock forces for a parachute, a coefficient of 8 is necessary to find the time it takes the parachute to open [13]. For the Fruity Chutes 96 in. parachute with a drogue descent rate of 110.13 ft/s, the time it takes to open is approximately 0.2905 seconds. From there the shock force can be found using the equation below where F is the shock force, m is the mass of the launch vehicle, Δv is the change is descent velocity from drogue to main, and t is the time it takes the main parachute to open.

$$F = \frac{m\Delta v}{t} \tag{23}$$

Shown below, Table 3.15 contains the maximum shock force the launch vehicle and some of its core components will experience. Note that the 5/8 in. Kevlar webbed shock cord is rated up to 6000 lbf, thus there are large factors of safety for these shock force loads experienced upon main deployment.

Table 3.15: Maximum Shock Forces

Section	Mass of Section	Parachute Opening Time	Parachute Opening Shock
Nose Cone with Payload	.493 slugs	.15 s	281.56 lbf
Main Parachute/ Payload Bay and Avionics Bay	.376 slugs	.29 s	122.61 lbf
Drogue Bay/ Fin Can	.540 slugs	.29 s	176.09 lbf
Separated 1Launch Vehicle	.916 slugs	.29 s	298.70 lbf

4 Payload Criteria

4.1 Payload Mission Statement and Success Criteria

The payload mission is to successfully land four STEMnauts that have human survivability characteristics. The payload must deploy between 400-800 ft. AGL and can not use parachutes or streamers for the recovery method. Additionally, the payload must land in a pre-define orientation, in this case vertically.

Table 4.1: Payload Success Criteria

Success Level	Payload Aspect	Safety Aspect
Complete Success	The SAIL lands in the pre-defined orientation and with a landing velocity of under 5 mph. Additionally, the SAIL does not experience any sustained forces greater than 3 G's.	No personnel are harmed or at risk during payload recovery
Partial Success	The SAIL lands in the pre-defined orientation but with a velocity between 5 mph and 15 mph OR the SAIL lands with a velocity under 5 mph but does not come to rest in the pre-defined orientation.	No personnel are harmed during payload recovery but there is at least one close call.
Partial Failure	The SAIL impacts the ground with a velocity greater than 15 mph but receives no major damage.	Personnel receive minor injuries during payload recovery.
Total Failure	The SAIL impacts the ground with a velocity greater than 15 mph AND sustains catastrophic damage.	Personnel receive major injuries during payload recovery.

4.2 FAA Classification

The following quotation was taken from FAA Advisory Circular No. 91-57A:

> Section 336 of P.L. 112-95 defines a model aircraft as an unmanned aircraft that is capable of sustained flight in the atmosphere, flown within visual line of sight of the person operating the aircraft, and flown only for hobby or recreational purposes. [27]

The SAIL has been designed in a way that it is not capable of sustained flight. It does not have any form of cyclic controls to allow for translational movements. Additionally, the thrust is limited by the flight computer to never produce enough thrust to lift the vehicle off of the ground. The function of the rotor blade system is to only slow the vehicle down prior to landing, not to fly. After communicating with the FAA, we received confirmation that our design would be viewed similarly to a helicopter duration model rocket and would NOT be considered an UAS because it cannot fly.

4.3 SAIL Final Design Overview

The SAIL uses a pair of contra-rotating rotor blades to autonomously control its descent velocity. Its components are broken down into the following subsystems: rotor blades, rotor hubs, gearbox, power plant, landing legs and electronics. Each subsystem is detailed in the following pages. Figures 4.1 and 4.2 shows the fully assembled SAIL in both the deployed and folded states.

Figure 4.1: SAIL in a deployed state.

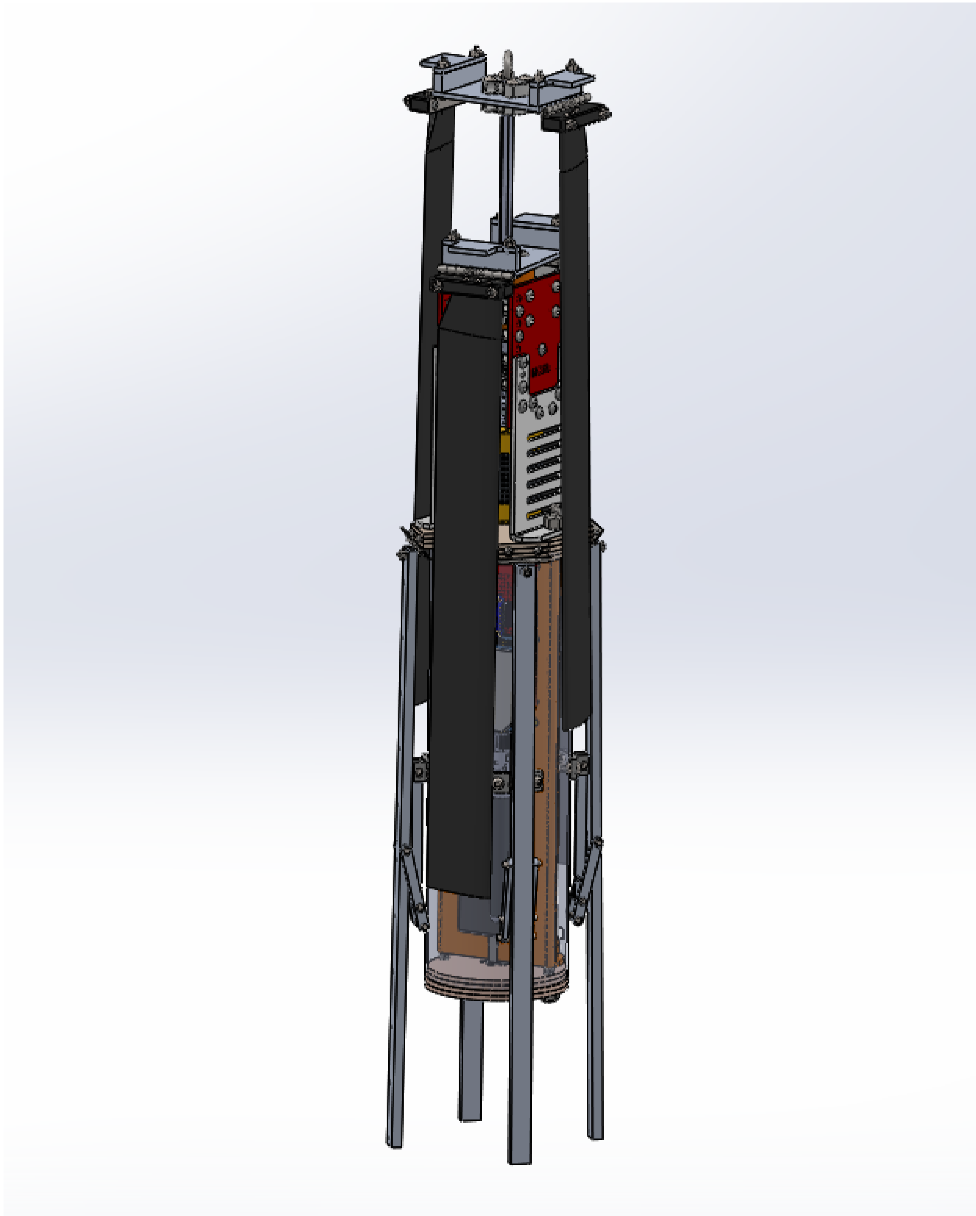

Figure 4.2: SAIL in a folded state.

4.3.1 Rotor Blades

CFD analysis was conducted on both 2 blade and 4 blade configurations. It was determined that by increasing the chord length to 2 in., 2 rotor blades would generate enough thrust to support the SAIL. This is beneficial for two reasons: reduced weight and reduced space. Team Derived Requirement PD 5 limits the SAIL weight to 8 lb. Using a 2 blade design will reduce the total weight by approximately 0.5 lbs. Additionally, space inside the payload bay is very limited. By reducing the total blade count from 8 to 4, more space is available for other SAIL components such as the landing legs.

The CFD analysis was performed in ANSYS Fluent using the 2 equation k-omega viscous model. A 3D model of the rotor blade system was created in SolidWorks and imported into ANSYS Geometry. Using DesignModeler, rotating regions were created around the rotor blades and a cylindrical boundary region was created around the entire vehicle, illustrated in Figure 4.3. A mesh was generated with properties listed below in Table 4.2. Setting the mesh motion around the rotor blades to RPM settings between 1000 and 1800 in 100 RPM intervals, the thrust profile in Figure 4.4 was created.

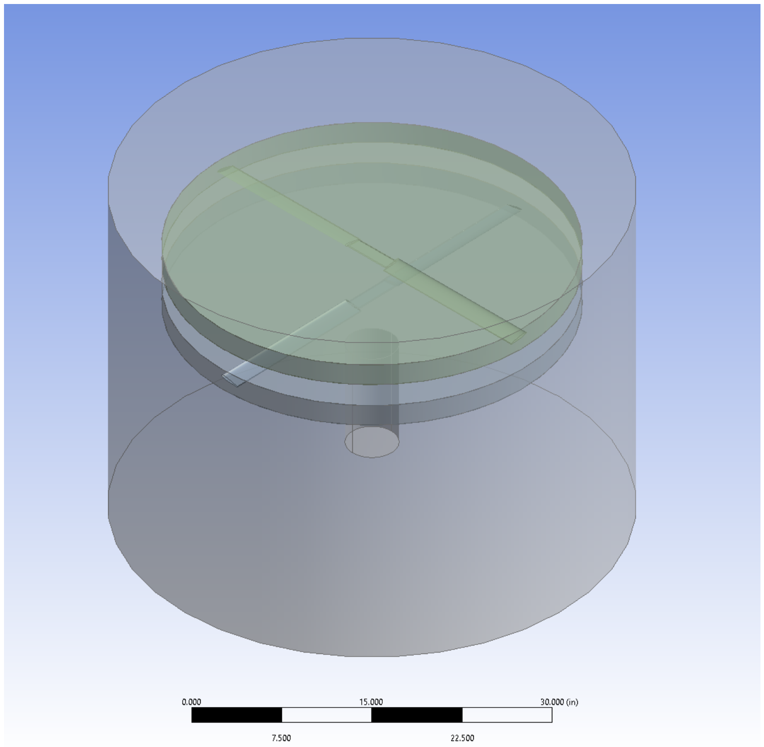

Figure 4.3: ANSYS geometry with cylindrical boundary.

Table 4.2: ANSYS Mesh Properties

Property	Value
Element Quality (average)	0.83315
Element Quality (worse)	0.19842
Aspect Ratio (average)	1.8527
Aspect Ratio (max)	9.9174
Skewness (average)	0.23545
Skewness (max)	0.80944
Orthogonal Quality (average)	0.76332
Orthogonal Quality (worse)	0.19056
Elements	1873585

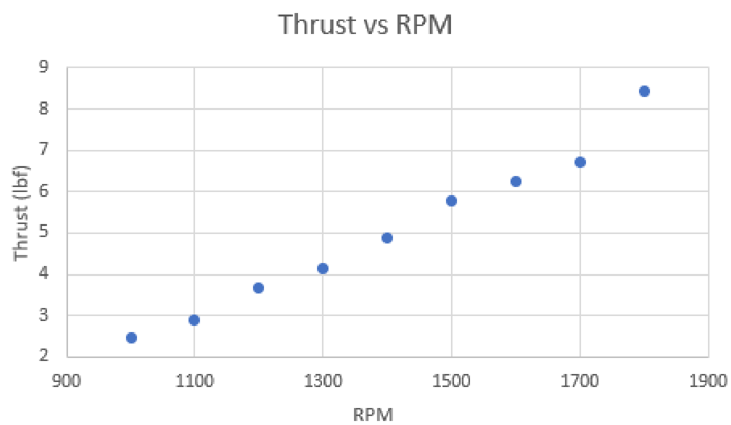

Figure 4.4: CFD Derived Thrust Curve

The CFD derived thrust curve shows that the rotors will have to rotate at roughly 1700 RPM to generate enough thrust to slow the vehicle down to acceptable descent velocities. The selected motor, described in section 4.3.4, will be able to operate in RPM ranges up to 3000 RPM, leaving plenty of headroom to allow for discrepancies between the theoretical values and actual values.

4.3.2 Rotor Hubs

Hub Assembly

To dissect the entire SAIL seen in Figure 4.1, a top-down approach will be used. There are two rotor hubs that hold two propeller blades each. To ensure coaxial rotation, these hubs have to be attached to individual parts with connecting pieces. The upper hub, seen in Figure 4.5, is attached to a central hex shaft (0.32 in. diameter, 7.72 in. tall), seen in Figure 4.6. This connection is made using two ”sonic hubs” that have a 0.32 in. hex bore and two set screws each to fasten to the hex shaft, visualized in Figure 4.7. In each sonic hub are four M4 x 0.7 mm threaded holes. Thus, four 4 mm holes are cut out in the upper hub. With a sonic hub on each side of the hub, 20 mm long, M4 x 0.7 mm bolts are threaded through both to easily fasten the hub to the topmost portion of the hex shaft. The middle hole is sized for the sonic hub’s slight protuberance. Lastly, the hub will be made out of 1/8 in. aluminum sheet metal and fabricated using a waterjet.

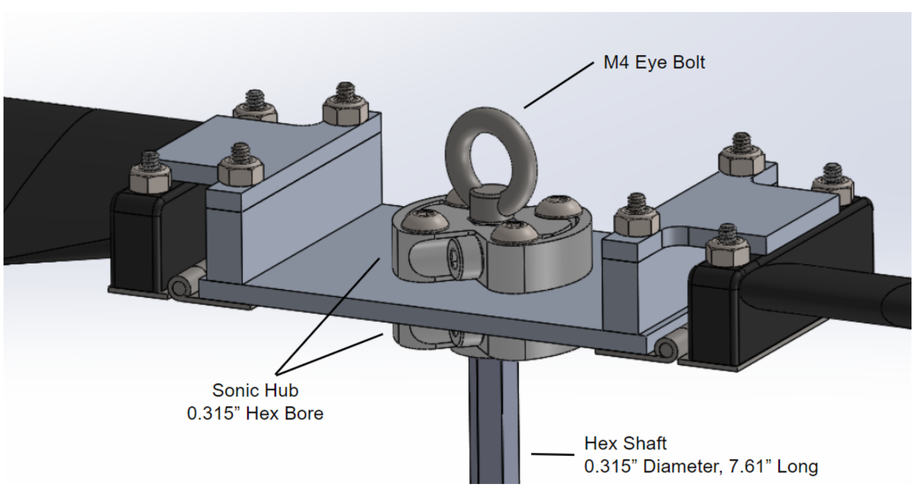

Figure 4.5: Upper hub assembly.

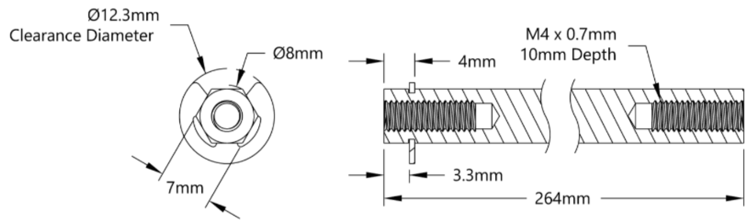

Figure 4.6: Central hex shaft drawing (mm). [1]

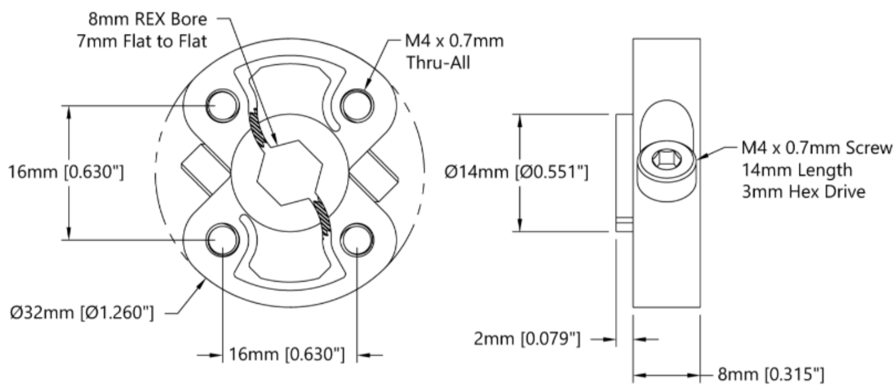

Figure 4.7: Hex bore sonic hub drawing (mm). [5]

To connect the upper hub to the propeller blades, spring hinges are used, seen in Figure 4.8. There are two 4-40 sized holes on each end of the upper hub that align with the spring hinge's holes. The drawing for the upper hub can be seen in Figure 4.9.

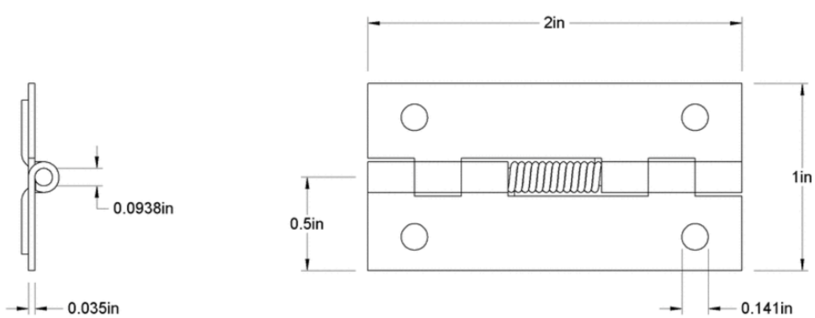

Figure 4.8: Spring hinge drawing(in.). [44]

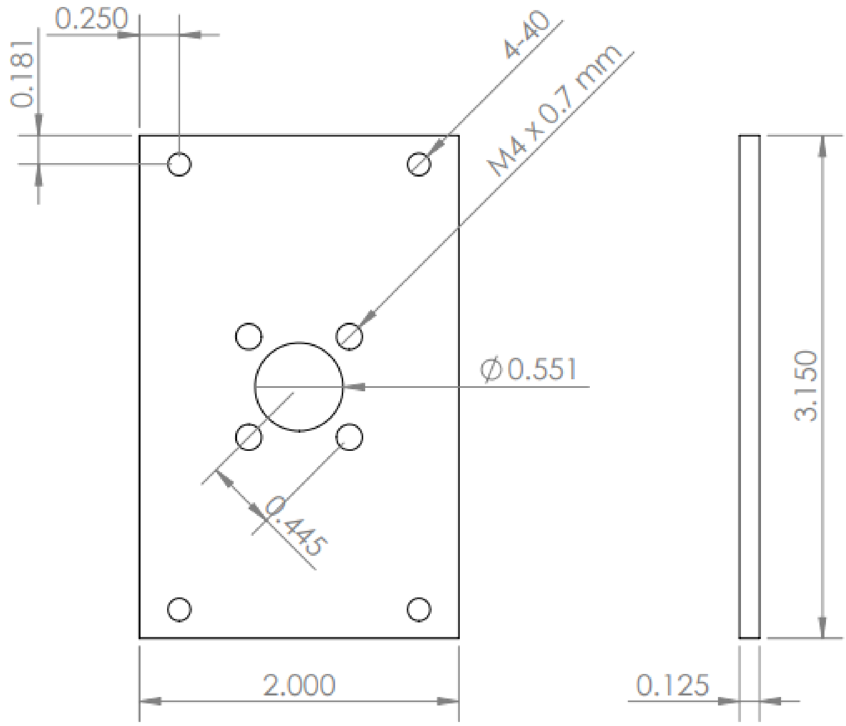

Figure 4.9: Upper hub drawing (in.).

Within this assembly (4.5), the top of the hex shaft is tapped with a M4 x 0.7 mm thread. This will be utilized for a fully sealed eye bolt that has an M4 x 0.7 mm extruded thread, seen in Figure 4.10. The eye bolt is used to hold onto the shock cord for release. This will hold the entire payload inside the deployment bay.

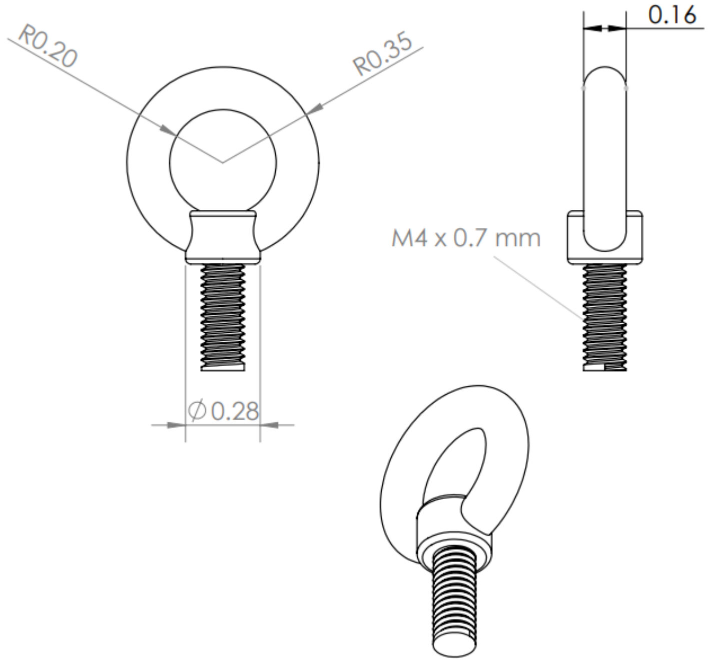

Figure 4.10: Eyebolt Drawing (in.).

The lower hub, as seen in Figure 4.11, is placed 4 in. below the upper hub to reduce any potential turbulent air that may affect airflow on the upper hub's propeller blades. The hub-to-propeller blades assembly remains the same for both the upper and lower hub. However, the difference is that the lower hub assembles to the GoTube, seen in Figure 4.13, where the hex shaft runs through. Four 0.472 in. long, M4 x 0.7 mm bolts are used to secure the hub to the GoTube. The middle hole of the hub is smaller to increase structural integrity but still large enough to avoid interference with the central hex shaft. These dimensions can be seen in Figure 4.12.

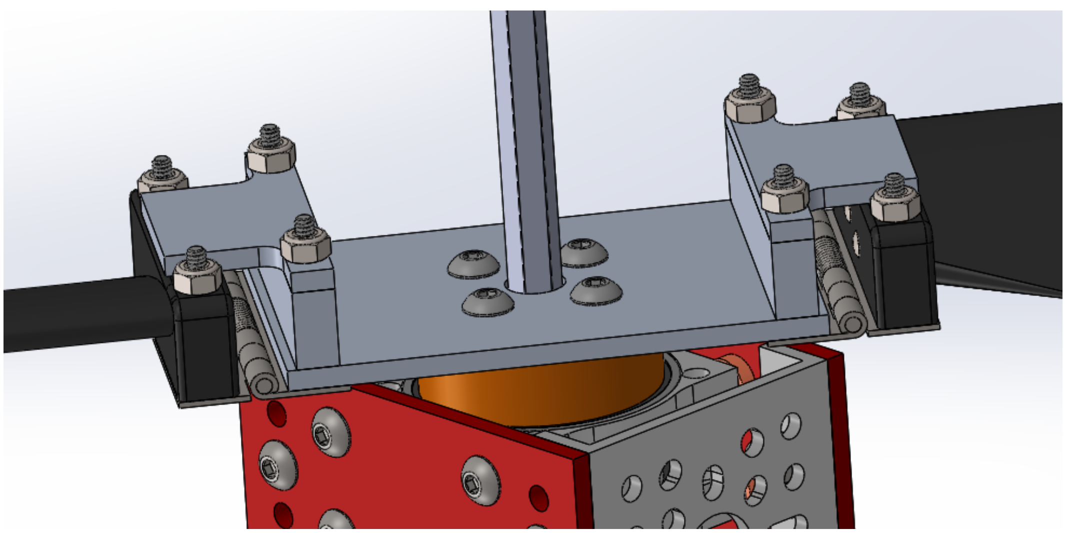

Figure 4.11: Lower hub assembly.

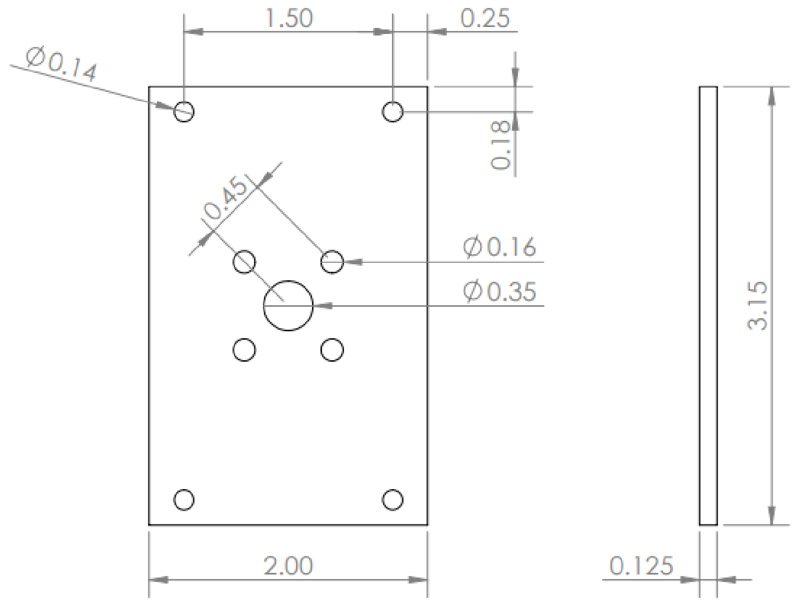

Figure 4.12: Lower hub drawing (in.).

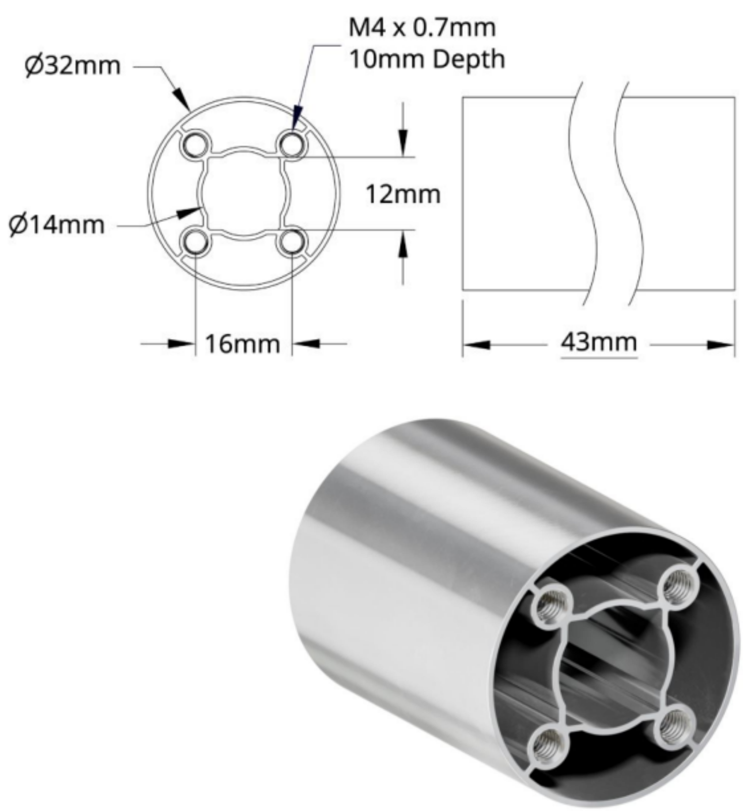

Figure 4.13: Drawing of GoTube component (in.). [10]

To secure the hubs in place to lock the contra-rotation, the GoTube and hex shaft are connected to their respective bevel gears that rotate in opposite directions. The GoTube is especially helpful as it opens up a 0.55 in. hole of central space for the hex shaft to rotate freely while also having M4 x 0.7 mm tapped holes to easily mount the lower hub. An area of concern was keeping the GoTube and hex shaft concentric, especially since the hex shaft extends over 4 in. beyond the GoTube. To aid this, an 8 mm hex flange bearing (seen in Figure 4.14) can fit on top of the GoTube to constrict the hex shaft's movement, making it purely rotational. With the flange bearing, however, a spacer is needed to fill the gap between the lower hub and GoTube.

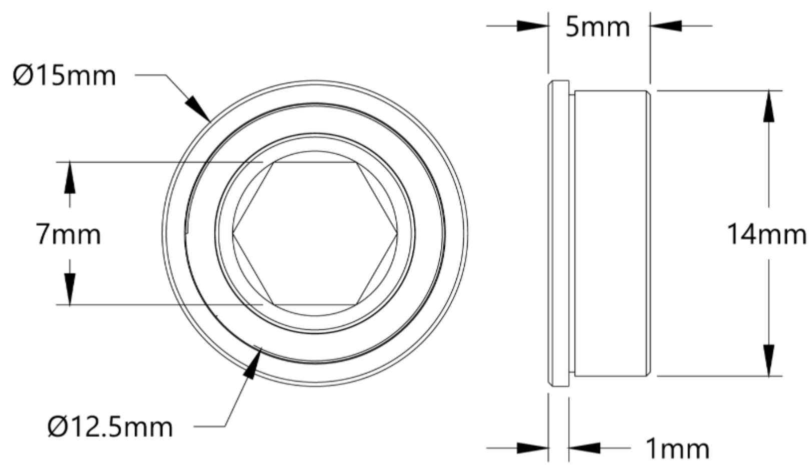

Figure 4.14: Hex flange bearing drawing (mm). [6]

To connect the hubs to the propeller blades, spring hinges are used. They will fold down to the sides of the payload bay and once released, the hinges will spring upwards to a horizontal position, maximizing propeller length (Figure 4.15). Without this mechanism, the propellers would only be able to extend to about 5.5 in. in diameter. It is important to note that the spring hinges will want to push upwards at all times, meaning they will be pushing against the deployment bay, coincidentally keeping the payload centered within the bay.

In the hub-to-propeller assembly, there is the spring hinge (Figure 4.8), a hard stop (Figure 4.16), a spacer (Figure 4.17), and the respective bolts and lock nuts. The springing motion of the hinge, or centripetal forces once the rotors are spinning, could potentially extend the blades beyond the horizontal position. Thus, hard stops are put in to prevent any unwanted movement, secured by two bolts and lock nuts. Additionally, to keep it in position directly above the propeller blade's connection block, an aluminum spacer is put in between the hard stop and hub.

The spring hinges, which have a 2 in. width to match the propeller blade chord length, have pre-fabricated hole sizes meant for 4-40 threads. Thus, 4-40 bolts and lock nuts are used for the entire hub-to-propeller assembly. The bolts have button heads to streamline the flow and reduce any unnecessary drag. At the top of the hard stop and propeller blade are 4-40 lock nuts to prevent any disassembly under high centripetal forces and vibrations.

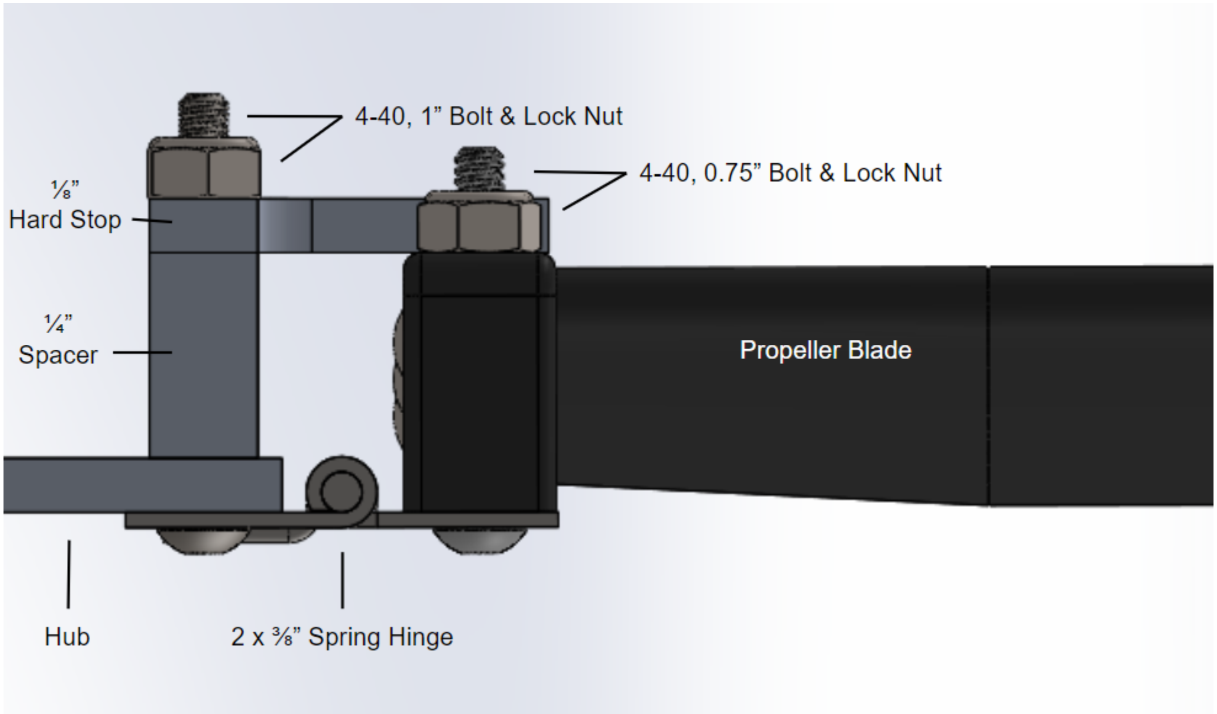

Figure 4.15: Side view of the extended, horizontal propeller blade position.

The spacer will be made out of 1/4 in. sheet metal while the hard stop will be made out of 1/8 in. sheet metal. Both pieces will be fabricated using a waterjet. The propeller blade will be printed in 3 pieces using a carbon fiber-polycarbonate composite filament and wrapped in uni-directional carbon fiber plies. Section 4.5.1 further discusses the propeller blade fabrication process.

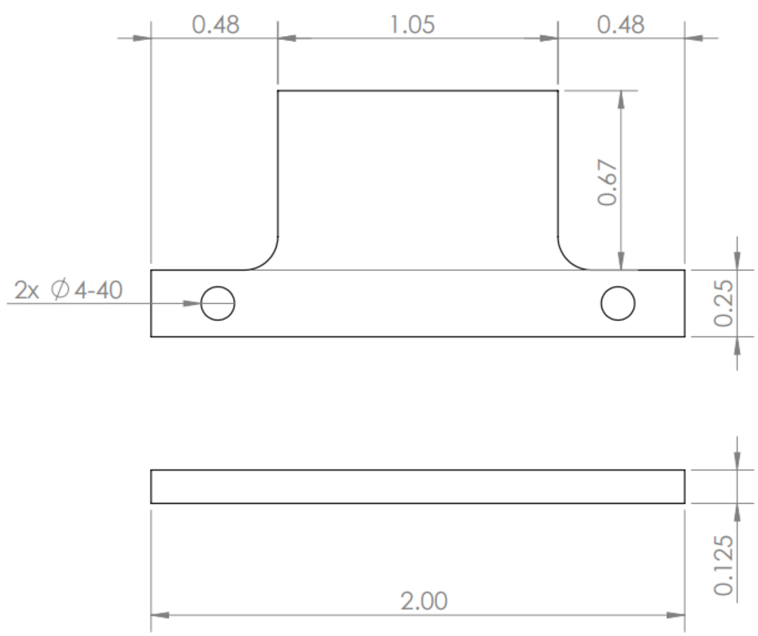

Figure 4.16: Hard stop drawing (in.).

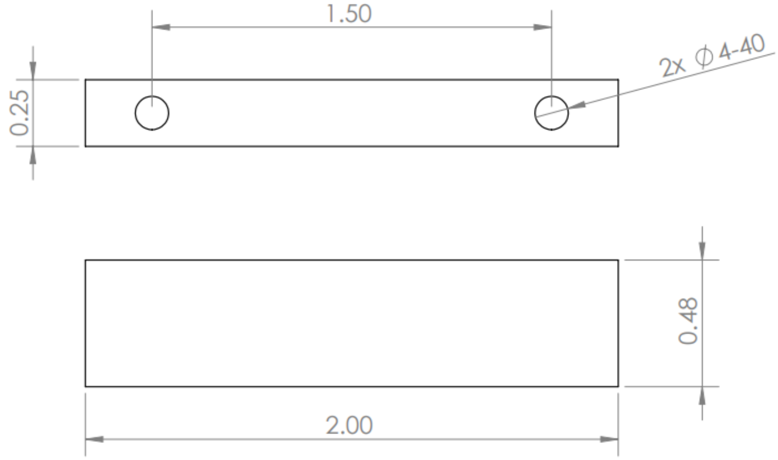

Figure 4.17: Hard stop spacer drawing (in.).

In Figure 4.18, the initial configuration of the propeller blade is shown. It will rotate further, towards the horizontal position, as the spring hinge will push it against the deployment bay wall. This is the maximum angle that it will need to rotate, thus showing the importance of the button head bolts not colliding. Regarding the full assembly, the propeller blades will fold down next to the SAIL body, slotting in between the landing legs (Figure 4.2).

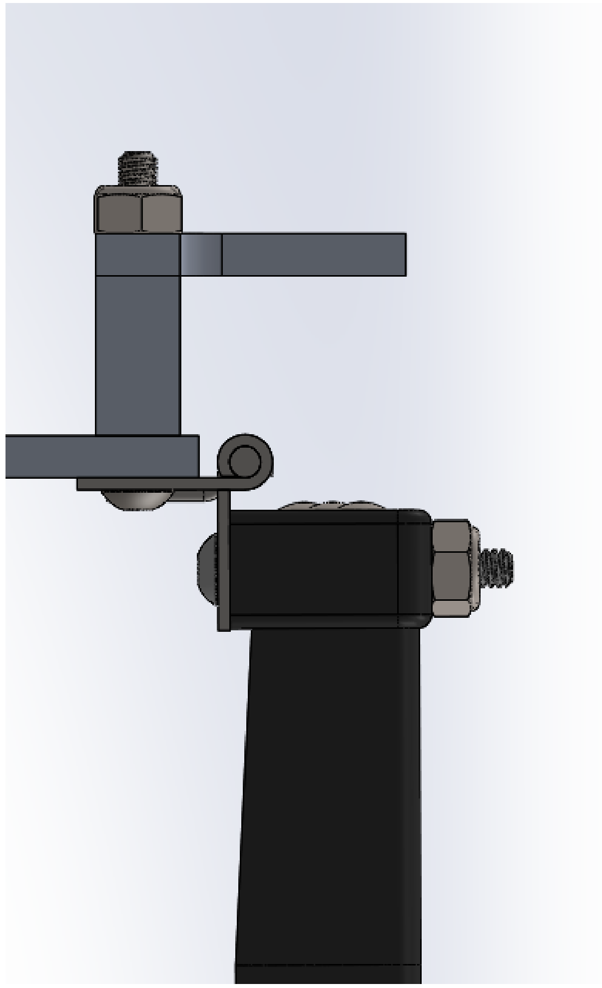

Figure 4.18: Side view of the folded, vertical propeller blade position.

4.3.3 Gearbox

The gearbox uses bevel gears to centralize the entire gearing system and make the payload as symmetric as possible. This helps to avoid any unnecessary body rotation and drifting.

To digest what is going on in the system, a condensed view (Figure 4.23) and an exploded view (Figure 4.26) were made. Looking at the condensed view, there are three bearings to prevent horizontal movement, two for the GoTube (Figure 4.19) and a 0.32 in. diameter hex bore bearing (Figure 4.20) for the central hex shaft. These have 0.47 in. long, M4 x 0.7 mm bolts run through them on both sides, which secure the system to the side plates. The positions of these bolts are noted by the orange circles in the condensed view, which are 3D-printed spacers (PLA) to fill the 0.1 in. space between side plate and the bearings. These bearings will help with stability and preventing the rotors from tilting. As seen in the exploded view, there is a fourth bearing constricting horizontal motion. This 0.32 in. diameter hex bore flange bearing (Figure 4.14) fits into the GoTube, positioned below the lower hub with the flange nesting within the upper spacer. This will help keep the two hub attachment pieces concentric to each other, avoiding any tilt of the central shaft relative to the GoTube.

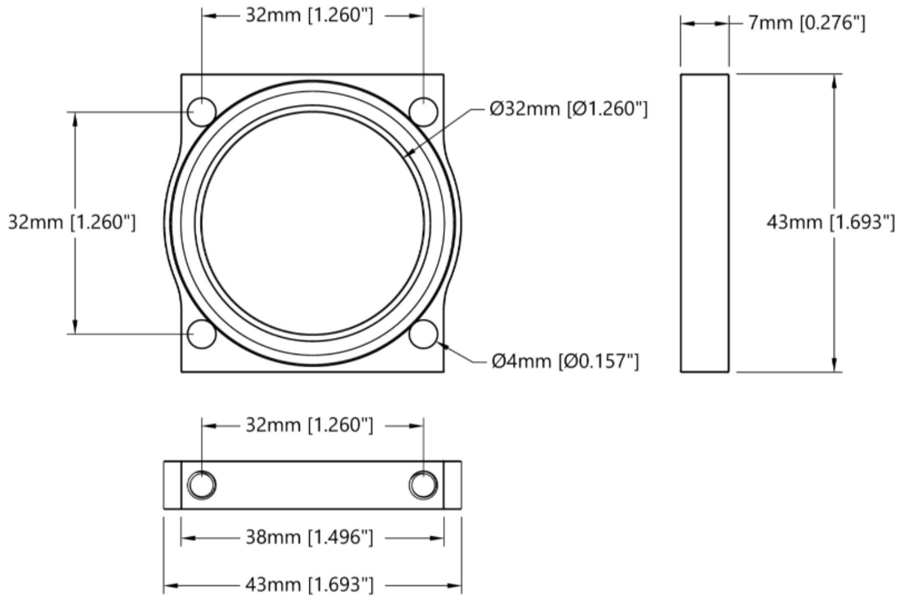

Figure 4.19: GoTube bearing drawing (mm). [9]

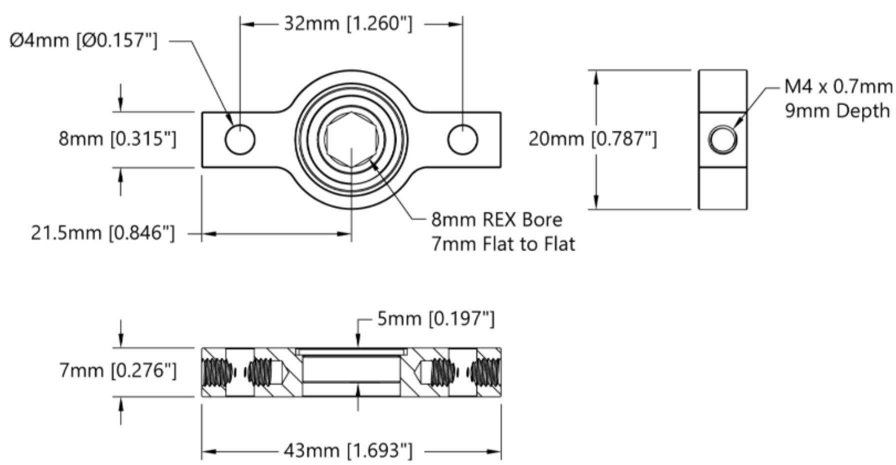

Figure 4.20: Central hex bore bearing drawing (mm). [12]

To alleviate pressure on the hub and flange bearing, the upper spacer (Figure 4.21) will be positioned between the upper GoTube bearing and the lower hub. This also prevents the lower hub from moving down, subsequently pushing the upper bevel gear down. To keep the upper bevel gear from moving up, the lower spacer (Figure 4.22) is placed in between the bevel gear and the lower GoTube bearing. Keeping the bevel gears at their respective heights is important to reduce any potential friction and wear. Both of these spacers will be 3D-printed using PLA.

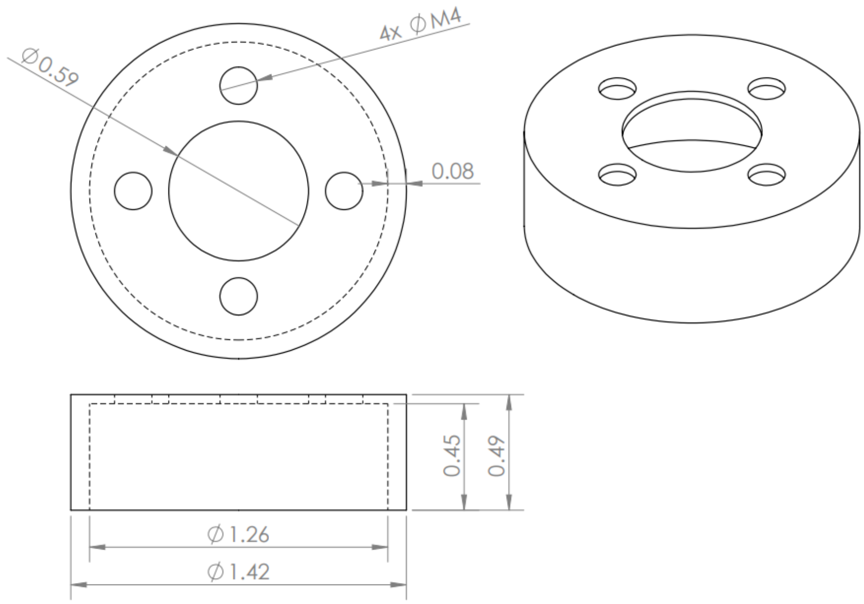

Figure 4.21: Upper spacer drawing (in.).

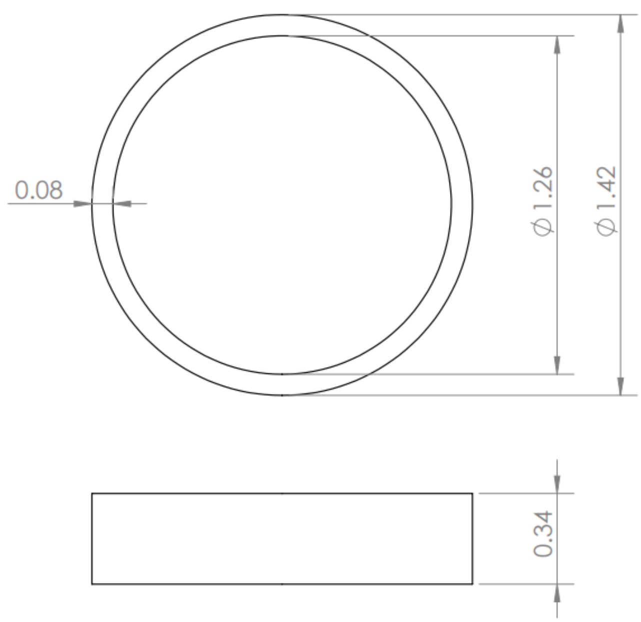

Figure 4.22: Lower spacer drawing (in.).

The other two flange bearings on the left and right of the condensed, side view (Figure 4.23) serve to hold the horizontal, 0.32 in. diameter, 0.95 in. long hex shafts (Figure 4.24) in place. Additionally, the hex shaft has a clip to make it flush against the flange bearing. There is a hole cut-out in the U-channel where the bearing will be placed within. Connected to these shafts are the side bevel gears with a set screw to fasten it to the hex shaft. However, there are slight gaps between the flange bearings and gears. Thus, 0.05 in. thick spacers are put in between these two components to prevent any horizontal motion. These will also be 3D-printed out of PLA.

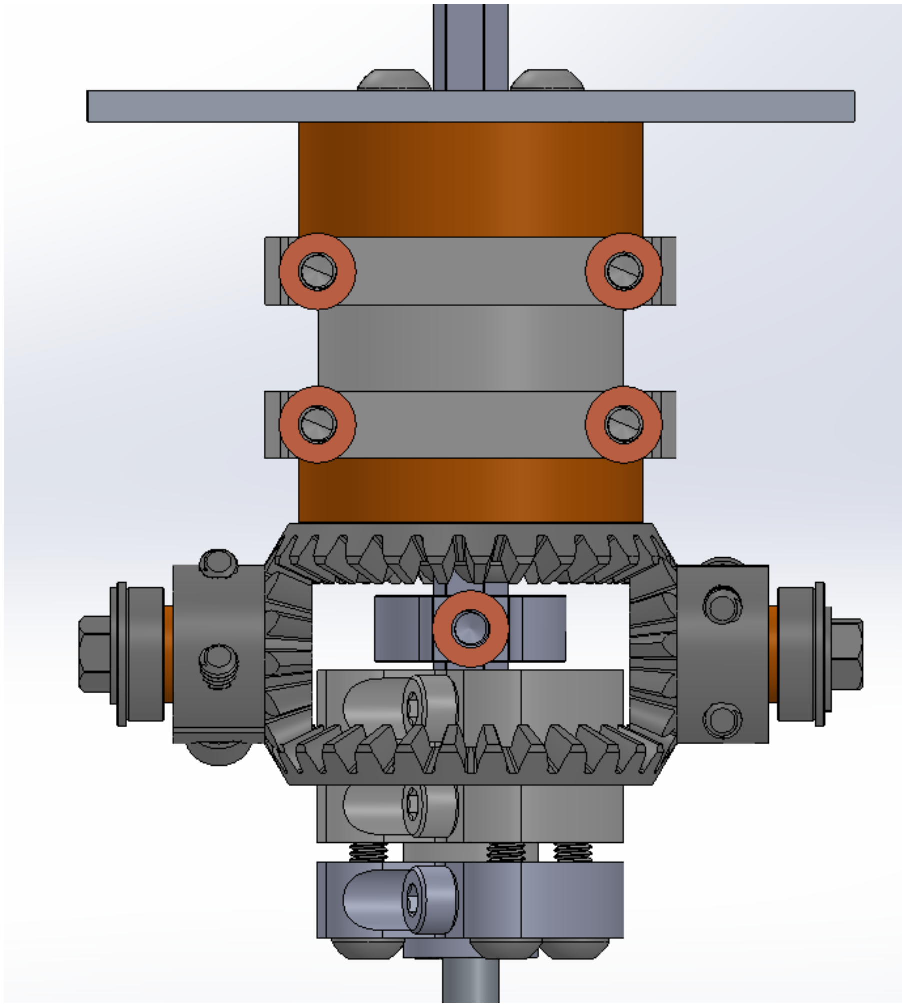

Figure 4.23: Bevel gear design for contra-rotation (condensed, side view).

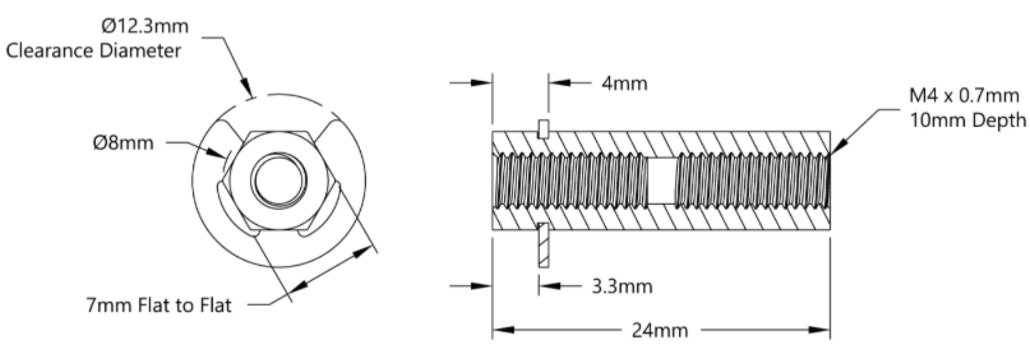

Figure 4.24: Side hex shaft drawing (in.). [8]

The upper, horizontal bevel gear (Figure 4.25) is bolted to the GoTube with four 0.47 in. long, M4 x 0.7 mm bolts using pre-cut holes on the bevel gear. The lower, horizontal bevel gear will be bolted to two 0.32 in. hex bore sonic hubs on each side with 1.1 in. long, M4 x 0.7 mm bolts. This will keep the lower bevel gear in place on the hex shaft. These bolts will also run through a 0.24 in. round bore sonic hub (Figure 4.36) to connect the central hex shaft to the motor shaft.

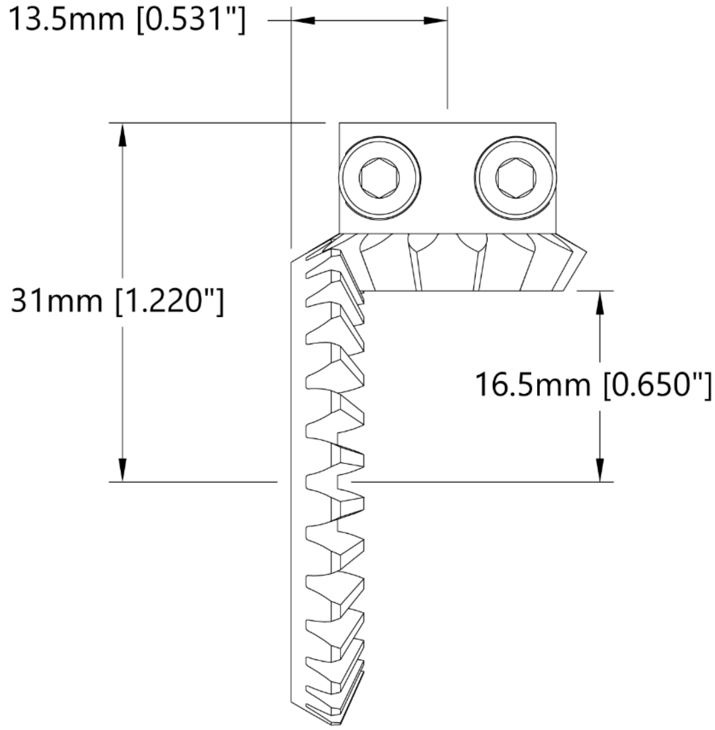

Figure 4.25: Bevel gears drawing (mm). [7]

Once all together, the upper and lower bevel gears will be rotating in opposite directions. The hex shaft will attach to the lower bevel gear, which will feed through the GoTube and lower hub, and attach to the upper hub. Meanwhile, the GoTube will be attached to the upper bevel gear, which is connected to the lower hub. Thus, the upper and lower hubs will rotate in opposite directions around the same axis using the same motor.

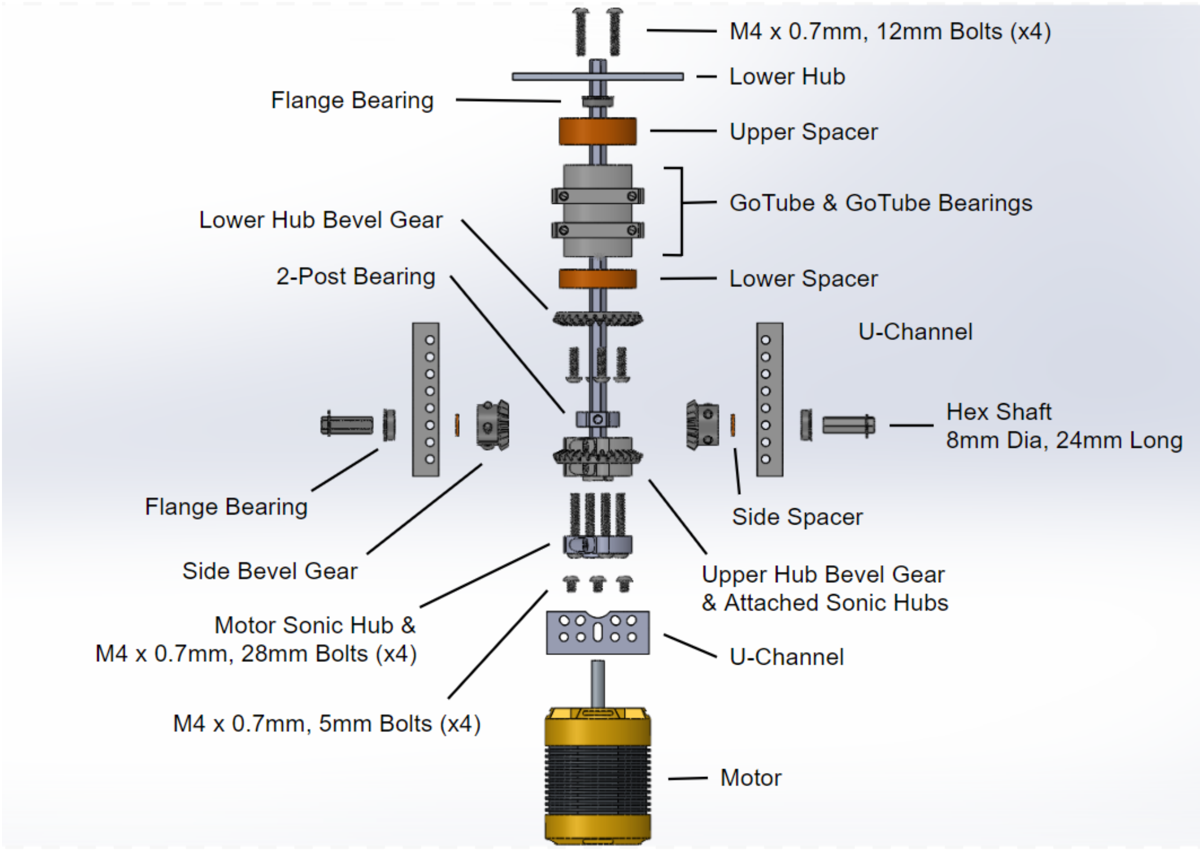

Figure 4.26: Bevel gear design for contra-rotation (exploded, side view).

To finalize the gearbox, the outer structure must be put together. An outside view of this can be seen in Figure 4.28. The U-channels (Figure 4.29) are used to hold the side bevel gears while the custom-made red plate (Figure 4.30) is bolted to the bearings. The U-channels and red plates are bolted to each other at the lips of the U-channels and ends of the red plates with 0.47 in. long, M4 x 0.7 mm bolts and lock nuts. Each are 1/8 in. thick and made of aluminum. There will be four sets of the bolts and lock nuts at each corner of the gearbox to maximize strength while reducing any unnecessary weight. In total, there will be 38 bolts, 10 for the bearings, 16 for the U-channel and red plate assembly, as well as 12 specifically for the brackets and the motor's supporting structure. These brackets (light gray in Figure 4.28) are meant to connect the gearbox to the main SAIL body. This full gearbox-to-body connection can be seen more clearly in Figure 4.31.

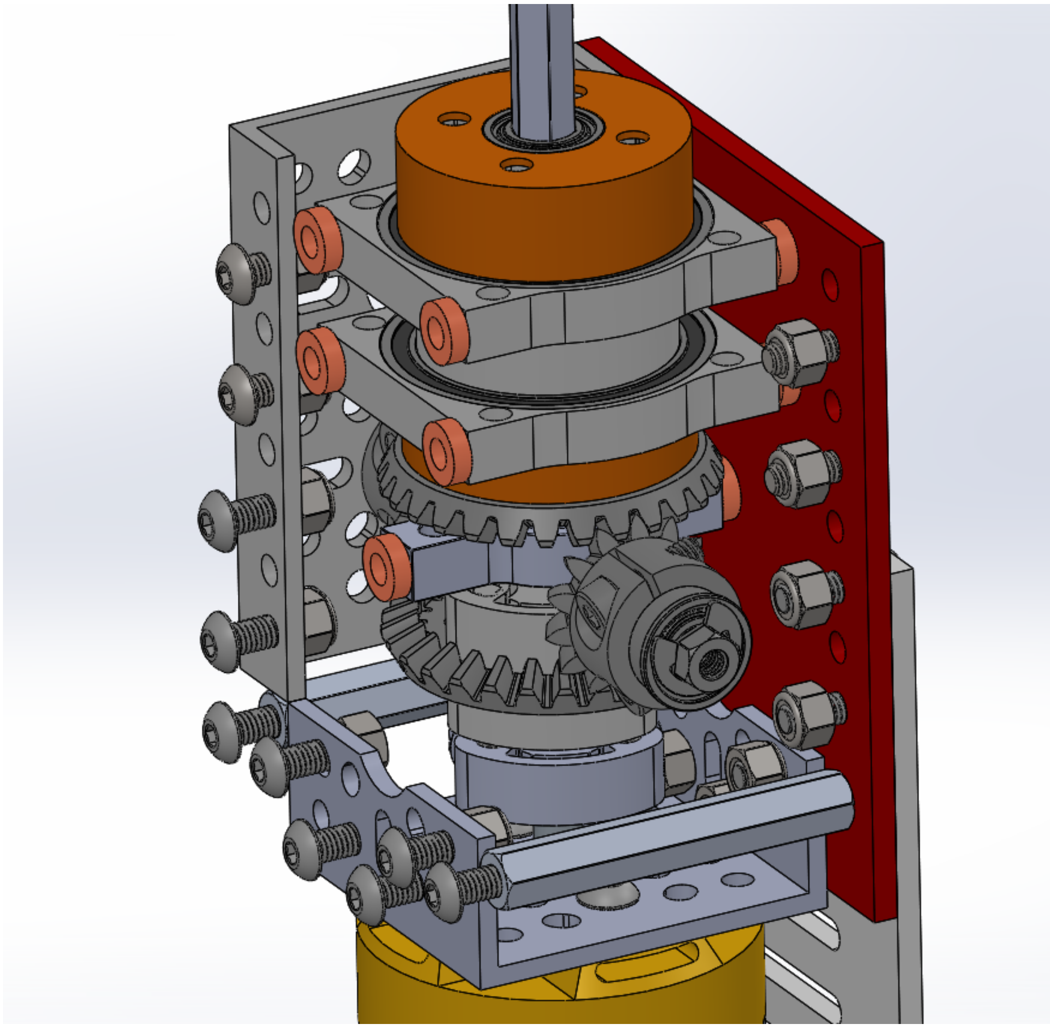

Figure 4.27: Gearbox (inside view).

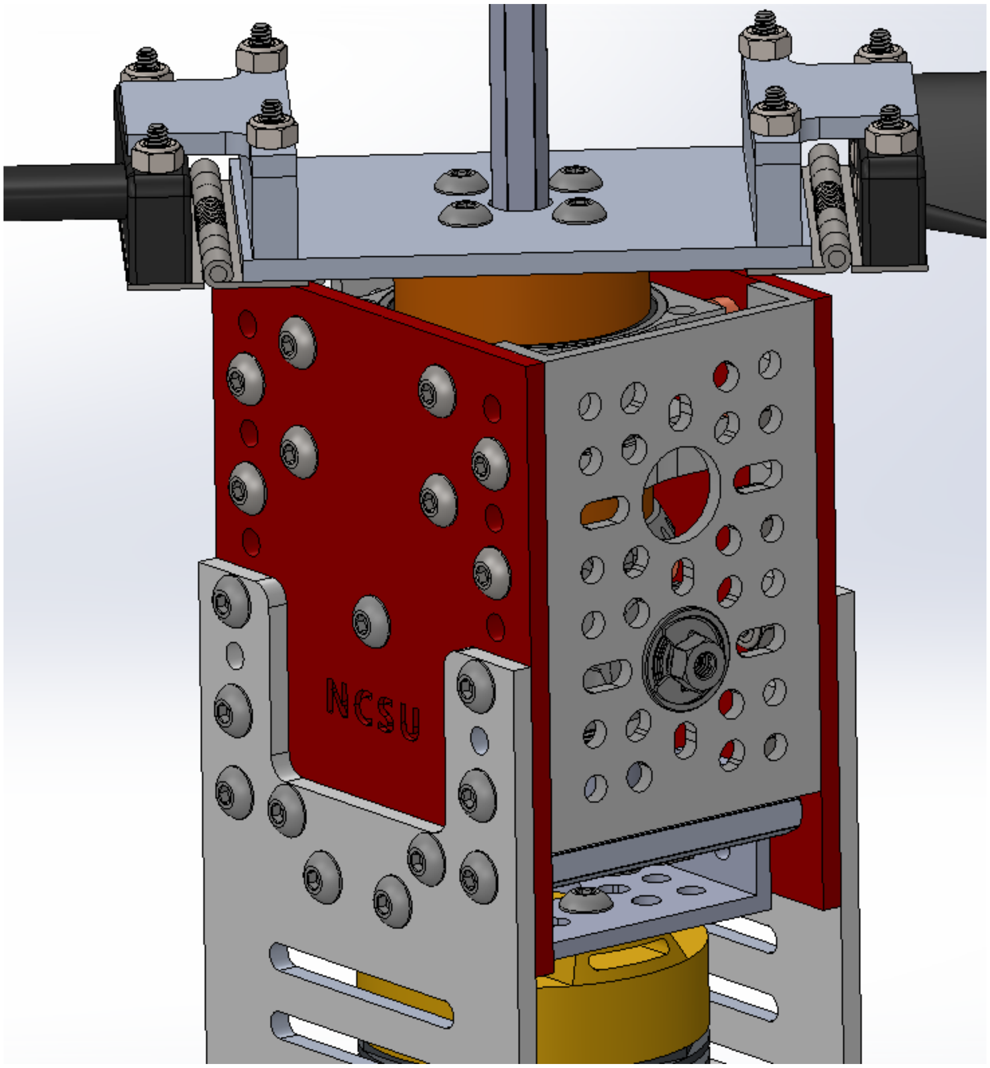

Figure 4.28: Gearbox to motor housing assembly (outside view).

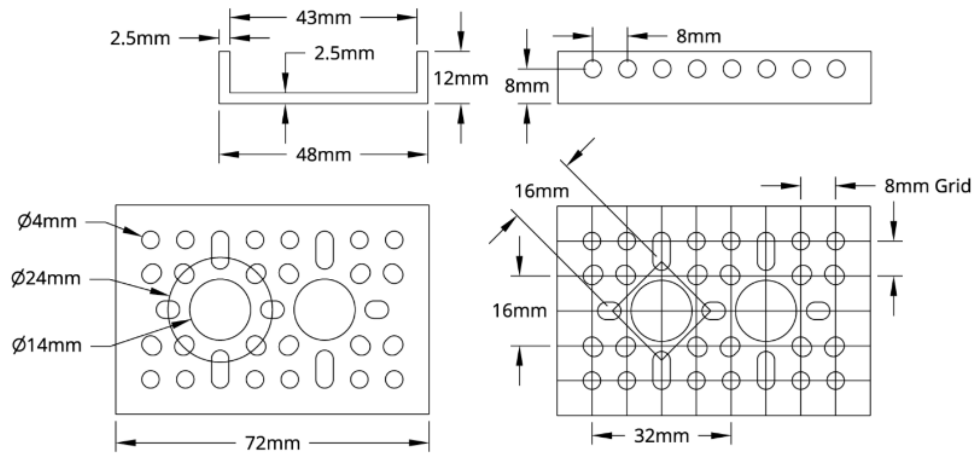

Figure 4.29: Side U-channel drawing (mm). [3]

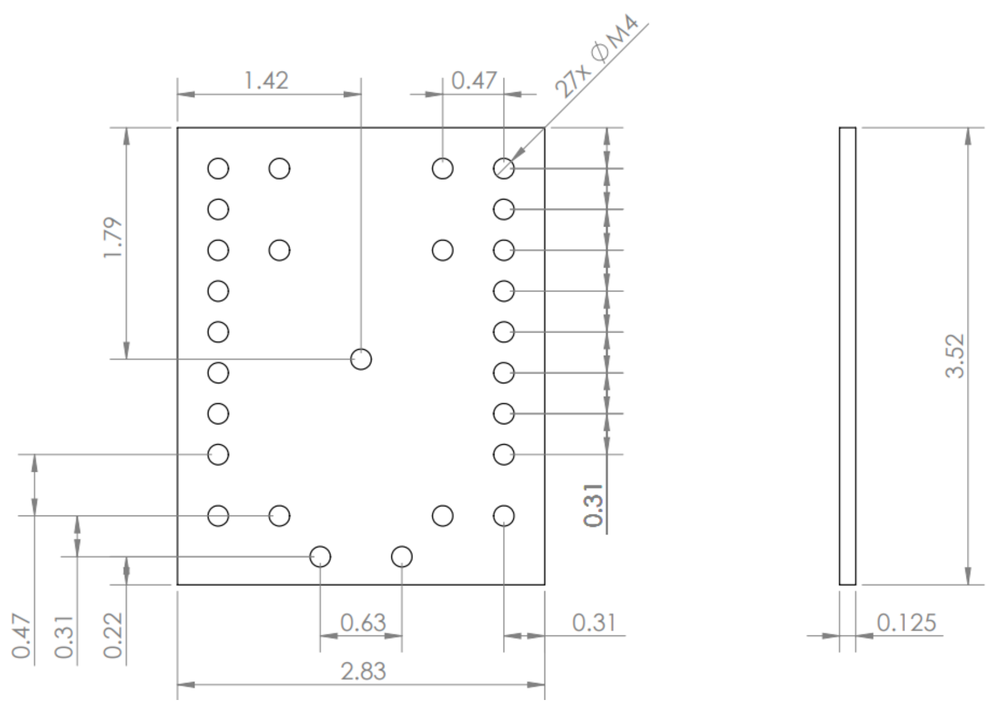

Figure 4.30: Red plate drawing (in.).

Further keeping the structure together are the hex standoffs where M4 x 0.7 mm bolts can thread through on each side of them. This helps to compress the structure together, ensuring that each component is positioned correctly with low tolerances. Additionally, this is also helped by the bottom, 1.9 in. long U-channel, where four bolts are secured to it through the red plate and the bracket on each side.

The bottom U-channel (Figure 4.33) is also used to connect to the motor. Since the bottom yellow portion of the motor spins with its axle, it cannot contact the SAIL body. Thus, the top of the motor, which has M4 x 0.7 mm threaded holes, is bolted to the U-channel with 0.2 in. long, M4 x 0.7 mm bolts. The motor can be more clearly visualized in Figure 4.32, which is shown in units given by the manufacturer. The bracket then helps to keep the gearbox and motor away from the SAIL body by being longer than the motor.

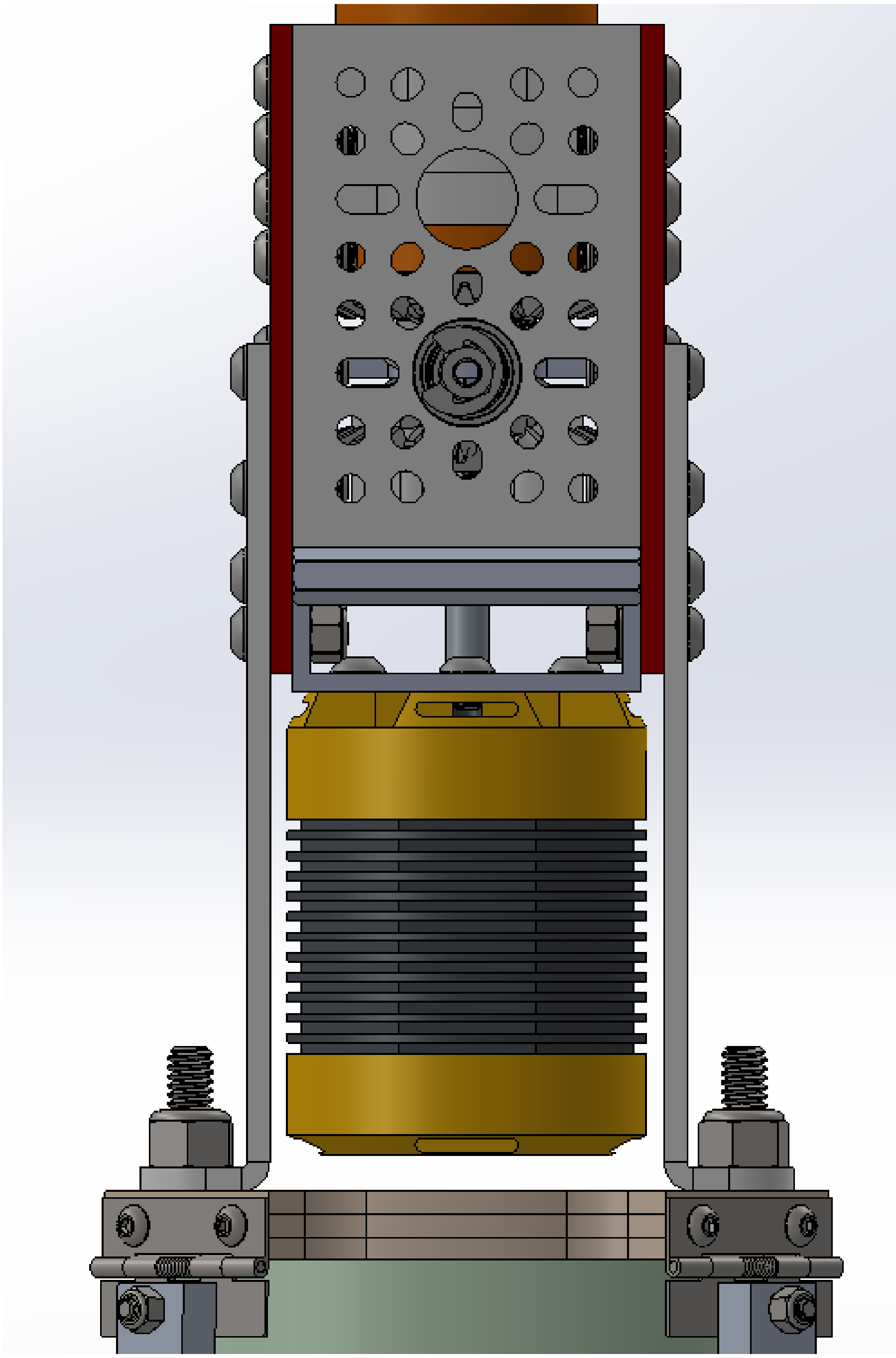

Figure 4.31: Gearbox to SAIL body assembly (side view).

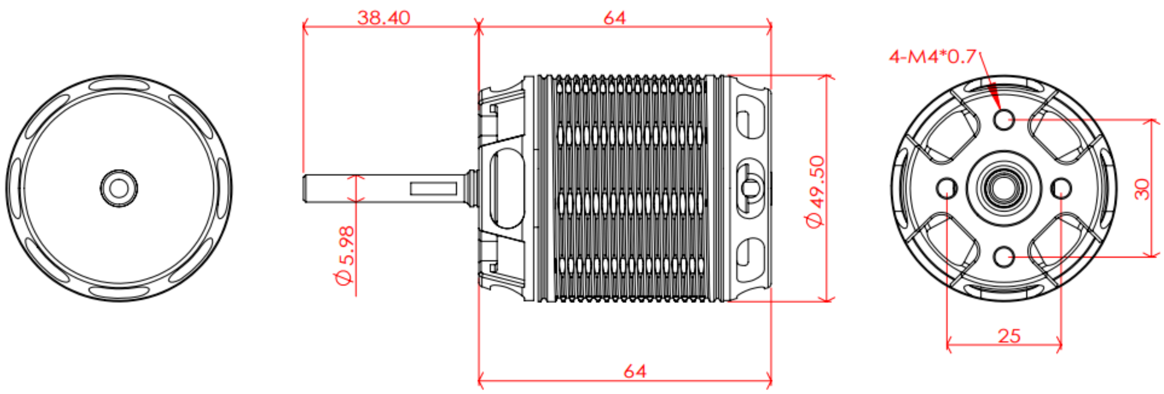

Figure 4.32: Motor drawing (mm).[39]

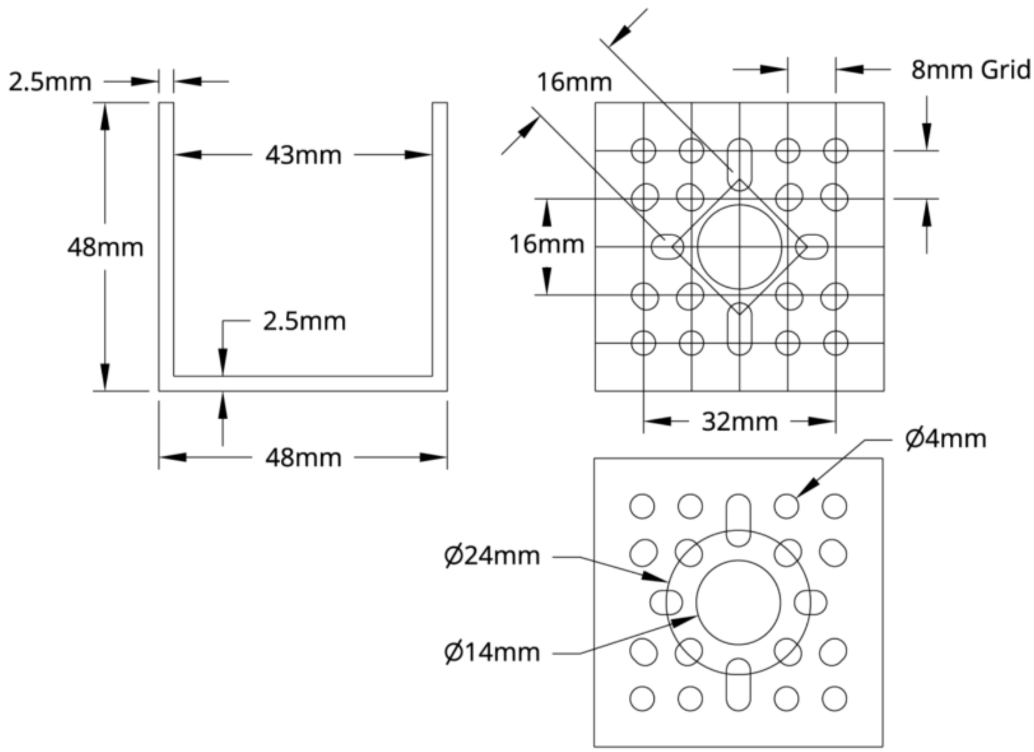

Figure 4.33: Bottom U-channel drawing (mm). [2]

The bracket connecting the gearbox to the SAIL body is visualized in Figure 4.34. It will be fabricated out of 1/8 in. aluminum sheet metal using the waterjet and sheet metal brake at NC State University. The hole at the lip is for the 1/4-20 in. threaded rod that goes through the SAIL body, holding it together with 1/4-20 in. lock nuts. This will be discussed further in Section 4.3.6.

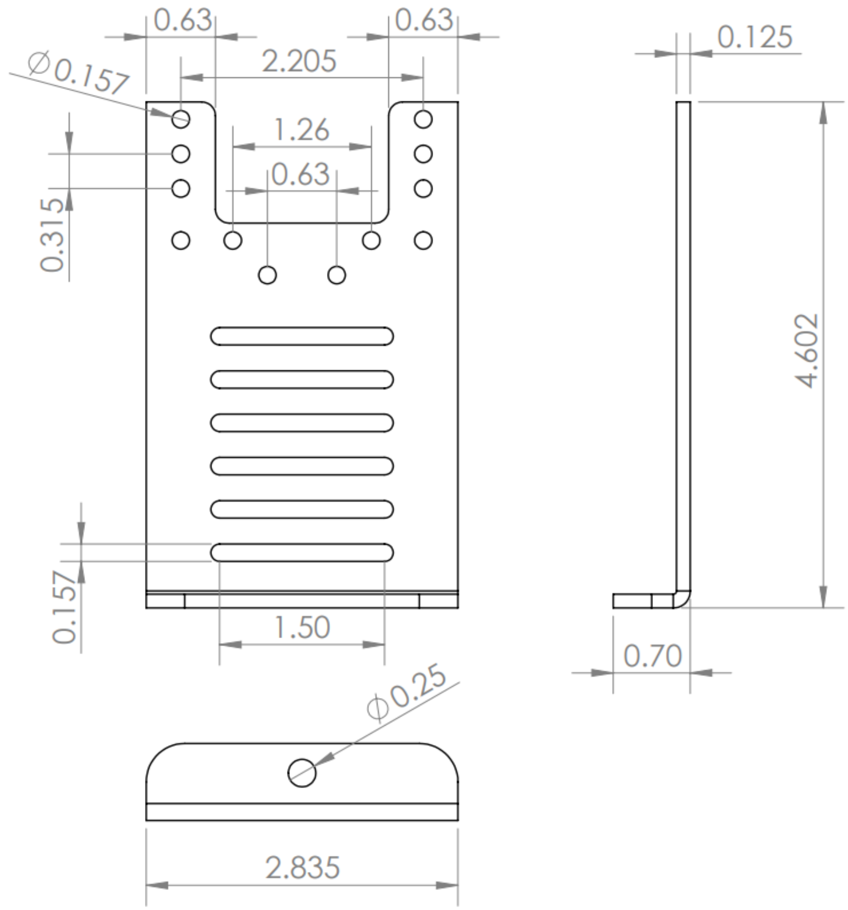

Figure 4.34: Gearbox bracket drawing (in.).

The motor shaft is secured to the central hex shaft through a series of sonic hubs, as seen in Figure 4.35. The bottom bevel gear is held in place by two 0.32 in. hex bore sonic hubs and the central hex shaft ends at the end of the bottom sonic hub. A third 0.24 in. round bore sonic hub, below these two, secures to the 0.23 in. motor shaft. This sonic hub's dimensions can be seen in Figure 4.36. This shaft continues up until the top of this round bore sonic hub, keeping flush with the central hex shaft. Since the sonic hubs are the same other than their bore, four 1.1 in., M4 x 0.7 mm bolts are threaded through them. This ensures that the motor shaft rotates the central hex shaft without any slipping.

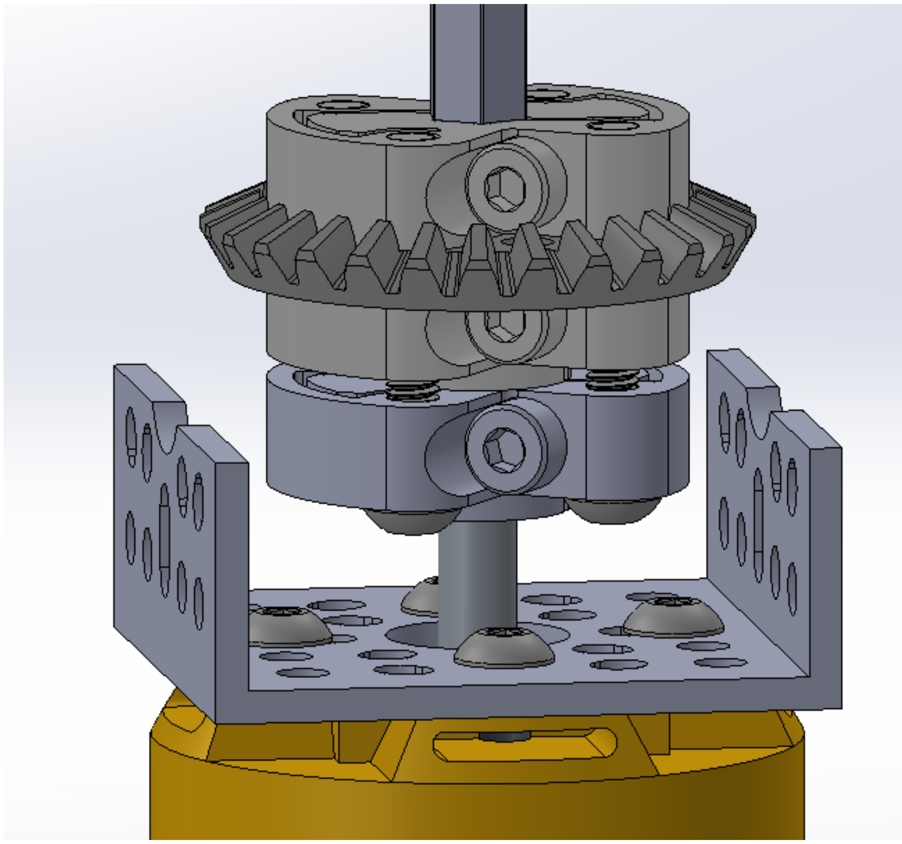

Figure 4.35: Motor shaft to hex shaft assembly.

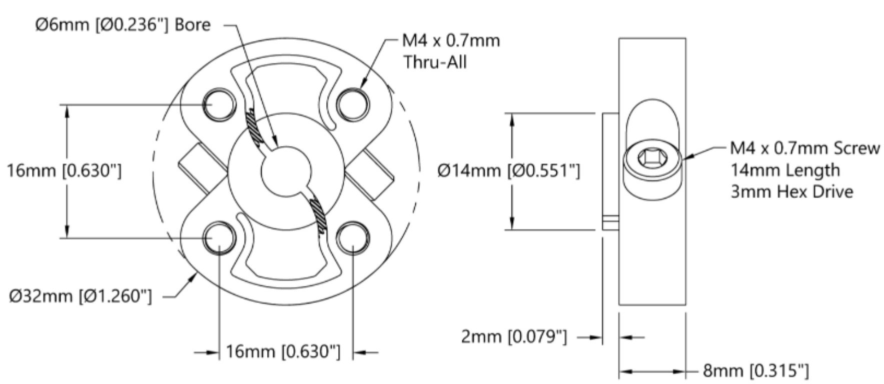

Figure 4.36: 0.24 in. Round bore sonic hub drawing (in.). [4]

4.3.4 Power Plant

The rotor assembly will be powered using a brushless DC motor, electronic speed controller, and LiPo battery. Each subsystem is detailed in the following paragraphs.

Motor

The Scorpion HKIV-4035 motor, shown in Figure 4.37, was selected for the brushless DC motor. This motor is designed for R/C helicopters in the 600-700 class (24 to 27.6 in. rotor diameter) and will provide ample power for the SAIL. It has a kV rating of 330, meaning that for every volt of input the motor will rotate 400 RPM. The peak current draw is 80A for 5 seconds and the max continuous current draw is 60A. Lastly, the motor is designed to use up to a 12s LiPo battery.

Figure 4.37: Scorpion HKIV-4035 [39]

Electronic Speed Controller

The Cobra 150A, shown in Figure 4.38, was selected for the electronic speed controller (ESC). This ESC is capable of providing up to 150A of current to the motor and is designed for use with 2-6 cell LiPo batteries. It features 3 braking settings, 3 acceleration rates, low voltage cutoff, and over temp protection. Additionally, the ESC has a built in battery eliminator circuit (BEC), allowing it to send power to the flight computer/sensors. This capability eliminates the need for a separate buck converter and power source for the on-board electronics.

Figure 4.38: Cobra ESC [23]

Battery

Estimating a descent velocity of 15 mph and a release altitude of 400 ft., the expected descent time is approximately 20 seconds. Decreasing the descent velocity to 5 mph results in an expected descent time of approximately 55 seconds. Using the maximum continuous current draw for the selected motor of 60A, a 4000 mAH LiPo battery will provide approximately 240 seconds of run time at max current draw. The HRB XT60, pictured below in Figure 4.39, was selected for the motor battery. It is a 4s LiPo with 4000 mAH capacity and a C rating of 60. The high C rating ensures that the battery can supply enough current to power the motor at the peak continuous current of 80A. The battery dimensions are 5.31 in. x 1.65 in. x 1.3 in. (L x W x H), allowing it to fit easily within the SAIL body. This battery will also power the Adafruit Feather and onboard sensors.

Figure 4.39: HRB 4S Li-Po Battery [30]

4.3.5 Landing Legs

There will be four 1/2 x 1/4 in., aluminum landing legs with 1/16 in. thickness at the sides of the SAIL body. The leg dimensions can be seen in Figure4.42. When deployed, seen in Figure 4.40 and more precisely in Figure 4.41, these 15 in. legs span a 23 in. diameter around the center of the payload and form a 38 degree angle from the vertical axis. With these two measurements combined, the SAIL will have a large, expanded cross-sectional area for it to land in an upright orientation.

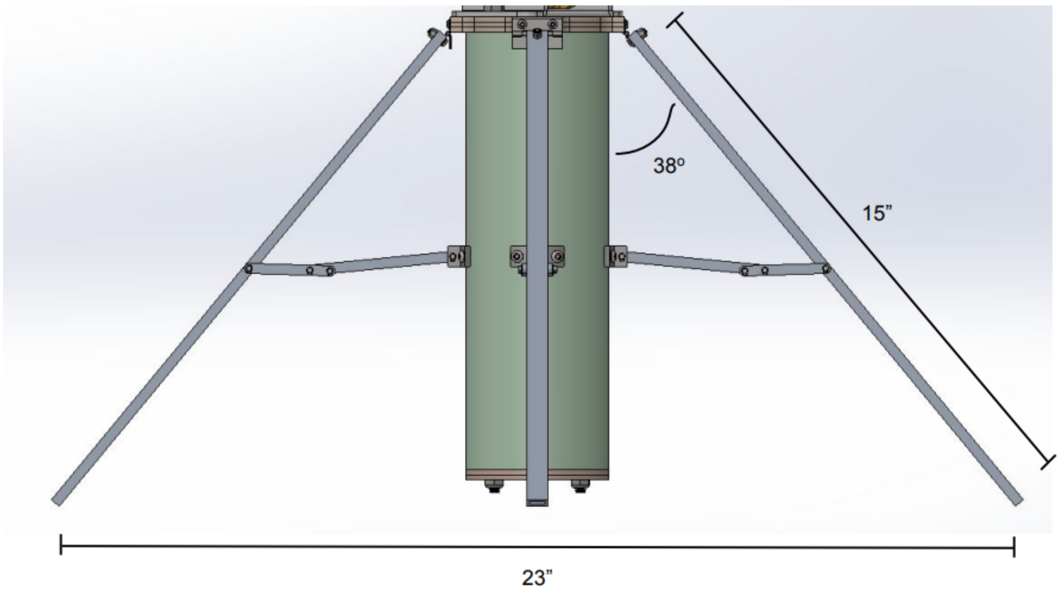

Figure 4.40: Front view of the landing legs.

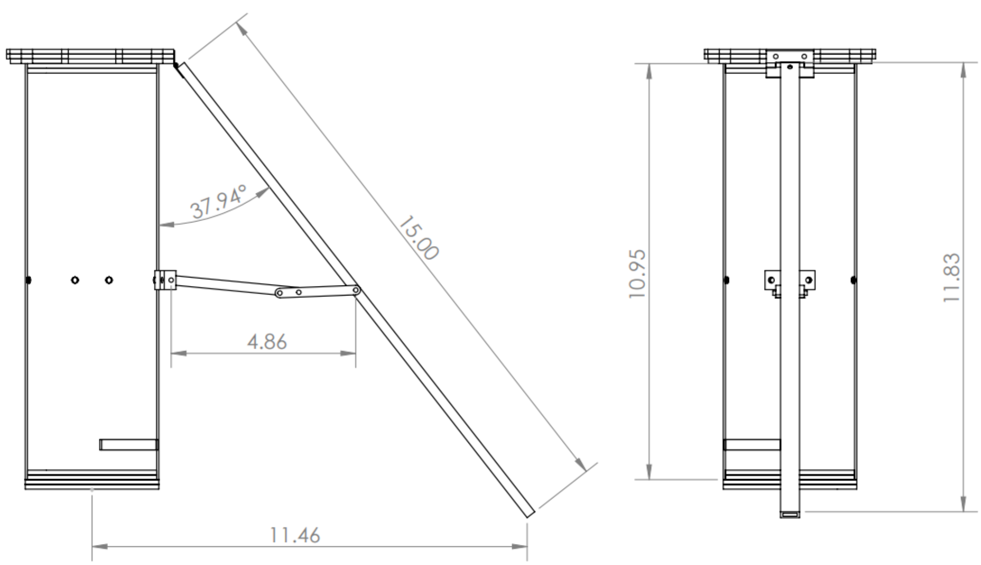

Figure 4.41: Landing leg deployed drawing (in.).

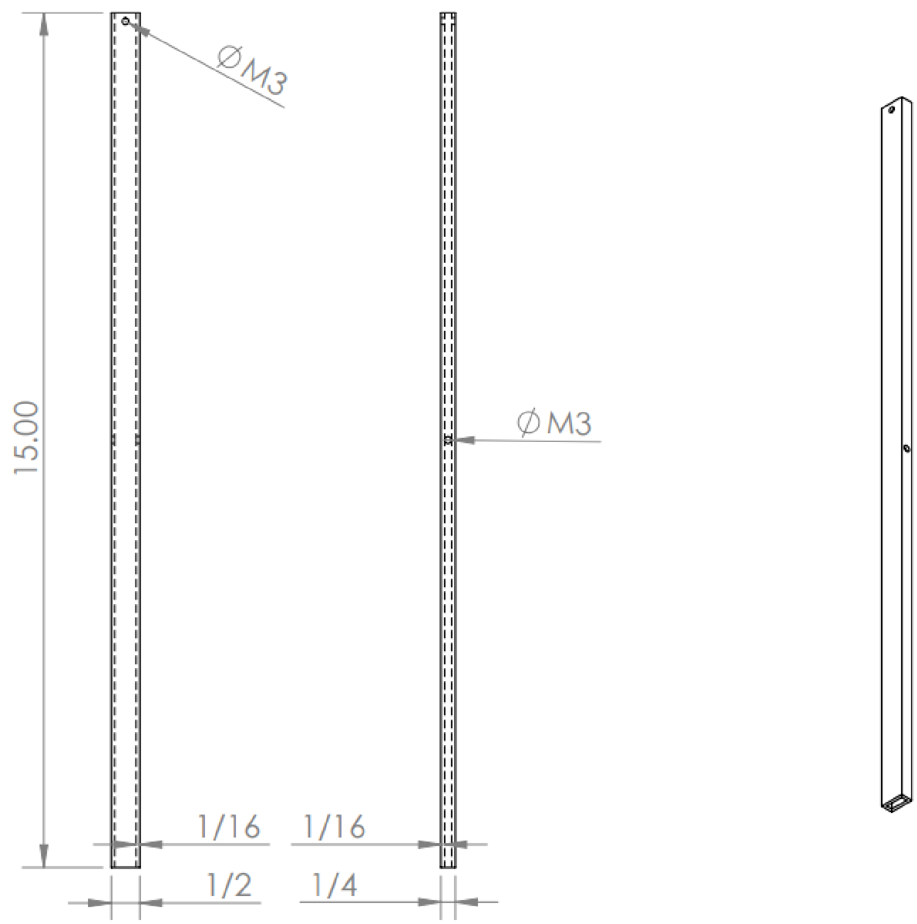

Figure 4.42: Landing leg drawing (in.).

The leg mechanism consists of a linkage and pin system with a spring hinge lifting the leg up. The spring hinge (Figure 4.44) will be secured to the top bulkhead with two M3 x 0.5 mm wood screws, as pictured in Figure 4.43. Additionally, the leg will be secured with a M3 x 0.5 mm bolt and lock nut. There is only one bolt because the spring would get in the way and the leg is only 1/2 in. wide, which does not bode well for fitting two bolts. However, the leg will be constrained by the two linkages on either side where the locking mechanism is, which can be seen more clearly in Figure 4.45.

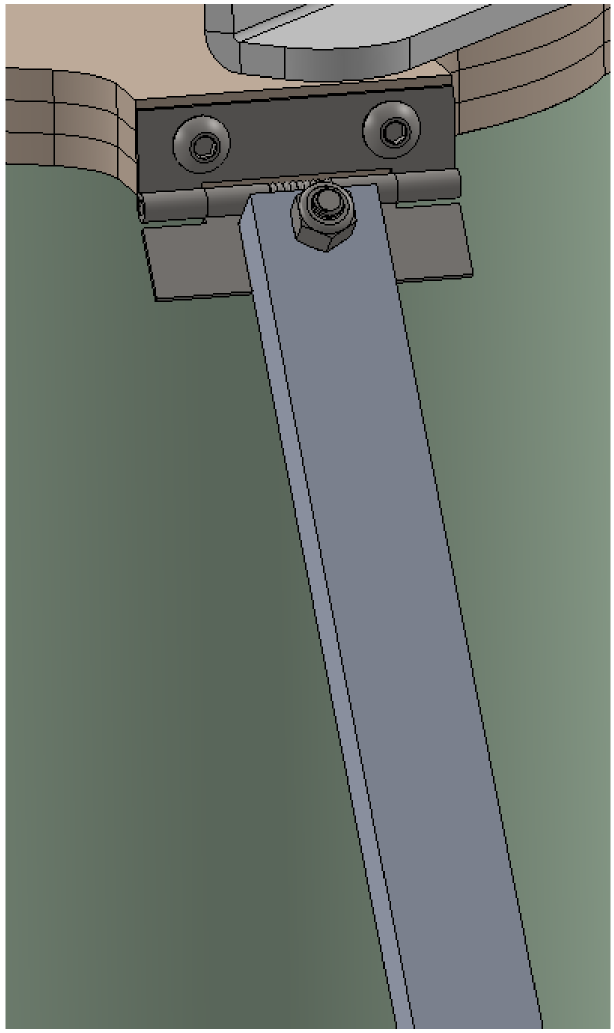

Figure 4.43: Leg mechanism spring hinge.

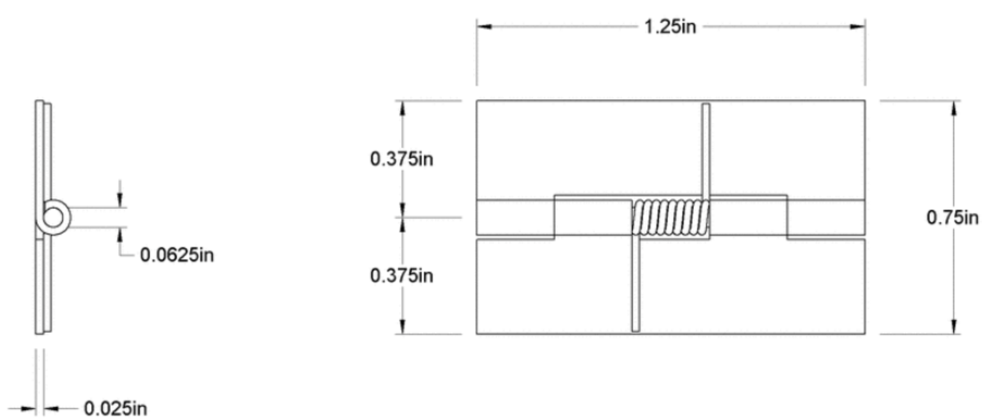

Figure 4.44: Landing leg drawing (in.). [43]

To lock the leg in place, a system of linkages and pins are used, seen in Figure 4.45. All pins have a 0.12 in. diameter and the linkages are made out of 1/8 in. aluminum sheet metal. Individual pin dimensions can be seen in Figure 4.46. The leg-linkage pin (Figure 4.48) is inserted through a hole in the leg and holds the ends of the two leg linkages. Further down these linkages is the linkage-linkage pin where all three linkages freely rotate around. The body linkage (Figure 4.47) has an opening for the latch pin. This pin is secured at the end of the leg linkages. The latch pin will then slot into this opening once the leg exits the deployment bay, preventing the linkages from moving further upwards. At the other end of the body linkage is the body-linkage pin. This pin runs through a 3D-printed piece that is secured to the fiberglass body (Figure 4.49). It will be made using carbon fiber-polycarbonate filament for extra strength and rigidity. 0.24 in., M4 x 0.7 bolts secure this mounting piece to the fiberglass body with lock nuts on the inside. To keep all of the pins and linkages aligned, retaining rings are placed on each sides of the linkages where deemed necessary (Figure 4.50).

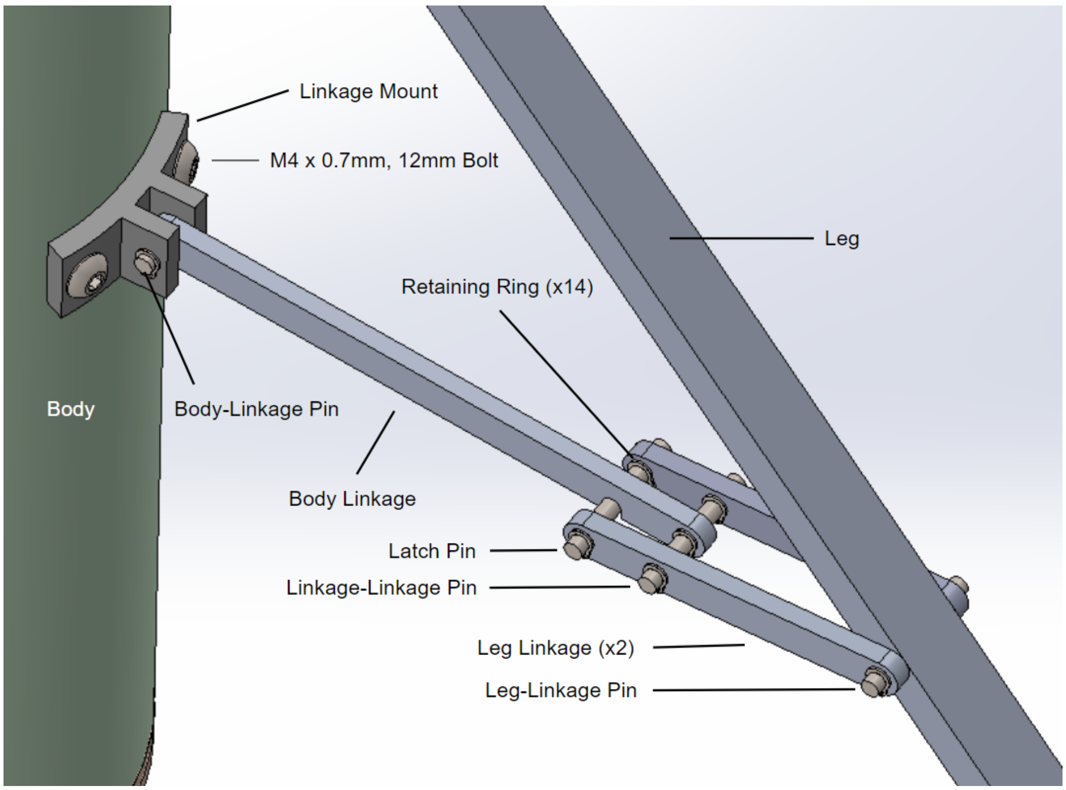

Figure 4.45: Landing leg locking mechanism.

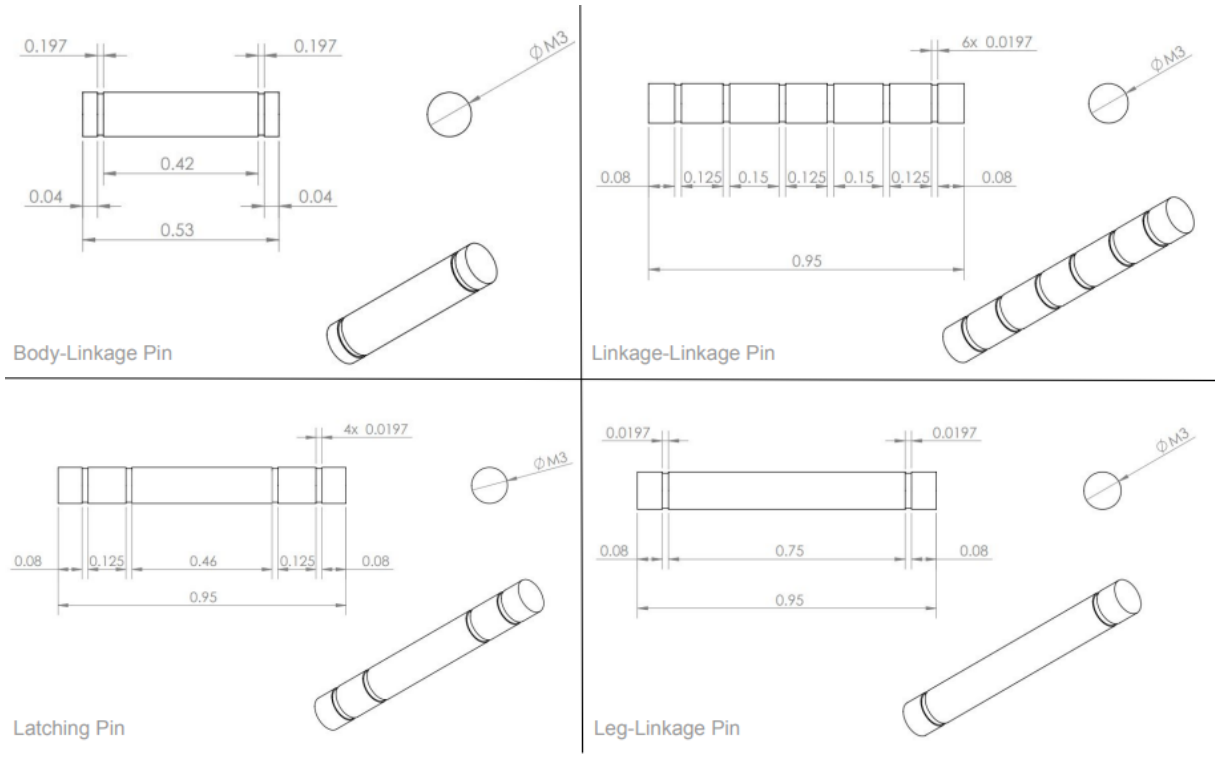

Figure 4.46: Pin drawings (in.).

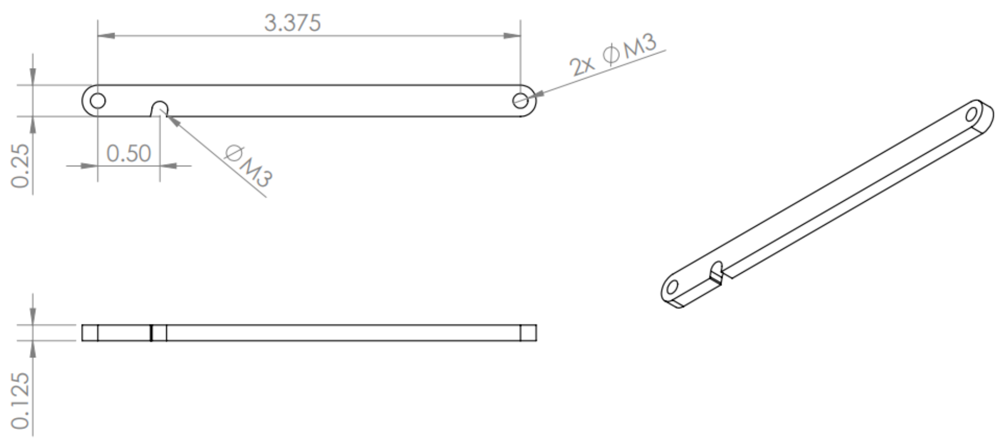

Figure 4.47: Body linkage drawing (in.).

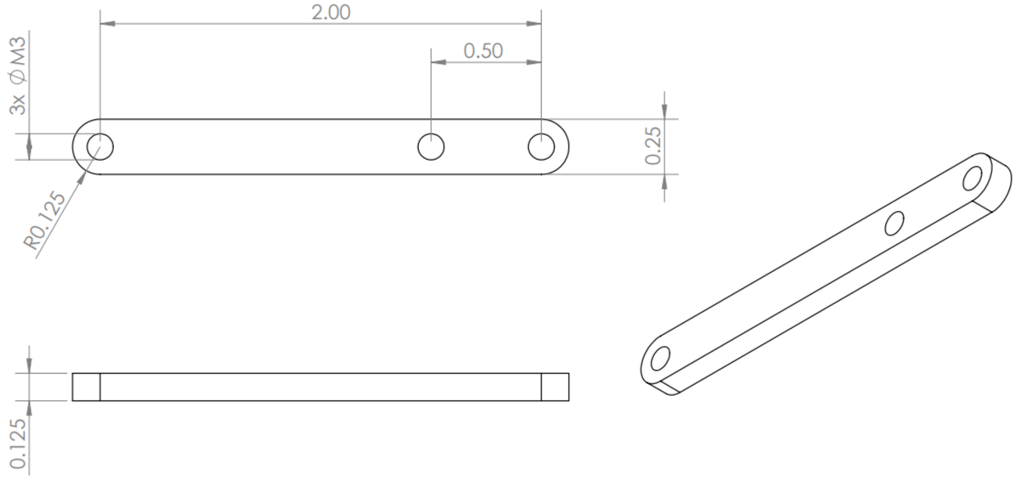

Figure 4.48: Leg linkage drawing (in.).

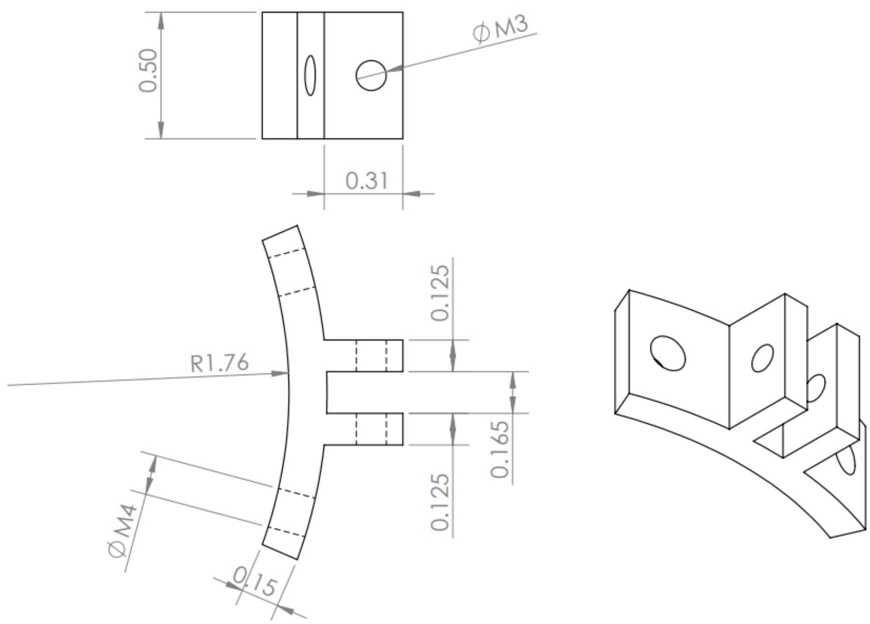

Figure 4.49: Linkage mount drawing (in.).

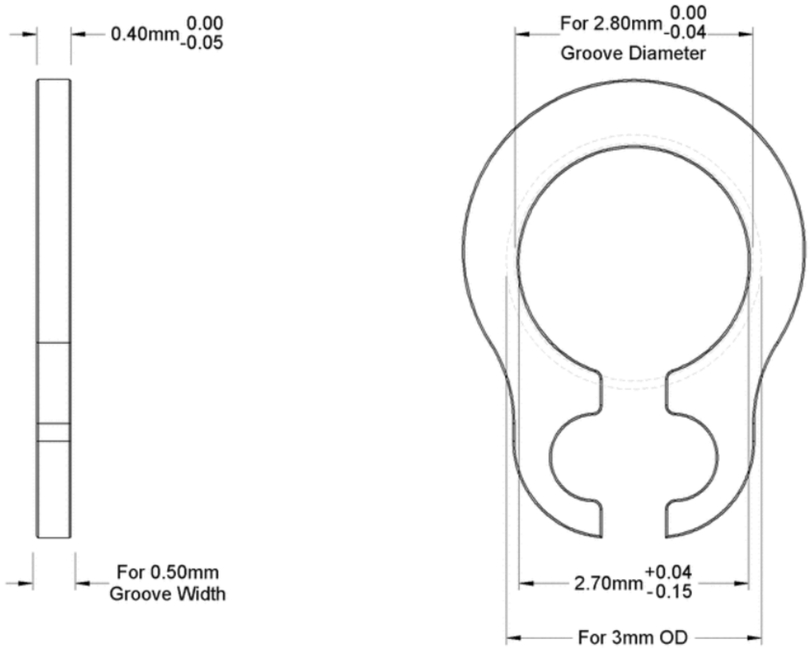

Figure 4.50: Retaining ring drawing (mm). [26]

When the SAIL is inside the deployment bay, it will remain in a folded position, the spring hinges pushing up against the bay tube. For the maximum folding angle, 90 degrees, Figure 4.51 serves as a visualization. The locking mechanism will fold snugly as shown, not interfering with any other components. This is possible because the linkages are offset from each other and the latch pin is extended far enough from the linkage-linkage pin as to not create too much distance between the body and leg. All of this is necessary to keep it within the deployment bay, which has 5.36 in. inner diameter. The legs will fill up this diameter since the spring hinge will push them against those inner walls. However, it is capable of filling a smaller diameter as pictured below.

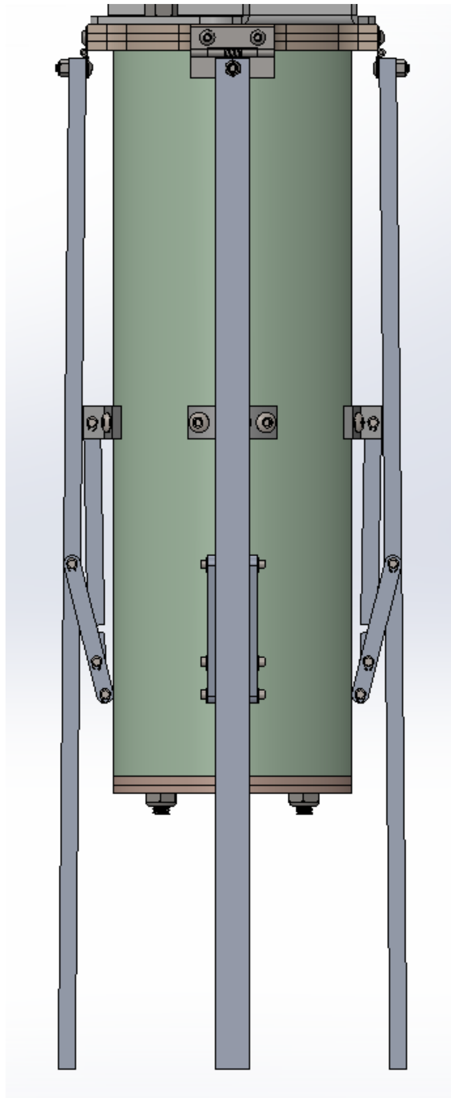

Figure 4.51: Landing legs folded.

A key issue with the legs is their ability to break or bend. To estimate the force that the leg will encounter, mass, velocity, and the time of impact are needed. The mass of the SAIL is 7.65 lb., the velocity is expected to be 5 mph right before contacting the ground, and the time will be estimated to be 0.1 seconds. With these numbers, the maximum impact force will be 34.9 lbf.

Performing a static analysis using SolidWorks, this direct, vertical force was applied to a singular extended leg. Both displacement and stress were evaluated. The yield strength of 6061 aluminum, which makes up the legs and linkages, is 35,000 psi. As seen in Figure 4.52, the maximum stress is 26,940 psi, meaning that the leg and body should not yield under such circumstances. For displacement, the bottom of the leg will bend approximately 0.324 in. as seen in Figure 4.53. This is within the 0.4 in. clearance between the bottom of the body's bolts and the edge of the leg. This means that on a flat surface, the body would take no impact. Thus, the leg system should withstand any landing forces.

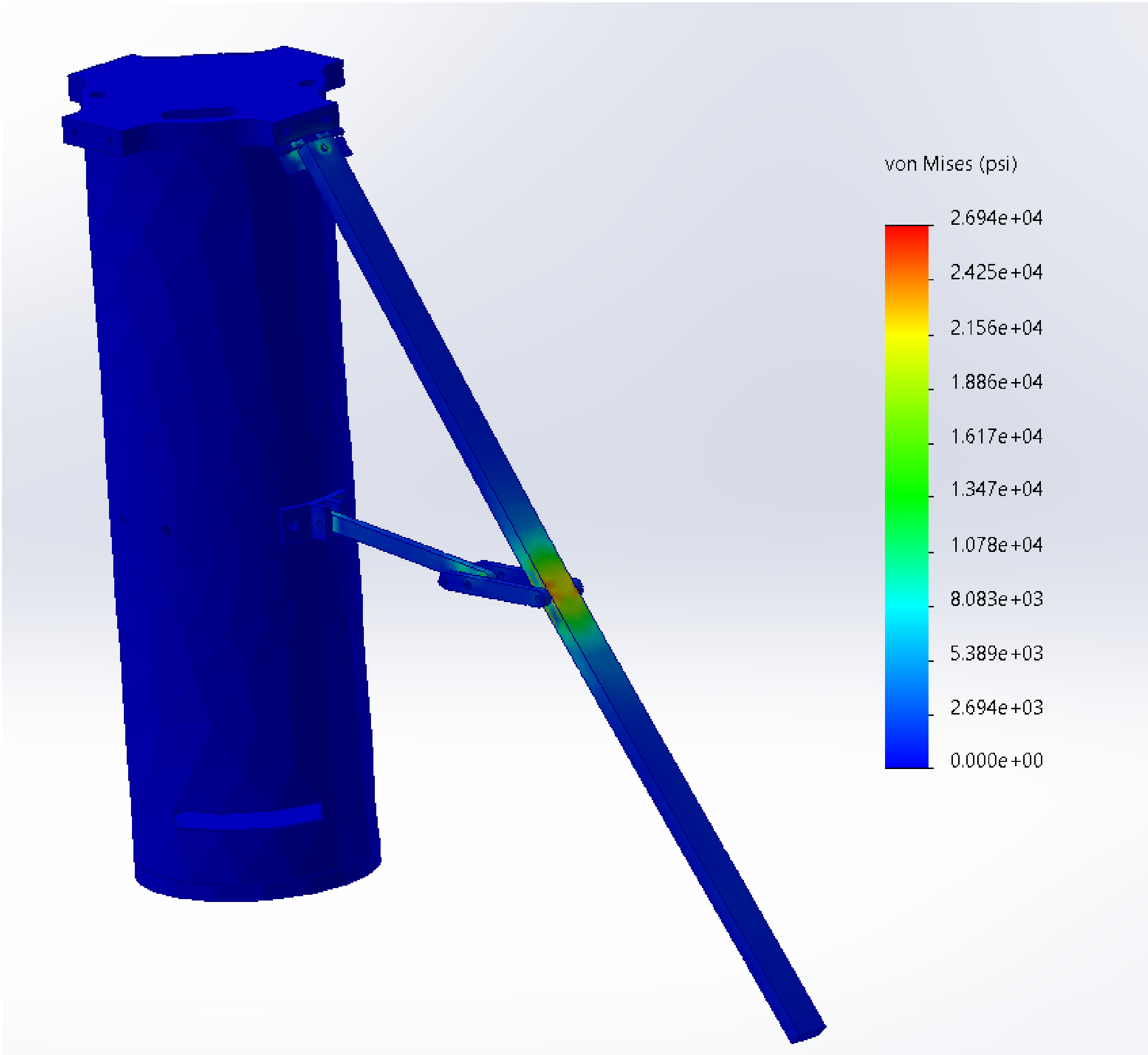

Figure 4.52: Static analysis: Stress from a 34.85 lbf on a singular leg.

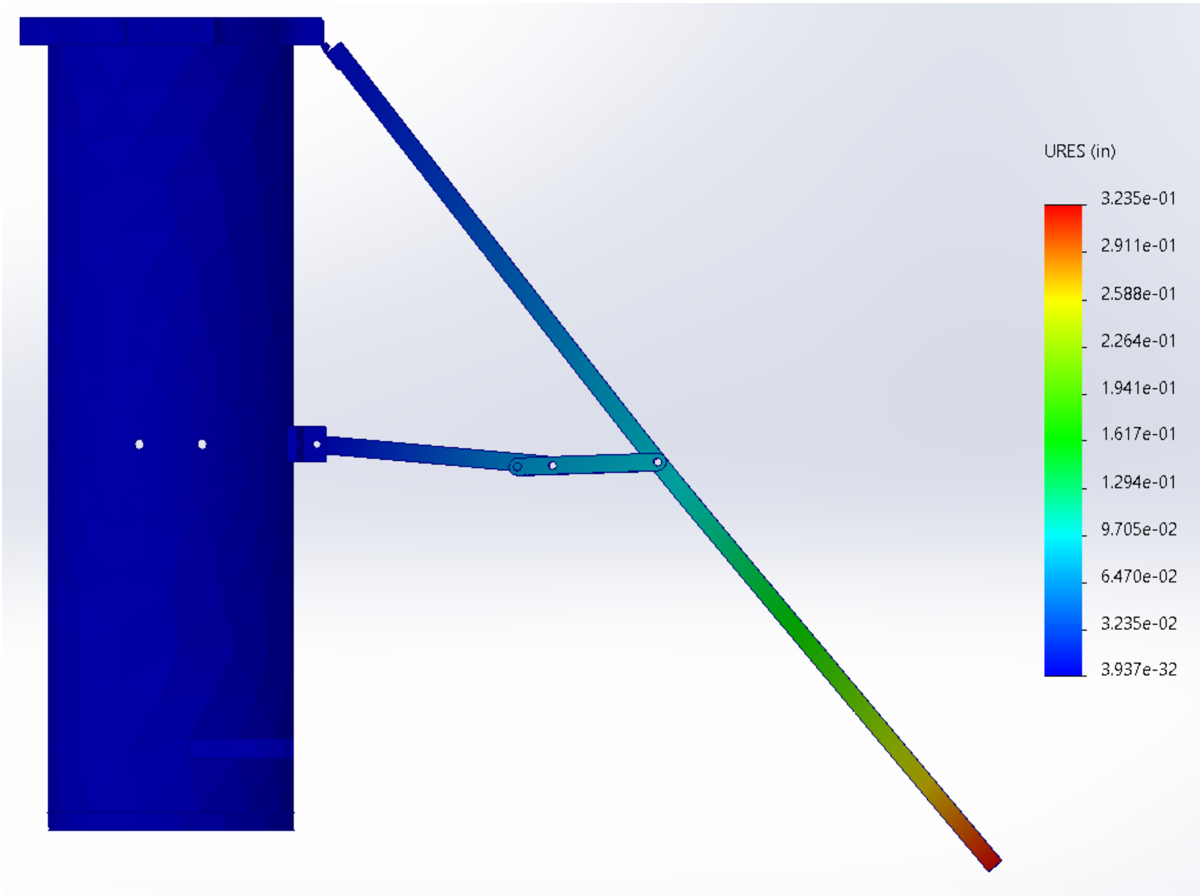

Figure 4.53: Static analysis: Displacement from a 34.85 lbf on a singular leg.

4.3.6 SAIL Body

The SAIL body will be made from G12 fiberglass pictured in Figure 4.54. The tube has an OD of 3.52 in., an ID of 3.40 in. and a weight of 0.6125 lb/ft, which can be further examined in Figure 4.55. G12 is a strong material capable of handling the impact forces of landing. Additionally, fiberglass does not block RF transmissions, enabling the SAIL to communicate with the ground station.

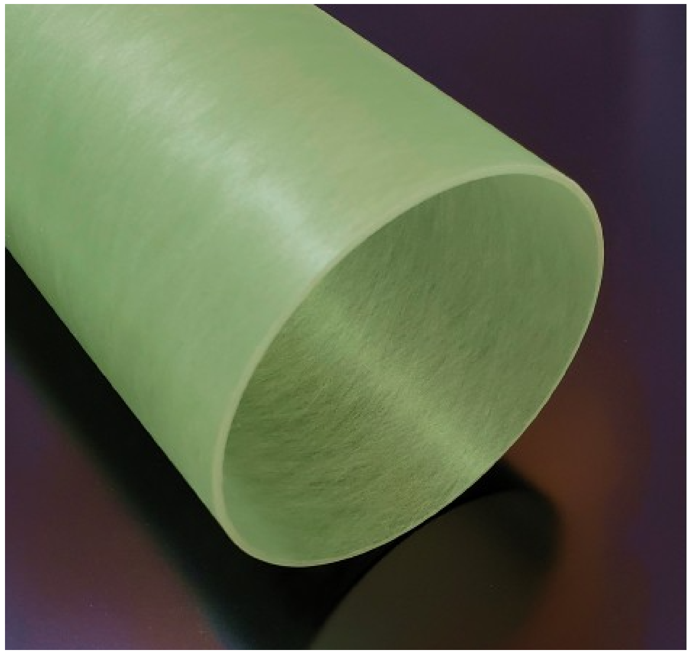

Figure 4.54: G12 fiberglass tube.

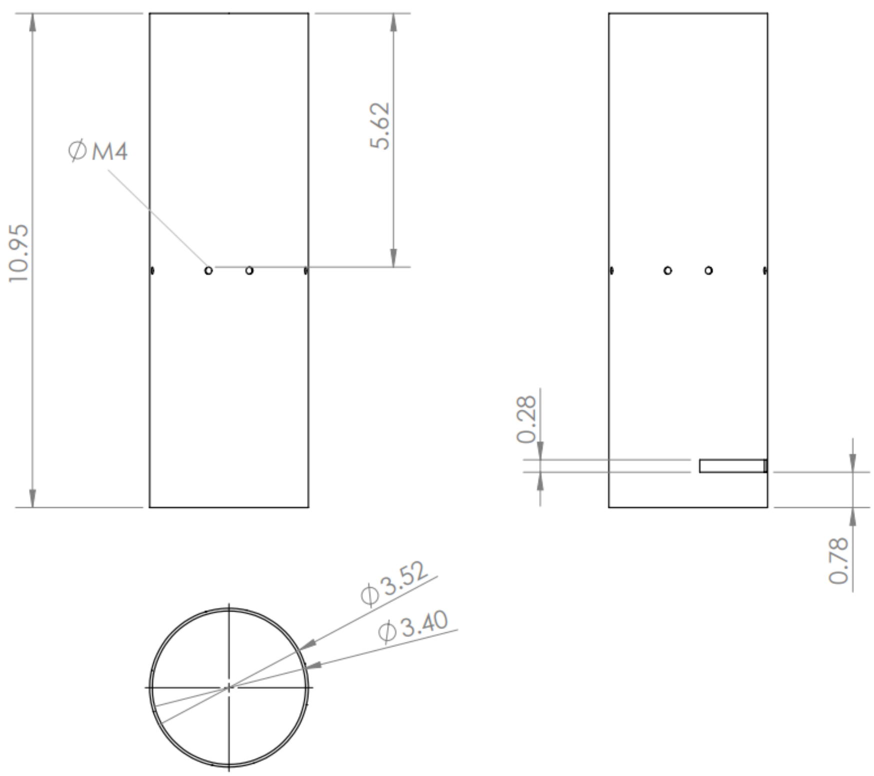

Figure 4.55: SAIL body tube drawing (in.).

The electronics are secured inside the fiberglass tube on a 3D-printed sled that will be secured to the two 1/4-20 threaded rods. These rods are bolted with lock nuts at each end of the body where bulkheads lie. As for the top bulkhead, it also secures the bracket, which connects to the gearbox, as discussed in Section 4.3.3. The top bulkhead is made out of 1/8 in. aircraft-grade birch plywood plies, where each ply is laser cut and epoxied together. It will slot on top of the fiberglass tube and settle inside with two plies to keep it concentric with the body. Additionally, it has two holes for the threaded rods and a hole for the electronic speed controller (ESC) wires to exit and connect to the motor. The wire hole is to the side to prevent interference with the spinning portion of the motor. There are three plies that lay on top of the fiberglass tube that extend outwards to mount the spring hinges. The two holes that extend into the bulkhead's thickness showcase where the M3 x 0.5 mm screws will be drilled into. These dimensions can be seen in Figure 4.56.

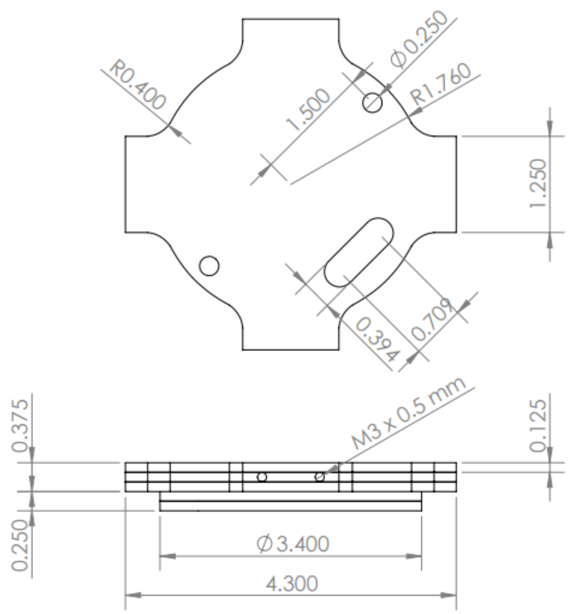

Figure 4.56: Top bulkhead drawing (in.).

On the bottom of the fiberglass body is the other bulkhead. This only has holes for the threaded rods. It has the same two internal plies to keep it concentric with the body and has two more plies that will lie on the edge of the fiberglass tube. This needs to be a strong bulkhead to withstand any forces applied from landing. With the legs giving approximately 0.5 in. of clearance from the threaded rods, there is a mound of some kind, thus the bulkhead will make contact with the ground first.

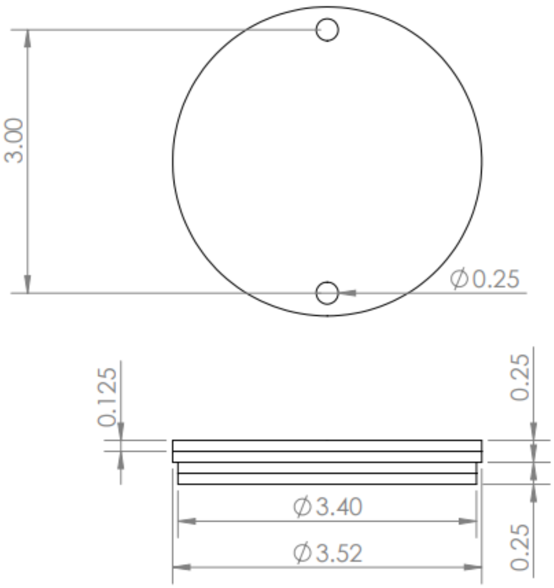

Figure 4.57: Bottom bulkhead drawing (in.).

4.3.7 Electronics

Flight Computer

The flight computer needs to able to control the motor as well as log data from the sensors. Additionally, it needs to consume a low amount of power due to size restraints for the battery. The Adafruit Feather M0 Adalogger, pictured in Figure 4.58, was selected for the flight computer. It is capable of simultaneously sending a PWM signal to the ESC to vary the motor speed and record data from the sensors. It is also able to store the data from the sensors on a local SD card.

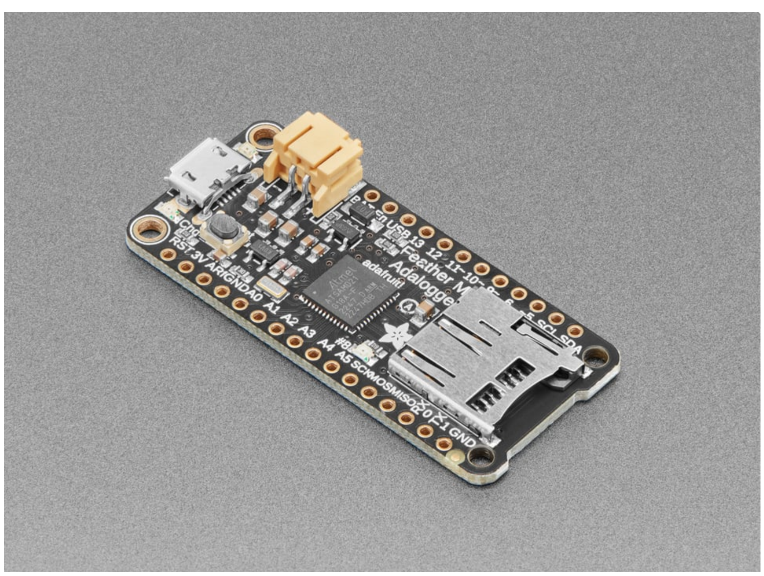

Figure 4.58: Adafruit Feather 32u4 Bluefruit LE [15]

Barometric Altimeter

The MPL3115A2, shown in Figure 4.59, was chosen for the barometric altimeter on board the SAIL. It has a pressure range of 50-110 kPa and can measure altitude within 0.98 ft. and can measure temperature within 1.8 degrees Fahrenheit. It connects to the Adafruit Feather using the I2C protocol. The flight computer will use the data from the altimeter to control the descent velocity of the SAIL.

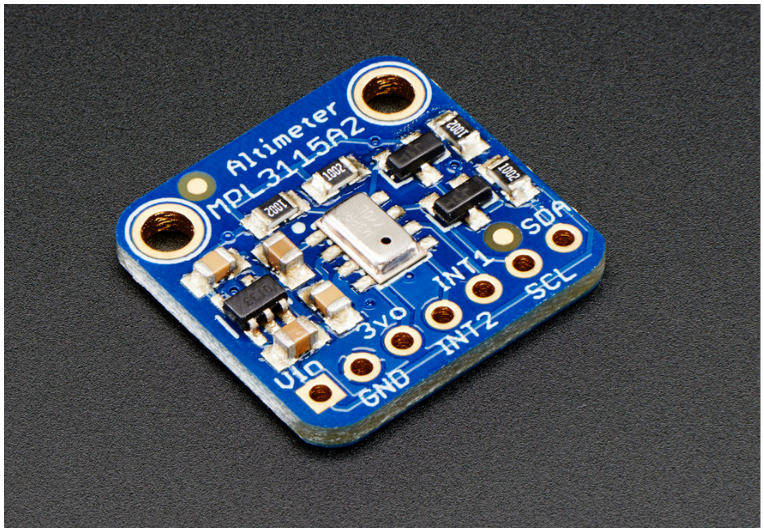

Figure 4.59: MPL3115A2 Altimeter [32]

Inertial Measurement Unit

The Adafruit BNO055, shown in Figure 4.60, was selected for the inertial measurement unit (IMU). The IMU has 9 degrees of freedom, resulting in three axis orientations. It can measure angular velocity, linear acceleration, magnetic field strength, and temperature. It connects to the Adafruit Feather via I2C.

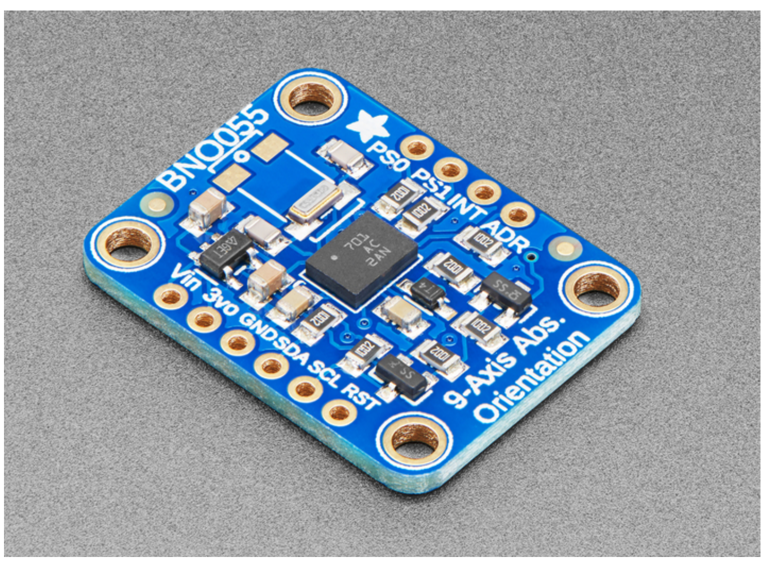

Figure 4.60: Adafruit 9-DOF Absolute Orientation IMU - BNO055 [14]

Spy Camera

The Adafruit Mini Spy Camera, pictured below in Figure 4.61, was chosen to capture in flight footage of the STEMnauts. The camera is capable of recording 480p video with a wide field of view. Furthermore, the circuit board is approximately 1.1 in. x 0.67 in., allowing it to easily fit on the bottom of the electronics sled.

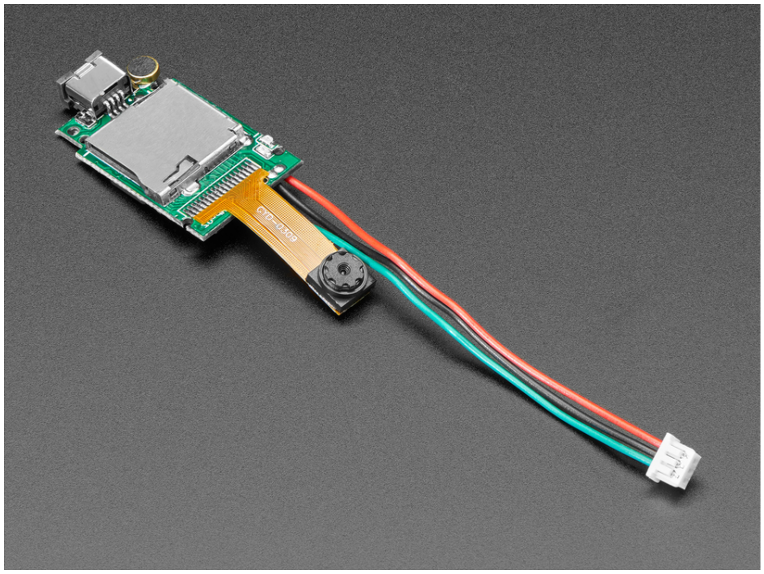

Figure 4.61: Adafruit Mini Spy Camera [31]

Breadboard

The altimeter, IMU, and flight computer will be mounted onto a breadboard. The breadboard shown below in Figure 4.62 will have a power rail that will be connected to the BEC. This allows the BEC to power both the Adafruit Feather and the XTend without needing to splice into the BEC cables.

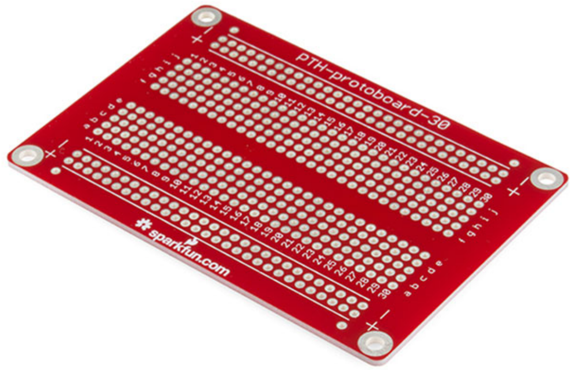

Figure 4.62: Breadboard [28]

Receiver/Transceiver

The XTend, pictured below in Figure 4.83, was chosen for the receiver/transceiver. It operates on the 900MHz band and has a theoretical range of up to 40 miles. It will receive commands from the ground station and transmit live telemetry.

Figure 4.63: XTend 900 [48]

Buck Converter

The XTend requires a 3.3V power input with at least 500 mA of current. While the Adafruit Feather is theoretically capable of providing this power, it would be reaching the limit of the available current. To ensure that the transceiver is able to maintain communication with the ground station, a 3.3V buck converter capable of outputting 1.2A will be used. The buck converter inputs will be connected to the power rail and the output will be connected directly to the XTend.

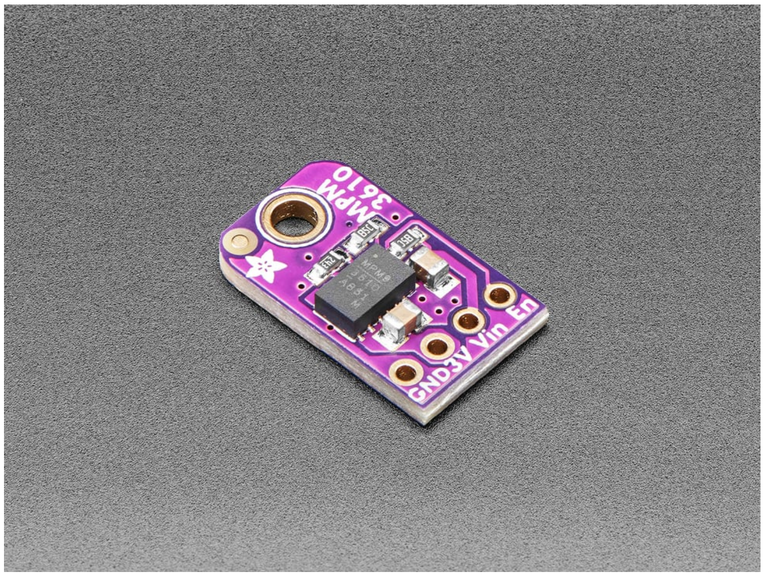

Figure 4.64: MPM3610 3.3V Buck Converter [34]

Mounting Configuration

The electrical components will be mounted on a 3D printed sled shown below in Figures 4.65 - 4.67. The electrical components will be mounted onto the sled using threaded inserts and M3 standoff-s/screws.

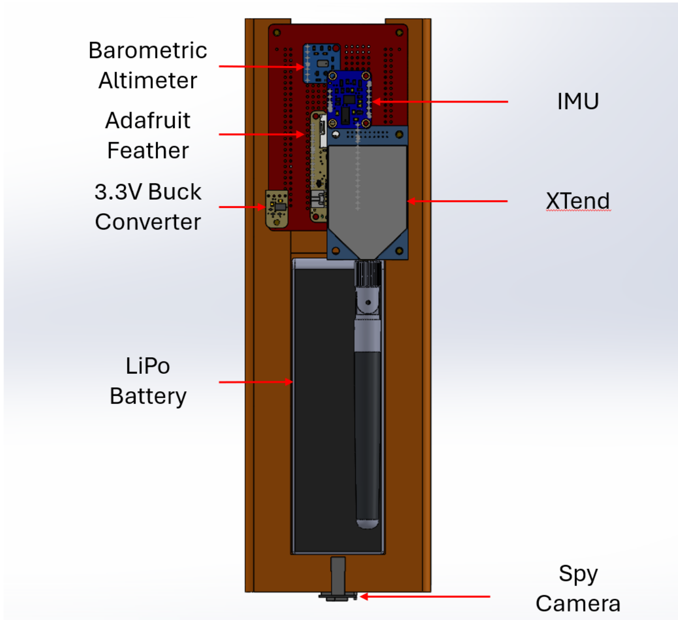

Figure 4.65: Front view of electronics sled.

Figure 4.65 shows the electronic layout. The Arduino Feather and the barometric altimeter will be soldered directly onto the breadboard. The IMU will be soldered onto standard PCB pins to allow it to rest over the Feather and altimeter, allowing all of the components to be fit onto a smaller form factor. Additionally, the buck converter will be mounted to the lower left standoff. Lastly, the spy camera PCB will be mounted to the bottom of the sled and the ribbon cable that the camera is connected to will be folded up and secured to a viewing port in the STEMnaut crew area.

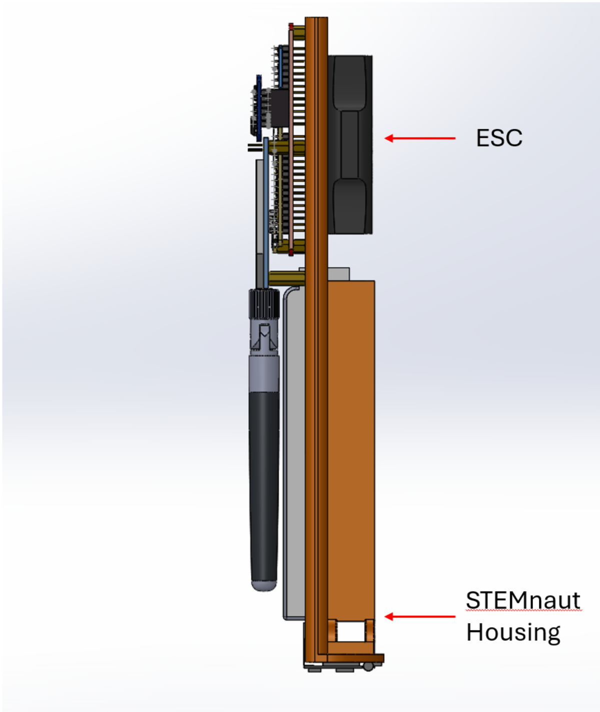

Figure 4.66: Side view of electronics sled.

Figures 4.66 and 4.67 better show the clearance between the components. The components on the bread board are staggered both vertically and horizontally. Additionally, there is a cutout beneath the breadboard to allow room for the pins and wires that will connect the altimeter and IMU to the Feather.

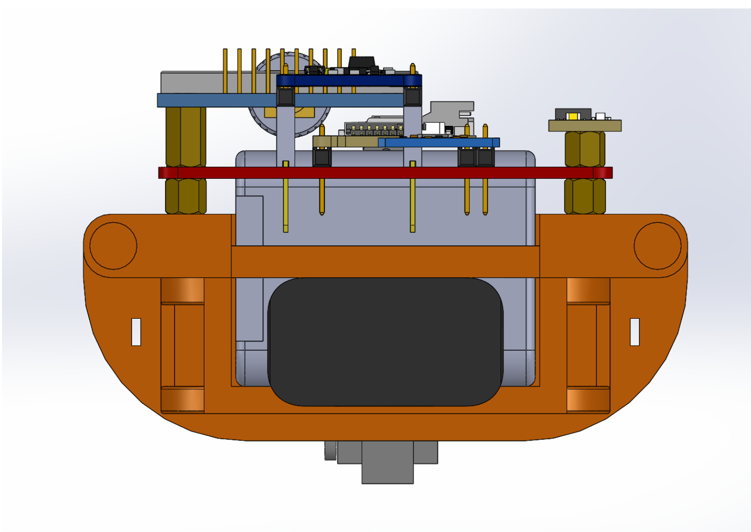

Figure 4.67: Top down view of electronics sled.

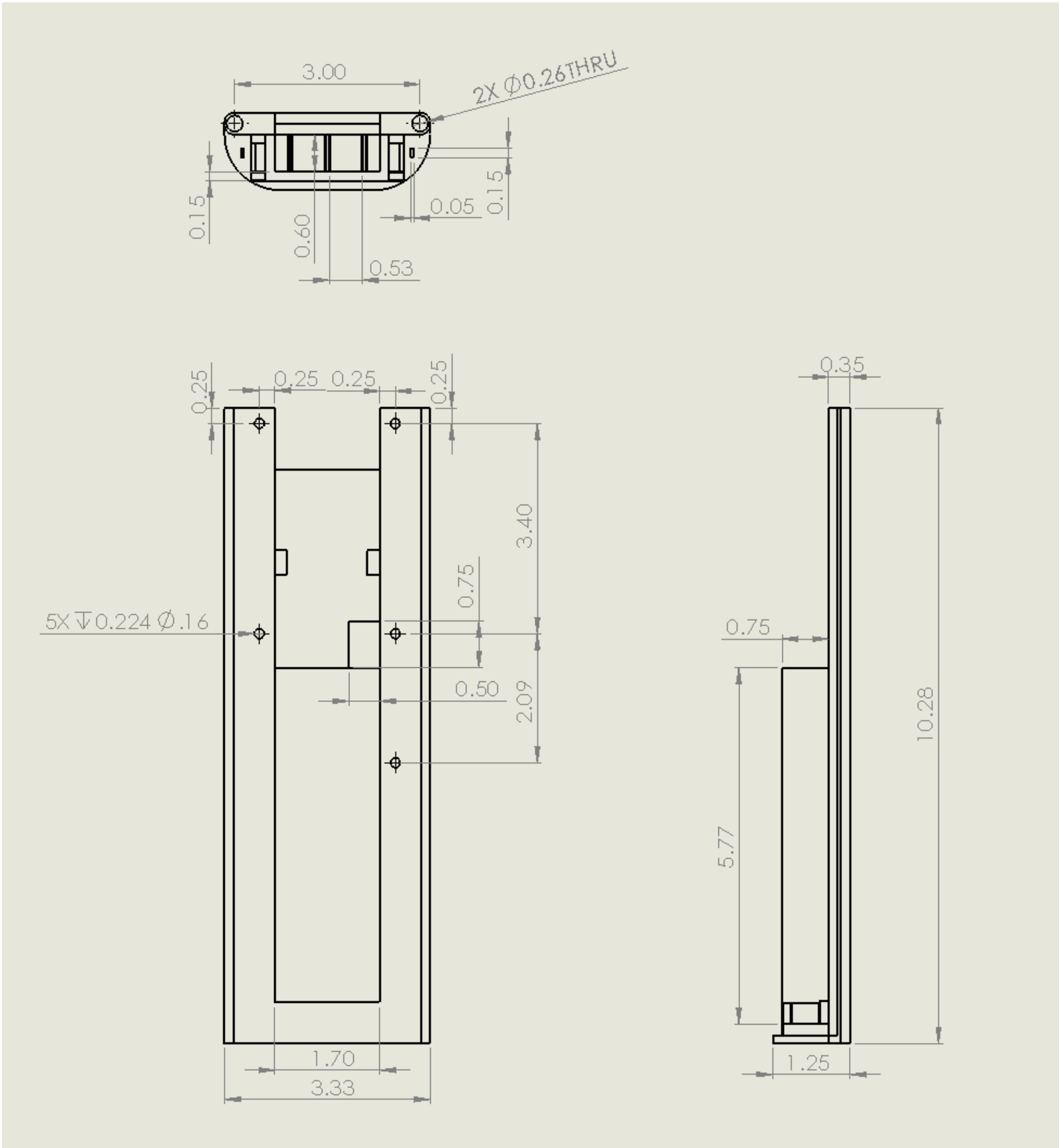

Figure 4.68: Electronics sled drawing with major dimensions annotated.

Figure 4.69 shows the final electronic wiring configuration. All electronics will draw power from the 4000 mAH battery. Additionally, the BEC output from the ESC will be connected to the breadboard's power rail. The Adafruit Feather and XTend 900 will be powered using the 5V rail while the altimeter, IMU, and spy camera will be powered from the Feathers 3V output.

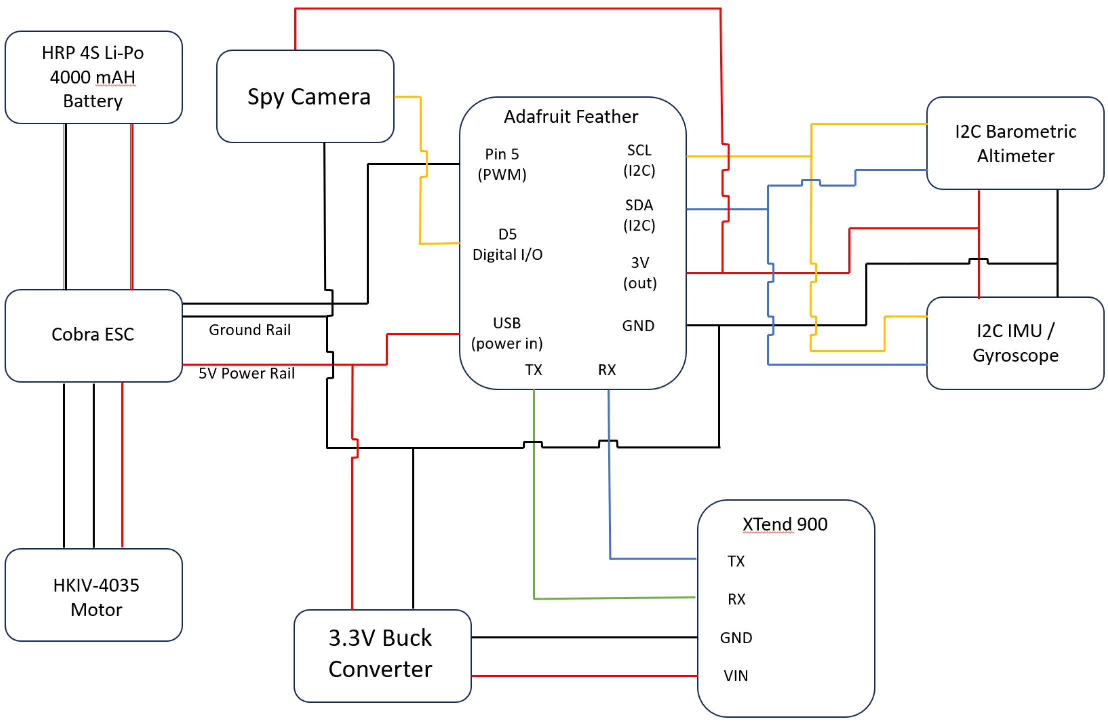

Figure 4.69: SAIL wiring diagram.

4.3.8 STEMnauts

Figure 4.70: Commander Jeffrey

Crew

Commander Jeffrey will be leading the mission, accompanied by Pilot Jean Baptiste Collin de Sussy, mission specialist Jebediah Heister and mission specialist Jeffrina von Quack. To ensure the safety of the crew, a crew cabin will be printed on the bottom of the electronics sled (Figure 4.71). Additionally, each STEMnaut will be secured to their chair using a 0.1 in. velcro straps. The STEMnauts are approximately 0.47 in. x 0.47 in. x 0.52 in. (L x W x H) and weigh approximately 0.003 lb. each.

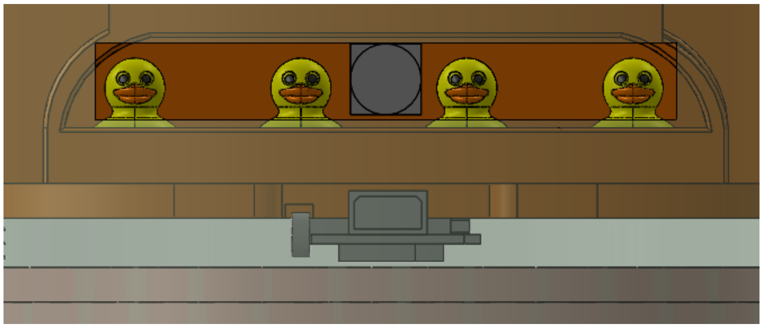

Figure 4.71: STEMnaut crew cabin.

Survivability Metrics

To verify that the flight is survivable for the STEMnauts, the following criteria was established:

- Impact velocity is less than 15 mph to ensure that the landing legs do not fail.
- The STEMnauts do not experience more than 6 G of force for more than 1 second.
- The STEMnauts do not experience more than 3 G of sustained force.
- The STEMnauts are restrained in their chairs for the entire flight and are recovered in their seated positions.
- The pressure inside the SAIL body remains approximately 1 atm after the SAIL is released.

Additionally, the altimeter will be measuring the descent velocity and the camera will show that the STEMnauts did not move during the flight. Lastly, the IMU will measure the force of impact as well as any rapid deceleration that the crew may experience.

4.3.9 Final SAIL Mission Performance Calculations

Weight

The final weights of each part of the SAIL is detailed in Table 4.3.

Table 4.3: SAIL Weight

Component	Unit Weight (lb)	Quantity	Component Weight (lb)
M4 Eye Bolt	0.0138	1	0.0138
Button-head Bolt: 4-40 7/8 in.	0.0003	8	0.0024
Button-head Bolt: 4-40 1 in.	0.0024	8	0.0192
Locknut: 4-40	0.0017	16	0.0272
Spring Hinge: 2 in. x 1/2 in.	0.0305	4	0.1220
Dowel Pin:4 mm dia, 40 mm length	0.0084	4	0.1008
Propeller Blades	0.2936	4	1.1744
Sonic Hub: 8 mm Hex Bore	0.0309	4	0.1236
Sonic Hub: 6 mm Round Bore	0.0309	1	0.0309
Hex Shaft	0.1378	1	0.1378
Rotor Hub	0.4419	2	0.8838

Upper Spacer	0.0089	1	0.0089
Lower Spacer	0.0050	1	0.0050
Side Spacer	0.0001	2	0.0002
Bearing Spacer	0.0002	10	0.0020
Electronics Sled	0.0800	1	0.0800
U-Channel: 72 mm	0.0942	1	0.0942
U-Channel: 48 mm	0.0479	1	0.0479
GoTube: 43 mm	0.0440	1	0.0440
GoTube Bearing	0.0419	2	0.0838
Flanged Bearing	0.0077	3	0.0231
2-Side, 1-Post Bearing	0.0192	1	0.0192
Shaft	0.0130	2	0.0260
Bevel Gear, 1:2	0.1060	2	0.2120
Button-head Bolt: M4x0.7, 30 mm	0.0500	1	0.0500
Button-head Bolt: M4x0.7, 5 mm	0.0003	4	0.0012
Button-head Bolt: M4x0.7, 12 mm	0.0032	54	0.1728
Locknut: High-Strength M4x0.7 mm	0.0027	46	0.1242
Standoff: 8 mm hex	0.0112	2	0.0224
Locknut: High Strength 1/4 in.-20	0.0106	4	0.0424
Threaded Rod: High Strength 1/4 in.-20	0.1269	2	0.2538
Spring Hinge	0.0089	4	0.0356
Top Bulkhead	0.1140	1	0.1140
Bottom Bulkhead	0.1600	1	0.1600
Fiberglass G12 Tube 3.52 in. OD	0.5600	1	0.5600
Button-head Bolt: M3x0.5 mm, 23 mm	0.0017	12	0.0204
Locknut: Medium-Strength M3x0.5 mm	0.0014	4	0.0056
Retaining Ring	0.0001	56	0.0056
Aluminum Legs	0.1140	4	0.4560
Dowel Pin:3 mm Dia, 24 mm Length	0.0103	4	0.0412
Scorpion HKIV-4035 Motor	1.0050	1	1.0050
4000 mAH LiPo	0.9313	1	0.9313
Electronic Speed Controller	0.1806	1	0.1806
XTend 900	0.0400	1	0.0400
MPM3610 Buck Converter	0.0176	1	0.0176
Adafruit Feather	0.0011	1	0.0011
BNO055 IMU	0.0066	1	0.0066
MPL3115A2 Altimeter	0.0026	1	0.0066
Mini Spy Camera	0.0062	1	0.0062
		Total Weight	7.65

Drift Distance and Kinetic Energy

The maximum drift distance for the SAIL was calculated by assuming a wind velocity of 20 mph, deployment of the SAIL at an altitude of 450 ft., and an initial descent velocity of 15 mph. At an altitude of 100 ft., the descent velocity will be decreased to 5 mph by increasing the thrust. The kinetic energy was calculated for both the target descent velocity and 15 mph, the highest acceptable descent velocity for a successful mission.

Table 4.4: SAIL Wind Drift Distances and Kinetic Energy

Drift Distance	Kinetic Energy (5 mph)	Kinetic Energy (15 mph)
2110.19 ft	6.38 ft-lb	57.46 ft-lb

4.4 SAIL Deployment

The SAIL will be housed in a protective deployment bay in order to prevent tangling of the SAIL with shock cords during descent and/or release. The deployment bay will contain the entire SAIL as well as the release electronics. This configuration will allow for manual release of the SAIL once RSO permission is given, per NASA Requirement 4.3.3.

4.4.1 Sequence of Events for Release

The SAIL deployment bay will have a U bolt on the top side which will be attached to a shock cord, which in turn will be attached to the nose cone. The main parachute recovery event will separate the SAIL deployment bay from the payload section of the launch vehicle. Afterwards, the deployment bay will be descending under the nose cone parachute. Once RSO permission is given, an RF command will be sent to the deployment bay, unlatching the SAIL. Next, the SAIL will fall out of the deployment bay which in turn will unfold the spring loaded rotor blades and landing legs. and start the descent process. A diagram of this sequence of events is shown in Figure 4.72

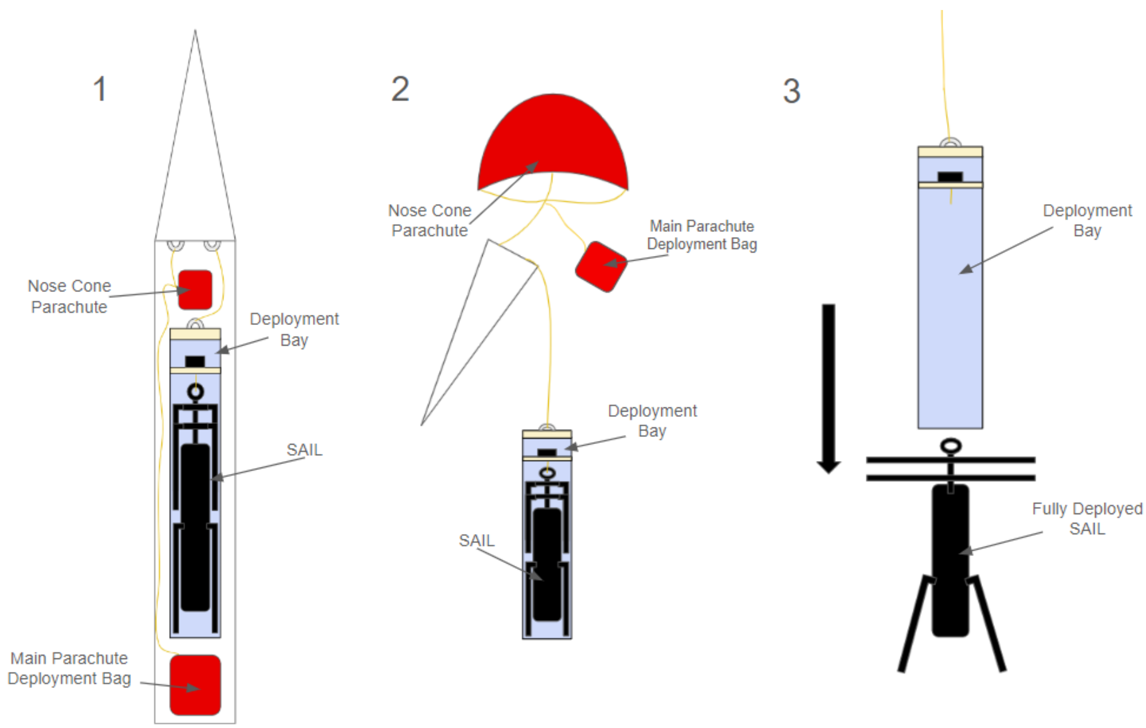

Figure 4.72: Sequence of events for SAIL deployment.

The top of the SAIL will be connected to a shock cord that will loop through a latch with the end secured on a U-bolt. This latch and the tension from the spring loaded rotor blades and legs will keep the SAIL secure within the deployment bay during launch, separation, and descent.

4.4.2 Deployment Bay

The SAIL deployment bay will utilize design concepts from the rest of the launch vehicle. The body of the bay will be a 5.50 in. diameter and 31.30 in. long Blue Tube section, the material shown in Figure 4.73. This length of the tube will accommodate the entire length of the SAIL as well as the release electronics.

Figure 4.73: Blue Tube for SAIL deployment bay [21].

Two birch plywood bulkheads will be used for housing the electronics and as the attachment point for the shock cord. The forward bulkhead will consist of four layers of plywood held together with an epoxy layup. A single U-bolt will be secured to the top of this bulkhead, where a shock cord will be attached. The aft bulkhead will be two plies of plywood, secured to the forward bulkhead with two 1/4 in. threaded rods that are 5 in. in length. Additionally, the aft bulkhead will be attached to the Blue Tube with four 12-24 stainless steel button head screws and four corner brackets. Housed in between the two bulkheads will be the release electronics. Both bulkheads will be removable to facilitate maintenance on the release electronics. A model of the deployment bay is shown in Figure 4.74.

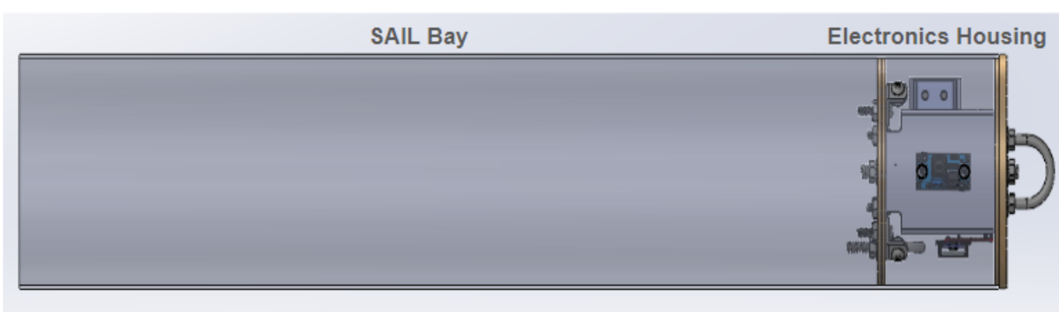

Figure 4.74: SAIL Deployment bay model.

The deployment electronics and latch will be housed in and around a 3D printed PLA sled. The configuration of the sled and electronics in the electronics bay is shown in Figures 4.75 and 4.76. The sled will be fitted along the threaded rods and will be flush with the insides of both bulkheads. Additionally, the latch will be secured to the aft bulkhead with four brackets, two 1/8 in. socket head screws, and two 1/8 in. hex nuts. As shown in Figure 4.76, the servo for opening the latch will be mounted onto the sled. A better view of the servo mounts is shown in Figure 4.77. The aft bulkhead will also have a 1/4 in. U-bolt with a 1.25 in. separation. This U-bolt will be used to secure the shock cord that will be attached to the latch and fed through the eye bolt of the SAIL. All of the electronics will be secured to the sled using heat inserts and nylon screws.

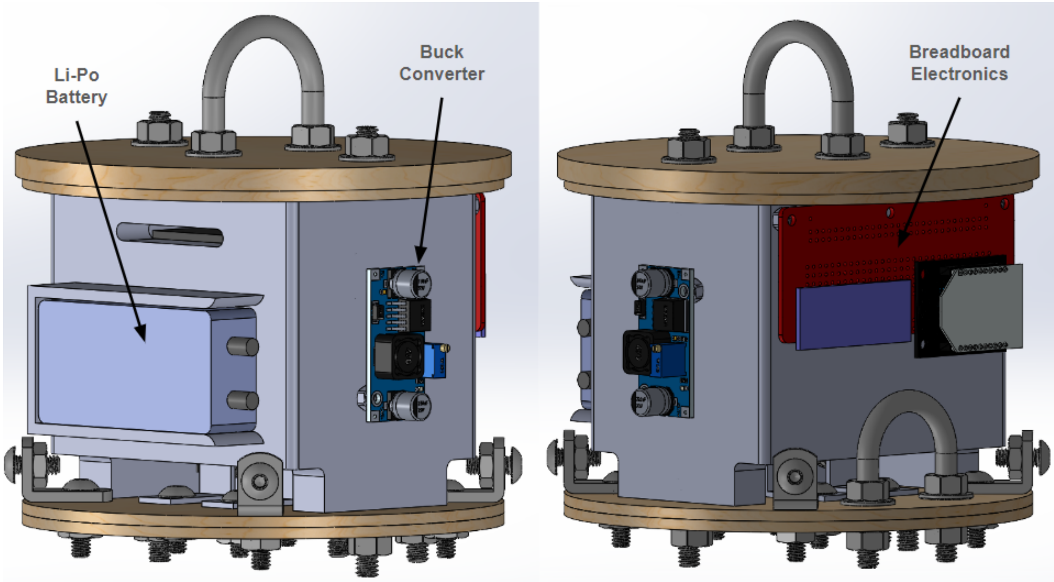

Figure 4.75: Electronics housing in the deployment bay.

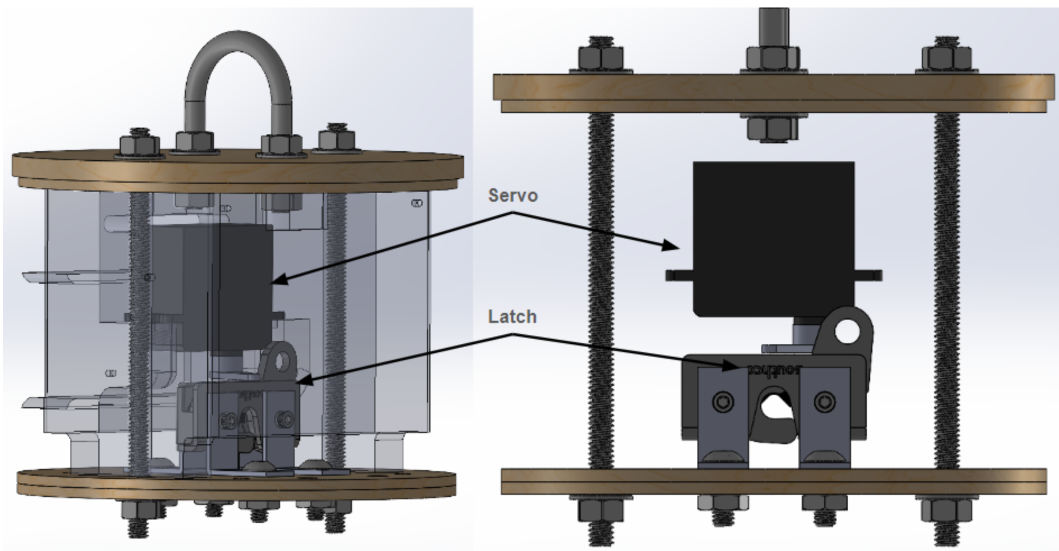

Figure 4.76: Sled interior in electronics housing.

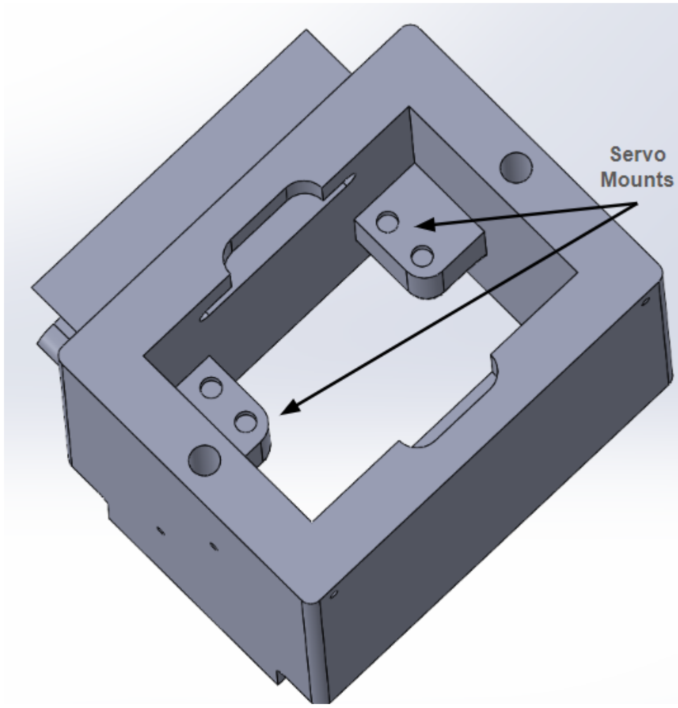

Figure 4.77: Servo mounts on electronics sled.

Detailed drawings with dimensions for the deployment bay, bulkheads, and sled are shown in Figures 4.78, 4.79, 4.80, and 4.81, respectively.

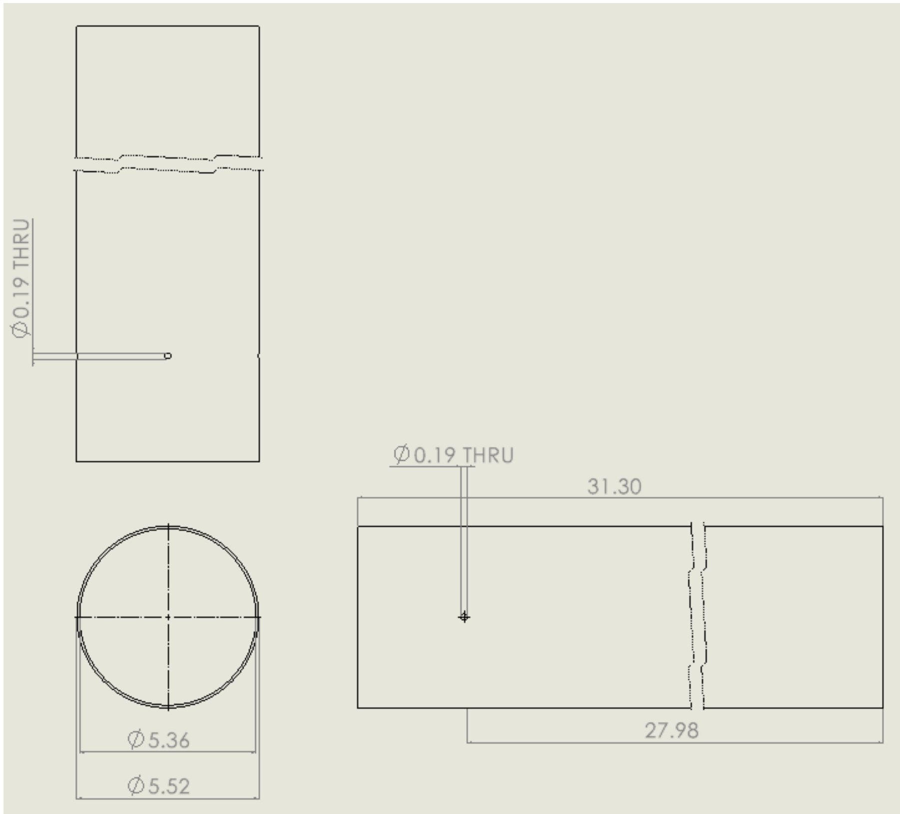

Figure 4.78: CAD drawing of deployment bay body (in.).

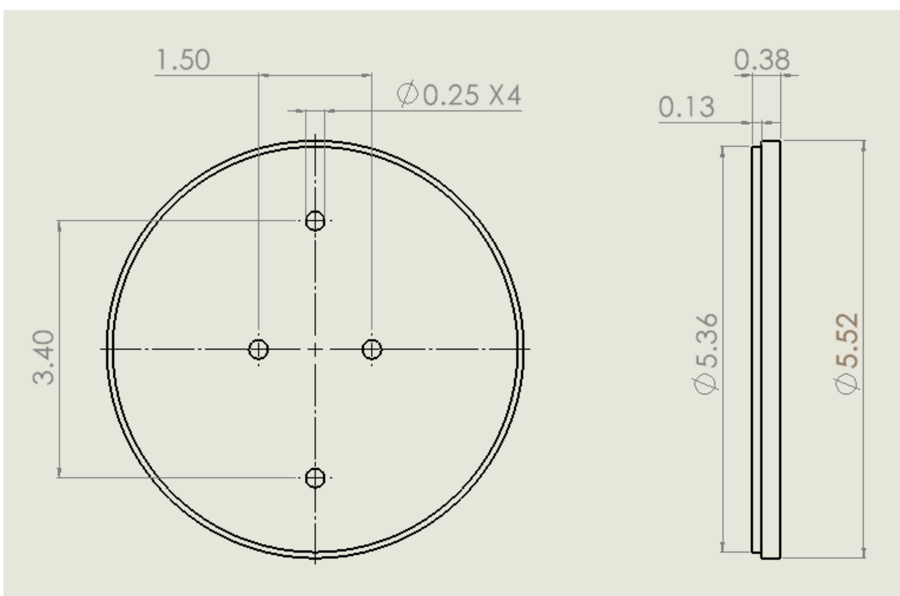

Figure 4.79: CAD drawing of forward bulkhead (in.).

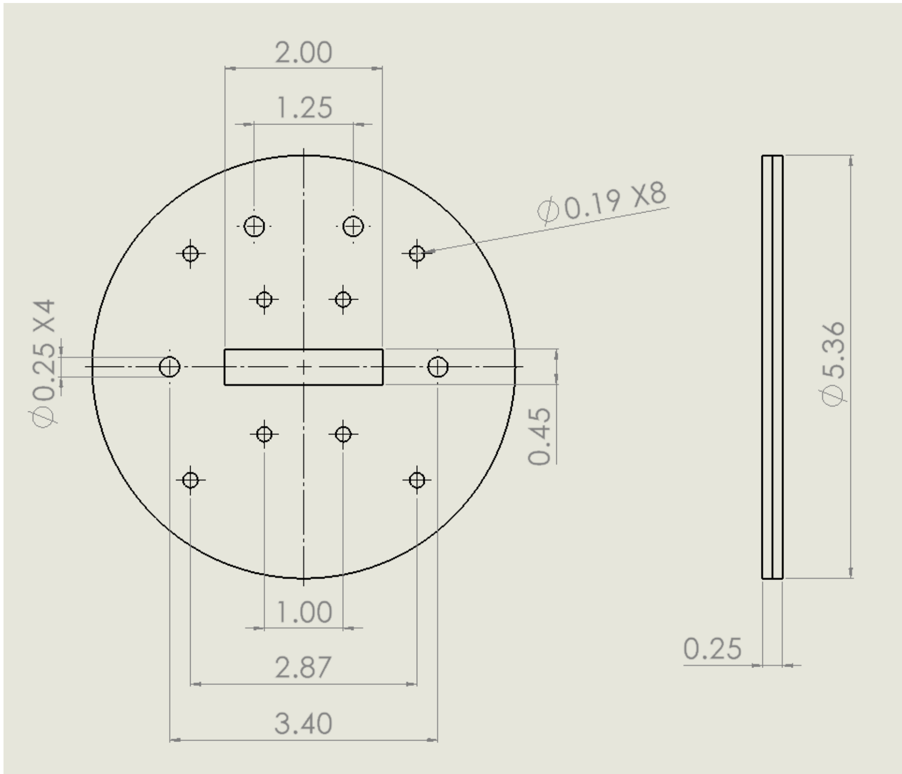

Figure 4.80: CAD drawing of aft bulkhead (in.).

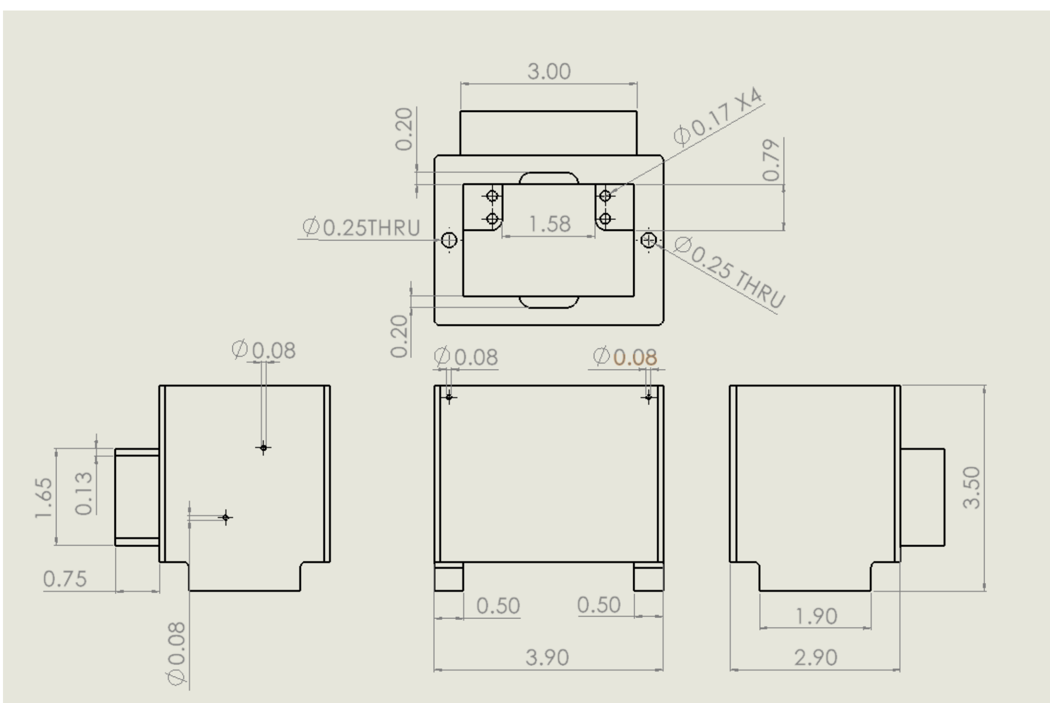

Figure 4.81: CAD drawing of electronics bay sled (in.).

4.4.3 Deployment Bay Weight Breakdown

The final weights of each part of the deployment bay is detailed in Table 4.5. The weight of the deployment bay is separate from the SAIL and will not be considered when evaluating Team Derived Requirement PD 5.

Table 4.5: Deployment Bay Weight

Component	Unit Weight (lb)	Quantity	Component Weight (lb)
Blue Tube Body	1.538	1	1.538
Forward Bulkhead	0.2229	1	0.2229
Aft Bulkhead	0.0024	1	0.0024
U-Bolt: 1/4”-20, 1.5” Ctr.-to-Ctr.	0.0081	1	0.0081
U-Bolt: 1/4”-20, 1.25” Ctr.-to-Ctr.	0.0071	1	0.0071
Electronics Sled	0.1229	1	0.1229
Southco Latch	0.0938	1	0.0938
HS-7950TH Servo	0.1484	1	0.1484
Breadboard Electronics	0.1016	1	0.1016
7.4V Li-Po Battery	0.1953	1	0.1953
Threaded Rods: 1/4”-20, 5” long	0.0068	2	0.0136
Hex Nuts: 1/4”-20	0.0077	12	0.0928
Washers: 1/4”	0.0034	12	0.0410
L-Bracket: 1”x1”x0.5”	0.0156	4	0.0625
L-Bracket: 11/16”x1”x0.5”	0.0030	4	0.0119
Hex Nuts: 12-24	0.0008	12	0.0091
Nylon Screws: 5-40, 3/4” long	0.0003	4	0.0012
Button Screw: 12-24, 0.75” long	0.0011	8	0.0090
Button Screw: 12-24, 0.5” long	0.0009	4	0.0034
Socket Head Screw: 5-40, 3/4” long	0.0004	2	0.0008
Hex Nut: 5-40	0.0003	2	0.0006
		Total Weight	2.82

4.4.4 Release Electronics and Latch

Below is an overview of the electronics within the deployment bay electronics housing, as well as the chosen latch for securing the SAIL before release. All electronics will interface with each other using a breadboard, the same model of which is shown in Figure 4.62.

Deployment Computer

The driving component of the release system is an Arduino Nano Every. The purpose of this micro controller is to send a signal to a servo to open the latch once the RF command is received. This is an important part of the release sequence, and as such a simple micro controller was chosen to facilitate communication between the receiver module and the latch. The chosen micro controller is shown in Figure 4.82.

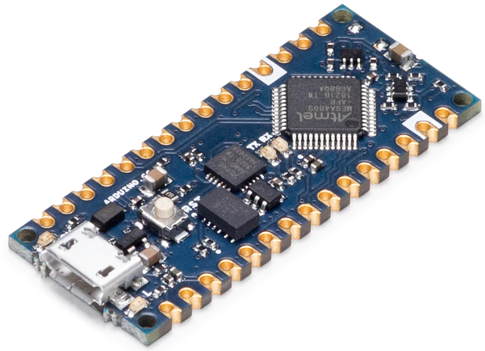

Figure 4.82: Arduino Nano Every for release control [19].

Transceiver

The Arduino will interface with an RF module to determine when the release command has been received. The chosen RF module is the XBee Pro S3B, which is the same module that will be used in the SAIL itself. This module, along with the XBee Explorer USB board, will be used for transmitting at the ground station as well as receiving the command to release. The XBee Pro is shown in Figure 4.83 and the XBee Explorer board in Figure 4.84.

Figure 4.83: XBee Pro S3B [47]

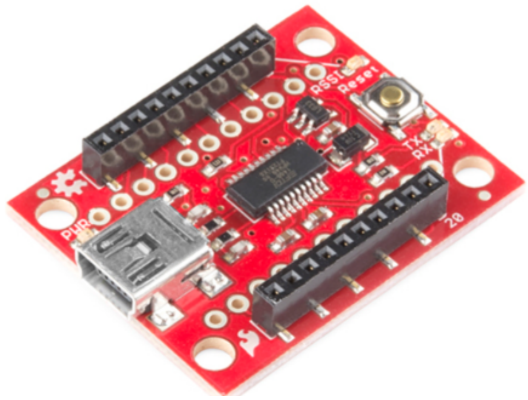

Figure 4.84: XBee Explorer Module [42]

Latch

The connecting point of the SAIL to the deployment bay will be a rotary door latch. This latch must be strong in order to withstand forces during launch vehicle separation and takeoff. Additionally, the latch must be small enough to leave room for the electronics in the electronics housing. For this reason, the Southco R4-05-22-505-10 latch will be used. This latch takes up little space at 1.8in. x 0.40 in. x 0.84 in. and is rated for a max load of 585 lb [41], as well as being simple to use with a single manual release lever. The chosen latch is shown in Figure 4.85.

Figure 4.85: Southco R4-05-22-505-10 Latch [41]

Servo

The Southco latch must be opened using the manual release lever. To accomplish this, a small high torque servo will be used to turn the lever. The chosen servo is the HS-7950TH Servo by Hitec, shown in Figure 4.86. This servo is capable of transmitting a torque of up to 25 lb/in [29], and as such is capable of opening the latch with a 1 in. servo horn.

Figure 4.86: HS-7950TH Servo for latch opening [29].

Battery

The electrical components for releasing the SAIL will be housed in the deployment bay. For powering the electronics, a 7.4V 1500 mAh LiPo will be used. The chosen LiPo is shown in Figure 4.87. The release electronics are estimated to have a current draw of 100 mA when idle, and having a current draw of around 2880 mA when operating under the load of the latch [29]. This LiPo will allow for a maximum of 7.5 hours of idle time with an operational time of about 30 minutes, providing ample time for potential launch pad delays and to fully release the SAIL.

Figure 4.87: Zeee 7.4V LiPo battery for release electronics [35].

Buck Converter

In order the step down the voltage for use by the Arduino and servo, a buck converter will need to be used. The chosen buck converter is the ATNSINC LM2596 DC-DC Buck Converter, due to its availability to the club and ease of use. This component is shown in Figure 4.88.

Figure 4.88: ATNSINC Buck Converter for release system [34].

4.4.5 Release Electronics Wiring Diagram

Figure 4.89 shows the wiring schematic for the release electronics.

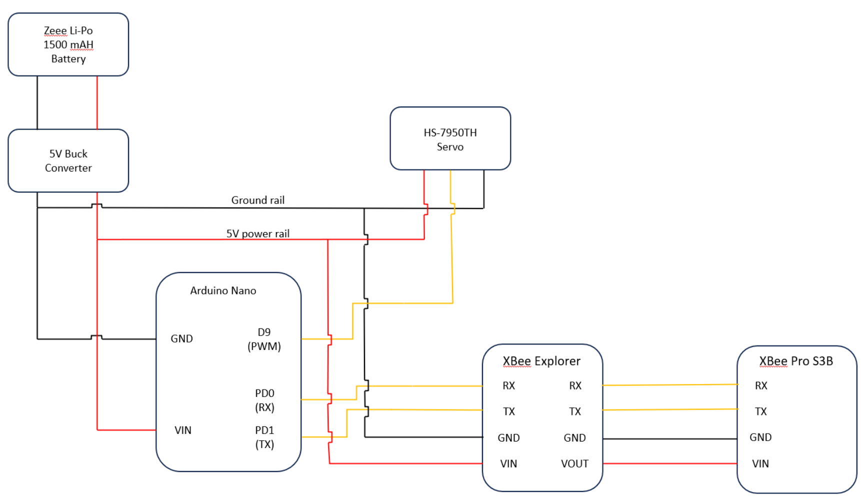

Figure 4.89: Release electronics wiring diagram.

4.5 SAIL Manufacturing

4.5.1 Blade Fabrication

The rotor blades will be constructed in three parts using CF-PC. These separate parts will then be joined using PET Gloop, a strong adhesive formulated for PET-G 3D prints. One section of rotor blade, illustrated below in Figure 4.90, will have a rectangular extrusion printed at the end of the blade. It is important to note that the root of the blade will be 1.5 in. wide to prevent the trailing edge from breaking. Since the moment arm of aerodynamic forces will be highest at this point, it needs to be thicker. The next section, illustrated below in

Figure 4.91, will have a corresponding void space as well as a rectangular extrusion on the other end. PET Gloop will be applied to both the rectangular extrusion and the void space. Then, the pieces will be connected and clamped together to allow for the adhesive to cure. The third section with only a void will be glued to the second piece with PET Gloop and clamped until cured. These three pieces will make up the 15 in. blade.

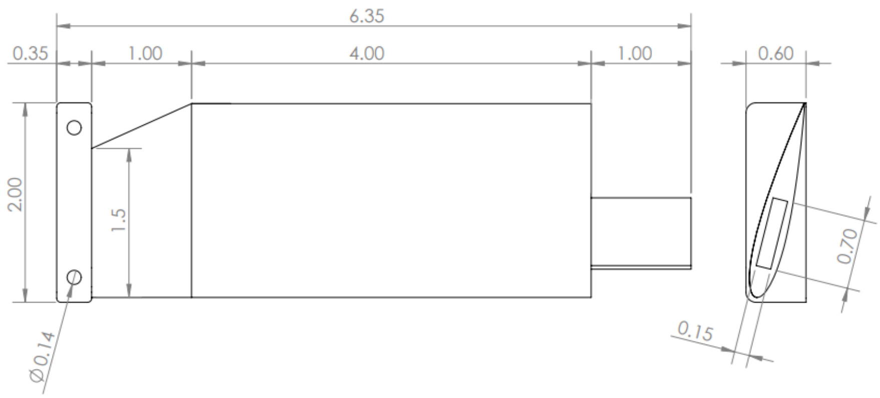

Figure 4.90: Propeller blade root with connection block.

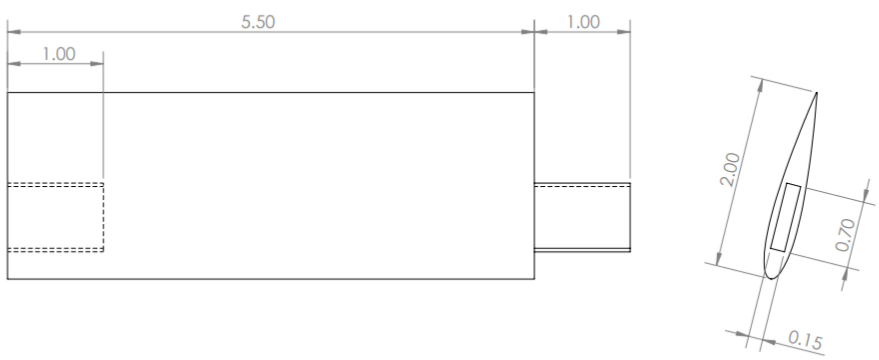

Figure 4.91: Propeller blade second section.

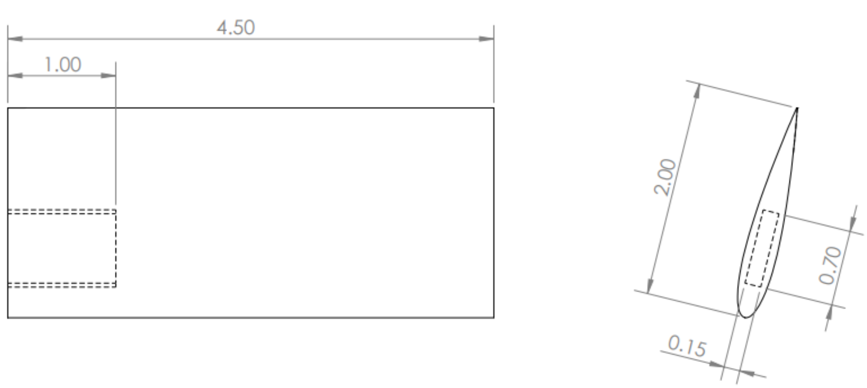

Figure 4.92: Propeller blade third section.

Since the blade is expected to undergo large forces, PET Gloop cannot be relied on as the sole bonding force. Thus, a carbon fiber wrap will be performed using the vacuum-assisted resin transfer molding (VARTM) process. It is a process by which West Systems epoxy will be transferred through the carbon fiber plies while inside a vacuumed bag. This ensures there is a smooth surface finish and the carbon fiber plies will not be distorted in ways that may affect the performance. The selected carbon fiber, as seen in Figure 4.93, will be a light, uni-directional ply.

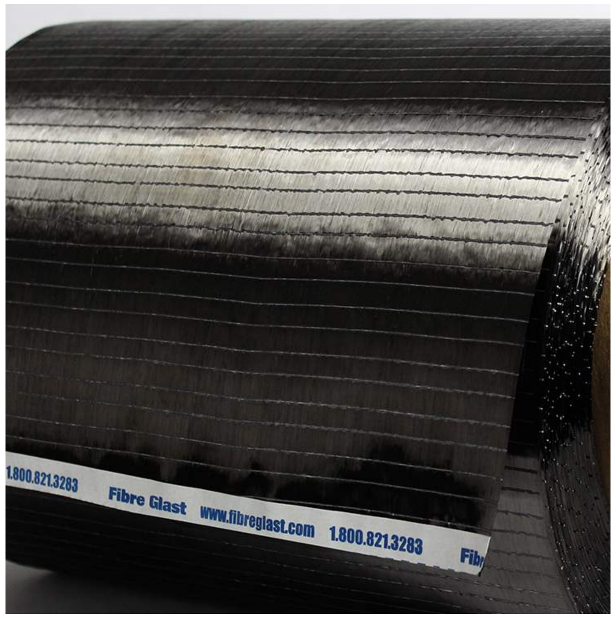

Figure 4.93: Uni-directional carbon fiber [46].

The assembled rotor blades will be tested using a universal test machine, as outlined in Section 6.2.3, to ensure that the joint will not fail under the centripetal force during operation.

The intersection where the airfoil and the connecting block meet is the most prone to breaking because there are no carbon fiber plies to reinforce it. Also, the centripetal force will be the highest because the total weight beyond this point is highest, creating a larger centripetal force. This is compounded by the fact that there is a smaller cross-sectional area resulting from the geometry. This geometry is in place to prevent any failure at the trailing edge. Since the force on the blade acts as a moment, it causes this point to break first. Thus, the trailing edge is set to be thicker at the root. To ensure there is rigidity, three steel pins will be epoxied inside as shown in Figure 4.94.

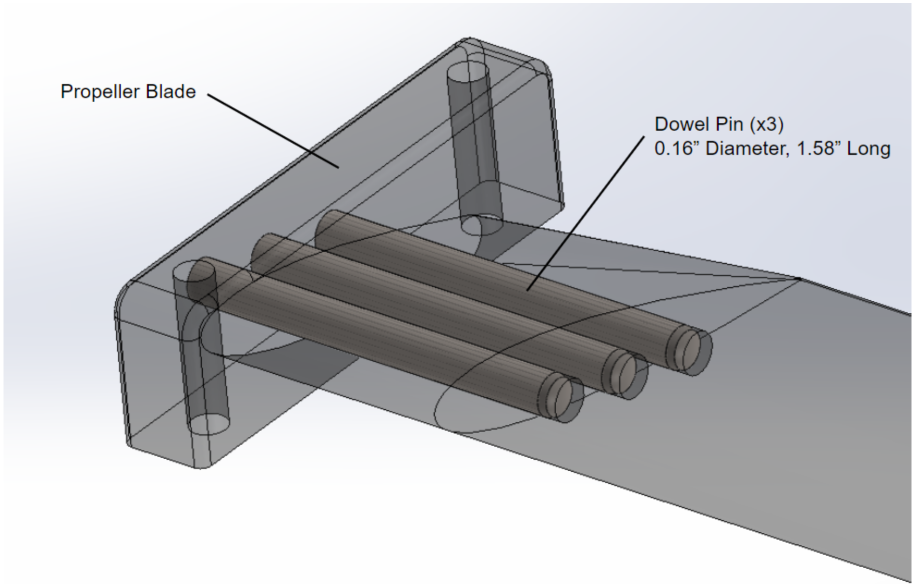

Figure 4.94: Propeller blade reinforcement.

4.5.2 Rotor Blade Hub Fabrication

The rotor blade hubs will be made from 1/8 in. 6061 aluminum. The hubs will be cut from the metal plate using a waterjet.

4.6 Deployment Manufacturing

4.6.1 Electronics Housing

The electronics will be mounted on a 3D printed sled using heat inserts and circuit board standoffs. This sled will be positioned between the two bulkheads and held in place using two high-strength steel threaded rods.

4.6.2 Structure

The bulkheads will be made from 1/8 in. thick aircraft-grade plywood. The top bulkhead will be made from four plies epoxied together. The lower bulkhead will be made from two plies. Both bulkheads will cure overnight inside a vacuum sealed environment to achieve the best possible bond. See Section 3.4.3 for more information.

4.7 System Operations

Operation of the SAIL will be divided into two parts: the release and the controlled descent. This sequence of operations will be imperative for a successful mission of the SAIL, and are outline below.

4.7.1 Sequence of Events

The descent and recovery of the SAIL, in compliance with NASA Requirement 4.1, is described in the following sequence of events:

1. Main parachute deployment occurs. Deployment bay is pulled out of the payload bay and is hanging underneath the nosecone/nosecone parachute.
2. At an altitude of approximately 450 ft., and after RSO permission is received, the ground station sends the command to release the SAIL from the deployment bay.
3. Deployment bay receives command and activates the servo, opening the latch and allowing the SAIL to fall from the deployment bay. Simultaneously, the SAIL receives a command to begin the startup sequence.

4. One second after the SAIL is released, the SAIL powers the DC motor and spins the rotor blades.
5. The flight computer adjusts the RPM of the rotor blades until it reaches a descent velocity of 15 mph.
6. At an altitude of 100 ft., the flight computer increases the RPM of the rotor blades until the SAIL reaches a descent velocity of 5 mph.
7. Accelerometer registers landing and the rotor blades immediately shut down.

4.7.2 Ground Station

The ground control station for the SAIL will serve two main purposes: releasing the SAIL and ending motor operation in case of emergency. Communication will be through a custom Python UI. A mock up of this UI is shown below in Figure 4.95. The PySerial module will be used for interfacing with the ground station XBee transmitter. This transmitter will be used for sending the deployment and kill switch commands.

Figure 4.95: Python UI for manual release command and data collection.

This UI will contain commands for releasing and ending operation of the SAIL motor. The ground station operator will be in close contact with the RSO to ensure that the SAIL is descending in a safe manner.

4.8 Payload Integration

The entirety of the payload will be contained within the deployment bay, covered in Section 4.4.2. This bay will be contained in the main/payload bay of the launch vehicle, greatly simplifying the integration of the payload system into the launch vehicle. Overall, the bay with the SAIL inside will occupy 31 in. of the payload bay. Additionally, the outside fiberglass air frame has an inner diameter of 6 in., while the outer diameter of the deployment bay is 5.518 in., giving enough room around the bay for parachute shock cords to pass through. In Figures 4.96 and 4.97, a top down view and bottom view can be seen of the propeller blades and landing legs extending until contact with the deployment bay due to their spring hinges. A complete assembly showing how the SAIL integrates into the deployment bay is seen in Figure 4.98.

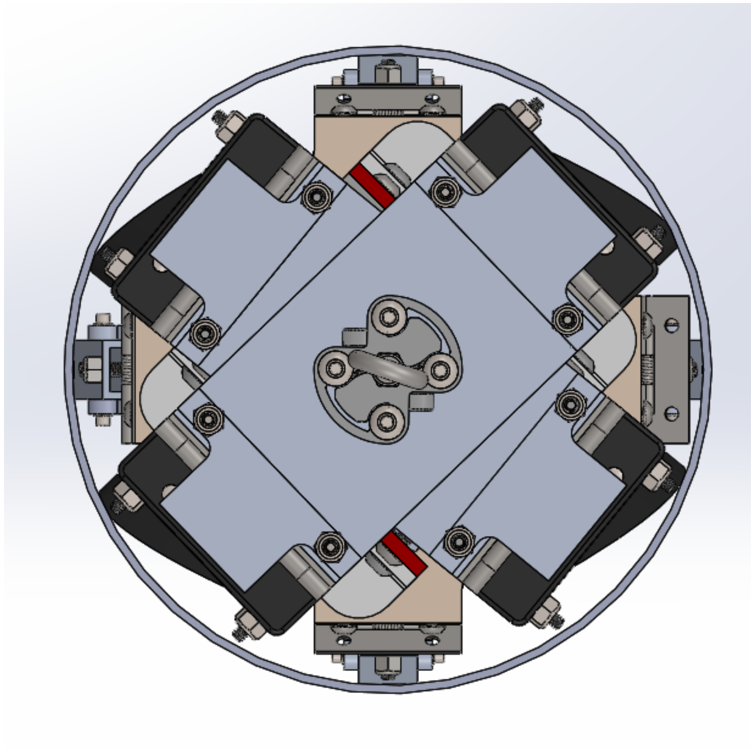

Figure 4.96: Top-down view of the SAIL inside the deployment bay.

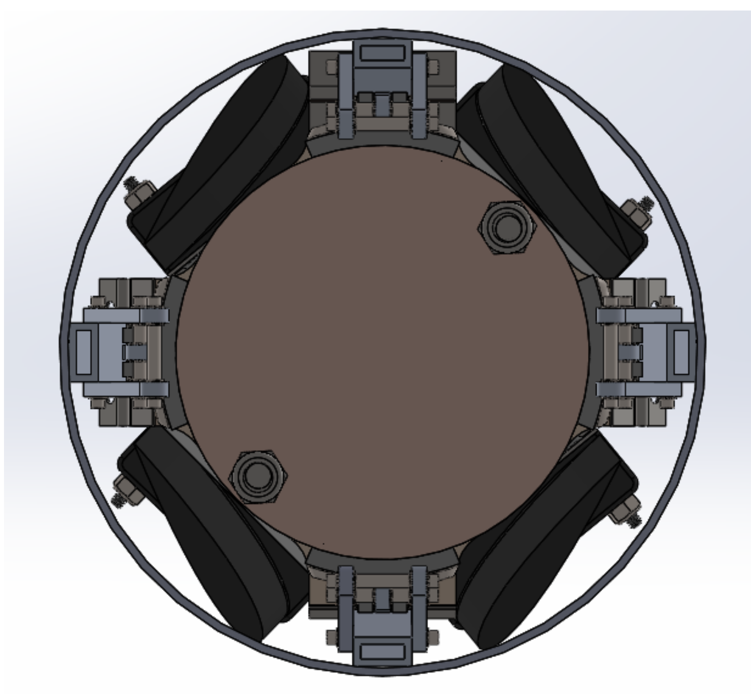

Figure 4.97: Bottom view of the SAIL inside the deployment bay.

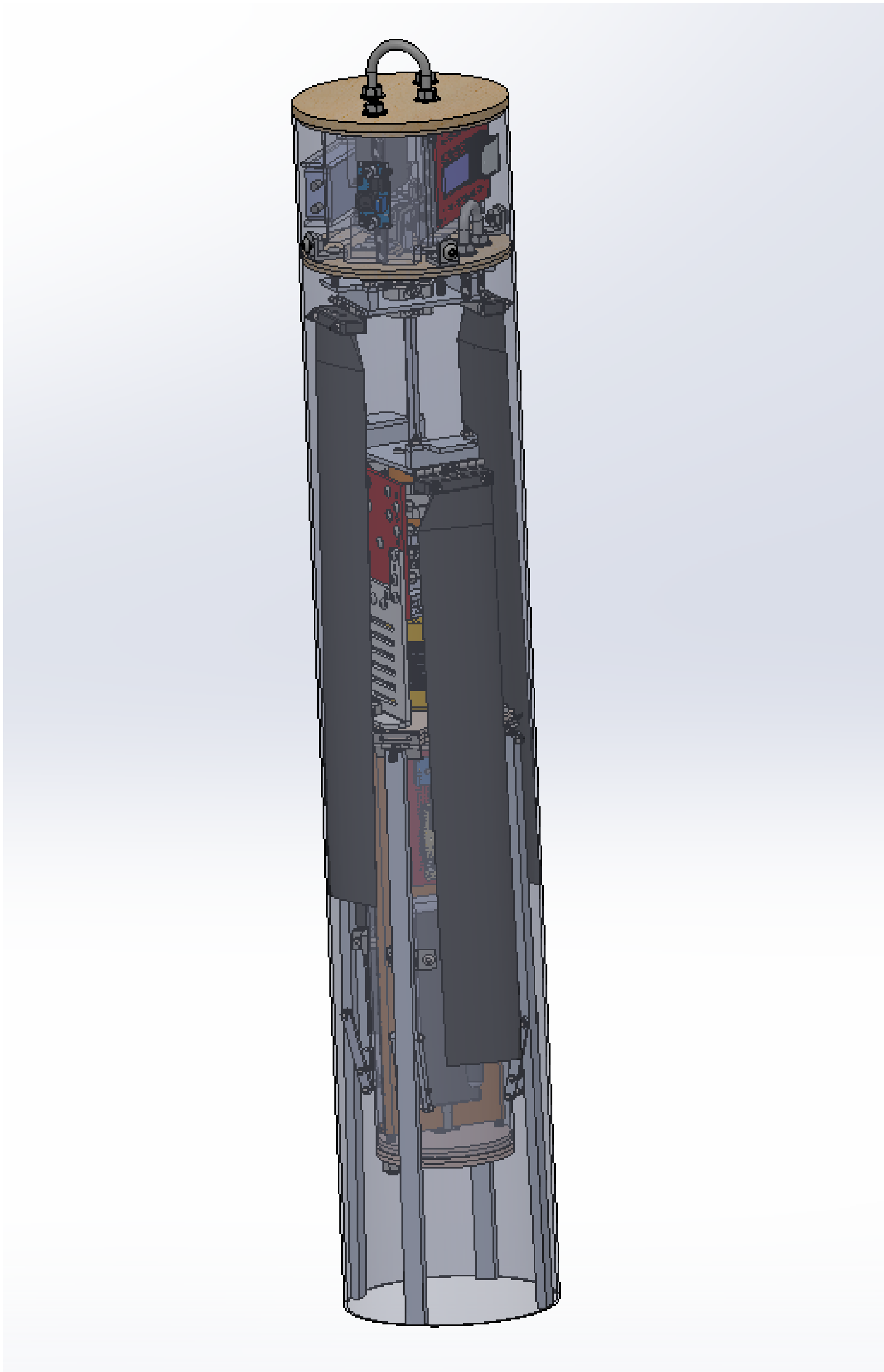

Figure 4.98: A full view of the SAIL integrated into the deployment bay.

5 Safety

5.1 Safety Officer

Megan Rink is the 2023-2024 Safety Officer. Megan is responsible for ensuring the safe operation of lab tools and materials, including, but not limited to, drill presses, hand tools, band saws, power tools, flammable items, and hazardous materials. She is required to attend all launches and must be present during the construction of the launch vehicle, payload, and associated components. She is responsible for maintaining all lab space and equipment to NASA, MAE, and Environmental Health and Safety standards. This includes, but is not limited to, displaying proper safety information and documentation, maintaining the safe operation of a flame and hazardous materials cabinet, keeping lab inventory, and stocking an appropriate first aid kit. She can be reached via email at mdrink@ncsu.edu.

5.2 Hazard Analysis Methods

Safety documentation is performed through FMEA analysis, Likelihood-Severity (LS) matrices, and Fault Tree Analysis (FTA). LS matrices detail each hazard and the corresponding causes, effects, and LS as determined by the matrix. Mitigation methods for each hazard have been analyzed and the LS after mitigation has been determined. Additionally, Fault Tree Analysis has been performed for the payload subsystem.

Verification of safety procedures are checked through various sources, including but not limited to, inspection, launch day checklists, NAR Safety Code, TRA Safety Code, and HPRC standards.

Below is the LS matrix upon which the FMEA tables are based. Failure modes are defined as hazards color-coded orange or red. LS ratings both before and after mitigation are analyzed systematically in order to determine the percent likelihood and percent severity of failure for each launch vehicle system. There are additional matrices to better visualize the LS percentages both before and after mitigation for each subsection.

Table 5.1: LS Matrix Key

		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	1A	2A	3A	4A
	B Unlikely	1B	2B	3B	4B
	C Likely	1C	2C	3C	4C
	D Very Likely	1D	2D	3D	4D

5.3 Failure Modes and Effects Analysis (FMEA)

Out of 94 hazards analyzed, none result in failure modes after mitigarion.

Risk Assessment Before Mitigation					
44.681% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	2.123%	2.123%	5.319%	7.447%
	B Unlikely	3.194%	10.638%	10.638%	5.319%
	C Likely	3.194%	5.319%	5.319%	6.383%
	D Very Likely	5.319%	14.894%	11.702%	1.064%

Risk Assessment After Mitigation					
0.00% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	12.766%	14.894%	9.574%	10.638%
	B Unlikely	5.319%	12.766%	14.894%	0%
	C Likely	7.497%	9.574%	0%	0%
	D Very Likely	2.123%	0%	0%	0%

Figure 5.1: Overall LS Figures

Table 5.2: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to and from Bulkheads							
S.B.1	U-bolt failure	Excessive deployment force	Ballistic reentry	4A	Distribution of load during construction	4A	Inspection: CDR 3.1.2
S.B.2	Nosecone bulkhead bolt failure			4A	Load management during construction	4A	Inspection: CDR 3.1.2
S.B.3	Cracked bulkhead	Excessive stress on stress points	Bulkhead separates from airframe	3D		3B	Tests and Verification Pending
S.B.4	Bulkhead delamination	Excessive axial stress caused by shock cord connection points		3D		3B	Tests and Verification Pending
S.B.5	Separation of bulkhead from airframe	Epoxy is softened Latch connections cause excessive force	LV stabilization is changed	3D		3B	Tests and Verification Pending
S.B.6	Bulkhead exposure to hot ejection gases	Motor or ejection charges cause excessive heat		3B	Ensure LV is kept in optimal environmental conditions	3A	Tests and Verification Pending
Hazards to and from Removable Fin System							
S.F.1	Bolt failure	Excessive force caused by motor or landing	CATO, loss of stability, potentially repairable damage to LV components	3B	Bolts and rods selected have a high safety factor	3A	Tests and Verification Pending
S.F.2	Fin runners, threaded rods, or fin can buckle		CATO, loss of stability	3B		3A	Tests and Verification Pending
S.F.3	Thrust plate failure		CATO, airframe damage	3A	Material selected during design phase has a high safety factor	2A	Tests and Verification Pending
S.F.4	Fin breakage	Excessive force upon landing or fin flutter	Loss of stability in flight	3B	Reinforcement during construction	1C	Tests and Verification Pending
S.F.5	Delamination of or cracks to centering ring	Excessive force caused by motor	CATO, loss of stability, motor not securely held	3A	Proper construction techniques	1A	Tests and Verification Pending
S.F.6	Motor retainer-airframe connection failure	Epoxy weakened by heat or other factors	Motor descends prematurely and separate from LV	2B	Epoxy selected during design phase is rated for expected temperatures	1A	Tests and Verification Pending

Table 5.2 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to and from Airframe							
S.A.1	Cracks in fin can body tube	Hoop stress caused by internal pressure	CATO, inability to relaunch LV	4A	Propellant grains are properly fastened in the appropriate motor tube, motor construction is overseen by mentors defined in Section 1.1.2	2A	Tests and Verification Pending
S.A.2	Cracks in AV bay body tube		Inadequate force to separate LV sections	3B	Calculations performed to determine necessary amount of black powder, ejection tests performed prior to each flight	3A	Tests and Verification Pending
S.A.3	Zippering of body tube	Shock cord causes excessive forces; Excessively low altitude parachute ejection	Airframe rupture	2B	Fiberglass body tube and appropriately-sized couplers are used per SL Requirements 2.4.1 and 2.4.2	2A	Tests and Verification Pending
S.A.4	High-energy impact with ground	No or late parachute deployment		3B	Appropriate recovery system is used to decrease LV descent velocity	3A	Tests and Verification Pending
S.A.5	LV sections collide	Insufficient length of shock cord		3B		3A	Tests and Verification Pending
S.A.6	Airframe exposed to water	Sudden inclement weather	Airframe disintegration/ rupture	2C	Full scale LV airframe is constructed with fiberglass, subscale LV not constructed in inclement conditions	2B	Tests and Verification Pending
		LV lands in wet area of launch field	CATO				
S.A.7	Airframe exposed to black powder	Uncontrolled ejection charges	Airframe disintegration/ rupture	1D	Airframes are constructed with heat-resistent materials	1C	Tests and Verification Pending
S.A.8	Body tube abrasion	High-energy impact with the ground	Changes in LV center of pressure/stability, damage to LV	1C	Appropriate recovery system is used to decrease LV descent velocity	1B	Tests and Verification Pending
		Body tube is dragged due to parachute re-inflation			Launches will not occur in high winds		

Table 5.3: Payload Hazards

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to/from Payload Structure							
PA.S.1	Cracking/breaking of payload	Impact between components of the payload and the inside of LV during launch/separation	Loss of power to payload electronics, loss of communication with payload, payload damage	1D	Payload is secured within the LV to prevent launch/separation forces from causing damage	1C	Verification Pending
PA.S.2	Payload rotor failure	Rotor system does not function properly, payload high-energy impact with ground	Payload is destroyed beyond repair	4C	Payload system is tested before it is dropped from the full required height	4A	Verification Pending
Hazards to/from Payload Electronics							
PA.E.1	Damage to LiPo battery connection/low power	LiPo battery is not fully charged, friction due to contact between cable and housing	Loss of power to payload electronics, loss of communication with payload	3D	Voltage of battery measured prior to flight, all wired connections secured	1A	Verification Pending
PA.E.2	Over-voltaging of electronic components	Voltage from LiPo battery is higher than components can withstand	Electronics are fried and no longer usable	2D	Use of buck converters to regulate voltage into components	1D	Verification Pending
PA.E.3	Wire shortage	Wires are loosely connected and contact each other	Incorrect voltages are passed through the circuit, excessive current flow, possible fire hazard	2D	Wires are properly soldered, all exposed wire is covered in shrink wrap and secured with electrical tape	1D	Verification Pending

Table 5.4: Hazards from Environmental Factors

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to LV Structure							
E.S.1	LV contact with water	LV lands in irrigation ditch, body of water	Structural damage to airframe	4C	LV is made of water-resistant materials	4A	Inspection: CDR 3.1.3
E.S.2	LV collides with birds	Birds fly in close proximity to LV flight path		2B	Flight path confirmed to be clear by RSO ahead of launch	2A	Inspection: Checklist Section Launch Pad, NAR Safety Code #9
E.S.3	LV lands in tree	Large gusts of wind, wind drift	Inability to recover LV	3D	Launches will not occur if wind speed at launch field exceed 20 mph	2C	
Hazards to Personnel							
E.PE.1	Personnel have excessive contact with sunlight and heat	Lack of appropriate PPE, hot launch conditions	Heatstroke, dehydration, sunburn	4B	Personnel are provided with sunscreen and are highly encouraged to bring sunglasses, a tent is set up at the launch field for personnel to take shelter	2B	Inspection: Checklist Section Launch Pad/Recovery
E.PE.2	Personnel slip, trip, or fall	Uneven ground, debris on the ground, working near/next to irrigation ditches	Bruising, broken bones, concussion	4C	Personnel are required to wear closed-toed shoes to all launch day activities, only specific personnel are allowed on the launch field itself	2B	Inspection: Checklist Section Launch Pad/Recovery
E.PE.3	Rain or hail	Inclement weather conditions	Damage to airframe	3C	No launches occur during periods of inclement weather, weather is monitored and launches may be postponed, personnel take shelter as appropriate	3A	Inspection: NAR Safety Code #9
E.PE.4	Lightning strike			1D		1A	Inspection: NAR Safety Code #9
E.PE.5	Wet and/or icy terrain		Personnel slip, trip, or fall	2C		1C	Inspection: Checklist Section Launch Pad/Recovery
E.PE.6	Pollen or other allergens present at launch site	Seasonal allergens, personnel allergic to crops grown at launch field	Potentially severe allergic reactions	3B	Personnel are asked to make the Safety Officer aware of any environmental allergies, antihistamines and other OTC allergy medications are kept in the Launch Day Safety Box	2B	Inspection: Checklist Section Launch Pad/Recovery

Table 5.4 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Payload System							
E.PA.1	Payload contact with water	LV lands in irrigation ditch, body of water	Damage to payload electronics	1C	Mitigation pending	1C	Inspection: CDR 3.1.3
E.PA.2	Lightning strike	Inclement weather conditions		3C	Launches will not occur in inclement weather, local Tripoli Prefect dictates if launch weekends are postponed	2A	Inspection: NAR Safety Code #9
Hazards to Mission Success							
E.M.1	Damp propellant grains	High humidity	No motor ignition, LV does not fly	1D	Launches will not occur in inclement weather	1B	Inspection: NAR Safety Code #9
E.M.2	Damp black powder grains			2D		1B	Inspection: NAR Safety Code #9
E.M.3	LV flight path blocked by birds	Flight path not clear at launch	LV does not reach intended apogee	2B	RSO confirms LV flight path is clear before launch	2A	Inspection: NAR Safety Code #9
E.M.4	Unauthorized aircraft in designated airspace	Aircraft knowingly ignores restricted airspace designations	Any and all launches suspended until further notice	4A	RSO has contact with local air traffic controllers	1A	RSO is contacted directly by air traffic control

Table 5.5: Hazards to Environmental Safety

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Wildlife							
E.W.1	Launch field catches fire	Motor ignition	Crop damage, harm to wildlife, personnel burns	3D	Areas surrounding launch pad are clear of flammable materials, blast plates are properly fitted to launch rails	3B	Inspection: NAR Safety Code #7
E.W.2		Black powder ignition		2C	Personnel are equipped with a functional fire extinguisher	1C	
E.W.3		Battery explosion		2D		2B	
E.W.4	Payload battery explosion	Battery is punctured, leading to contact with moisture; Excessive heat surrounding battery	Hazmat leakage onto launch field, water contamination, fire on launch field	3D	Batteries are isolated from moisture, abrasion, and heat	3B	Inspection: NASA 2.22
E.W.5	LV comes into contact with flying birds	Birds fly in close proximity to LV	Wildlife injury or death, bird migration patterns are obstructed	1C	RSO confirms airways are clear ahead of launch	1A	Inspection: Checklist Section Launch Pad
E.W.6	Nomex permanently jettisons	Rips or tears in Nomex	Contamination of wildlife habitats, food supply, or water supply	2A	Nomex is rated to withstand flight forces, sheets are inspected before launch to ensure no rips or tears are present	1A	Inspection: Checklist Section Main/Drogue Recovery
E.W.7		Breakage in Nomex connection		1A	Nomex sheets are properly connected to shock cord with quick links, Safety Officer verifies proper connections	1A	
E.W.8	Parachute permanently jettisons	Quick link is not properly tightened and secured before parachute is inserted into LV	LV descends at an unsafe speed	1A	Parachutes are properly connected to shock cord with quick links, Safety Officer verifies proper connections	1A	
E.W.9	Hazmat deposit in irrigation ditch	Battery explosion; Explosion byproducts	Toxins remain in food crops and could be consumed by humans/wildlife	2B	Any additional protective insulation is biodegradable	2A	Verification Pending
E.W.10	Wildlife consumes hazmats or other toxins	Littering of hazmats	Wildlife develop digestive issues or incur injury or death	3D		3B	

Table 5.5 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
E.W.11	CATO	Motor defects	Water supply is contaminated, wildlife incur injury or death	2D	AeroTech motors are selected for their low likelihood of catastrophic failure and personnel experience with the brand	2C	Verification Pending
E.W.12	LV lands in tree	Premature parachute deployment, wind drift	Destruction of wildlife habitats	4C	Recovery systems are tested and LV is flown away from trees	3B	Verification Pending
E.W.13	Emission of microplastics	Exceptionally high usage of single-use plastics	Wildlife infertility, bodily inflammation, choking/strangling/digestive hazard	4B	Personnel are encouraged to use reusable containers	3B	Inspection: Team Safety Briefing
Hazards to Land							
E.L.1	LV impacts with ground	Late or no deployment of parachute	Permanent ruts left in launch field, inability for soil to be used in future farming endeavors	3A	Recovery system utilizes altimeters to ensure accuracy in parachute deployment	2A	Verification Pending
E.L.2	Non-recoverable landing in tree	Premature parachute deployment, wind drift	Permanent tree damage	4C	Launch pads are placed far from trees or other hazards	4A	Verification Pending
E.L.3	Launch field catches fire	CATO, motor ignition, black powder detonation, battery explosion	Trees and crops destroyed, inability for land to be used in future farming endeavors	2D	Areas surrounding launch pad is clear of flammable materials, blast plates are properly fitted to launch rails	2B	Inspection: NAR Safety Code #3
Hazards to Air/Water							
E.A.1	Emission of greenhouse gases	Transportation to/from launch field, byproducts from motor and black powder ignition, use of power-drawing electronics	Air pollution, further contribution to climate change	4A	Personnel are encouraged to carpool, take public transportation, or walk to any club activities	4A	Inspection: Safety Briefing Slides
E.A.2	Emission of microplastics	Exceptionally high usage of single-use plastics	Pollution of air and water	4A	Use of single use plastics is limited in LV design	4A	Verification Pending

Table 5.5 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
E.A.3	Chemical off-gassing	Working with hazmats	Air pollution	1B	Hazmats that off-gas are used in well-ventilated areas with proper PPE	1A	Inspection: HPRC Safety Handbook
E.A.4	Emission of smoke	CATO		2B	AeroTech motors are selected for their low likelihood of catastrophic failure and personnel experience with the brand	2A	Inspection: PDR 3.2.9
E.A.5		Motor ignition		2B	LV operation produces few combustion byproducts in nominal conditions	2A	Verification Pending
E.A.6		Black powder detonation		2B		1A	Inspection: NAR Safety Code #3
E.A.7		Man-made wildfire		2D	Heat sources are not allowed within 25 feet of LV motors	2B	Inspection: Aerotech Motors Safety Data Sheet

Table 5.6: Hazards to Personnel Safety

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Skin and Soft Tissue							
PE.S.1	Slips, trips, falls	Material spills Wet or uneven launch field conditions	Skin abrasion or bruising	3B	Lab floors are inspected for spills after handling assembly materials Only authorized personnel recover LV, recovery personnel are required to wear treaded closed-toe shoes	1B	Inspection: HPRC Safety Handbook, Checklist Section Field Recovery
PE.S.2	Appendage caught in bandsaw	Improper operation of bandsaw Jewelry or clothing caught in bandsaw blade	Skin or muscle tear/abrasion	2D	Personnel are trained how to properly handle manufacturing tools, appropriate PPE is always used	2C	Inspection: HPRC Safety Handbook
PE.S.3	Skin comes into contact with hot soldering iron	Personnel negligence	Mild to severe burns	3C	Personnel are trained how to properly handle manufacturing tools, appropriate PPE is always used	3B	Inspection: Checklist Section Launch Pad
PE.S.4	LV collides with personnel	Launch rail tips with assembled LV	Skin or muscle tear/abrasion	2C	Launch rails are provided by TRA/NAR, launch rails have a locking mechanism that is engaged when LV is righted	2B	Inspection: Checklist Section Night Before Checklist
PE.S.5	LV collides with personnel	Severe instability causes sideways propulsion	Skin or muscle tear/abrasion	2B	The stability of LV is no less than 2.0	1B	Inspection: NASA 2.14
PE.S.6	LV collides with personnel	LV lands within close proximity to personnel	Skin or muscle tear/abrasion	1B	The LV is angled away from any personnel or spectators	1A	Inspection: NAR Safety Code
PE.S.7	Personnel muscles placed under high load	Heavy LV components	Muscle strain or tear	4C	At least two personnel carry the assembled LV, proper lifting techniques are always used	4A	Inspection: Checklist Section Launch Pad
PE.S.8	Insect sting/bite	Prolonged exposure to wildlife during launch day activities	Itchiness, rash, and/or anaphylaxis	4A	Bug spray is provided to personnel, personnel have knowledge on appropriate use of EpiPens	3A	Inspection: Checklist Section Launch Pad
PE.S.9	Personnel come into contact with black powder charges	Contact with unblown charges during recovery	Mild to severe burns or abrasions	3C	Personnel recovering the LV are provided with heavy duty gloves, LV sections are inspected for unblown charges before handling	3B	Inspection: Checklist Section Final Measurements

Table 5.6 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
PE.S.10	Contact with large, airborne shrapnel	CATO	Severe skin abrasion or laceration	2D	Personnel are separated from the launch pad according to the minimum distance table, AeroTech motors are selected for their low likelihood of failure	2B	Inspection: NAR Safety Code
PE.S.11	Contact with small, airborne shrapnel	Sanding, cutting, drilling brittle or granular materials	Cuts or bruises	3C	Appropriate PPE is provided for personnel working with power tools	2C	Inspection: HPRC PPE Cabinet
PE.S.12	Exposure to uncured epoxy	Working with epoxy	Skin rash/irritation	3A	Appropriate PPE is provided for personnel working with hazardous materials	2A	
PE.S.13	Exposure to vaporous chemicals	Hazmat off-gassing		2A		2A	
PE.S.14	Excessive amount of walking	LV lands far from recovery personnel	Muscle strain, shin splints	3A	LV is equipped with a GPS, personnel wear shoes appropriate for walking large distances	2A	Inspection: Checklist Section Field Recovery
			Hazards to Bones and Joints				
PE.B.1	Slips, trips, falls	Material spills, wet or uneven field conditions	Bone fracture/bruise, joint dislocation	1D	Lab floors are inspected for spills after handling assembly materials, only authorized personnel recover LV, recovery personnel are required to wear treaded closed-toe shoes	1C	Inspection: Checklist Section Field Recovery
PE.B.2	Excessive amount of walking	LV lands far from recovery personnel	Stress fracture	2D	LV is equipped with a GPS, personnel wear shoes appropriate for walking large distances	2C	Inspection: Checklist Section Field Recovery
PE.B.3	Appendage caught in bandsaw blade	Improper operation of bandsaw	Broken bone	2D	Personnel are trained how to properly handle manufacturing tools, appropriate PPE is always used	2C	Inspection: HPRC Safety Handbook
		Jewelry or clothing caught in bandsaw blade				2C	
PE.B.4	Contact with large, airborne shrapnel	CATO	Bone fracture/break/loss requiring immediate medical attention	2D	Personnel are separated from the launch pad according to the minimum distance table, AeroTech motors are selected for their low likelihood of failure	2C	Inspection: NAR Safety Code, RSO instruction

Table 5.6 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Respiratory System							
PE.R.1	Inhalation of carcinogenic particles	Working with filet epoxy	Respiratory infection and/or irritation, cancer	4D	Personnel working with fillet epoxy are provided with appropriate PPE	3B	Inspection: HPRC PPE Cabinet
PE.R.2	Inhalation of epoxy fumes	Working with epoxy	Respiratory irritation, difficulty breathing	2C	Personnel working with epoxy are provided with appropriate PPE, an oxygen sensor is triggered if there is insufficient oxygen in the lab	2B	
PE.R.3	Inhalation of aerosolized particles	Sanding, cutting, drilling brittle or granular materials		4B	Personnel are provided with appropriate PPE, including particle masks	4A	
PE.R.4	Inhalation of paint fumes	Use of spray paint for LV aesthetics		4B		4A	
PE.R.5	Inhalation of combustion reactants	Personnel are in close proximity to ejection charges		3B		3A	Inspection: NAR Safety Code, RSO instruction
Hazards to Head							
PE.H.1	High energy LV components come into contact with personnel	High energy LV components are in proximity to personnel during descent	Concussion, brain damage, memory loss, skull fracture	2D	Personnel are separated from the launch pad according to the minimum distance table, the LV recovery system is dual-redundant	2C	Inspection: NAR Safety Code
PE.H.2	LV tips during assembly	Launch rail is improperly assembled		3D	Launch rails are provided by TRA/NAR, launch rails have a locking mechanism that is engaged when LV is righted	3B	Inspection: Checklist Section Launch Pad
PE.H.3	Slips, trips, falls	Attempting to jump over irrigation ditches at launch field		3D	Personnel are made aware that jumping over ditches is forbidden	3B	Inspection: Checklist Section Field Recovery
PE.H.4	Contact with large, airborne shrapnel	CATO		2D	Personnel are separated from the launch pad according to the minimum distance table	2B	Inspection: NAR Safety Code
Hazards to Eyes							
PE.E.1	Exposure to epoxy fumes	Working with epoxy	Eye irritation, temporary blindness, permanent or semi-permanent blindness	3D	Personnel are provided with appropriate PPE	3B	Inspection: HPRC PPE Cabinet
PE.E.2	Exposure to aerosolized particles	Working with spray paint, sanding, cutting, drilling		2D		2B	
PE.E.3	Extended exposure to the sun	Maintained eye contact with descending LVs	Temporary or permanent blindness	1B	Personnel maintaining eyes with descending launch vehicles are encouraged to wear sunglasses or other forms of eye protection	1A	Inspection: Checklist Section Field Recovery

Table 5.6 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards from Payload							
PE.P.1	Personnel contact spinning rotor blades while payload is powered on	LV is released above personnel, recovery personnel approaches payload	Personnel injury to head, skin, bones, or soft tissue	4B	Payload is not released above or near crowds, payload is confirmed to be powered down before recovery personnel approach	2A	RSO permission to deploy payload required on launch day

5.4 Fault Tree Analysis

Fault Tree Analysis has been performed for the payload and recovery systems as these are the systems that change the most from year to year. This allows the team leads to identify and further mitigate any failure modes within these systems.

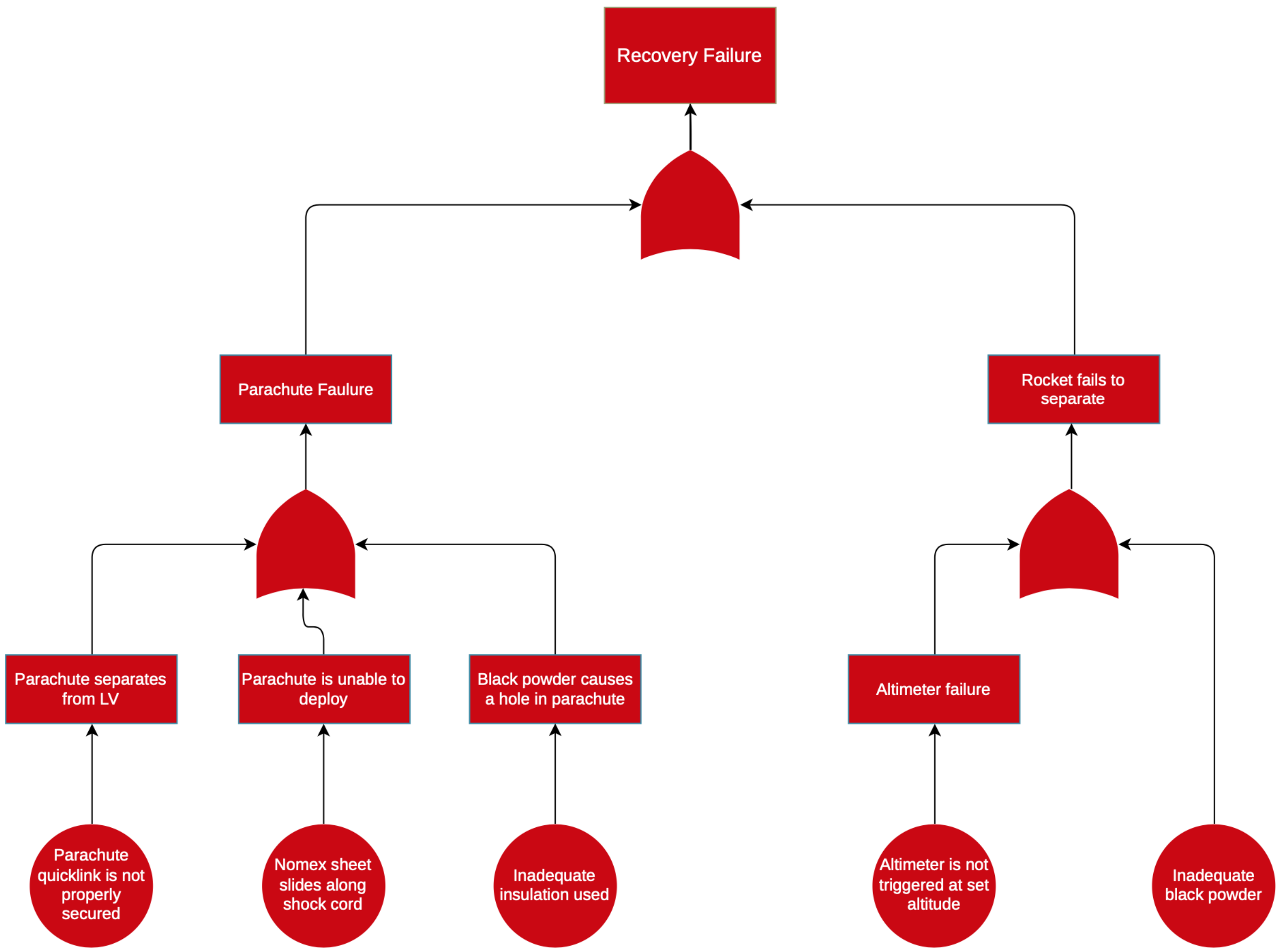

Figure 5.2: Recovery System FTA

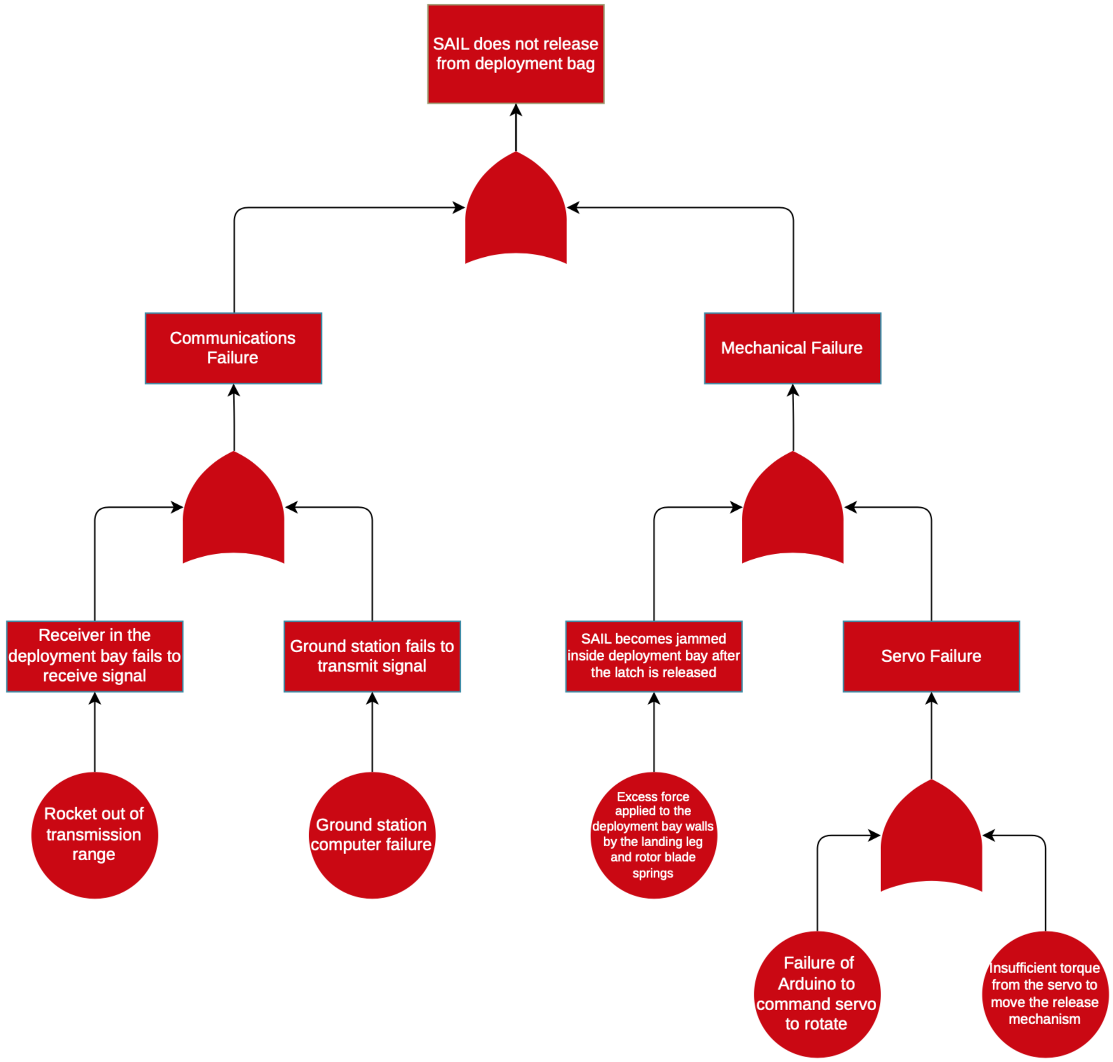

Figure 5.3: SAIL Deployment FTA

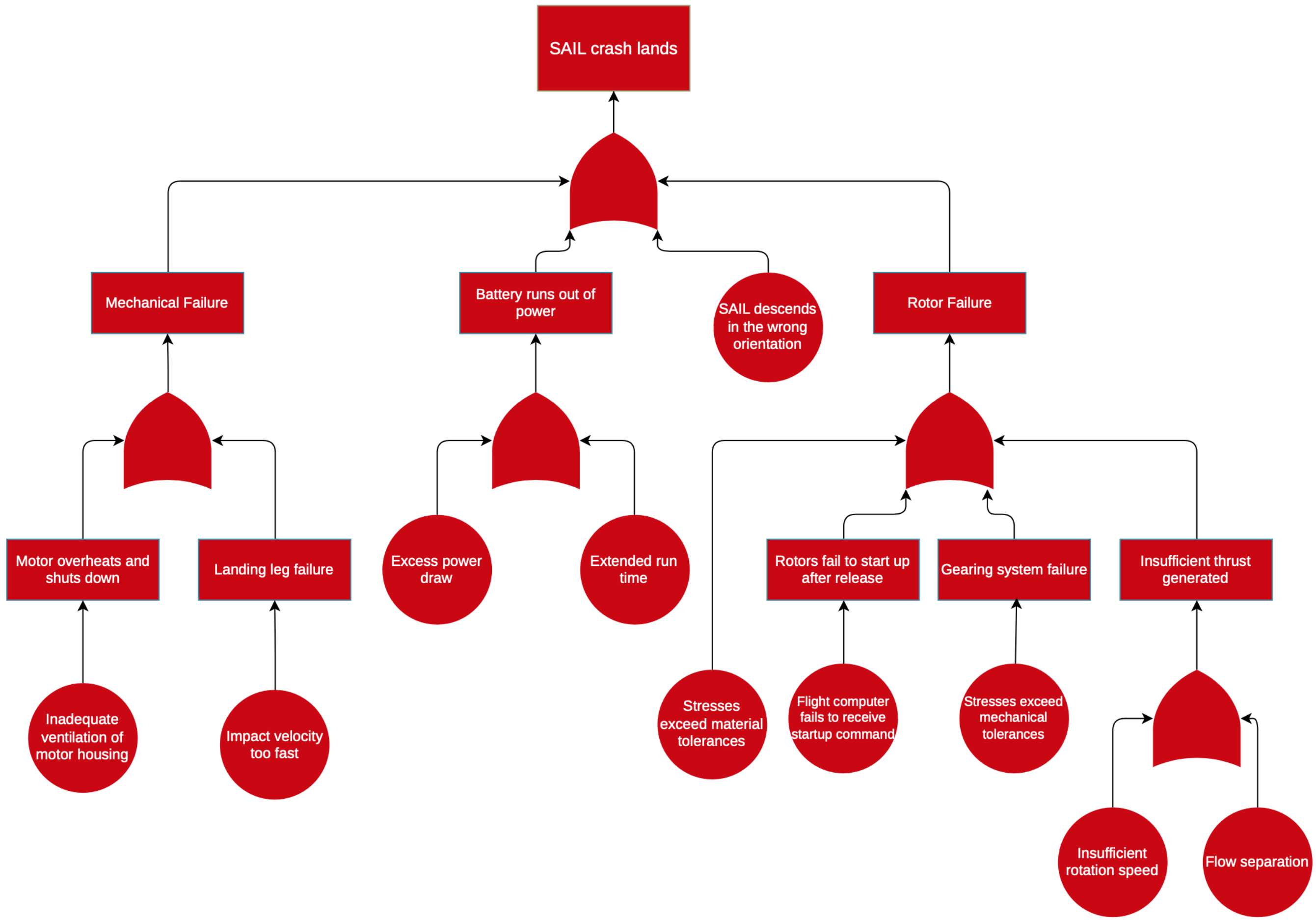

Figure 5.4: SAIL Operation FTA

5.5 Launch Procedures

During all demonstration launches, a launch procedure in the form of an assembly checklist will be utilized to ensure the proper, timely, and safe assembly of the launch vehicle. Below is the checklist used for the assembly, launch, and recovery of the subscale launch vehicle on November 18th, 2023. Each step was appropriately checked off upon completion and important assembly items were verified with the designated safety officer and/or the team lead. This checklist will be modified to include steps for payload assembly for the Payload Demonstration Flight.

THE JOCKET

(THIS IS HOW A ROCKET WEARS JEANS)

Launch Day Checklists

This checklist completed by: Megan Rink

On: 11 / 18 / 23

Checklist Legend

PPE Required - In procedure, the highlighted step signifies that PPE is needed for the steps following.

Explosives/Energetics - DANGER!

NOTE: Any completion blocks with a personnel title require that individual either to stamp or their initials to be placed in the completion block.

NOTE: First 3 checklists are night before checklists. Then the count starts again at the AV bay assembly checklist for launch day checklists.

BEGIN NIGHT-BEFORE CHECKLIST

1. E-MATCH INSTALLATION

Required Personnel		Confirmation
Student Team Lead	Hanna McDaniel	HM
Safety Officer	Megan Rink	MR
E-Match Personnel 1	Cameron Brown	CB
E-Match Personnel 2	Katelyn Yount	KY

Required Materials			
Item	**Quantity**	**Location**	
Bulkhead #2 (Fwd AV)	1	Recovery Box	✓
Bulkhead #3 (Aft AV)	1	Recovery Box	✓
Blue tape	1	LD Toolbox (Top Drawer)	✓
E-Match	4	LD Toolbox (Top Drawer)	✓
Scissors	1	LD Toolbox (Top Drawer)	✓
Needle Nose Pliers	1	LD Toolbox (Middle Drawer)	✓
Wire Strippers	1	LD Toolbox (Middle Drawer)	✓
Terminal block screwdriver (small black Lincoln Lab case, blue flathead screwdriver)	1	LD Toolbox (Middle Drawer)	✓

Note: The following steps are to be followed on Bulkheads 2 and 3 simultaneously.

Bulkhead 2 uses labels **MP** and **MS**. Bulkhead 3 uses labels **DP** and **DS**.

Procedure		
Number	**Task**	**Completion**
1.1	Unscrew all *UNOCCUPIED* terminal blocks on **Bulkhead 2** and **Bulkhead 3**.	✓
1.2	Take four **e-matches** and trim the e-matches to approximately 6.5 inches in length from the red cap using wire cutters.	✓
1.3	Remove each red plastic protective **e-match** cover by sliding it down the e-match wire.	✓

1.4	Feed one **e-match** through the **MP** (Bulkhead 2) wire hole, with the e-match head on the side with the blast caps, and another **e-match** through the **MS** wire hole.	✓
1.5	Feed one **e-match** through the **DP** (Bulkhead 3) wire hole, with the e-match head on the side with the blast caps, and another **e-match** through the **DS** wire hole.	✓
1.6	Flip **Bulkhead 2** over and use a fingernail to separate the two e-match wires. Do the same for the two e-matches on **Bulkhead 3**.	✓
1.7	Use wire strippers to strip 1 inch of insulation from the end of each **e-match** wire.	✓
1.8	Bend the exposed **e-match** wire sections into a loop.	✓
1.9	Place **e-match** wire loops into the **MP** and **MS** terminal block, one into each unoccupied block. Place the other **e-match** wire loops into the **DP** and **DS** terminal block, one into each unoccupied block.	✓
1.10	Tighten the screws on the **MP, MS, DP**, and **DS** terminal blocks.	✓
1.11	Verify **e-match** security by lightly tugging on the wires coming out of the **MP**, **MS, DP,** and **DS** terminal blocks.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
1.12	Place each **e-match** head into its designated blast cap (**MP, MS, DP,** and **DS**).	✓
1.13	Bend each **e-match** wire such that the head lies flat against the bottom of each blast cap.	✓
1.14	Bend each **e-match** wire such that it is flush with the inner and outer walls of each blast cap.	✓
1.15	Using **blue tape**, tape each **e-match** wire to the outside of its respective blast cap.	✓
1.16	Using **blue tape**, tape each **e-match** wire to the bulkhead.	✓
1.17	Confirm that the **e-matches** in the **MP, MS, DP,** and **DS** connect to the correct terminal blocks (**MP, MS, DP,** and **DS** terminal blocks).	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
1.18	Confirm that all bulkhead and wiring labels are still visible.	✓

2. MAIN BLACK POWDER

Required Personnel		Confirmation
Student Team Lead	Hanna McDaniel	HM
Safety Officer	Megan Rink	MR
Black Powder Personnel 1	Cameron Brown	CB
Black Powder Personnel 2	Katelyn Yount	KY

Required Materials

Item	Quantity	Location	
Bulkhead #2 (Fwd AV)	1	AV Bulkhead Box	✓
Funnel	1	LD Toolbox (Top Compartment)	✓
8x11" Copy Paper	1	Recovery Tupperware	✓
Paper Towel Roll	1	Recovery Tupperware	✓
Blue Tape	1	LD Toolbox (Top Drawer)	✓
Plumbers Putty	1	LD Toolbox (Top Compartment)	✓
Scissors	1	LD Toolbox (Top Drawer)	✓
Anti-Static Bag	1	-	✓
Safety Glasses	4	PPE Toolbox	✓
Nitrile Gloves	4	PPE Toolbox	✓
Heavy Duty Gloves	1	PPE Toolbox	✓
Main Primary Charge (2.75 g)	1	AV HDX Box	✓
Main Secondary Charge (3.00 g)	1	AV HDX Box	✓

Procedure

Number	Task	Completion
2.1	Confirm that all members within the assembly tent are wearing **safety glasses** (black powder).	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
2.2	Confirm that members handling black powder are wearing **nitrile gloves**.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State

2.3	Place the bottom of the **funnel** into the **MP** blast cap and carefully pour the **Main Primary Charge** of black powder into the **MP** blast cap over the e-match head.	✓
2.4	Slowly lift the **funnel** and tap it so the black powder falls into the blast cap only.	✓
2.5	Lift the **e-match** head so that it rests just on top of the black powder.	✓
2.6	Fill the remaining space in the blast cap with fingertip-sized pieces of **paper towel**. The paper towel pieces should fill the space, but not be packed in tightly.	✓
2.7	Place small 2-3 inch strips of **blue tape** over the top of the **MP** blast cap to cover the blast cap completely. Do NOT have any overlaps of blue tape greater than 1 mm, but leave no gaps.	✓
2.8	Wrap **blue tape** around the outside wall of the blast cap to keep the top layers of tape tight and fold the excess tape to be flush with the top of the blast cap.	✓
2.9	Confirm all edges of the **MP** blast cap are covered with **blue tape**.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
2.10	Place the bottom of the **funnel** into the **MS** blast cap and carefully pour the **Main Secondary Charge** of black powder into the **MS** blast cap over the e-match head.	✓
2.11	Slowly lift the **funnel** and tap it so the black powder falls into the blast cap only.	✓
2.12	Lift the **e-match** head so that it rests just on top of the black powder.	✓
2.13	Fill the remaining space in the blast cap with fingertip-sized pieces of **paper towel**. The paper towel pieces should fill the space, but not be packed in tightly.	✓
2.14	Place small 2-3 inch strips of **blue tape** over the top of the **MS** blast cap to cover the blast cap completely. Do NOT have any overlaps of blue tape greater than 1 mm, but leave no gaps.	✓
2.15	Confirm all edges of the **MS** blast cap are covered with **blue tape**.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
2.16	Wrap **blue tape** around the outside wall of the blast cap to keep the top layers of tape tight and fold down the excess tape to be flush with the top of the blast cap.	✓

2.17	Place a sheet of **white copy paper** on the assembly table and turn the bulkhead over above the paper.	✓
2.18.1	Confirm that **no black powder has leaked** onto the copy paper.	✓
2.18.2	**If black powder has leaked**, wipe copy paper clean and repeat checklist items **2.3-2.9** or **2.10-2.16** depending on which charge leaked, then repeat checklist items **2.17-2.18.1.**	✓
2.19	Use **plumber's putty** to seal any holes in the bulkhead.	✓
2.20	Wrap the entire bulkhead in an **anti-static bag**.	✓

3. DROGUE BLACK POWDER

Required Personnel		Confirmation
Student Team Lead	Hanna McDaniel	HM
Safety Officer	Megan Rink	MR
Black Powder Personnel 1	Cameron Brown	CB
Black Powder Personnel 2	Katelyn Yount	KY

Required Materials			
Item	**Quantity**	**Location**	
Bulkhead #3 (Aft AV)	1	-	✓
Funnel	1	LD Toolbox (Top Compartment)	✓
8.5x11 copy paper	2	Recovery Tupperware	✓
Paper Towel Roll	1	Recovery Tupperware	✓
Blue Tape	1	LD Toolbox (Top Drawer)	✓
Plumbers Putty	1	LD Toolbox (Top Compartment)	✓
Scissors	1	LD Toolbox (Top Drawer)	✓
Safety Glasses	4	PPE Toolbox	✓
Nitrile Gloves	4	PPE Toolbox	✓
Heavy Duty Gloves	1	PPE Toolbox	✓
Drogue Primary Charge (0.5 g)	2	AV HDX Box	✓
Drogue Secondary Charge (1 g)	2	AV HDX Box	✓
Anti-static bag	1	-	✓

Procedure		
Number	**Task**	**Completion**
3.1	Confirm that all members within the assembly tent are wearing **safety glasses** (black powder).	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
3.2	Confirm that members handling black powder are wearing **nitrile gloves**.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State

3.3	Place the bottom of the **funnel** into the **DP** blast cap and carefully pour the **Drogue Primary Charge** of black powder into the **DP** blast cap over the e-match head.	✓
3.4	Slowly lift the **funnel** and tap it so the black powder falls into the blast cap only.	✓
3.5	Lift the **e-match** head so that it rests just on top of the black powder.	✓
3.6	Fill the remaining space in the blast cap with fingertip-sized pieces of **paper towel**. The paper towel pieces should fill the space, but not be packed in tightly.	✓
3.7	Place small 2-3 inch strips of **blue tape** over the top of the **DP** blast cap to cover the blast cap completely. Do NOT have any overlaps greater than 1mm, but leave no gaps.	✓
3.8	Confirm all edges of the **DP** blast cap are covered with **blue tape**.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
3.9	Wrap **blue tape** around the outside wall of the blast cap to keep the top layers of tape tight and fold down the excess tape to be flush with the top of the blast cap.	✓
3.10	Place the bottom of the **funnel** into the **DS** blast cap and carefully pour the **Drogue Secondary Charge** of black powder into the **DS** blast cap over the e-match head.	✓
3.11	Slowly lift the **funnel** and tap it so the black powder falls into the blast cap only.	✓
3.12	Lift the **e-match** head so that it rests on top of the black powder.	✓
3.13	Fill the remaining space in the blast cap with fingertip-sized pieces of **paper towel**. The paper towel pieces should fill the space, but not be packed in tightly.	✓
3.14	Place small 2-3 inch strips of **blue tape** over the top of the **DS** blast cap to cover the blast cap completely. Do NOT have any overlaps greater than 1mm, but leave no gaps.	✓
3.15	Confirm all edges of the **DS** blast cap are covered with **blue tape**.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
3.16	Wrap **blue tape** around the outside wall of the blast cap to keep the top layers of tape tight and fold down the excess tape to be flush with the top of the blast cap.	✓
3.17	Place a sheet of **white copy paper** on the assembly table and turn the bulkhead over above the paper.	✓

3.18.1	Confirm that **no black powder has leaked** onto the copy paper.	✓
3.18.2	**If black powder has leaked**, wipe copy paper clean and repeat checklist items **3.3-3.9** or **3.10-3.16** depending on which charge leaked, then repeat checklist items **3.17-3.18.1.**	✓
3.19	Use **plumber's putty** to seal any holes in the bulkhead.	✓
3.20	Wrap the entire bulkhead in an **anti-static bag**.	✓

END NIGHT-BEFORE CHECKLIST

BEGIN LAUNCH DAY CHECKLIST

1. AVIONICS BAY ASSEMBLY

Required Personnel		Confirmation
Safety Officer	Megan Rink	MR
Team Lead	Hanna McDaniel	HM
Recovery Lead	Braden Rueda	BR
AV Bay Personnel 1	Shaan Stephen	[signature]
AV Bay Personnel 2	Luke Pollard	LP

Required Materials			
Item	**Quantity**	**Location**	
Bulkhead #2	1	Energetics Box	✓
Bulkhead #3	1	Energetics Box	✓
AV Sled (assembled)	1	Recovery Box	✓
Pull Pin Switch	1	AV Sled	✓
RRC3 Altimeter	1	AV Sled	✓
Eggtimer Quasar	1	AV Sled	✓
AV Bay Section	1	-	✓
9V Battery	1	AV HDX Box	✓
2S 7.4 V LiPo	1	Lipo Bag	✓
¼ inch Nuts	4	Structures HDX Box	✓
¼ inch Washers	2	Structures HDX Box	✓
7/16" Wrench	1	LD Toolbox	✓
Adjustable Wrench	1	LD Toolbox	✓
Multimeter	1	LD Toolbox	✓
AV Receiver	1	Recovery Box	✓
Safety Glasses	1	PPE Toolbox	✓

Procedure		
Number	**Task**	**Completion**
1.1	Use the **multimeter** to test the voltage of the primary **9V battery.**	Note Voltage: 9.68
1.2	**If the battery measures below 9V**, replace with a fresh battery and repeat checklist item **1.1**.	n/a

1.3	Connect each battery to its battery clip in each battery compartment on the **AV sled** and secure with **zip ties.**	✓
1.4	Ensure that **pull pin switch** is inserted in both altimeters.	✓
1.5	Connect **batteries** to their respective altimeters.	✓
1.6	Turn on the **AV receiver**.	✓
1.7	Wait for one minute and verify connection on **AV receiver**.	✓
1.8	Confirm all members within the assembly tent are wearing **safety glasses** (packed charges).	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
1.9	Remove **Bulkhead #3** from its anti-static bag.	✓
1.10	Lightly tug on the wires coming out of the **DP** and **DS** terminal blocks on **Bulkhead #3** to verify security.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
1.11	Slide **AV sled** onto the threaded rods secured to **Bulkhead #3.** Make sure you can read the word "Antenna!" and see the antenna at the same time.	✓
1.12	Secure **AV sled** to the threaded rods with **two ¼ inch hex nuts** (one on each threaded rod).	✓
1.13	Confirm that the **AV sled** is secure by pulling on the AV sled and observing that it does not move up or down the threaded rods.	Recovery Lead Confirm: BR
1.14	Ensure that the **pull pin switch** is inserted in both **primary and secondary altimeters.**	✓
1.15	While pointing the blast caps away from personnel, insert the **DP** (black label) and **DS** (blue label) wires on the AV sled into the **DP** and **DS** terminal blocks on **Bulkhead #3.**	✓
1.16	Lightly tug on the wire connection between the **AV sled** and **Bulkhead #3** to verify security.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
	Take pull pin switch out of both altimeters	✓
1.17	Slide **Bulkhead #3**, with the **AV sled** attached via threaded rods, into the **AV bay** section, using the **red alignment marks**, until **Bulkhead #3** is snug with the **AV bay** coupler. <u>Note</u>: Avoid pinching wires.	✓
1.18	Replace the **pull pin switch** through the hole in the **AV bay** band and tape to the airframe with **blue tape.**	✓

1.19	Remove **Bulkhead #2** from its anti-static bag.	✓
1.20	Lightly tug on the wires coming out of the **MP** and **MS** terminal blocks on **Bulkhead #2** to verify security. Ensure that alignment of terminal blocks is correct (MS terminal block on side with altimeters) (align bulkhead w/ gold alignment marks).	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
1.21	While pointing the blast caps away from personnel, insert the **MP** (black label) and **MS** (blue label) wires on the **AV sled** into the **MP** and **MS** terminal blocks on **Bulkhead #2.**	✓
1.22	Lightly tug on the wire connection between the **AV sled** and **Bulkhead #2** to verify security.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
1.23	Slide the **Bulkhead #2** onto the threaded rods, ensuring that the **MS** terminal block aligns with the altimeters (gold alignment marks), until the bulkhead is snug with the coupler. <u>Note</u>: Avoid pinching wires.	✓
1.24	Secure **Bulkhead #2** to the **AV bay** coupler with **two ¼ inch washers** and **two ¼ inch hex nuts** (one on each threaded rod). Tighten with **wrench** until snug.	✓
1.25	Use a **small screwdriver** to probe the **pressure ports** on the **AV bay** switch band to confirm they are clear.	Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State
1.26	Confirm all nuts are snug and **AV bay** is properly aligned	Recovery Lead Confirm: BR Safety Officer Confirm: Safety Officer High-Powered Rocketry NC State

2. NOSE CONE ASSEMBLY

Required Personnel		Confirmation
Safety Officer	Megan Rink	MR
Team Lead	Hanna McDaniel	HM
Payload Systems Lead	Michael Wax	MW
Recovery Lead	Braden Rueda	BR
Nose Cone Personnel 1	Craig Abell	[illegible]
Nose Cone Personnel 2	Aditya Chadha	AMC

Required Materials			
Item	**Quantity**	**Location**	
Nose Cone	1	-	✓
Removable Nose Cone Bulkhead #1	1	Payload Box	✓
Nose Cone Sled	1	Payload Box	✓
3.7 V Lipo	1	Lipo Bag	✓
7.4 V Lipo	1	Lipo Bag	✓
Duct Tape	1	LD Toolbox	✓
Phillips Head Screwdriver	1	LD Toolbox	✓

Procedure		
Number	**Task**	**Completion**
2.1	Retrieve **nose cone sled** (electronics already attached) and insert **two Lipo batteries** into their slots.	✓
2.2	Secure each **battery** to the nose cone sled with **zip ties**.	✓
2.3	Connect the **3.7V Lipo battery** to the **Big Red Bee 900**	✓
2.4	Turn on **receiver**.	✓
2.5	Wait for one minute and verify connection on **receiver**.	Recovery Lead Confirm: BR
2.6	Connect **7.4V Lipo** to **buck converter**.	✓
2.7	Confirm that **power light on XBee explorer board** is lit up, indicating that the **XBee has power**. Confirm that **light on Arduino** is lit up, indicating that the **Arduino has power**.	Payload Systems Confirm: MW
2.8	Plug in **XBee transmitter** to computer USB port.	✓

2.9	Open **command window (cmd)** on laptop.	✓
2.10	In the command window, **enter** the following commands: 1. **cd C:\Users\micha\Downloads\PotatoStation-master\PotatoStation-master** 2. **venv\Scripts\activate.bat** 3. Type **python ports.py** to get port number of XBee explorer 4. Type **python main.py <PORT NAME>** to start program.	✓
2.11	**Send test command** by pressing the big button labeled "PRESS DA BUTTON". Confirm that **LED lights up. Type** the letter "b" into the Serial Console dialogue box and hit enter. Confirm that **LED turns off. Leave LED off for launch.**	Payload Systems Confirm: MW
2.12	Slide **nose cone sled** onto **Bulkhead #1** threaded rods.	✓
2.13	Secure **nose cone sled** to threaded rods by screwing and tightening **two ¼ inch nuts** (one nut pure threaded rod) onto the forward end of the threaded rods.	✓
2.14	Verify that **nose cone sled** does not move up/down on the threaded rods.	Payload Systems Confirm: MW
2.15	Insert **nose cone sled** and **Bulkhead #1** into the **nose cone.** Secure with ¼ inch-20 x ¾ inch bolts.	✓
2.16	Pull on Bulkhead 1 eye-bolt and U-bolt to verify that the removable bulkhead remains in place under force.	Safety Officer: Safety Officer High-Powered Rocketry NC State

3. FINCAN ASSEMBLY

Required Personnel		Confirmation
Safety Officer	Megan Rink	MR
Team Lead	Hanna McDaniel	HM
Structures Lead	Cameron Brown	CB
Personnel 1	James Holley	JH
Personnel 2	Jesus Luiz Martinez	JLM

Required Materials			
Item	**Quantity**	**Location**	
Fin Can	1	-	✓
Removable Fin System	1	Recovery Box	✓
Aft Rail Button	1	Structures HDX (RFS to Airframe)	✓
#8-32 x ½ inch Screws and washers	7	Structures HDX (RFS to Airframe)	✓
Phillips Screwdriver	1	LD Toolbox	✓

Procedure		
Number	**Task**	**Completion**
3.1	Ensure that there is a sufficient gap between the top of each fin and the bulkhead, that all bolts through the removable fin slats are tightened, that the fins do not wobble, and that added ballasts are not in the way.	Structures Lead Confirm: CB
3.2	Slide **removable fin system** into **fin can**. Align all L bracket holes with airframe holes.	✓
3.3	Confirm that **motor tube** can be inserted without obstruction.	Structures Lead Confirm: CB
3.4	Insert **aft rail button** into bottom hole aligned with forward rail button.	✓
3.5	Insert **7 #8-32 screws** into the holes between the fins to secure the **removable fin system** to the airframe.	✓
3.6	Confirm that rail buttons and screws are tight.	Structures Lead Confirm: CB

3.7	Pull on the fins to ensure the assembly is secure.	Structures Lead Confirm:

4. DROGUE RECOVERY ASSEMBLY

Required Personnel		Confirmation
Safety Officer	Megan Rink	MR
Team Lead	Hanna McDaniel	HM
Structures Lead	Cameron Brown	CB
Personnel 1	Sofia Antinozzi	SA
Personnel 2	Lauren Scott	LS

Required Materials			
Item	**Quantity**	**Location**	
Fin Can Assembly	1	-	✓
AV Bay Assembly	1	-	✓
Safety Glasses	1	PPE Toolbox	✓
Drogue Parachute (15 in)	1	Recovery Box	✓
Small Nomex Sheet	1	Recovery Box	✓
Drogue Parachute Shock Cord (DP 1-3)	1	Recovery Box	✓
Quicklink (#1-3)	3	Recovery Box	✓
Shear Pins	4	AV HDX Box	✓
Blue Tape	1	LD Toolbox	✓
Rubber Bands	2	LD Toolbox	✓

Procedure		
Number	**Task**	**Completion**
4.1	Confirm that all members within the assembly tent are wearing safety glasses (charges loaded).	Safety Officer: Safety Officer High-Powered Rocketry NC State
4.2	Fold the length of shock cord between **Loops 1 and 2** accordion-style with 8-inch lengths.	✓
4.3	Confirm the shock cord is folded accordion-style.	Structures Lead Confirm: CB
4.4	Fold the accordion folds in half between **Loops 1 and 2** and secure the length of shock cord with a single rubber band. Two fingers should fit snugly under the rubber band.	✓
4.5	Attach the hole in the **Nomex** sheet to **Quicklink 2.** Do not tighten.	✓

4.6	Firmly grasp the **drogue parachute** and remove the rubber band securing the drogue parachute.	✓
4.7	Confirm all rubber bands are removed from drogue parachute and shroud lines.	Team Lead Confirm: HM
4.8	Attach **Quicklink 2** to the **drogue parachute** while still firmly holding the drogue parachute. Do not tighten.	✓
4.9	Wrap the **Nomex** cloth around the drogue parachute like a burrito, continuing to firmly grasp the drogue parachute. Wrap a rubber band around the folded up Nomex with the parachute inside to hold everything in place.	✓
4.10	Attach **Quicklink 2** to shock cord **Loop 2** and tighten by hand until secure. Duct tape over the quicklink connection to ensure the shock cord will not unthread the closure.	Structures Lead Confirm: CB
4.11	Fold the length of shock cord between **Loops 2 and 3** accordion-style with 8-inch lengths.	✓
4.12	Confirm the shock cord is folded accordion-style.	Structures Lead Confirm: CB
4.13	Fold the accordion folds in half between **Loops 2 and 3** and secure the length of shock cord with a single rubber band. Two fingers should fit snugly under the rubber band.	✓
4.14	Attach **Quicklink 3** to shock cord **Loop 3.** Do not tighten.	✓
4.15	Attach **Quicklink 3** to fin can **Bulkhead #4** and tighten by hand until secure. **Duct tape** over the quicklink connection to ensure the shock cord will not unthread the closure.	✓
4.16	Confirm the shock cord is secured to fin can **Bulkhead #4** by visual inspection and by pulling on the shock cord.	Structures Lead Confirm: CB
4.17	**Remove rubber band** from Nomex wrapped drogue parachute (Team Lead: place rubber band on wrist). Firmly grasping the wrapped parachute, slide the rest of the shock cord and drogue parachute into the fin can.	✓

4.18	Attach **Quicklink 1** to shock cord **Loop 1**. Do not tighten.	✓
4.19	Attach **Quicklink 1** to payload **Bulkhead #3** and tighten by hand until secure. **Duct tape** over the quicklink connection to ensure the shock cord will not unthread the closure.	✓
4.14	Confirm the shock cord is secured to AV bay **Bulkhead #3** by visual inspection and by pulling on the shock cord.	Structures Lead Confirm: CB
4.15	Place a handful of **biodegradable insulation** into the **fin can.**	✓
4.16	Slide **AV bay** coupler into **fin can** using alignment marks (gold arrows), ensuring that shock cord and parachute are properly stuffed into the fin can. Reorient if needed and make sure all holes are free for shear pins.	✓
4.17	Team Lead: Confirm that one rubber band is around wrist.	Team Lead Confirm: HM
4.18	Insert **4 #4-40, ½-inch long nylon shear pins** into the shear pin holes.	✓
4.18	Place a small piece of **blue tape** over each shear pin head.	✓
4.27	Hold the AV bay, letting the fin can hang free, and confirm that the launch vehicle holds its own weight.	Structures Lead Confirm: CB

5. MAIN RECOVERY / PAYLOAD ASSEMBLY

Required Personnel		Confirmation
Safety Officer	Megan Rink	MR
Team Lead	Hanna McDaniel	HM
Payload Structures Lead	Joseph Alonso	JA
Payload Electronics Lead	Franklin Rice	FSR
Personnel 1	Elizabeth Bruner	EB
Personnel 2	Tony Ugorji	TU

Required Materials			
Item	**Number**	**Location**	
Nose Cone	1	-	✓
Fin Can + AV Bay	1	-	✓
Main/Payload Bay	1	-	✓
Safety Glasses	6	PPE Toolbox	✓
Main Parachute (48 in)	1	Recovery Box	✓
Nose Cone Parachute	1	Recovery Box	✓
Large Nomex	1	Recovery Box	✓
Deployment Bag	1	Recovery Box	✓
Main Parachute Shock Cord (MP)	1	Recovery Box	✓
Nose Cone Parachute Shock Cord (NC)	1	Recovery Box	✓
Payload Shock Cord (PL)	1	Recovery Box	✓
Deployment Bag Shock Cord (DB)	1	Recovery Box	✓
Payload Mass Simulator	1	Recovery Box	✓
Quicklink (#4-10)	1	Recovery Box	✓
Rivets	4	Structures HDX Box	✓
Shear Pins	3	AV HDX Box	✓
Blue tape	1	AV HDX Box	✓
Lithium Grease	1	LD Toolbox	✓
Plumber's Putty	1	LD Toolbox	✓

Procedure		
Number	**Task**	**Completion**
5.1	Confirm that all members within the assembly tent are wearing **safety glasses** (loaded charges).	Safety Officer: Safety Officer High-Powered Rocketry NC State

5.2	Fold the length of **MP shock cord** between **Loops 4 and 5** accordion-style with 8-inch lengths.	✓
5.3	Confirm the shock cord is folded accordion-style.	Payload Structures Confirm: JA
5.4	Fold the accordion folds in half between **Loops 4 and 5** and secure the length of shock cord with a single **rubber band**. Two fingers should fit snugly under the rubber band.	✓
5.5	Fold the length of **DB shock cord** between **Loops 7 and 8** accordion-style with 8-inch lengths.	✓
5.6	Confirm the shock cord is folded accordion-style.	Payload Structures Confirm: JA
5.7	Fold the accordion folds in half between **Loops 7 and 8** and secure the length of shock cord with a single **rubber band**. Two fingers should fit snugly under the rubber band.	✓
5.8	Fold the length of **NC shock cord** between **Loops 8 and 9** accordion-style with 8-inch lengths.	✓
5.9	Confirm the shock cord is folded accordion-style.	Payload Structures Confirm: JA
5.10	Fold the accordion folds in half between **Loops 8 and 9** and secure the length of shock cord with a single **rubber band**. Two fingers should fit snugly under the rubber band.	✓
5.11	Fold the length of **NC shock cord** between **Loops 9 and 10** accordion-style with 8-inch lengths.	✓
5.12	Confirm the shock cord is folded accordion-style.	Payload Structures Confirm: JA

5.13	Fold the accordion folds in half between **Loops 9 and 10** and secure the length of shock cord with a single **rubber band.** Two fingers should fit snugly under the rubber band.	✓
5.14	Apply a liberal amount of **lithium grease** to the **forward AV bay coupler**.	✓
5.15	Slide **main/payload bay** onto the **forward AV bay coupler**, using alignment marks. Make sure all holes align and are unobstructed.	✓
5.16	Insert **four rivets** into the holes to connect **forward AV bay coupler** to the **main/payload bay.**	✓
5.17	Hold launch vehicle vertically by the main/payload bay to ensure it can hold its own weight.	Payload Structures Lead Confirm: SA
5.18	Attach **Quicklink 4** to **MP shock cord Loop 4**. Do not tighten.	✓
5.19	Attach **Quicklink 4** to AV bay **Bulkhead #2** and tighten by hand until secure. Keep **Loop 5** hanging out of main/payload bay **Duct tape** over the quicklink connection to ensure the shock cord will not unthread the closure.	✓
5.20	Insert a handful of **biodegradable insulation** down into the main bay.	✓
5.21	Ensure that parachute is properly folded in deployment bag and that deployment bag is rubber banded to keep everything together.	✓
5.22	Attach **Quicklink 5** to **main parachute.** Do not tighten.	✓
5.23	Attach **Quicklink 5** to **MP shock cord Loop 5** and tighten by hand until secure. **Duct tape** over the quicklink connection to ensure the shock cord will not unthread the closure.	✓
5.24	Attach **Quicklink 7** to **deployment bag**. Do not tighten.	✓
5.25	Attach **Quicklink 7** to **DB shock cord Loop 7** and tighten by hand until secure. **Duct tape** over the quicklink connection to ensure the shock cord will not unthread the closure.	✓
5.26	Firmly grasp deployment bag and **remove rubber band** (Team Lead: place rubber band on wrist).	✓
5.27	Insert **MP shock cord**, **deployment bag**, and **DB shock cord** into main/payload bay. Keep **DB shock cord Loop 8** hanging out of the main/payload bay.	✓
5.28	Attach **Quicklink 8** to **DB shock cord Loop 8**. Do not tighten.	✓
5.29	Attach **Quicklink 8** to **NC shock cord Loop 8** and tighten by hand until secure. **Duct tape** over the quicklink connection to ensure the shock cord will not unthread the closure.	✓

5.30	Pull one end of **PL shock cord** through the **eye-bolt** on the **payload mass simulator**. Hold both **Loops 6** in hand and ensure that payload can hang from shock cord.	✓
5.31	Attach **Quicklink 6** to **PL shock cord Loops 6**. Do not tighten.	✓
5.32	Insert **payload mass simulator** and part of **NC shock cord** into **main/payload bay**. Keep **Loops 6, 9, and 10** hanging out of the bay.	✓
5.33	Attach **Quicklink 10** to **medium Nomex**. Do not tighten.	✓
5.34	Firmly grasp the **nose cone parachute** and remove the rubber band securing the drogue parachute.	✓
5.35	Confirm all **rubber bands** are removed from drogue parachute and shroud lines.	Team Lead Confirm: HM
5.36	Wrap the **Nomex** cloth around the **nose cone parachute** like a burrito, continuing to firmly grasp the nose cone parachute. Wrap a **rubber band** around the folded up Nomex with the parachute inside to hold everything in place.	✓
5.37	Attach **Quicklink 10** to **NC shock cord Loop 10** and tighten by hand until secure. **Duct tape** over the quicklink connection to ensure the shock cord will not unthread the closure.	Payload Structures Confirm: JJ
5.38	<u>**Remove rubber band**</u> from Nomex wrapped **nose cone parachute** (<u>Team Lead</u>: place rubber band on wrist). Firmly grasping the wrapped parachute, slide the rest of the shock cord and drogue parachute into the fin can.	✓
5.39	While firmly grasping the Nomex wrapped nose cone **parachute**, stuff remaining **shock cord** and **parachute** into the **main/payload bay**. Keep **Loops 9 and 6** hanging out of the bay.	✓
5.40	Attach **Quicklink 6** to **eye-bolt** on nose cone **Bulkhead #1** and tighten by hand until secure. **Duct tape** over the quicklink connection to ensure the shock cord will not unthread the closure.	✓
5.41	Attach **Quicklink 9** to **U-bolt** on nose cone **Bulkhead #1** and tighten by hand until secure. **Duct tape** over the quicklink connection to ensure the shock cord will not unthread the closure.	✓
5.42	Insert the **nose cone shoulder** into the **main/payload bay** using alignment marks. Ensure that all holes line up and are clear.	✓

5.43	Insert **3 sheer pins** into the holes to connect the nose cone shoulder to the main/payload bay. Use small pieces of **blue tape** to tape sheer pins to the airframe.	✓
5.44	Hold launch vehicle vertically by nose cone to ensure that it holds its weight.	Payload Structures Confirm: DA

6. MOTOR ASSEMBLY

Required Personnel		Confirmation
L3 Mentor	Alan Whitmore/Jim Livingston	✓
Aerodynamics Lead	Matthew Simpson	MS
Personnel 1	Aubri Sprouse	AES
Personnel 2	Alex Key	AK

Required Materials			
Item	**Quantity**	**Location**	
Aerotech J500G Reload Kit	1	Motor Box	✓
Aerotech RMS 38/720 Motor Casing	1	Motor Box	✓
Motor Igniter	1	LD Toolbox	✓
Lube	1	LD Toolbox	✓
Needle Nose Pliers	1	LD Toolbox	✓
Baby Wipes	1	LD Toolbox	✓
Sharpie Marker	1	LD Toolbox	✓
Blue Tape	1	LD Toolbox	✓
Nitrile Gloves	2	PPE Toolbox	✓
Paper Towels	1	Recovery Box	✓

NOTE: Follow all manufacturer procedures for assembling the motor!

Procedure		
Number	**Task**	**Completion**
6.1	Gather all **materials** and **L3 mentor** at table and **receive permission** to begin motor assembly from mentor.	✓
6.2	Ensure that personnel constructing motor are wearing **nitrile gloves**.	Aero Lead Confirm: MS
6.3	Use **Lube** to lightly grease included **O-Rings** identified by motor manual.	✓
6.4	Use **Lube** to lightly grease **threads** on motor casing.	✓
6.5	Install **smoke grain** into **insulator tube** with **spacer** until snug.	✓
6.6	Use **Lube** to lightly grease one end of the **smoke grain**.	✓
6.7	Install **smoke grain** into **forward closure**, greased side facing forward, until snug.	✓

6.8	Install forward seal disk **O-Ring** on **forward seal disk.**	✓
6.9	Install **forward seal disk** and **O-Ring** into one **end of motor liner** until snug.	✓
6.10	Install **three propellant grains** into motor liner.	✓
6.11	Install **motor liner** into **motor casing**, holding the liner centered within the casing.	✓
6.12	Install **forward O-Ring** into forward end of motor casing. The O-Ring MUST be seated against the forward end of the forward seal disk assembly.	✓
6.13	Install the **forward closure** with smoke grain assembly onto the forward end of the motor casing, on top of the forward O-Ring. Tighten until finger tight.	✓
6.14	Install **aft nozzle** on the aft end of the motor casing.	✓
6.15	Install **aft O-Ring** onto aft nozzle.	✓
6.16	Install **aft closure** onto aft O-Ring.	✓
6.17	Install **aft closure assembly** into **aft end of motor casing**. Tighten until finger tight. NOTE: **There will be exposed threads** when the aft closure is snug.	✓
6.18	Install **nozzle cap** with a corner cut.	✓
6.19	Prepare motor **ignitor.**	✓
6.20	Hold **ignitor** wire along the side of the motor casing.	✓
6.21	Designate appropriate length by marking **ignitor** wire with **Sharpie**.	✓
6.22	Separate ends of **ignitor** wire.	✓
6.23	Strip ends of **ignitor** wire with **wire strippers.**	✓
6.24	Coil **ignitor** wire back into original orientation.	✓
6.25	Tape **ignitor** to side of casing.	✓
6.26	Thank the mentor for assisting with motor assembly.	✓
6.27	Return to launch vehicle assembly location with motor and prepared ignitor. Designate one person to hold the motor. **KEEP MOTOR AWAY FROM OTHER PERSONNEL UNTIL CHECKLIST ITEM 7.2!**	✓

7. FINAL MEASUREMENTS

Required Personnel		Confirmation
Safety Officer	Megan Rink	MR
Team Lead	Hanna McDaniel	HM
Integration Lead	Shyanne Large	SL
Personnel 1	~~Abhi Temmanaboyina~~ Aidan McCloskey	AiM
Personnel 2	Liam Trzebunia-Niebies	LTJ

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Fish Scale	1	LD Toolbox	✓
Calculator	1	Phone	✓
Rope	1	LD Toolbox	✓
Circle Stickers	2	LD Toolbox	✓
Sharpie	1	LD Toolbox	✓
Launch Vehicle (assembled)	1	-	✓
Motor (assembled)	1	-	✓

Number	Task	Completion
7.1	Unscrew **motor retainer**.	✓
7.2	Slide **motor casing** into **motor tube**.	✓
7.3	Secure motor casing using **motor retainer** screw.	Safety Officer: Safety Officer High-Powered Rocketry NC State
7.4	Measure the **center of pressure** of the launch vehicle. This point is **51.25 inches** from the tip of the nose cone. Ensure tape measure is straight and not following the curvature of the nose cone.	✓
7.5	Use a **circular sticker** or blue tape **labeled "CP"** to mark the center of pressure of the launch vehicle.	✓
7.6	Using the **rope** and **fish scale**, locate the **center of gravity** of the launch vehicle. Tie the rope around the launch vehicle and move the rope until the launch vehicle balances.	✓
7.7	Record the **weight** of the launch vehicle using the **fish scale**.	Record weight here: 15.1 lbs

7.8	Use a **circular sticker** or blue tape **labeled "CG"** to mark the center of gravity of the launch vehicle.	✓
7.9	**Measure the center of gravity's distance** from the tip of the nose cone using the tape measure. Ensure the tape measure is straight.	Record CG location here: 42"
7.10	Calculate the **stability margin** using the formula (CP-CG)/D. This is (51.25 - CG)/4. **<u>The stability margin must be at least 2.0</u>**.	Record stability margin here: 2.31 Team Lead Confirm: HM ✓
7.11	Load the **field recovery box** with the items required by **Checklist 8: Launch Pad**.	
7.12	Team Lead: Confirm that there are THREE rubber bands around wrist.	Team Lead Confirm: HM ✓
7.13	Proceed to the **RSO desk**.	

8. LAUNCH PAD

Required Personnel		Confirmation
Safety Officer	Megan Rink	MR
Team Lead	Hanna McDaniel	HM
Recovery Lead	Braden Rueda	BR
Structures Lead	Cameron Brown	CB
Personnel 1	Emily Cates	EC
Personnel 2	Ryan Keever	RK

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Launch Vehicle (assembled)	1	-	✓
Motor Ignitor	1	Field Recovery Box	✓
Lube	1	LD Toolbox	✓
Nitrile Gloves	1	PPE Box	✓
Heavy Duty Gloves	2	PPE Box	✓
Safety Glasses	1	PPE Box	✓
Adjustable Wrench	1	LD Toolbox	✓
Rubber Bands	6	LD Toolbox	✓
Phone	1	-	✓
Wire Cutters	1	LD Toolbox	✓
Wire Strippers	1	LD Toolbox	✓
Blue Tape	1	LD Toolbox	✓
Fire Extinguisher	1	Field Recovery Box	✓

Number	Task	Completion
8.1	Confirm with **RSO** that field conditions are **safe for launch**.	✓
8.2	Submit **flight card** to RSO for review.	✓
8.3	Proceed to the **launch pad**.	✓
8.4	**Record coordinates** of launch pad.	✓

8.5	Confirm **blast deflector** is mounted on launch rail.	Safety Officer: ✓ MR
8.6	Carefully slide the **launch vehicle** onto the **launch rail**.	✓
8.7	Visually confirm the launch vehicle **slides smoothly** along the rail.	Safety Officer: ✓
8.8	**If there is resistance in sliding along the rail,** remove the launch vehicle, apply **lube** to the launch rail, then repeat items 8.6 and 8.7	✓
8.9	Rotate **launch rail** into the **upright** position and **lock** into place.	✓
8.10	Orient the **launch rail** such that it is pointed **5 degrees away from spectators**.	✓
8.11	Confirm the launch rail is **locked**.	Safety Officer: ✓ MR
8.12	Take **team pictures** as necessary.	✓
8.13	All **non-essential personnel leave** the launch pad.	✓
8.14	Confirm that all remaining individuals are wearing **safety glasses**.	Safety Officer: ✓ MR
	Altimeter Arming Procedure:	
8.15	Pull **pin switch** out of **secondary altimeter slot**.	✓
8.16	Confirm **secondary altimeter** is programmed correctly using **Appendix B – Secondary Beep Sheet**.	✓
8.17	Pull **pin switch** out of **primary altimeter** slot.	✓
8.18	Confirm **primary altimeter** is programmed correctly using **Appendix A – Primary Beep Sheet**.	✓
8.19	Confirm **both altimeters** are powered on with **full continuity**.	Safety Officer: ✓ MR

Ignitor Installation Procedure		
8.20	**Insert ignitor** fully into the motor.	✓
8.21	**Tape ignitor** into place at the bottom of the launch vehicle.	✓
8.22	Confirm that **launch pad power is turned off**.	✓
8.23	Connect **ignitor wires to launch pad power.**	✓
8.24	Confirm **launch pad continuity**, measurement should read between 1.5 and 3.5.	✓
8.25	All personnel **navigate to safe location** behind the launch table.	✓
8.26	Pass the **primary checklist** and **field recovery toolbox** to the **Safety Officer.**	✓
8.27	Inform the **RSO** the team is **ready for launch**.	✓
8.28	**Launch!**	✓

9. FIELD RECOVERY

Required Personnel		Confirmation
Safety Officer	Megan Rink	MR
Team Lead	Hanna McDaniel	HM
Recovery Lead	Braden Rueda	BR
Payload Structures Lead	Joseph Alonso	JA
Personnel 1	Andrew Simon	AS
Personnel 2	Peter Tolman	[illegible]
Personnel 3	Connor Ferlito	CF
Personnel 4	Shaan Stephen	[illegible]

Required Materials			
Item	**Quantity**	**Location**	✓
Nitrile Gloves	1	Field Recovery Box	✓
Heavy Duty Gloves	1	Field Recovery Box	✓
Safety Glasses	5	Field Recovery Box	✓
Adjustable Wrench	1	Field Recovery Box	✓
Rubber Bands	6	Field Recovery Box	✓
Phone	1	Field Recovery Box	✓
Wire Cutters	1	Field Recovery Box	✓
Wire Strippers	1	Field Recovery Box	✓
Blue Tape	1	Field Recovery Box	✓
Fire Extinguisher	1	Field Recovery Box	✓
Pull Pin Switch	1	Field Recovery Box	✓

Procedure		
Number	**Task**	**Completion**
9.1	Confirm that all personnel are wearing **safety glasses**.	Safety Officer: Safety Officer High-Powered Rocketry NC State
9.2	Confirm that all personnel handling the launch vehicle are wearing **nitrile gloves**.	Safety Officer: Safety Officer High-Powered Rocketry
9.3	Approach the launch vehicle on foot.	✓
9.4	**If a parachute is open and pulling the launch vehicle**, follow items **9.5-9.7.** Otherwise, proceed to item **9.8**.	✓
9.5	Approach the parachute from the billowed side.	✓

9.6	Use hands and body to pull down the parachute by the CANOPY. **Do not grab the shroud lines or shock cord.**	✓
9.7	Repeat for second parachute if necessary.	✓
9.8	**If the launch vehicle appears to be on fire or smoking,** use the **fire extinguisher** to put out the flame.	✓
9.9	Use a **rubber band** to secure the **main parachute**.	✓
9.10	Use a **rubber band** to secure the **drogue parachute**.	✓
9.11	Use a **rubber band** to secure the **nose cone parachute**.	✓
9.12	**Take pictures** of the landing configuration before moving any piece of the launch vehicle.	✓
9.13	Equip **heavy-duty gloves** before handling any section of body tube.	Safety Officer: Safety Officer High-Powered Rocketry NC State
9.14	Carefully pick up the **forward end of the main/payload bay** just enough to inspect the forward AV bulkhead for **un-blown black powder** charges.	✓
9.15	Inspect the aft AV bulkhead for **un-blown black powder** charges.	✓
9.16	Listen to the **altimeters** and **record flight data** using **Appendix C - Post-Flight Beep Sheet.**	✓
9.17	**Power off both altimeters** by inserting the **pull pin switch** into the **AV bay**.	✓
9.18	**Record the coordinates** of the final resting position of the launch vehicle.	✓
9.19	**Take pictures of any damage** to the launch vehicle.	✓
9.20	Inspect for and **collect non-biodegradable waste** from the landing site.	✓
9.21	Collect each launch vehicle section and return to the launch site.	✓

APPENDIX A – PRIMARY BEEP SHEET

RRC3

NOTE: There is a quick low beep between each line

The Beeps: What do they mean	Expected Output
Drogue only- 1 beep repeating every 5 seconds Main only- 2 beeps repeating every 5 seconds Drogue and Main- 3 beeps repeating every 5 seconds (for Dual Deploy)	3 beeps repeating every 5 seconds, no need to record.

APPENDIX B – SECONDARY BEEP SHEET

Eggtimer Quasar

The Beeps: What do they mean	Expected Output
Beeps every 60 seconds while unarmed	Beep every 60 seconds, no need to record.
Continuous trill when armed	Continuous trill, no need to record.

APPENDIX C – POST-FLIGHT BEEP SHEET

The Beeps: What do they mean	Primary Beeps	Expected Output
A three to six-digit number representing the peak altitude in feet	1414	Should be approximately 1500 ft. Record.
Low buzz signaling sequence is complete		Ignore, currently not important.

The Beeps: What do they mean	Secondary Beeps	Expected Output
An extra-long tone to indicate the start of the reporting sequence	—	Ignore, currently not important
A three to six-digit number representing the peak altitude in feet	1439	Should be approximately 1500 ft. Record.
Long pause signaling sequence us complete	—	Ignore, currently not important.

6 Project Plan

6.1 Launch Vehicle Testing Suite

Table 6.1 below lists all planned tests of the launch vehicle, the requirement(s) each test verifies, and the required facilities and personnel for the completion of the tests. The test schedule for all of the launch vehicle and payload tests can be viewed in Figure 6.4.

Table 6.1: Launch Vehicle Tests

Test	Requirement Verified	Required Facilities	Required Personnel
Subscale Ejection Test	NASA SL Req. 3.2, RF 5	Flat Outdoor Area	Recovery Lead, Team Lead, Safety Officer
Subscale Demonstration Flight	NASA SL Req. 2.18	FAA Approved Launch Field	Team Lead, Safety Officer
GPS Operational Test	RF 4	Mode of Transportation	Recovery Lead
Altimeter Testing	RF 3	Vacuum Container	Recovery Lead
G10 Fin Durability Test	LVF 4	HPRC Lab	Structures Lead
Rivet Shear Loading Test	LVF 5	Universal Testing Machine	Structures Lead
Shear Pin Shear Loading Test	LVF 6	Universal Testing Machine	Structures Lead
Nose Cone Bulkhead Tensile Test	LVD 3	Universal Testing Machine	Structures Lead
AV Bay Bulkhead Tensile Test	LVD 3	Universal Testing Machine	Structures Lead
Full-scale Ejection Testing	NASA SL Req. 3.2, RF 5	Flat Outdoor Area	Recovery Lead, Team Lead, Safety Officer
Full-scale Demonstration Flight	NASA SL Req. 2.19.1	FAA Approved Launch Field	Team Lead, Safety Officer

6.1.1 Subscale Ejection Test

Ejection testing ensures that the black powder charges calculated are sufficient in separating the appropriate sections of the fully assembled subscale launch vehicle for parachute deployment and ensures a safe and successful recovery during launch. The subscale ejection test verifies NASA SL Requirement 3.2 and Team Derived Requirement RF 5. This test was completed on November 14th, 2023. Table 6.2 below defines the success criteria for this test.

Table 6.2: Subscale Ejection Testing Success Criteria

Success Criteria	Achieved (Yes/No)
Complete and vigorous separation of AV bay and drogue parachute bay/fin can	Yes
Complete and vigorous separation of nose cone and main parachute/payload bay	Yes
No damage to launch vehicle	Yes
No damage to recovery materials and hardware	Yes

Controllable Variables

- Ejection charge size

Required Facilities, Equipment, Tools, and Software

- HPRC Lab
- All launch vehicle assembly tools identified in the launch procedure (Section 5.5)
- Subscale launch vehicle, fully assembled
- Safety glasses
- Fireproof gloves
- Fire extinguisher
- Ejection testing wires with battery clip attached
- Charged 9V battery

Procedure

The field assembly checklist is used to assemble to launch vehicle in its launch day configuration (See Section 5.5). The items below are required changes to the launch procedure to conduct this test.

- The AV sled and recovery electronics are not placed in the AV bay.
- Only the primary blast caps are filled with black powder.
- The E-match wires are not cut, but are instead threaded through the pin switch hole

After the launch vehicle has been assembled, the steps below are followed.

1. The launch vehicle is placed horizontally on a piece of foam outdoors. Ensure that forward and aft ends of the vehicle are at least 3 feet away from walls or obstructions and that the vehicle is laying as flat as possible on the foam.
2. Any walls directly in front of or behind the vehicle are protected with another piece of foam.
3. All team members retreat to a safe distance of at least 10 feet away from the sides of the launch vehicle.
4. Ensure battery is not connected to battery clip.
5. One designated team member, equipped with safety glasses and fireproof gloves, approaches the launch vehicle to secure the ejection testing wires to the wires labeled ”drogue” on the exterior of the vehicle.
6. The team member retreats to a safe distance.
7. Ensure that everyone is wearing safety glasses and that no one is standing behind or in front of the launch vehicle.
8. The team member conducts a verbal countdown.
9. The team member connects a 9V battery to the connector, detonating the drogue ejection charge.
10. The team member and safety officer approach the vehicle, and, with fireproof gloves on, ensure adequate separation of the sections and dumb out the contents of each section. Put out any sparks and check the source of any smoke.

11. Repeat Steps 4-10 with the ejection testing wires secured to the wires labeled ”main.”

6.1.2 Subscale Demonstration Flight

The subscale demonstration flight ensures that the launch vehicle's design functions as predicted on a smaller scale. It confirms that the structural integrity, aerodynamic design, and recovery system are successful and do not have to be modified for full-scale application. A successful subscale demonstration flight verifies NASA SL Requirement 2.18. This test was completed on November 18th, 2023. Table 6.3 below defines the success criteria for this test.

Table 6.3: Subscale Demonstration Flight Success Criteria

Success Criteria	Achieved (Yes/No)
Launch vehicle departs launch rail and travels vertically until motor burnout	Yes
Main and fin can launch vehicle sections deploy at least one parachute during decent	Yes
Nose cone separates from the rest of launch vehicle	Yes
All launch vehicle sections endure only minimal damage and retain integrity to safely re-launch	Yes

Controllable Variables

- Motor selection
- Ejection charge sizing
- Altimeter selection
- Launch vehicle weight

Required Facilities, Equipment, Tools, and Software

- Tripoli Range Safety Officer
- NASA SL Competition mentor(s)
- FAA approved launch field
- 15-15 launch rail
- Launch controller
- Assembled launch vehicle
- All tools and hardware identified in the launch procedure (Section 5.5).

Procedure

The subscale launch day procedure is detailed in Section 5.5.

6.1.3 GPS Operational Test

The GPS operational test ensures that the GPS is functioning correctly before launch and can successfully locate the launch vehicle after it is launched. This test verifies Team Derived Requirement RF 4. This test will be conducted between February 19th, 2024 and February 23rd, 2024. Table 6.4 below defines the success criteria for this test.

Table 6.4: GPS Operational Test Success Criteria

Success Criteria	Achieved (Yes/No)
GPS receiver accurately locates the transmitter within a range of 100 feet	TBD
GPS transmitter and receiver stay active and powered on for at least 1 hour	TBD

Controllable Variables

- Distance
- Location
- Voltage
- Type of Transmitter and Receiver

Required Facilities, Equipment, Tools, and Software

- Eggtimer Quasar GPS Transmitter
- Big Red Bee 900 Transmitter
- Eggfinder LCD Receiver
- Nose Cone Receiver (for BRB900)
- 2 cell LiPo battery
- 1 cell LiPo battery
- 4 AA batteries
- Mode of transportation

Procedure

1. Power on the GPS transmitter and receiver.
2. Ensure the receiver is connected to the transmitter.
3. One person stays in a designated spot with the receiver (still connected to the transmitter).
4. A second person drives to a different location with the transmitter.
5. Once the second person is at the secondary location, the transmitter is used to record their coordinates.
6. The person with the receiver records the coordinates displayed on the receiver from the transmitter.
7. The person with the transmitter repeats steps 4 and 5 at least 5 times while the person with the receiver stays in the same location.
8. Once complete, the person with the receiver and the person with the transmitter will compare the two sets of coordinates.
9. After the experiment, the GPS transmitter and receiver will stay on until one of the batteries runs out.
10. Record the time it takes for one of the batteries to run out.

6.1.4 Altimeter Testing

The altimeter test ensures that both primary and secondary altimeters used on the full-scale launch vehicle operate properly and are programmed correctly before launch. This test verifies Team Derived Requirement RF 3. This test will be conducted between February 19th, 2024 and February 23rd, 2024. Table 6.5 below defines the success criteria for this test.

Table 6.5: Altimeter Testing Success Criteria

Success Criteria	Achieved (Yes/No)
Drogue and main deployment lights light up at their appropriate times given the change of pressure in the chamber	TBD
Flight data of test indicates that drogue and main charges deployed	TBD

Controllable Variables

- Pressure
- Altimeter selection

Required Facilities, Equipment, Tools, and Software

- RRC3 altimeter
- EggTimer Quasar
- Altimeter cable
- Lab computer
- 9V battery
- Handmade Altimeter Test System (HATS)
- Pressure vessel
- Vacuum pump

Procedure

1. The RRC3 altimeter is programmed using the MissleWorks mDAC program on the lab computer.
2. The altimeter is connected to the HATS.
3. The altimeter and HATS are placed into the pressure vessel.
4. The pressure vessel is sealed.
5. Slowly increase the pressure in the pressure vessel.
6. Slowly decrease the pressure in the pressure vessel to atmospheric pressure and watch the HATS to ensure that drogue and main deployment lights are lighting up at the right times. If the lights are not lighting up, first check that the pressure is sealed properly.
7. Remove the altimeter and HATS from the pressure vessel and connect to the lab computer to check that the flight data recorded indicates drogue and main deployment.
8. Program the EggTimer Quasar on a cell phone, following the manufacturers instructions, and repeat Steps 2-7 with the Quasar.

6.1.5 G10 Fin Durability Test

The G10 fin durability test ensures that the tips of the full-scale vehicle's fins will not experience cracking or breakage in the event of a direct impact with the ground. This test verifies Team Derived Requirement LVF 4. This test is planned for January 23rd, 2024. Table 6.6 below defines the success criteria for this test.

Table 6.6: G10 Fin Durability Test Success Criteria

Success Criteria	Achieved (Yes/No)
Fin shows minimal to no damage upon hitting the ground at 1 mph	TBD

Controllable Variables

- Fin shape
- Fin size
- Fin material
- Amount of ballast
- Height at which the fin is released

Procedure

1. Fix rail buttons, threaded rods, and any ballast to the fin.
2. Have someone hold the launch rail vertically.
3. Slide the rail buttons onto the launch rail.
4. Have someone ready to start a timer and release the fin so that it slides down the launch rail.
5. Record the time it took for the fin to hit the ground.
6. Compute the ground hit velocity and compare it to the simulated ground hit velocity.
7. Inspect the fin for damage.
8. Repeat Steps 2-7 if the calculated ground hit velocity was less than 1 mph of the predicted ground hit velocity.

Required Facilities, Equipment, Tools, and Software

- Full scale G10 fiberglass test fin (1/8 in. thick)
- 7.75 ft. 1515 launch rail
- 1515 Delrin rail buttons
- 1/4 in. stainless steel threaded rods
- Ballast
- Timer

6.1.6 Rivet Shear Loading Test

Nylon rivets are used to secure non-separating sections together during flight. The rivet shear loading test ensures that the rivets used will withstand a predicted load of 25 pounds with a factor of safety greater than or equal to 2 during flight and recovery events. If the rivets fail, the amount of rivets used between non-separating sections of the launch vehicle will be increased. This test verifies Team Derived Requirements LVF 5. This test is planned for January 16th, 2024. Table 6.7 below defines the success criteria for this test.

Table 6.7: Rivet Shear Loading Test Success Criteria

Success Criteria	Achieved (Yes/No)
Rivets have a calculated factor of safety >2	TBD
Rivets do not break under a 25 lb load	TBD

Controllable Variables

- Size of rivets
- Type of rivets
- Number of rivets
- Applied force

Required Facilities, Equipment, Tools, and Software

1. 6 x 8 mm nylon push clip rivets
2. 1/8 in. thick 6061 aluminum shear plates
3. 1/4 in. stainless steel quick links
4. Tensile testing machine in NC State's Structural Mechanics Lab

Procedure

1. Insert rivet into its respective hole in both aluminum shear plates.
2. Attach each of the quick links to the tensile testing machine.
3. Increase the loading on the tensile testing machine until the rivet breaks or the machine is maxed out.
4. Record the maximum loading the rivet experienced before failure or termination of the test.
5. Calculate the factor of safety and ensure that it is greater than or equal to 2.

6.1.7 Shear Pin Shear Loading Test

Nylon shear pins are used to secure separating sections together during flight. The shear pin shear loading test ensures the shear pins fail under the manufacturer's specified loading and allow black powder charges to separate the launch vehicle. If the shear pins do not fail at expected loads, the number of shear pins used between separating sections will be changed. This test verifies Team Derived Requirements LVF 6. This test is planned for January 16th, 2024. Table 6.8 below defines the success criteria for this test.

Table 6.8: Shear Pin Shear Loading Test Success Criteria

Success Criteria	Achieved (Yes/No)
Shear pins fail at 35 $\pm$ 1 lb.	TBD

Controllable Variables

- Size of shear pins
- Type of shear pins
- Number of shear pins
- Applied force

Required Facilities, Equipment, Tools, and Software

1. 4/40 x 1/2 in. nylon shear pins
2. 1/8 in. thick 6061 aluminum shear plates
3. 1/4 in. stainless steel quick links
4. Tensile testing machine in NC State's Structural Mechanics Lab

Procedure

1. Insert shear pin into its respective hole in both aluminum shear plates.
2. Attach each of the quick links to the tensile testing machine.
3. Increase the loading on the tensile testing machine until the shear pin breaks.
4. Record the maximum loading the shear pin experienced before failure or termination of the test.

6.1.8 Nose Cone Bulkhead Tensile Test

The removable nose cone bulkhead (see Section 3.2.3) is used as an attachment point for both the payload deployment bay (see Section 4.4.2) and for the nose cone parachute recovery harnesses. The AV bay bulkheads are used as an attachment point for the drogue and main parachute recovery harnesses. The bulkhead tensile test ensures that the nose cone and AV bay bulkheads can withstand their predicted loads (see Section 3.2.8) with a factor of safety greater than or equal to 2. If either bulkhead fails this test, the thickness of the respective bulkhead will be increased and the test repeated. This test verifies Team Derived Requirement LVD 3. This test is planned for February 6th, 2024. Table 6.9 below defines the success criteria for this test.

Table 6.9: Nose Cone Bulkhead Tensile Test Success Criteria

Success Criteria	Achieved (Yes/No)
Nose cone bulkhead has a calculated factor of safety >2	TBD
Nose cone bulkhead centering ring has a calculated factor of safety >2	TBD
Nose cone bulkhead suffers no visible damage under a 281.56 lb. load	TBD

Controllable Variables

- Bulkhead width
- Bulkhead material
- U-bolt size
- Placement of U-bolt
- Force applied

Required Facilities, Equipment, Tools, and Software

- 2 U-bolts
- Nose cone bulkhead test piece
- Nose cone bulkhead centering ring test piece
- Epoxy
- 8 nuts
- 8 washers
- Short length of 1" shock cord
- Tensile testing machine in NC State's Structural Mechanics Lab

Procedure

1. Follow steps in Section 3.4.3 to construct a test nose cone and AV bay bulkhead as it would be constructed for use in the full-scale launch vehicle.
2. Attach nose cone bulkhead test piece to centering ring using four 1/4 in.-20 x 1/2 in. bolts.
3. Insert the U-bolts on the same side of the bulkhead and secure with 4 nuts for each U-bolt.
4. Place the bulkhead test piece into the bottom clamp of the tensile testing machine.
5. Secure the U-bolts into the top clamp using Kevlar shock cord.
6. Ensure that the universal testing machine is tared and is reading properly.
7. Apply force in steps of 10 lb, allowing the test piece to settle for 5-10 seconds between each application.
8. Continue applying force until the bulkhead fails.
9. Record at what force the bulkhead fractured and any noticeable defections throughout the experiment.

6.1.9 Avionics Bay Bulkhead Tensile Test

The AV bay bulkheads are used as an attachment point for the drogue and main parachute recovery harnesses. The bulkhead tensile test ensures that the AV bay bulkheads can withstand their predicted loads (see Section 3.2.8) with a factor of safety greater than or equal to 2. If the AV bulkhead fails this test, the thickness of the AV bulkhead will be increased and the test repeated. This test verifies Team Derived Requirement LVD 3. This test is planned for February 6th, 2024. Table 6.10 below defines the success criteria for this test.

Table 6.10: AV Bay Bulkhead Tensile Test Success Criteria

Success Criteria	Achieved (Yes/No)
AV bay bulkhead has a calculated factor of safety >2	TBD
AV bay bulkhead suffers no visible damage under a 122.61 lb. load	TBD

Controllable Variables

- Bulkhead width
- Bulkhead material
- U-bolt size
- Placement of U-bolt
- Force applied

Required Facilities, Equipment, Tools, and Software

- 1 U-bolt
- AV bay bulkhead test piece
- Epoxy
- 4 nuts
- 4 washers
- Short length of 1” shock cord
- Tensile testing machine in NC State’s Structural Mechanics Lab

Procedure

1. Follow steps in Section 3.4.3 to construct a test AV bay bulkhead as it would be constructed for use in the full-scale launch vehicle.
2. Insert the U-bolt into the bulkhead test piece and secure with 4 nuts.
3. Place the bulkhead test piece into the bottom clamp of the tensile testing machine.
4. Secure the U-bolts into the top clamp using Kevlar shock cord.
5. Ensure that the universal testing machine is tared and is reading properly.
6. Apply force in steps of 10 lb, allowing the test piece to settle for 5-10 seconds between each application.
7. Continue applying force until the bulkhead fails.
8. Record at what force the bulkhead fractured and any noticeable defections throughout the experiment.

6.1.10 Full-scale Ejection Testing

Ejection testing ensures that the black powder charges calculated are sufficient in separating the appropriate sections of the fully assembled full-scale launch vehicle for parachute deployment and ensures a safe and successful recovery during launch. The full-scale ejection test verifies NASA SL Requirement 3.2 and Team Derived Requirement RF 5. This test is planned for February 16th, 2024. Table 6.11 below defines the success criteria for this test.

Table 6.11: Full-scale Ejection Testing Success Criteria

Success Criteria	Achieved (Yes/No)
Complete and vigorous separation of AV bay and drogue parachute bay/fin can	TBD
Complete and vigorous separation of nose cone and main parachute/payload bay	TBD
No damage to launch vehicle	TBD
No damage to recovery materials and hardware	TBD

Controllable Variables

- Ejection charge size

Required Facilities, Equipment, Tools, and Software

- HPRC Lab
- All launch vehicle assembly tools identified in the launch procedure (Section 5.5)
- Full-scale launch vehicle, fully assembled
- Safety glasses
- Fireproof gloves
- Fire extinguisher
- Ejection testing wires with battery clip attached
- Charged 9V battery

Procedure

The field assembly checklist is used to assemble to launch vehicle in its launch day configuration (See Section 5.5). The items below are required changes to the launch procedure to conduct this test.

- The AV sled and recovery electronics are not placed in the AV bay.
- Only the primary blast caps are filled with black powder.
- The E-match wires are not cut, but are instead threaded through the pin switch hole

After the launch vehicle has been assembled, the steps below are followed.

1. The launch vehicle is placed horizontally on a piece of foam outdoors. Ensure that forward and aft ends of the vehicle are at least 3 feet away from walls or obstructions and that the vehicle is lying as flat as possible on the foam.
2. Any walls directly in front of or behind the vehicle are protected with another piece of foam.
3. All team members retreat to a safe distance of at least 10 feet away from the sides of the launch vehicle.

4. Ensure battery is not connected to battery clip.
5. One designated team member, equipped with safety glasses and fireproof gloves, approaches the launch vehicle to secure the ejection testing wires to the wires labeled ”drogue” on the exterior of the vehicle.
6. The team member retreats to a safe distance.
7. Ensure that everyone is wearing safety glasses and that no one is standing behind or in front of the launch vehicle.
8. The team member conducts a verbal countdown.
9. The team member connects a 9V battery to the connector, detonating the drogue ejection charge.
10. The team member and safety officer approach the vehicle, and, with fireproof gloves on, ensure adequate separation of the sections and dump out the contents of each section. Put out any sparks and check the source of any smoke.
11. Repeat Steps 4-10 with the ejection testing wires secured to the wires labeled ”main.”

6.1.11 Full-scale Demonstration Flight

The full-scale demonstration flight confirms the structural integrity, aerodynamic design, and recovery system are successful and do not need modifications for use during competition launch. This test verifies NASA SL Requirement 2.19.1. This test is planned for February 24th-25th, 2024. Table 6.12 below defines the success criteria for this test.

Table 6.12: Full-scale Demonstration Flight Success Criteria

Success Criteria	Achieved (Yes/No)
Launch vehicle departs launch rail and travels vertically until motor burnout.	TBD
Main and fin can launch vehicle sections deploy at least one parachute during decent.	TBD
Nose cone separates from the rest of launch vehicle.	TBD
All launch vehicle sections endure only minimal damage and retain integrity to safely re-launch.	TBD

Controllable Variables

- Motor selection
- Ejection charge sizing
- Altimeter selection
- Launch vehicle weight

Required Facilities, Equipment, Tools, and Software

- Tripoli Range Safety Officer
- NASA SL Competition mentor(s)
- FAA approved launch field
- 15-15 launch rail

- Launch controller
- Assembled full-scale launch vehicle
- All tools and hardware identified in the launch procedure (Section 5.5).

Procedure

The procedure for full-scale demonstration flight(s) will be similar to the procedure of the subscale flight demonstration (Section 5.5). Edits will be made to clarify procedures and a payload checklist section will be included in the full-scale version of the launch procedure.

6.2 Payload Testing Suite

Table 6.13 below lists all planned tests of the payload, the requirement(s) each test verifies, and the required facilities and personnel for the completion of the tests. The test schedule for all of the launch vehicle and payload tests can be viewed in Figure 6.4.

Table 6.13: Payload Tests

Test	Requirement Verified	Required Facilities	Required Personnel
Subscale Launch SAIL Deployment Test	NASA SL Req. 2.18, PF 2	FAA Approved Launch Field	Payload Systems Lead
Rotor Blade/Landing Leg Deployment Test	PF 4, PD 3	Deployment system, large, open outdoor area	Payload Electronics Lead
Rotor Blade Adhesion Strength Test	PF 6	Applied Test Systems 1620C	Payload Structures Lead
Landing Leg Bending Test	PD 3	HPRC lab	Payload Structures Lead
RF Signal Test	PF 2	Launch field	Payload Systems Lead
Latch Tensile Test	PF 3	Universal Testing Machine	Payload Systems Lead
Thrust Verification Test	PF 5, PD 4	Thrust stand	Payload Electronics Lead
Payload Demonstration Flight	NASA SL Req. 2.19.2	FAA Approved Launch Field	Payload Systems Lead, Payload Structures Lead, Payload Electronics Lead

6.2.1 Subscale Launch SAIL Deployment Test

The subscale launch SAIL deployment test ensures that the recovery system designed to deploy the sail from the launch vehicle during flight operates properly and ensures that the RF receiver can receive signals from the transmitter during the launch vehicle's descent. This test verifies NASA SL Requirement 2.18 and Team Derived Requirement . This test was completed on November 18th, 2023. Table 6.14 below defines the success criteria for this test.

Table 6.14: Subscale Launch SAIL Deployment Test Success Criteria

Success Criteria	Achieved (Yes/No)
SAIL mass simulator exits the main bay during recovery	Yes
SAIL mass simulator remains attached to nose cone under parachute during descent	Yes
LED connected to RF receiver is lit up upon post-flight inspection	Yes

Controllable Variables

- Recovery system design
- Parachute and recovery harness packing
- Ejection charges
- RF transmitter and receiver separation distance
- RF receiver location within launch vehicle

Required Facilities, Equipment, Tools, and Software

- RF receiver and transmitter
- Laptop computer
- SAIL mass simulator
- Tripoli Range Safety Officer
- NASA SL Competition mentor(s)
- FAA approved launch field
- 15-15 launch rail
- Launch controller
- Assembled launch vehicle
- All tools and hardware identified in the launch procedure (Section 5.5).

Procedure

See the steps for Nose Cone Assembly in the Launch Procedure (Section 5.5).

6.2.2 Rotor Blade and Landing Leg Deployment Test

The rotor blade and landing leg deployment test ensures that the rotor blade and landing leg spring-loaded deployment systems operate as expected once deployed from the payload deployment bay. If the rotor blades and landing legs do not deploy within 1 second of exiting the deployment bay, the release mechanism for the blades and legs will be modified before the Payload Demonstration Flight. This test verifies Team Derived Requirements PF 4 and PD 3. This test is planned for January 31st, 2024. Table 6.15 below defines the success criteria for this test.

Table 6.15: Rotor Blade/Landing Leg Bend Test Success Criteria

Success Criteria	Achieved (Yes/No)
The rotor blades and landing legs deploy within 1 second of exiting the deployment bay.	TBD

Controllable Variables

- Release height

Required Facilities, Equipment, Tools, and Software

- Assembled SAIL
- Deployment system
- Camera
- Crash pad

Procedure

1. Place the SAIL inside of the deployment bay.
2. Raise the deployment bay approximately 6 ft. off the ground.
3. Set crash pad underneath deployment bay.
4. Place the camera so that it has a view of both the deployment bay and the crash pad.
5. Start recording.
6. Send command to drop the SAIL from the deployment bay.
7. Analyze footage to determine the time to full rotor/landing leg deployment.

6.2.3 Rotor Blade Adhesion Strength Test

The rotor blade adhesion strength test ensures that the adhesive used to bind sections of the rotor blade is strong enough to withstand the SAIL's forces of operation. In the event of failure, a new adhesive will be researched and the test repeated. If no alternative adhesive is found, the construction of the rotor blades may be subject to change. This test verifies Team Derived Requirement PF 6. This test is planned for January 24th, 2024. Table 6.16 below defines the success criteria for this test.

Table 6.16: Rotor Blade Adhesion Strength Test Success Criteria

Success Criteria	Achieved (Yes/No)
Rotor blade does not fracture at adhesion interfaces under a 300 lb. load	TBD

Controllable Variables

- Blade chord
- Machine loading
- Type of adhesive

Required Facilities, Equipment, Tools, and Software

- Applied Test Systems 1620C
- 5,000 pound load cell

Procedure

1. Apply the 5,000 pound load cell.
2. Clamp the propeller blade at equidistant locations such that the joint is in the middle. This is done on the testing rig.
3. Stretch the propeller blade in increments of 20 pounds and document the displacement until 300 pounds.
4. Stretch the propeller blade in increments of 5 pounds until failure.

6.2.4 Landing Leg Bend Test

The landing leg bend test ensures that the SAIL landing legs can withstand the force of impact with the ground after descent at predicted velocities. Upon failure, the material, construction, and/or configuration of the landing legs will be changed and the test repeated. This test verifies Team Derived Requirements PF 7 and PD 3. This test is planned for January 31st, 2024. Table 6.17 below defines the success criteria for this test.

Table 6.17: Landing Leg Bend Test Success Criteria

Success Criteria	Achieved (Yes/No)
Landing leg suffers minimum deformation under a 35 lb. load	TBD

Controllable Variables

- Load applied
- Landing leg material
- Landing leg construction
- Landing leg configuration

Procedure

1. Place the extended leg assembly on a flat surface.
2. Measure the height of the assembly.
3. Apply 20 pounds of weight to the top of the assembly.
4. Measure the height of the assembly.
5. Repeat Steps 3 and 4 at increments of 5 lb. up to 50 lb. or until failure.

Required Facilities, Equipment, Tools, and Software

- 100 pound weight
- Assembled legs and payload body

6.2.5 RF Signal Testing

The RF signal testing verify the operational range of the manual release command and motor startup command, as well as the supplied power to the transmitter. This test will satisfy Team Derived Requirement PF 2. This test is planned for January 27th, 2024. Table 6.18 below defines the success criteria for this test.

Table 6.18: RF Signal Test Success Criteria

Success Criteria	Achieved (Yes/No)
The servo turns for every distance that the release command is sent.	TBD
The servo turns inside of the deployment bay for every distance the command is sent.	TBD
The servo turns with at least 7.4V.	TBD

Controllable Variables

- Transmitter and receiver separation distance
- Location of receiver in launch vehicle
- Supplied voltage

Required Facilities, Equipment, Tools, and Software

- Bayboro launch field
- 2 XBee RF Modules
- 2 XBee Explorer Boards
- XTend 900
- Laptop computer
- Micro USB cable
- Arduino Nano Every
- 2 cell Li-Po battery
- Buck converter
- Breadboard
- Wires for connections
- Measuring wheel for distance
- SAIL deployment bay

Procedure

1. Supply power to XBee receiver and transmitter.
2. Place the receiver a specified distance away from the transmitter, between 100 ft and 2500 ft.
3. Send command using transmitter to open latch.
4. Verify that servo has turned.
5. Repeat Steps 1-4 varying the supplied voltage and separation distance.

6. Repeat Steps 1-5 with the receiver inside the deployment bay to test if signal is blocked.
7. Repeat Steps 1-6 with the XTend 900.

6.2.6 Latch Tensile Test

The latch tensile test will verify the maximum load the latch can withstand during operation, as well as the power required to open the latch using a servo. This test will satisfy Team Derived Requirement PF 3. This test is planned for January 31st, 2024. Table 6.19 below defines the success criteria for this test.

Table 6.19: Latch Tensile Test Success Criteria

Success Criteria	Achieved (Yes/No)
The latch does not open and/or fracture under a load of 100 lb. without being opened manually	TBD
The servo turns the manual release under a load of 100 lb. and opens the latch	TBD

Controllable Variables

- Tensile load
- Type of electric latch

Required Facilities, Equipment, Tools, and Software

- Tensile testing machine in NC State's Structural Mechanics Lab
- Camlock rotary latch
- Shock cord

Procedure

1. Secure Southco latch to tensile testing machine.
2. Attach shock cord to latch opening.
3. Close latch
4. Set tensile load.
5. Prepare servo using micro controller.
6. Open the latch using the servo.
7. Repeat Steps 1-5 for each load, from 5 lb to 100 lb.
8. Repeat Steps 1-6, increasing the supplied power to the servo.

6.2.7 Thrust Verification Test

The thrust verification test ensures that the SAIL generates enough thrust to safely descend to the ground. This test verifies Team Derived Requirement PF 5 and PD 4. This test is planned for February 7th, 2024. Table 6.20 below defines the success criteria for this test.

Table 6.20: Thrust Verification Test Success Criteria

Success Criteria	Achieved (Yes/No)
The SAIL generates at least 7.7 lbs of thrust.	TBD

Controllable Variables

- Rotor blade shape
- Rotor blade size
- RPM

Required Facilities, Equipment, Tools, and Software

- Assembled rotor blade system
- Adafruit Feather
- Potentiometer
- Scale
- Stand
- Electronic speed controller
- Li-Po battery

Procedure

1. Secure the assembled rotor blade system to the stand.
2. Connect the ESC to the brushless motor.
3. Clear all personnel from the test area.
4. Connect the potentiometer to the Adafruit Feather.
5. Set the potentiometer to the off position.
6. Connect the battery to the ESC.
7. Set the potentiometer to 1000 RPM.
8. Record the scale readout.
9. Repeat steps 7-8 until the thrust equals 8 lbf.
10. Set the potentiometer to the off position.
11. Disconnect the battery.

6.2.8 Payload Demonstration Flight

The payload demonstration flight ensures that all payload subsystems operate as designed during flight of the full-scale launch vehicle. This test verifies NASA SL Requirement 2.19.2. This launch is planned for February 24thth-25th, 2024 with a backup on MArch 23rd-24th, 2024. Table 6.21 below defines the success criteria for this test.

Table 6.21: Payload Demonstration Flight Success Criteria

Success Criteria	Achieved (Yes/No)
SAIL deployment bay separates from the rest of the launch vehicle with the nose cone at 800 ft.	TBD
RSO gives verbal permission for SAIL deployment	TBD
SAIL released from deployment bay on command	TBD
SAIL rotors and landing legs deploy	TBD
Minimum damage to SAIL is observed in post-flight analysis	TBD

Controllable Variables

- SAIL weight
- SAIL rotor motor
- Ejection charges

Required Facilities, Equipment, Tools, and Software

- Tripoli Range Safety Officer
- NASA SL Competition mentor(s)
- FAA approved launch field
- 15-15 launch rail
- Launch controller
- Assembled full-scale launch vehicle
- Assembled SAIL
- SAIL deployment bay
- RF transmitter and reciever
- Laptop computer
- All tools and hardware identified in the launch procedure (Section 5.5).

Procedure

The procedure for payload demonstration flight will be similar to the procedure of the subscale flight demonstration (Section 5.5). Edits will be made to clarify procedures and a payload assembly checklist section will be included in the full-scale version of the launch procedure.

6.3 Requirements Compliance

6.3.1 Competition Requirements

Table 6.22: 2023-2024 NASA Requirements

NASA Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
General Requirements						
1.1	Students on the team SHALL 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). Teams SHALL submit new work. Excessive use of past work SHALL merit penalties.	Members of NC State's High-Powered Rocketry Club fabricate a solution to the criteria given in the Student Launch Handbook, implementing past ideas while developing new ones.	Inspection	Project Management	Verified	Students on the team use original work done by the team to complete the project.
1.2	The team SHALL 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.	The Project Management Team, consisting of the Team Lead, Vice President, Integration Lead, Treasurer, Secretary, Safety Officer, Webmaster, and Social Media Lead manage the tasks related to this requirement.	Inspection	Project Management	Verified	See Section 6.5 for the project timeline.
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.	The Team Lead determines the team members attending Huntsville and ensures team members register and their application status is "submitted" in the NASA Gateway system no later than October 27th, 2023.	Inspection	Project Management	Verified	A list of team members attending is provided with the CDR submission.
1.3.1	Team members attending competition SHALL include students actively engaged in the project throughout the entire year.	The Project Management Team determines the students that have been actively engaged to invite them to competition.	Inspection	Project Management	Verified	Team members that have been actively assisting the senior design group will be eligible to attend launch week.
1.3.2	Team members SHALL include one mentor (see Requirement 1.13).	The Team Lead invites the mentor(s) identified in Section 1.1.2 to attend competition.	Inspection	Project Management	Verified	Team mentors are listed in Section 1.1.2.
1.3.3	Team members SHALL include no more than two adult educators.	The Team Lead invites the adult educator(s) shown in Section 1.1.2 to attend competition.	Inspection	Project Management	Verified	See Section 1.1.2 for team mentors and advisors.

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.	The Outreach Lead offers STEM engagement opportunities to K12 students for the duration of project development and submits STEM Engagement Activity Reports within two weeks of the event.	Inspection	Project Management	Not Verified	The Outreach Lead has begun to conduct and schedule STEM engagement activities, but the minimum number of participants as not been reached.
1.5	The team SHALL establish and maintain a social media presence to inform the public about team activities.	The Webmaster and Social Media Officer collaborate to maintain our website and social media presence to educate the public about activities and events held by the team. Our social media platforms include, but are not limited to: our club website, TikTok, Facebook, and Instagram.	Inspection	Project Management	Verified	Any form of social media in relation to the team has been sent to the NASA project management team.
1.6	Teams SHALL upload all deliverables to the designated NASA SL Box submission portal by the deadline specified in the handbook for each milestone. No PDR, CDR, and FRR milestone documents SHALL be accepted after the due date and time. Teams that fail to submit the PDR, CDR, and FRR milestone documents SHALL be eliminated from the project.	The Team Lead uploads all documents to the designated NASA SL Box submission portal by the deadline specified.	Inspection	Project Management	Not Verified	Before the deadline the team lead upload all deliverables to the designated NASA SL Box submission portal.
1.7	Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) SHALL be provided action items 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 team's status in the program and the team SHALL be notified shortly thereafter.	If a milestone review is not completed satisfactorily, the team completes any action items given and attends the delta review session to maintain their status in the program.	Inspection	Project Management	Not Verified	The team satisfactorily completes each milestone review and submits before the deadline.
1.8	All deliverables SHALL be in PDF format.	The Team Lead sends all deliverables in PDF format to the NASA Project Management Team.	Inspection	Project Management	Verified	All documents are changed to PDF format before submission.
1.9	In every report, teams SHALL provide a table of contents including major sections and their respective sub-sections.	The Team Lead creates and adjusts a table of contents in every report.	Inspection	Project Management	Verified	A table of contents is included in every report as seen in the Table of Contents above.

1.10	In every report, the team SHALL include the page number at the bottom of the page.	The team uses a template which displays the page number at the bottom of each page for every report.	Inspection	Project Management	Verified	The page number will be included at the bottom of the page in every report as seen in this document.
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.	The team obtains the equipment needed to attend a video teleconference with the review panel.	Inspection	Project Management	Verified	The team will continue to obtain and test any equipment needed to perform a video teleconference with the review panel.
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 ft. 1010 rails and 12 ft. 1515 rails SHALL be provided. The launch rails SHALL be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant SHALL depend on Launch Day wind conditions.	The Aerodynamics Lead designs a launch vehicle that utilizes 8 ft. 1010 rails or 12 ft. 1515 rails. The Structures Lead builds the launch vehicle according to these specifications.	Inspection	Aerodynamics, Structures	Not Verified	The team plans to use the launch pads provided for Launch Day.

1.13	Each team SHALL identify a "mentor." A mentor is defined as an adult who is included as a team member who SHALL 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 mentor SHALL maintain a current certification and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the launch vehicle for liability purposes and must travel with the team to Launch Week. One travel stipend SHALL be provided per mentor regardless of the number of teams he or she supports. The stipend SHALL only be provided if the team passes FRR and the team and mentor attend Launch Week in April.	The Team Leader determines a qualified adult to mentor the team throughout project development and attend Launch Week.	Inspection	Project Management	Verified	See Section 1.1.2 for team mentors.
1.14	Teams SHALL track and report the number of hours spent working on each milestone.	The team records the number of hours spent working on each milestone and documents this in the designated report.	Inspection	Project Management	Verified	See Section 1.1.4 pertaining to time spent on CDR.
Vehicle Requirements						
2.1	The vehicle SHALL deliver the payload to an apogee altitude between 4,000 and 6,000 ft. above ground level (AGL). Teams flying below 3,500 ft. or above 6,500 ft. on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.	The Aerodynamics and Structures Leads design a launch vehicle to deliver the payload to an apogee between 4,000 and 6,000 ft. AGL. The team fabricates the launch vehicle as designed.	Analysis, Demonstration	Aerodynamics, Structures	Not Verified	See Section 1.2.1 for launch day target apogee.
2.2	Teams SHALL declare their target altitude goal at the PDR milestone. The declared target altitude SHALL be used to determine the team's altitude score.	The Aerodynamics Lead reports the target altitude goal by October 26, 2023 in the PDR milestone.	Inspection	Aerodynamics	Verified	See Section 1.2.1 for official target apogee.

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 Recovery and Structures Lead design a recovery system that prevents the launch vehicle from being damaged upon ground impact.	Demonstration	Recovery, Structures	Verified	See Section 1.2.4 for the recovery design.
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.	The Aerodynamics and Recovery Leads design the launch vehicle to have no more than four independent sections.	Inspection	Aerodynamics, Recovery	Verified	See Section 3.2 to view independent sections.
2.4.1	Coupler/airframe shoulders which are located at in-flight separation points SHALL be at least 2 airframe diameters in length (one body diameter of surface contact with each airframe section).	The Aerodynamics Lead designs the coupler/airframe shoulders at in-flight separation points at least 2 airframe diameters in length. The Structures Lead builds the couplers to the specified lengths.	Inspection	Aerodynamics, Structures	Verified	See Section 3.2 for the launch vehicle design.
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.)	The Aerodynamics Lead designs the coupler/airframe shoulders at non-in-flight separation points at least 1.5 airframe diameters in length. The Structures Lead builds the couplers to the specified lengths.	Inspection	Aerodynamics, Structures	Verified	See Section 3.2 for the launch vehicle design.
2.4.3	Nose cone shoulders which are located at in-flight separation points SHALL be at least 0.5 body diameters in length.	The Aerodynamics Lead designs the nose cone shoulders at in-flight separation points to be a minimum of 0.5 body diameter in length.	Inspection	Aerodynamics	Verified	See Section 3.2 for the launch vehicle design.
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.	The Project Management Team and Safety Officer creates a launch day checklist that can be completed within two hours.	Demonstration	Project Management, Safety	Not Verified	The team will practice launch vehicle assembly before the VDF.
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.	The Project Management Team and Safety Officer ensure functionality of electrical components for a minimum of three hours by monitoring power consumption.	Demonstration	Project Management, Safety	Not Verified	The team tests powered electronics as outlined in Section 6.
2.7	The launch vehicle SHALL be capable of being launched by a standard 12-volt direct current firing system. The firing system SHALL be provided by the NASA-designated launch services provider.	The Project Management Team and Safety Officer pick a motor from a designated launch services provider that can be ignited by a 12-volt direct current firing system.	Demonstration	Project Management, Safety	Not Verified	See Section 1.2.2 for the selected motor.

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).	The Project Management Team and Safety Officer design the launch vehicle such that no external circuitry or special ground support equipment is needed for launch.	Demonstration	Safety	Verified	No use of external circuitry will be used as shown in Section 3.2.
2.9	Each team SHALL use commercially available e-matches or igniters. Hand-dipped igniters SHALL not be permitted.	The Project Management Team and Safety Officer utilize commercially available e-matches and igniters.	Inspection	Project Management, Safety	Verified	The team uses commercially available e-matches or igniters for ejection testing and vehicle launches.
2.10	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).	The Aerodynamics Lead selects a commercially purchased solid motor propulsion system with APCP certified by NAR, TRA, and/or CAR.	Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 1.2.2.
2.10.1	Final motor choice SHALL be declared by the Critical Design Review (CDR) milestone.	The Aerodynamics Lead states the finalized motor choice in the CDR milestone by January 8, 2024.	Inspection	Aerodynamics	Verified	See section 1.2.2 for the final motor choice.
2.10.2	Any motor change after CDR SHALL be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment SHALL not be approved. A penalty against the team's overall score SHALL be incurred when a motor change is made after the CDR milestone, regardless of the reason.	The Project Management Team requests approval from NASA RSO for a motor changed after the CDR milestone deadline.	Inspection	Project Management	Not Verified	See Section 1.2.2 for the current motor choice.
2.11	The launch vehicle SHALL be limited to a single motor propulsion system.	The Aerodynamics Lead designs the launch vehicle to use a single motor propulsion system.	Inspection	Aerodynamics	Verified	See Section 3.2 for the launch vehicle design.
2.12	The total impulse provided by a College or University launch vehicle SHALL not exceed 5,120 Ns (L-class).	The Aerodynamics Lead picks a motor that does not exceed a total impulse of 5,120 Ns.	Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 1.2.2.
2.13	Pressure vessels on the vehicle SHALL be approved by the RSO.	The Structures Lead gets RSO approval for any on-board pressure vessels.	Inspection	Structures	Not Verified	See section 3.2 for the launch vehicle design.
2.13.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) SHALL be 4:1 with supporting design documentation included in all milestone reviews.	The Structures Lead provides design documentation in each milestone report supporting a minimum factor of safety of 4:1.	Analysis, Inspection	Structures	Not Verified	See section 3.2 for the launch vehicle design.

2.13.2	Each pressure vessel SHALL include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	The Structures Lead picks pressure vessels which include a pressure relief valve system that sees the full pressure of the tank and can withstand the maximum pressure and flow rate of the tank.	Analysis, Inspection	Structures	Not Verified	See section 3.2 for the launch vehicle design.
2.13.3	The full pedigree of the tank SHALL be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	The Structures Lead describes the entire history of each pressure vessel, including the number of pressure cycles, the dates of pressurization/depressurization, and name of the person or entity administering each pressure event.	Inspection	Structures	Not Verified	See section 3.2 for the launch vehicle design.
2.14	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 Aerodynamics Lead designs the launch vehicle to have a minimum static stability margin of 2.0 at the rail exit.	Analysis	Aerodynamics	Verified	See Section 3.6 for the projected stability margin.
2.15	The launch vehicle SHALL have a minimum thrust to weight ratio of 5:1.	The Aerodynamics Lead designs the launch vehicle to have a minimum thrust to weight ratio of 5:1.	Analysis, Inspection	Aerodynamics	Verified	The current motor choice can be seen in Section 1.2.2.
2.16	Any structural protuberance on the launch vehicle SHALL be located aft of the burnout center of gravity. Camera will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the launch vehicle's stability.	The Aerodynamics Lead designs the launch vehicle to have any protuberances located aft of the burnout center of gravity. If camera's are included, the Aerodynamics Lead will prove the housings cause minimal aerodynamic effect on the launch vehicle's stability.	Analysis, Inspection	Aerodynamics	Verified	See Section 3.2 for the launch vehicle design.
2.17	The launch vehicle SHALL accelerate to a minimum velocity of 52 ft/s at rail exit.	The Aerodynamics Lead designs the launch vehicle to reach a minimum velocity of 52 ft/s at the rail exit.	Analysis	Aerodynamics	Verified	See Section 3.6 for the projected velocity of the launch vehicle.

2.18	All teams SHALL successfully launch and recover a subscale model of their launch vehicle prior to CDR. 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 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).	The Project Management Team launches a subscale model of the launch vehicle before CDR using an impulse motor of class E or higher. The Project Management Team and Safety Officer successfully recovers the subscale and reports flight data in the CDR milestone by January 8, 2024.	Demonstration	Project Management, Safety	Verified	See Section 3.3 for subscale flight data.
2.18.1	The subscale model should resemble and perform as similarly as possible to the full scale model. However, the full scale SHALL not be used as the subscale model.	The Aerodynamics Lead designs a subscale model that performs similarly to the full scale model.	Inspection	Aerodynamics	Verified	See Section 3.3 pertaining to the subscale design and performance.
2.18.2	The subscale model SHALL carry an altimeter capable of recording the model's apogee altitude.	The Recovery Lead attaches an altimeter to record the apogee altitude of the subscale model.	Inspection	Recovery	Verified	See Section 3.3 for the subscale altimeters.
2.18.3	The subscale launch vehicle SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The Aerodynamics and Structures Leads design and fabricate a new subscale launch vehicle that meets the criteria for this year's project.	Inspection	Aerodynamics, Structures	Verified	See Section 3.3 for subscale fabrication.
2.18.4	Proof of a successful subscale flight SHALL be supplied in the CDR report.	The Project Management Team shows proof of successful subscale flight in the CDR report by January 8, 2024.	Inspection	Project Management	Verified	See Section 3.3 for subscale launch data.
2.18.4.1	Altimeter flight profile graph(s) OR a quality video showing successful launch, recovery events, and landing as deemed by the NASA management panel are acceptable methods of proof. Altimeter flight profile graph(s) that are not complete (liftoff through landing) SHALL not be accepted.	The Recovery Lead makes an altimeter flight profile graph which displays all altitudes recorded from liftoff through landing.	Analysis	Recovery	Verified	See Section 3.3.2 for subscale data and altimeter flight profile graphs.
2.18.4.2	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.	The Project Management Team and Recovery Lead takes pictures of the landing configuration of all sections of the launch vehicle and includes them in the CDR milestone by January 8, 2024.	Analysis, Demonstration	Project Management, Recovery	Verified	See Section 3.3.2 pertaining to the as-landed configuration of each section of the subscale launch vehicle.

2.18.5	The subscale launch vehicle SHALL not exceed 75% of the dimensions (length and diameter) of the designed full scale launch vehicle (if the full scale launch vehicle is a 4 in. diameter, 100 in. length rocket, your subscale SHALL not exceed 3 in. diameter and 75 in. in length).	The Aerodynamics and Structures Lead design the subscale launch vehicle to not exceed 75% of the dimensions used for the full scale launch vehicle.	Inspection	Aerodynamics, Structures	Verified	See Section 3.3.3 regarding the scaling factors of the subscale launch vehicle.
2.19.1	**Vehicle Demonstration Flight**. All teams SHALL successfully launch and recover their full scale launch vehicle prior to FRR in its final flight configuration. The launch vehicle flown SHALL be the same launch vehicle flown at competition launch. Requirements 2.19.1.1-9 SHALL be met during the Vehicle Demonstration Flight:	The Project Management Team launches and recovers the full scale vehicle, to be flown for competition, in its final flight configuration before the FRR milestone.	Demonstration	Project Management	Not Verified	See Section 6.5 for the project timeline and projected date of VDF.
2.19.1.1	The vehicle and recovery system SHALL function as designed.	The Project Management Team identifies no abnormalities in the performance of the vehicle and recovery system.	Demonstration	Project Management	Not Verified	The full scale launch vehicle has yet to be constructed.
2.19.1.2	The full scale launch vehicle SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The Aerodynamics and Structures Leads design and build a new full scale launch vehicle, meeting the criteria for this year's project.	Inspection	Aerodynamics, Structures	Not Verified	The full scale launch vehicle has yet to be constructed.
2.19.1.3.1	If the payload is not flown during the Vehicle Demonstration Flight, mass simulators SHALL be used to simulate the payload mass.	The Structures Lead installs mass simulators to mimic payload mass if the payload is not flown during VDF.	Inspection	Structures	Not Verified	The payload has yet to be constructed.
2.19.1.3.2	The mass simulators SHALL be located in the same approximate location on the launch vehicle as the missing payload mass.	The Structures Lead installs mass simulators at the approximate location on the launch vehicle as the missing payload if the payload is not flown during VDF.	Inspection	Structures	Not Verified	Considering the complexity of the payload design, a mass simulator will most likely be used for VDF.
2.19.1.4	If the payload changes the external surfaces of the launch vehicle (such as camera housings or external probes) or manages the total energy of the vehicle, those systems SHALL be active during the full scale Vehicle Demonstration Flight.	The Payload Team activates systems during VDF if the payload changes the external surface or manages the total energy of the vehicle.	Inspection	Payload	Not Verified	The payload design does not change the external surfaces of the launch vehicle.
2.19.1.5	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.	The Aerodynamics Lead selects the same motor for both competition launch and the VDF. If the selected motor cannot be flown for VDF due to extenuating circumstances, the Project Management Team requests a waiver for an alternative motor in advance.	Inspection	Aerodynamics, Project Management	Not Verified	The motor selection can be viewed in Section 1.2.2.

2.19.1.6	The launch vehicle SHALL be flown in its fully ballastsed configuration during the full scale test flight. Fully ballastsed refers to the maximum amount of ballasts that SHALL be flown during the competition launch flight. Additional ballasts SHALL not be added without a re-flight of the full scale launch vehicle.	The Aerodynamics Lead determines the fully ballastsed configuration. The Structures Lead installs the needed ballasts for the full scale test.	Inspection	Aerodynamics, Structures	Not Verified	The ballasts used during full scale tests will be the same amount used on Launch Day.
2.19.1.7	After successfully completing the full scale Vehicle Demonstration Flight, the launch vehicle or any of its components SHALL not be modified without the concurrence of the NASA Range Safety Officer (RSO).	The Project Management Team does not allow any further modifications of the launch vehicle or its components after VDF without NASA and RSO approval.	Inspection	Project Management	Not Verified	The launch vehicle will remain unchanged after VDF.
2.19.1.8	Proof of a successful Vehicle Demonstration Flight SHALL be supplied in the FRR report.	The Project Management Team provides proof of successful VDF in the FRR report.	Inspection	Project Management	Not Verified	Full-scale has net yet been constructed.
2.19.1.8.1	Altimeter flight profile graph(s) that are not complete (liftoff through landing) SHALL not be accepted.	The Recovery Lead provides complete altimeter data acquired from the VDF in the FRR milestone.	Inspection	Recovery	Not Verified	Full-scale has net yet been constructed.
2.19.1.8.2	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.	The Project Management Team and Recovery Lead takes pictures of the landing configuration of all sections of the launch vehicle and includes them in the FRR milestone.	Inspection	Project Management, Recovery	Not Verified	Full-scale has net yet been constructed.
2.19.1.9	The Vehicle Demonstration Flight SHALL be completed by the FRR submission deadline. No exceptions SHALL be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. Teams completing a required re-flight SHALL submit an FRR Addendum by the FRR Addendum deadline.	The Project Management Team completes the VDF by the FRR submission deadline. If re-flight is necessary, the team submits an FRR Addendum by the FRR Addendum deadline.	Inspection	Project Management	Not Verified	See Section 6.3 for the projected VDF.
2.19.2	**Payload Demonstration Flight**. All teams SHALL successfully launch and recover their full scale launch vehicle containing the completed payload prior to the Payload Demonstration Flight deadline. The launch vehicle flown SHALL be the same launch vehicle to flown at competition launch. Requirements 2.19.2.1-4 SHALL be met during the Payload Demonstration Flight.	The Project Management Team launches and recovers the full scale launch vehicle containing the completed payload before the PDF deadline.	Inspection	Project Management	Not Verified	See Section 6.5 for the projected timeline and projected date of PDF.

2.19.2.1	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.	The Integration and Payload Leads ensure the payload is fully retained until the intended point of deployment, with each retention mechanism functioning as designed and not sustaining damage during flight.	Inspection	Integration, Payload	Not Verified	See Section 4.4 for the SAIL deployment method.
2.19.2.2	The payload flown SHALL be the final, active version of the payload.	The Project Management and Payload Teams ensures the payload flown during the PDF is the final active version of the payload.	Inspection	Project Management, Payload	Not Verified	The payload has yet to be constructed.
2.19.2.3	If Requirements 2.19.2.1-2 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 SHALL not be required.	The Project Management Team verifies all requirements are met for the VDF and are submitted prior to the FRR deadline. If all requirements are not met, the team performs an additional flight for PDF and submits the FRR Addendum.	Inspection	Project Management	Not Verified	The teams plans to meet the aforementioned requirements.
2.19.2.4	Payload Demonstration Flights SHALL be completed by the FRR Addendum deadline.	The Project Management Team ensures the PDF is completed by the FRR Addendum deadline.	Inspection	Project Management	Not Verified	See Section 6.5 for the projected timeline and projected date of PDF.
2.20	An FRR Addendum SHALL be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR.	The Project Management Team submits an FRR Addendum if the team completes the PDF or NASA required re-flight after the submission of the FRR.	Inspection	Project Management	Not Verified	The teams does not plan to re-launch after the FRR deadline.
2.20.1	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.	The Project Management Team ensures PDF and re-flight completion before the FRR Addendum deadline.	Inspection	Project Management	Not Verified	The teams does not plan to re-launch after the FRR deadline.
2.20.2	Teams who complete a Payload Demonstration Flight which is not successful may petition the NASA RSO for permission to fly the payload at the final competition launch. Permission SHALL not be granted if the RSO or the Review Panel have any safety concerns.	The Project Management Team petitions the NASA RSO for permission to fly the payload at the final competition launch if the PDF is not successful.	Demonstration	Project Management	Not Verified	See Section 6.2 for the projected testing to ensure payload success.

2.21	The team's name and launch day contact information SHALL be in or on the launch vehicle 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.	The Project Management Team includes the team name and launch day contact information on the launch vehicle airframe, and any sections that separate during flight, such that it can be retrieved without the need to open or separate the vehicle.	Inspection	Project Management	Not Verified	After construction, the team will add the team name and contact information.
2.22	All Lithium Polymer batteries SHALL be sufficiently protected from impact with the ground and SHALL be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	The Project Management Team and Safety Officer clearly mark all lithium polymer batteries as a fire hazard and sufficiently protects them from impact with the ground.	Analysis, Inspection	Project Management, Safety	Not Verified	See Section 3.5 pertaining to battery suspension.
2.23.1	The launch vehicle SHALL not utilize forward firing motors.	The Aerodynamics Lead selects a motor that is not forward firing.	Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 1.2.2.
2.23.2	The launch vehicle SHALL not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The Aerodynamics Lead selects a motor that does not utilize motors that expel titanium sponges.	Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 1.2.2.
2.23.3	The launch vehicle SHALL not utilize hybrid motors.	The Aerodynamics Lead selects a motor that is not hybrid.	Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 1.2.2.
2.23.4	The launch vehicle SHALL not utilize a cluster of motors.	The Aerodynamics Lead designs the launch vehicle to be launched on a single motor.	Inspection	Aerodynamics	Verified	See Section 3.2 regarding launch vehicle design.
2.23.5	The launch vehicle SHALL not utilize friction fitting for motors.	The Structures Lead fabricates a motor retention system that does not use friction fitting to hold the motor.	Inspection	Structures	Verified	See Section 3.2.10 for motor retention design.
2.23.6	The launch vehicle SHALL not exceed Mach 1 at any point during flight.	The Aerodynamics Lead designs the launch vehicle so that it does not reach Mach 1 at any point in flight.	Analysis	Aerodynamics	Verified	See Section 3.6 for the predicted vehicle velocity.
2.23.7	Vehicle ballasts SHALL not exceed 10% of the total unballastsed weight of the launch vehicle as it would sit on the pad (i.e. a launch vehicle with an unballastsed weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballasts).	The Aerodynamics Lead designs the launch vehicle such that vehicle ballasts does not exceed 10% of the total unballastsed weight of the launch vehicle.	Analysis, Inspection	Aerodynamics	Verified	See Section 3.6 pertaining to the addition of ballasts.
2.23.8	Transmissions from onboard transmitters, which are active at any point prior to landing, SHALL not exceed 250 mW of power (per transmitter).	The Recovery and Payload Leads choose onboard transmitters that do not exceed 250 mW of power (per transmitter).	Analysis	Recovery, Payload	Verified	The GPS transmitters can be viewed in Section 3.5.4.

2.23.9	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.	The Recovery and Payload Leads select transmitters that create minimal interference. The Safety Lead ensures the use of unique frequencies to mitigate interference with other teams.	Analysis, Demonstration	Recovery, Payload, Safety	Verified	The transmitters can be viewed in Section 3.5.
2.23.10	Excessive and/or dense metal SHALL not be utilized in the construction of the launch vehicle. Use of lightweight metal SHALL be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	The Structures Lead fabricates the launch vehicle to have the minimal amount of metal used in the construction of the vehicle.	Inspection	Structures	Verified	See Section 3.2.2 for the launch vehicle materials.
Recovery Requirements						
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.	The Recovery Team ensures the launch vehicle is configured to fire a drogue parachute at apogee and a main parachute no later than 500 ft. AGL for both halves of the launch vehicle.	Demonstration	Recovery	Verified	See Section 3.5 pertaining to parachute deployment.
3.1.1	The main parachute SHALL be deployed no lower than 500 ft.	The Recovery Team ensures the main parachute deployment charge is programmed to fire prior to reaching 500 ft. for any and all independently descending launch vehicle segments.	Demonstration	Recovery	Verified	See Section 3.5 pertaining to parachute deployment.
3.1.2	The apogee event SHALL contain a delay of no more than 2 seconds.	The Recovery Team designs a recovery system that has an apogee event delay of no more than 2 seconds.	Demonstration	Recovery	Verified	See Section 3.5 pertaining to recovery design.
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.	The Recovery Team designs a recovery system that does not utilize motor ejection.	Inspection	Recovery	Verified	See Section 3.6.8 pertaining to parachute ejection.
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 launch vehicles.	The Recovery Team performs ejection tests prior to each launch, confirming all recovery electronics are performing correctly.	Demonstration	Recovery	Verified	See Section 6.1.10 pertaining to ejection testing.

3.3	Each independent section of the launch vehicle SHALL have a maximum kinetic energy of 75 ft-lbf at landing. Teams whose heaviest section of their launch vehicle, as verified by Vehicle Demonstration Flight data, stays under 65 ft-lbf will be awarded bonus points.	The Recovery Team designs a recovery system such that the maximum kinetic energy experienced by the heaviest section of the launch vehicle does not exceed 65 ft-lbf.	Analysis	Recovery	Verified	See Section 3.6.5 for kinetic energy calculations.
3.4	The recovery system SHALL contain redundant, commercially available barometric altimeters that are specifically designed for initiation of launch vehicle recovery events. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	The Recovery Team designs a recovery system that uses primary and secondary altimeters for any and all AV bays.	Inspection	Recovery	Verified	See Section 3.5.2 for altimeter selection.
3.5	Each altimeter SHALL have a dedicated power supply, and all recovery electronics SHALL be powered by commercially available batteries.	The Recovery Team designs a recovery system that uses a separate, dedicated power supply, utilizing commercially available batteries, for any and all AV bays.	Inspection	Recovery	Verified	See Section 3.5.2 for the altimeter power supply.
3.6	Each altimeter SHALL be armed by a dedicated mechanical arming switch that is accessible from the exterior of the launch vehicle airframe when the launch vehicle is in the launch configuration on the launch pad.	The Recovery Team designs a recovery system that uses pin switches to activate any and all altimeters from the exterior of the launch vehicle.	Inspection	Recovery	Verified	See Section 3.5.3 for the altimeter arming method.
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 Recovery Team designs a recovery system that uses arming switches that can be locked in the ON position for launch.	Inspection	Recovery	Verified	See Section 3.5.3 for the arming method.
3.8	The recovery system, including GPS and altimeters, electrical circuits SHALL be completely independent of any payload electrical circuits.	The Recovery Team designs a recovery system containing recovery electronics that are completely independent of the payload electronics.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.
3.9	Removable shear pins SHALL be used for both the main parachute compartment and the drogue parachute compartment.	The Recovery Team designs a recovery system that uses removable shear pins such that separable sections of the launch vehicle are secured together on the pad and during launch.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.
3.10	Bent eyebolts SHALL not be permitted in the recovery subsystem.	The Recovery Team designs a recovery system that does not use any bent eyebolts.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.

3.11	The recovery area SHALL be limited to a 2,500 ft. radius from the launch pads.	The Recovery Team designs a recovery system containing parachutes that does not allow any separately descending segment of the launch vehicle to drift more than a 2,500 ft radius from the launch pad.	Analysis, Demonstration	Recovery	Verified	See Section 3.6.7 regarding wind drift calculations.
3.12	Descent time of the launch vehicle SHALL be limited to 90 seconds (apogee to touch down). Teams whose launch vehicle descent, as verified by Vehicle Demonstration Flight data, stays under 80 seconds SHALL be awarded bonus points.	The Recovery Team designs a recovery system containing parachutes that allows any separately descending segments of the launch vehicle to safely land within 80 seconds of launch.	Analysis, Demonstration	Recovery	Verified	See Section 3.6.6 for the calculated descent time.
3.13	An electronic GPS tracking device SHALL be installed in the launch vehicle and SHALL transmit the position of the tethered vehicle or any independent section to a ground receiver.	The Recovery Team designs a recovery system containing a GPS tracking device that transmits the position of each independent section of the launch vehicle.	Inspection, Demonstration	Recovery	Verified	See Section 3.5.4 for the tracking system.
3.13.1	Any launch vehicle section or payload component, which lands untethered to the launch vehicle, SHALL contain an active electronic GPS tracking device.	The Recovery Team installs GPS tracking devices on any independent sections that land untethered to the launch vehicle.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.
3.13.2	The electronic GPS tracking device(s) SHALL be fully functional during the official competition launch.	The Recovery Team tests GPS devices to ensure they remain completely functional during the official launch competition.	Inspection, Demonstration	Recovery	Not Verified	See Section 3.5 for the recovery design.
3.14	The recovery system electronics SHALL not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The Recovery Team designs a recovery system containing recovery electronics that are not affected by any other on-board electronic device.	Inspection, Demonstration	Recovery	Not Verified	See Section 3.5 for the recovery design.
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.	The Recovery Team designs an AV bay containing altimeters in a compartment that is physically separate from any other radio frequency transmitting or magnetic wave-producing devices.	Inspection	Recovery	Verified	See Section 3.5.6 for the avionics placement.
3.14.2	The recovery system electronics SHALL be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The Recovery Team designs an AV bay containing recovery electronics that is shielded from all other onboard transmitting devices.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.
3.14.3	The recovery system electronics SHALL be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The Recovery Team designs an avionics bay containing recovery electronics that is shielded from all other onboard magnetic wave generating devices.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.

3.14.4	The recovery system electronics SHALL be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The Recovery Team designs an AV bay containing recovery electronics that is shielded from all other onboard devices that may adversely affect the proper operation of the recovery system electronics.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.
Payload Requirements						
4.1	**SL Payload Mission Objective** — College/University Division — Teams SHALL design a STEMnauts Atmosphere Independent Lander (SAIL). SAIL is an in-air deployable payload capable of safely retaining and recovering a group of 4 STEMnauts in a unique predetermined orientation without the use of a parachute or streamer. The landing SHALL occur under acceptable descent and landing parameters for the safe recovery of human beings. A STEMnaut SHALL be defined as a non-living crew member, to be physically represented as the team chooses, and is assumed to have human astronaut survivability metrics. The method(s)/design(s) utilized to complete the payload mission SHALL be at the team's discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. NASA reserves the right to require modifications to a proposed payload.	The Payload and Integration Teams design a payload that is capable of safely returning the STEMnauts from the flight, follows all safety, FAA and NAR requirements, and is in accordance with the spirit of the competition.	Demonstration	Payload Electronics, Payload Structures, Payload Systems, Integration	Verified	See Section 1.3 for the payload design.
4.2.1	Teams SHALL not use parachutes or streamers that are commercially available or custom made. A parachute is defined as an open-faced canopy whose primary function is to reduce descent speed or increase drag. A streamer is defined as a long, narrow strip of material (typically affixed at one end) whose primary function is to reduce descent speed or increase drag.	The Payload Structures Team designs a SAIL that does not utilize any parachutes or streamers for recovery operations.	Inspection	Payload Structures	Verified	See Section 4.4 for the SAIL release system.
4.2.2	The SAIL SHALL be a minimum of 5 lbs inclusive of the jettisoned or separated landing capsule and the 4 STEMnauts.	The Payload Structures Team designs a SAIL that has a final weight of at least 5 lbs.	Inspection	Payload Structures	Verified	See Section 4.3 for the SAIL design.

4.2.3	Deployment of the SAIL SHALL occur between 400 and 800 ft. AGL. See Requirement 4.3.3 for deployment/jettison of payloads.	The Payload Structures, Recovery, and Integration Teams ensure SAIL ejection is designed to be within 400 and 800 ft. AGL.	Demonstration	Payload Structures, Recovery, Integration	Verified	See Section 4.4 for the SAIL deployment method.
4.2.4	The team SHALL pre-determine and land in a unique landing orientation to be verified by NASA personnel in Huntsville or by a non-affiliated NAR/TRA rep for at-home launches.	The Payload Teams design a SAIL that has a clear and defined landing orientation.	Demonstration	Payload Electronics, Payload Structures, Payload Systems	Not Verified	See Section 4.3 pertaining to landing orientation.
4.2.5	Teams SHALL design and implement a method of retention and ingress/egress for the STEMnauts.	The Payload Teams design a SAIL that retains the STEMnauts and allows easy access to the crew cabin for ingress/egress operations.	Inspection	Payload Electronics, Payload Structures, Payload Systems	Verified	See Section 4.3 for the the payload design.
4.2.6	Teams SHALL determine acceptable descent and landing parameters, to be approved by NASA, and design their lander to meet those requirements.	The Payload Teams design a SAIL that has a final landing speed of 15 mph (according to criteria for NASA's Orion spacecraft) and limits angular velocity so that the STEMnauts experience a maximum of 3gs (according to NASA's Space Shuttle launch criteria).	Demonstration	Payload Electronics, Payload Structures, Payload Systems	Verified	See Section 4.3 for the payload design.
4.3.1	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.	The Payload, Recovery, and Integration Teams ensure that no energetics are used outside of in-flight recovery operations.	Inspection	Payload Structures, Recovery, Integration	Verified	See Section 4.3 for the payload design.
4.3.2	Teams SHALL abide by all FAA and NAR rules and regulations.	The Safety Team reviews the SAIL design throughout the design process to ensure compliance with all FAA and NAR rules and regulations.	Inspection	Safety	Not Verified	See Section 5 pertaining to all safety regulations.
4.3.3	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.	The Payload Systems and Safety Teams ensure that payload is not jettisoned without receiving RSO authorization.	Demonstration	Payload Systems, Safety	Not Verified	See Section 4.4 for the SAIL release system.
4.3.4	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.	The Payload Systems and Safety Teams ensures that any UAS that is deployed during the descent phase of flight is tethered to the vehicle and released on command after RSO permission is received.	Demonstration	Payload Systems, Safety	Not Verified	See Section 4.3 for the payload design.

4.3.5	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).	The Payload and Safety Teams ensure that any UAS is flown in full compliance with FAA regulations.	Inspection	Payload Electronics, Payload Structures, Payload Systems, Safety	Verified	See Section 4.2 pertaining to UAS status.
4.3.6	Any UAS weighing more than .55 lbs. SHALL be registered with the FAA and the registration number marked on the vehicle.	The Payload and Safety Teams ensure that any UAS weighing more than .55 lbs is registered with the FAA and the registration number is clearly marked on the vehicle.	Inspection	Payload Structures, Payload Systems, Payload Electronics, Safety	Verified	See Section 4.2 pertaining to UAS status.
Safety Requirements						
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.	Checklists are included in the FRR and are used during LRR and Launch Day activities.	Validation of Records	All	Verified	See Section 5.5 for the current launch and safety checklist. The final checklist used during launch day will be included in FRR.
5.2	Each team SHALL identify a student Safety Officer who will be responsible for all requirements in Section 5.3.	The student Safety Officer, Megan Rink, is responsible for requirements listed in Section 5.3.	Validation of Records	Safety	Verified	The team has identified the student Safety Officer for the 2023-2024 year.
5.3.1.1	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during design of vehicle and payload.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer has and will continue to monitor team activities.
5.3.1.2	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during construction of vehicle and payload components.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer has and will continue to monitor team activities, tracking injuries with an incident report sheet.
5.3.1.3	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during assembly of vehicle and payload.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer has and will continue to monitor team activities, tracking injuries with an incident report sheet.
5.3.1.4	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during ground testing of vehicle and payload.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer is present for all ejection tests and tracks any injuries with an incident report sheet.
5.3.1.5	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during subscale launch test(s).	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The safety checklists for subscale launch can be viewed in Section 5.5.

5.3.1.6	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during full scale launch test(s).	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Not Verified	The Safety Officer is planning to attend any full-scale launches.
5.3.1.7	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during competition launch.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Not Verified	The Safety Officer is listed to attend the competition launch.
5.3.1.8	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during recovery activities.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Not Verified	The Safety Officer plans to attend recovery activities.
5.3.1.9	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during STEM engagement activities.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer monitored previous STEM engagement activities and will continue to do so for future events.
5.3.2	The designated student Safety Officer SHALL implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The Safety Team writes and implements procedures and checklists for assembling, launching, and recovering the launch vehicle.	Demonstration	Safety	Not Verified	Safety checklists from subscale launch can be viewed in Section 5.5. The full scale safety checklists will be included in FRR.
5.3.3	The designated student Safety Officer SHALL manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	The student Safety Officer manages all safety documentation for the team.	Inspection	Safety	Verified	See Section 5 for safety documentation.
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.	The Safety Team ensures all local rocketry club rules and regulations are followed by all team members.	Demonstration	Safety	Not Verified	The team has previously and will continue to abide by local RSO guidelines during test flights.
5.5	The team SHALL abide by all rules set forth by the FAA.	The Safety Team ensures all rules from the FAA are followed.	Demonstration	Safety, Project Management	Verified	The Safety Team ensures team members follow FAA regulations at all times.
Final Flight Requirements						

6.1	Teams SHALL conduct the final flight in Huntsville during Launch Week, NASA Launch Complex, by the applicable deadlines as outlined in the Timeline for NASA Student Launch.	The team completes final flight at the NASA Launch Complex by the deadline given in the timeline for NASA Student Launch.	Demonstration	Project Management	Not Verified	See Section 6.5 for the project timeline.
6.1.1	Teams SHALL not show up at the NASA Launch Complex outside of launch day without permission from the NASA management team.	The team requests permission from the NASA management team if needing to show up at the NASA Launch Complex outside of launch day.	Demonstration	Project Management	Not Verified	The team plans to show up to the NASA Launch Complex on launch day.
6.1.2	Teams SHALL complete and pass the Launch Readiness Review conducted during Launch Week.	The team completes and passes the Launch Readiness Review.	Inspection; Demonstration	Project Management	Not Verified	The team plans to prepare for LRR prior to launch week.
6.1.3	The team mentor SHALL be present and oversee launch vehicle preparation and launch activities.	The team mentor oversees all launch activities.	Demonstration	Team Mentor	Not Verified	The team mentor has and will continue to oversee launch related activities.
6.1.4	The scoring altimeter SHALL be presented to the NASA scoring official upon recovery.	The recovery lead presents the scoring altimeter to the NASA scoring official.	Demonstration	Recovery	Not Verified	The Recovery Lead is responsible for altimeter recovery.
6.1.5	Teams SHALL launch only once. Any launch attempt resulting in the launch vehicle exiting the launch pad, regardless of the success of the flight, SHALL be considered a launch. Additional flights beyond the initial launch, SHALL not be scored and SHALL not be considered for awards.	The team launches the launch vehicle only once.	Inspection; Demonstration	Project Management	Not Verified	The team plans to perform extensive testing to ensure launch vehicle success.

6.3.2 Team Derived Requirements

Table 6.23: Launch Vehicle Team Derived Requirements

ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
			Functional Requirements			
LVF 1	The launch vehicle SHALL be designed with removable ballasts.	Design changes made to the vehicle or payload after the PDR milestone may dictate a modification to the total ballasts of the vehicle.	Ballasts is not permanently mounted to the vehicle allowing for removal or addition with hand tools.	Inspection	Verified	See Section 3.6 pertaining to ballasts and Section 3.2.7 for the removable fin system.
LVF 2	The launch vehicle apogee verification SHALL be conducted by no less than 3 separate analysis programs.	Multimodal analysis of the apogee of the vehicle will increase the confidence in the apogee declared in the competition.	At least three different analysis programs are used in the development of a target apogee for the launch vehicle.	Inspection	Verified	See Section 3.6 regarding apogee calculations.
LVF 3	Vehicle Demonstration Flights SHALL be completed at least 3 weeks prior to NASA Student Launch Week.	In the event the launch vehicle sustains heavy damage, this gives adequate time to make any repairs before competition.	The date of the VDF is at least 3 weeks before the start of NASA Student Launch Week.	Demonstration	Not Verified	See Section 6.5 for the expected VDF date.
LVF 4	Fins SHALL experience minimum damage hitting the ground at 1 mph.	As the launch vehicle lands, the fins will need to sustain minimal damage in case of a re-launch.	The fins are tested to determine how much damage, if any, is inflicted when dropped at 1 mph.	Inspection, Demonstration	Not Verified	See Section 6.1.5 for fin test plans.
LVF 5	Rivets SHALL have a factor of safety greater than or equal to 2.	The rivets are responsible for holding non-separating launch vehicle sections together during flight and must be reliable.	Rivets used on the launch vehicle are tested and only used if the factor of safety is greater than or equal to 2.	Inspection, Demonstration	Not Verified	See Section 6.1.6 for rivet test plans.
LVF 6	Shear pins SHALL fail under a 35 ± 1 lb. load.	The shear pins are responsible for holding separating launch vehicle sections together during flight and must be reliably fail to separate desired sections with black powder charges.	Shear pins used on the launch vehicle are tested and only used if they fail reliably under a 35 ± 1 lb. load.	Inspection, Demonstration	Not Verified	See Section 6.1.6 for shear pin plans.
			Design Requirements			
LVD 1	The launch vehicle SHALL have four symmetrical fins.	Maximizing the aerodynamic surface area of the fins will increase the fin control authority of the launch vehicle's trajectory, reducing the risk of launch vehicle instability during flight as well as ensure the CG is centered.	The launch vehicle has four symmetrical fins mounted to the removable fin system.	Inspection	Verified	See Section 3.2.9 for the fin design.
LVD 2	The launch vehicle SHALL be designed with fins that do not contain curved geometry.	Complex fin geometry reduces the manufacturability of the fins increasing the amount of labor and cost of producing flight and critical spares of the fins.	The fins contain a linear external profile.	Inspection	Verified	See Section 3.2.9 pertaining to fin design.

LVD 3	Bulkheads SHALL not fracture under tensile stress less than the maximum shock force.	Bulkheads are in place for structural integrity as well as parachute and shock cord attachments. Thus, the bulkheads need to withstand any forces experienced during flight.	The fabricated bulkheads will are made with a material strong enough to withstand shock forces.	Inspection, Demonstration	Not Verified	See Section 3.4.3 for bulkhead fabrication.
LVD 4	The motor tube SHALL be supported by at least 2 centering rings.	Provides adequate support to the motor tube when the motor is experiencing forces during launch.	The launch vehicle has three centering rings supporting the motor tube.	Inspection	Verified	See Section 3.2 pertaining to launch vehicle design.
LVD 5	The launch vehicle SHALL have a stability margin between 2.0 and 3.0 upon rail exit.	A stability margin of 2.0 or greater is needed per NASA Requirement 2.14. With a maximum stability of 3.0, undesired weather cocking can be avoided when launching in high winds.	The estimated launch vehicle stability will be between 2.0 and 3.0.	Analysis	Verified	See Section 3.6 for expected stability margin of the launch vehicle design.
LVD 6	The launch vehicle stability margin SHALL maintain a variability of no more than 0.75 calibers between the subscale and full scale vehicle.	Modification of the launch vehicle's center of pressure and center of gravity by more than 5 percent of the launch vehicle's length degrades the validity of subscale testing.	The stability of the subscale and full scale launch vehicle evaluate to a difference of no more than 0.75 calipers.	Analysis	Verified	See Section 3.6 for expected stability margin of the launch vehicle design.
LVD 7	The launch vehicle SHALL not exceed a maximum velocity of Mach 0.7.	High launch vehicle atmospheric loading increases the risk of structural component and payload hardware damage.	Simulations dictate a maximum launch vehicle velocity of no more than Mach 0.7.	Analysis	Verified	See Section 3.6 for the calculated velocity.
LVD 8	The Launch vehicle SHALL not exceed a maximum instantaneous acceleration of 14 G's during flight.	High acceleration of the vehicle during flight increases the risk of structural safety margin degradation along with the risk of payload hardware damage.	Simulations dictate a maximum launch vehicle acceleration of no more than 14 G's of acceleration during the entire flight profile.	Analysis	Verified	See Section 3.6 for performance predictions.
LVD 9	The launch vehicle SHALL use no more than 4 pounds of ballasts in the nose cone.	Volume constraints within the nose cone of the launch vehicle dictate a finite amount of ballasts that can reasonably be placed within the section.	The ballasts measurement of the full scale vehicle is at or below 4 pounds.	Inspection	Not Verified	See Section 3.6 pertaining to ballasts.
LVD 10	The launch vehicle SHALL be developed with a methodology for altering the final mass of the vehicle by at least 0.25 lb on the day of launch.	Variability of wind speeds on the day of launch may dictate the addition of additional ballasts to compensate for cosine losses of total apogee.	A system for the alteration of the final vehicle mass by at least 0.25 lb is incorporated into the vehicle.	Inspection	Verified	See Section 3.6 pertaining to ballasts and Section 3.2.9 for the removable fin system.
LVD 11	The launch vehicle SHALL be designed to minimize cyclical angle of attack oscillations during liftoff.	Minimization of cyclical oscillations of the launch vehicle during flight will improve the probability of the vehicle achieving the target apogee.	Specific targeted analysis is presented in the CDR regarding design decisions made to minimize cyclical angle of attack oscillations	Inspection	Verified	See Section 3.2 pertaining to launch vehicle design.

Table 6.24: Recovery Team Derived Requirements

ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirements						
RF 1	All batteries (9 V and LiPos) SHALL be fully charged before every flight.	The tracker may not sufficiently work or black powder might not be properly ignited if there is insufficient voltage.	All batteries will be determined as fully charged before being inserted into the AV sled.	Inspection, Analysis	Not Verified	Fully charged 9 V batteries and LiPos were utilized during subscale launch and will be used for full scale flight.
RF 2	The secondary black powder charges SHALL be 0.5 grams larger than the primary charge.	The secondary charges are in place if the primary charges do not initially separate the sections of the launch vehicle. The secondary charges have to be larger than the primary charges to ensure complete separation during flight.	The black powder added to the secondary blast cap will be 0.5 grams more than the amount in the primary blast cap.	Inspection	Verified	See Section 3.6.8 for ejection charge sizing.
RF 3	Altimeter testing SHALL be successful and accurate before any vehicle launch.	Altimeters are detrimental to ensuring parachute deployment at desired altitudes and therefore needs to precisely measure the vehicle height.	All altimeters are tested and only placed on the AV sled if working properly.	Analysis, Demonstration	Not Verified	See Section 6.1.4 for altimeter test plans.
RF 4	Any GPS used on the launch vehicle SHALL detect the vehicle within 100 ft. of its actual location.	The launch vehicle may not be recovered if the tracker does not accurately locate the section.	Any tracker used in the launch vehicle is tested to ensure it detects the transmitter location within 100 ft.	Demonstration	Not Verified	See Section 6.1.3 for tracker test plans.
RF 5	Successful ejection testing, meaning separation of launch vehicle sections, SHALL be completed before any launch.	Ejection testing ensures the black powder charges are strong enough to break the shear pins and separate the vehicle sections.	The vehicle is not launched until sections are separated during ejection testing.	Demonstration	Not Verified	See Section 6.1.10 for full-scale ejection testing.
RF 6	All shock cord SHALL be accordion folded before being placed into the launch vehicle.	This type of folding prevents the shock cord from being tangled while stored within the launch vehicle.	All shock cord will be accordion folded before being attached to U-bolts and placed inside the launch vehicle.	Inspection, Demonstration	Not Verified	The Project Manager and Recovery Lead will verify that the shock cords have been properly folded before being inserted into the launch vehicle.
RF 6.1	After folding, all shock cord SHALL be loosely secured with a rubber band.	To keep shock cord properly folded until separation, a rubber band is used to keep the shock cord from unraveling. Additionally, the rubber band is tied loosely in order to allow the shock cord to come apart during separation.	All shock cord is folded in half and secured with a rubber band after being accordion folded.	Inspection	Not Verified	The project manager and Recovery Lead will verify that rubber bands have been tied around any shock cord before being place in the launch vehicle.

RF 7	Parachute shroud lines SHALL be detangled before folding the parachute.	Tangled shroud lines may prevent the parachute from fully opening during descent.	Parachute shroud lines will be detangled to the point they are mostly separated from other shroud lines before folding the parachute.	Inspection, Demonstration	Not Verified	Shroud lines are detangled prior to folding the parachutes.
RF 8	Parachutes SHALL be folded accordion style and tightly rolled before being placed within the launch vehicle.	By folding the parachutes this way, it allows the parachute to open fully during descent while keeping them compact when placed in the launch vehicle.	All parachutes are folded accordion style and tightly rolled before being inserted into the launch vehicle.	Inspection, Demonstration	Not Verified	The parachutes will be properly folded before or on launch day.
Design Requirements						
RD 1	A deployment bag SHALL be used to protect the main parachute from ejection gasses.	If exposed to ejection gasses, the main parachute may burn/melt causing the parachute to fail. Additionally, the deployment bag prevents the main parachute shock cords from tangling with other shock cords within the launch vehicle.	The main parachute will be fully inserted into a deployment bag before being put into the launch vehicle.	Inspection	Verified	See Section 3.5 for recovery system design.
RD 2	Drogue and payload parachutes SHALL be wrapped in Nomex cloth.	If exposed to ejection gasses, the parachutes may burn/melt causing the parachutes to fail.	The drogue and payload parachutes will be fully wrapped inside a Nomex cloth before being attached to the respective shock cords and bays.	Inspection	Verified	See Section 3.5 pertaining to Nomex cloth.
RD 3	U-Bolts SHALL be used for all shock chord connections.	Using U-bolts disperses the shock to multiple points, increasing bulkhead stability.	U-bolts are used on every bulkhead as an anchor point for the recovery harness.	Inspection	Verified	U-bolts will be added to bulkheads for shock chord connections.
RD 4	Threaded quick-links SHALL be used for all recovery harness and U-bolt connections.	Threaded quick links are easy to install around U-bolts and are unlikely to detach during flight.	Quick links will be used to attach any recovery harness to its respective U-bolt.	Inspection	Verified	Threaded quick links will be used to attach recovery harnesses during launch vehicle assembly.
RD 4.1	All quick links used for recovery harness and U-bolt connections SHALL be wrapped in electrical tape at the threaded link.	Quick links are the only thing holding the recovery harnesses to the U-bolts. Therefore, to prevent them from unscrewing when experiencing flight forces, electrical tape is used to keep the quick links fastened.	All quick links will be wrapped in electrical tape during launch vehicle assembly.	Inspection, Demonstration	Not Verified	Adding electrical tape onto the quick links is a step on the checklist for previous and future launches.
Environmental Requirements						
RE 1	Protective insulation SHALL be biodegradable.	In the case insulation falls out of the launch vehicle, the insulation used will have no negative environmental consequences.	There will be verification of biodegradable insulation before inserting into the parachute bays.	Inspection	Verified	See Section 3.5 for insulation use.

RE 2	Rubber bands used for shock cord folding SHALL be biodegradable.	The rubber bands will fall off the shock cord during separation. Thus, the rubber bands used will have no negative environmental impacts.	The rubber bands purchased will be verified as biodegradable before using them for shock cord.	Inspection	Verified	The rubber bands that have been purchased for club use are biodegradable.

Table 6.25: Payload Team Derived Requirements

ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirements						
PF 1	All electronic components in the launch vehicle SHALL be removable.	With removable electronics, easier adjustments can be made to the payload design.	No electronic components within the launch vehicle are fixed in place.	Inspection, Demonstration	Verified	See Section 3.2 pertaining to payload electronics.
PF 2	The RF transmitter and receiver for release SHALL have an operational range of at least 2500 ft.	While the SAIL will be deployed at a maximum of 800 ft, the possibility of wind drift increases the chance of a large distance between the receiver and transmitter. This minimum specification will allow for the release latch to be operational over long distances.	Before inserting the transmitter and receiver in the SAIL, it will be tested and verified to have an operational range of at least 2500 ft.	Inspection, Demonstration	Not Verified	See Section 6.2.5 for RF transmitter testing.
PF 3	The SAIL deployment latch SHALL withstand up to 100 lb. of tensile force.	The latch must not release the SAIL while experience forces during flight until given the command to do so.	The latch used can withstand at least 100 lb. of tensile force.	Inspection, Demonstration	Not Verified	See Section 6.2.6 for the testing of the SAIL deployment latch.
PF 4	Rotor blades and landing legs SHALL immediately deploy after leaving the deployment bay.	Extended rotor blades are needed to immediately produce thrust while the landing legs need to be extended to create drag and ensure vertical landing orientation.	The rotor blades and landing legs are designed to immediately extended after exiting the deployment bay.	Demonstration	Not Verified	See Section 4.4 for the SAIL deployment method.
PF 5	The SAIL rotor blades SHALL produce up to 8 lb. of thrust.	The rotor blades need to produce enough thrust to counteract the weight of the SAIL, but only needs to generate enough thrust to slow the SAIL's descent.	The motor and propeller blades are designed to allow the rotors to produce up to 8 lb. of thrust.	Analysis, Demonstration	Not Verified	See Section 6.2.7 for testing of rotor blades.
PF 6	Adhesion methods used for propeller blade sections SHALL withstand at least 300 lb.	During the SAIL's descent, the propeller blades must remain intact to produce lift and spin at the desired RPM.	A strong adhesive is used to connect the propeller blade sections.	Inspection, Demonstration	Not Verified	See Section 6.2.3 for the testing of rotor blade adhesion.
PF 7	SAIL landing legs SHALL withstand a force of 35 lb during impact with the ground.	To remain in its upright orientation, the SAIL landing legs must be able to withstand the force of impact with the ground during landing.	The landing legs are designed to withstand the forces of impact during landing.	Inspection, Demonstration	Not Verified	See Section 6.2.4 for the testing of the landing legs.
Design Requirements						
PD 1	The SAIL SHALL land with an impact velocity of less than 15 mph.	Having a descent velocity greater than 15 mph increases risk to the STEMnauts by applying greater G forces and higher velocity upon landing.	The rotor blades produce enough thrust to maintain a descent velocity less than or equal to 15 mph.	Analysis, Demonstration	Not Verified	See Section 4.3 pertaining to the SAIL thrust calculations.

PD 2	The SAIL SHALL not experience more than 3 G's of sustained centripetal forces or 6 G's of force for 1 second during the descent.	Having more than 3 G's of centripetal force and a maximum of 6 G's increases risk to the STEMnauts during descent.	Contra-rotating blades spinning at a similar RPM will help minimize spinning of the SAIL.	Analysis, Demonstration	Not Verified	See Section 4.3.8 pertaining to survivability metrics.
PD 3	The SAIL SHALL land in a vertical orientation resting on the extended landing legs.	Landing in a vertical orientation reduces risk to STEMnauts upon landing at a higher velocity. Resting upon the landing legs prevents the hub from tipping over.	The landing legs span wider than the base of the hub to provide sufficient support upon landing.	Inspection, Demonstration	Not Verified	See Section 4.3.5 pertaining to the landing legs.
PD 4	The contra-rotating rotor blades SHALL rotate at the same RPM.	This eliminates rotation caused by imbalanced aerodynamic torque on the rotors.	The contra-rotating rotors will be designed to work off one motor to ensure the rotors are operating at the same RPM.	Analysis, Demonstration	Not Verified	See Section 4.3.3 pertaining to gearbox assembly.
PD 5	The SAIL SHALL be a maximum of 8 lb. in total.	Keeping the weight at a reasonable value facilitates a lightweight launch vehicle and improves the performance of the rotor blades.	The SAIL will be a minimum of 5 lb., as per NASA Requirement 4.2.2, and a maximum of 8 lb.	Inspection	Not Verified	See Section 4.3 pertaining to the predicted SAIL weight.

Table 6.26: Safety Team Derived Requirements

ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirements						
SF 1	Epoxy SHALL cure for at least 24 hours.	The chances of structural failure increases when using uncured epoxy as it weakens the structural integrity of the launch vehicle.	Parts using epoxy are labeled and untouched until the time and date shown on the label.	Inspection	Not Verified	Current fabrication procedures require at least 24 hours of curing for all epoxied parts.
SF 2	Persons working with or around power tools SHALL wear safety glasses.	Wearing PPE during power tool operation reduces the risk of skin and eye injury from debris.	Safety glasses provided for every working HPRC member are located in the rocketry lab's PPE closet.	Inspection	Verified	25 pairs of safety glasses are kept in the PPE closet which exceeds lab capacity.
SF 3	Persons working with explosive liquids and/or powders SHALL wear nitrile gloves, safety glasses, and particulate masks.	Wearing PPE when working with hazardous liquids and/or powders reduces the risk of skin and eye injury from debris.	Gloves, safety glasses, and masks provided for every working HPRC member are located in the rocketry lab's PPE closet.	Inspection	Verified	7 boxes of nitrile gloves, 25 pairs of safety glasses, and 2 cases of masks are kept in the PPE closet which exceeds lab capacity.
SF 4	When attending the launch field, all personnel SHALL maintain a walking pace.	Walking at a steady pace decreases the risk of falling, tripping, or slipping.	Members attending launch day will maintain a steady walking place while on the launch field.	Inspection	Not Verified	Team members will be briefed before the launch on launch field safety and etiquette.
SF 5	Hazards labeled orange or red during risk assessment SHALL be decreased to yellow or green by CDR.	Filtering frequent and/or potentially dangerous hazards allows for a more durable launch vehicle and payload system.	After mitigation, all hazards included in CDR will fall in the yellow or green zones.	Inspection	Verified	All potential hazards fall in the green or yellow zones.
SF 6	All hazardous or flammable liquids and powders SHALL be stored in the flame cabinet when not in use.	Storing hazardous powders and liquids in a fireproof cabinet reduces risk of injury to students and lab equipment.	Hazardous liquids and powders remain in the flame cabinet unless actively being used by a team member.	Inspection	Verified	All hardeners, resins, lubricants, cleaners, aerosol paints, black powder, oxidizers, and igniters used by the team are stored in a JUSTRITE Flammable Liquid Storage Cabinet.
SF 7	Persons observing ejection testing SHALL stand at least 5 ft. to the side of the launch vehicle.	During ejection testing, the distance at which the launch vehicle separates or the effects of the black powder explosion are unknown. As a safety precaution, all observers should be at a safe distnace away.	During ejection testing, spectators do not stand in front or less than 5 ft. away from the launch vehicle.	Inspection	Verified	The Safety Officer is present during any ejection testing to ensure onlookers maintain a safe distance away.
SF 8	Persons attending SAIL deployment demonstrations SHALL refrain from being directly under the deployment bay.	The SAIL is dropped out of the deployment bay. Thus, in the event the rotors do not produce enough thrust, there is risk of injury.	Personnel attending SAIL deployment experimentation will refrain from being directly under the deployment bay.	Inspection, Demonstration	Not Verified	Once SAIL deployment experimentation takes place, everyone will remain a safe distance from the deployment drop site.

SF 9	SAIL electronics SHALL contain a kill switch.	If the SAIL does not work as intended or risks harming onlookers, a kill switch eliminates the rotor blades from spinning.	A kill switch will be utilized to stop the SAIL's motor in any case deemed necessary.	Demonstration	Not Verified	A tested kill switch is integrated into the SAIL electronics.
SF 10	Buckets filled with sand SHALL be brought to launches if any electronics utilize LiPo batteries.	LiPo batteries are at risk of exploding which can be stifled by submerging the batteries in sand.	Pre filled sand buckets are brought to every vehicle launch.	Inspection	Verified	Buckets of sand are kept in the HPRC lab and brought to every launch.
SF 11	All energetics SHALL be stored in a locking energetics container during travel.	Energetics have the potential to combust and therefore need to be secured inside a fireproof container to ensure everyone's safety during transport.	Any explosive or combustible products are kept inside a locking energetics container when traveling to the launch site.	Inspection, Demonstration	Verified	The club owns a locking energetics container that remains in the lab and is used for transporting hazardous materials.
SF 12	Altimeters SHALL not be armed while connected to live black powder charges.	If altimeters are armed and connected to live black powder charges, there is risk of accidentally detonating the black powder.	The pull-pin switch used to disarm the altimeters will remain inserted until the rocket is ready to launch on the launch pad.	Inspection	Verified	The Safety Officer and Recovery Lead ensure the pull-pin switch remains inserted until the vehicle is on the launch pad.
Environmental Requirements						
SE 1	All trash SHALL be disposed of before leaving the launch site.	Leaving trash may be harmful to the launch field as not everything used throughout launch day is biodegradable.	The team brings garbage bags to the launch site to dispose of any trash.	Inspection, Demonstration	Verified	The team picks up and disposes of any trash found at the launch site.
SE 2	All non-hazardous electronics SHALL be disposed of in the designated electronic recycling buckets.	Electronics that are not properly disposed of may later cause harm to the environment by contributing to toxic pollutants.	All non-hazardous electronics will be disposed of in the yellow recycling buckets located on NC State's campus.	Demonstration	Verified	There are various recycling buckets located on campus for proper electronic disposal.
SE 3	Live energetics and disarmed LiPo batteries SHALL be disposed of at a waste disposal facility.	Hazardous electronics need to be properly disposed of prevent environmental harm and ensure the safety of club members.	The Safety Officer will transport any live energetics or LiPos to the nearest waste disposal facility.	Demonstration	Verified	The Safety Officer has identified the nearest facility as the Wake County Household Hazardous Waste Facilities.

6.4 Budget

Table 6.27 below details the year-long budget for the 2023-2024 Student Launch Competition.

Table 6.27: 2023-2024 NASA Student Launch Competition Budget

	Item	Quantity	Price Per Unit	Item Total
Subscale Structure	Plastic 4 in. 4:1 Ogive Nosecone	1	$ 29.80	$ 29.80
	4 in. Blue Tube	2	$ 43.95	$ 87.90
	4 in. Blue Tube Pre-Slotted	1	$ 53.50	$ 53.50
	4 in. Blue Tube Coupler	4	$ 12.31	$ 49.24
	AeroTech I435T-14A Motor	2	$ 80.24	$ 160.48
	Aero Pack 38mm Retainer	2	$ 29.17	$ 29.17
	AeroTech RMS-38/600 Motor Casing	1	$ 98.86	$ 98.86
	Standard Rail Button - 1010	2	$ 4.25	$ 8.50
	U-Bolts	4	$ 1.00	$ 4.00
	Blast Caps	4	$ 1.80	$ 7.20
	Terminal Blocks	4	$ 3.00	$ 12.00
	Double Pull Pin Switch	2	$ 11.95	$ 23.90
	Subtotal:			**$ 564.55**
Full Scale Structure	6 in. Nosecone Fiberglass Ogive 4:1	1	$ 149.99	$ 149.99
	6 in. G12 Fiberglass Tube (48 in.)	2	$ 228.00	$ 456.00
	AeroTech High-Power L1940X Motor	2	$ 289.99	$ 579.98
	Aero Pack 75mm Retainer	1	$ 59.50	$ 59.50
	AeroTech RMS-75/3840 Motor Casing	1	$ 526.45	$ 526.45
	Domestic Birch Plywood 1/8”x2x2	5	$ 57.99	$ 289.95
	G-10 Fiberglass Sheet Stock	2	$ 72.64	$ 145.28
	Large Rail Button -1515	2	$ 4.25	$ 8.50
	U-Bolts	8	$ 1.00	$ 8.00
	Blast Caps	4	$ 1.80	$ 7.20
	Terminal Blocks	4	$ 3.00	$ 12.00
	Double Pull Pin Switch	2	$ 11.95	$ 23.90
	Subtotal:			**$ 2,464.75**
Payload	Carbon Fiber PETG Filament	1	$ 48.99	$ 48.99
	Unidirectional Carbon Fabric	2	$ 15.95	$ 31.90
	Aluminum Sheets	2	$ 13.35	$ 26.70
	PLA Filament	1	$ 25.00	$ 25.00
	Bevel Gear	2	$ 24.99	$ 49.98
	5.5 in. Blue Tube	1	$ 75.50	$ 75.50
	Aluminum Tube Leg	1	$ 19.88	$ 19.88
	Scorpion HKIV Motor	1	$ 320.00	$ 320.00
	Lithium Polymer Battery	1	$ 37.49	$ 37.49
	Cobra 150A ESC	1	$ 104.99	$ 104.99
	XTend 900 Modem	1	$ 283.20	$ 283.20
	MPM3610 Buck Converter	1	$ 5.95	$ 5.95
	Adafruit Feather	1	$ 19.95	$ 19.95
	ESC Programming Card	1	$ 11.95	$ 11.95
	Filament Binding Adhesive	1	$ 34.99	$ 34.99
	Misc. Nuts, Bolts, Springs, etc.	1	$ 298.39	$ 298.39
	Subtotal:			**$ 1,061.48**

Recovery and Avionics	Iris Ultra 96 in. Standard Parachute	1	$ 477.28	$ 477.28
	12 in. Compact Elliptical Parachute	1	$ 67.41	$ 67.41
	Eggtimer Quasar	2	$ 99.99	$ 199.98
	Eggtimer TX Transmitter	1	$ 70.00	$ 70.00
	6 in. Deployment Bag	2	$ 54.40	$ 108.80
	4 in. Deployment Bag	2	$ 47.30	$ 94.60
	18 in. Nomex Cloth	2	$ 26.40	$ 52.80
	13 in. Nomex Cloth	2	$ 17.60	$ 35.20
	5/8 in. Kevlar Shock Cord (per yard)	25	$ 6.99	$ 174.75
	3/16 in. Stainless Steel Quick Links	14	$ 6.98	$ 97.72
	Firewire Electric Match	16	$ 2.00	$ 32.00
	AeroTech Ejection Charge - 1.4g	24	$ 1.25	$ 30.00
	Small Nylon Shear Pins	40	$ 0.18	$ 7.20
	Subtotal:			**$ 1,447.74**
Miscellaneous	Paint	12	$ 18.00	$ 216.00
	West Systems 105 Epoxy Resin	2	$ 109.99	$ 219.98
	West Systems 206 Slow Hardener	2	$ 62.99	$ 125.98
	PLA 3D Printer Filament Spool	1	$ 26.00	$ 26.00
	ClearWeld Quick Dry 2-Part Epoxy	1	$ 20.28	$ 20.28
	Wood Glue	1	$ 7.98	$ 7.98
	Tinned Copper Wire Kit	1	$ 25.00	$ 12.00
	Zip Ties Pack	1	$ 6.59	$ 6.59
	Hook and Loop Strips Box	1	$ 10.00	$ 10.00
	9V Battery Pack	1	$ 12.00	$ 12.00
	Misc. Tape	1	$ 20.00	$ 20.00
	Estimated Shipping			$ 1,000.00
	Incidentals (replacement tools, hardware, safety equipment, etc.)			$ 1,500.00
	Subtotal:			**$ 3,197.79**
Travel	6 Person Student Hotel Rooms (# Rooms)	2	$ 1,418.24	$ 2,836.48
	Student Hotel Rooms (# Rooms)	4	$ 1,326.24	$ 5,304.96
	Mentor Hotel Rooms – 4 nights (# Rooms)	2	$ 556.03	$ 1,112.06
	NCSU Van Rental (# Vans)	3	$ 798.00	$ 2,394.00
	Subtotal:			**$ 11,647.50**
Promotion	T-Shirts	40	$ 15.00	$ 600.00
	Polos	15	$ 25.00	$ 375.00
	Stickers	500	$ 0.43	$ 215.00
	Subtotal:			**$ 1,190.00**
Total Expenses:				**$ 21,573.81**

As highlighted in Figure 6.1, our expenses can be divided into different sub-sections with travel funds taking up the majority of our spending for this year.

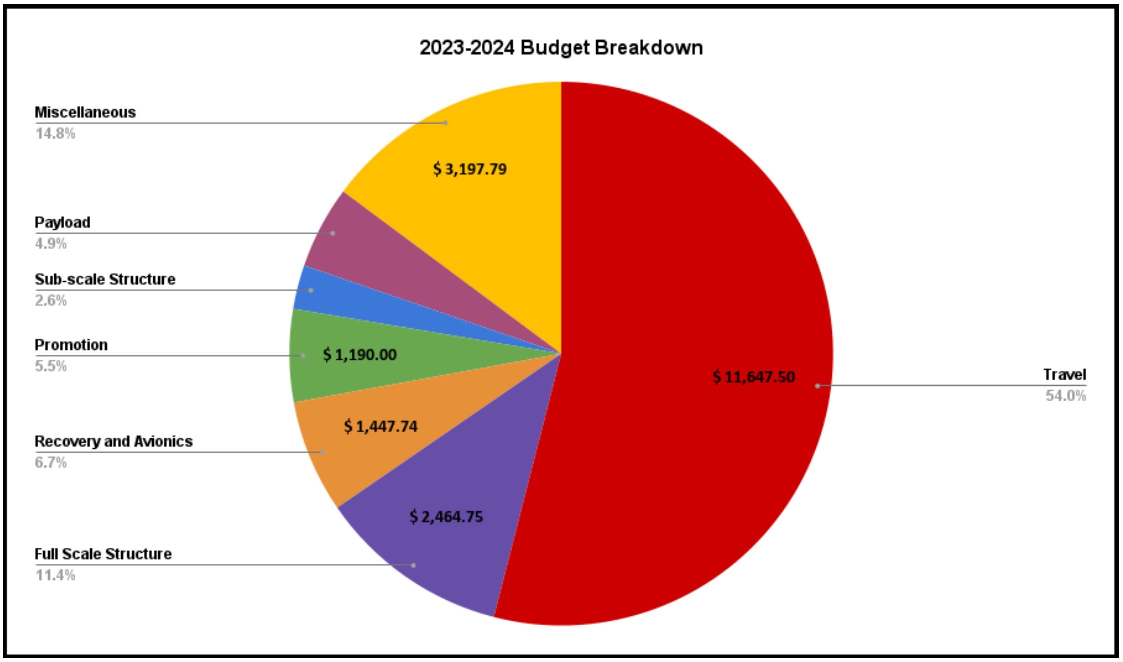

Figure 6.1: 2023 - 2024 Budget Breakdown

6.4.1 Funding Plan

HPRC receives funding from a variety of NC State University's resources, as well as North Carolina Space Grant (NCSG). Below is an in depth breakdown of the team's current funding sources.

NC State's Student Government Association's (SGA) Appropriations Committee is responsible for distributing university funding to nearly 600 different organizations on campus. Each semester the application process consists of a proposal where the club outline's what they are requesting from SGA, how much money they estimate to receive from other sources, and the anticipated club expenses for the academic year. The club then meets with representatives from SGA and give a presentation outlining club activities and the overall benefit the club provides the university. SGA then collectively allocates money to each organization on campus. In the 2022-2023 academic year, HPRC received $1,592.00 from SGA; $796.00 in the fall semester and $796.00 in the spring semester. For this academic year, a request of $2,000 was submitted for the fall semester and another $2,000 request will be submitted in the spring semester, assuming SGA regulations and budget remain the same.

The Educational and Technology Fee (ETF) is an NC State University fund that allocates funding for academic enhancement through student organizations. In the 2022-2023 academic year, HPRC received $3,000 from ETF and the club anticipates to receive $3,000 for this academic year. This funding will be used primarily to pay for the team's faculty advisors' travel costs.

Student travel costs will primarily be covered by NC State's College of Engineering Enhancement Funds. These funds come from a pool of money dedicated to supporting engineering extracurricular activities at NC State. Based on the 2022-2023 academic year, it is estimated HPRC will receive $8,000 this year.

In addition to funding through NC State organizations, North Carolina Space Grant is a large source of HPRC's funds. NCSG accepts funding proposals during the fall semester and teams can request up to $5,000 for participation in NASA competitions. NCSG will review the proposal and inform the club of the amount awarded. In previous academic years, this has been the maximum amount of $5,000, which will be available for use starting November 2023.

In the past, HPRC has held sponsorship's with Collins Aerospace, Jolly Logic, Fruity Chutes, and more. The team is currently seeking out new sponsorship's and reaching out to past sponsors. The team has found that companies are more likely to donate gifts in kind rather than provide monetary sponsorship. The team estimates to receive

$1,000 in gifts of kind this academic year.

These totals are listed in Table 6.28 below, which outlines the projected costs and incoming revenue for the 2023-2024 academic year.

Table 6.28: Projected Funding Sources

Organization	Fall Semester	Spring Semester	Academic Year
Educational and Technology Fee	$0	$3,000	$3,000
Engineering Enhancement Fund	$0	$8,000	$8,000
NC State Student Government	$2,000	$2,000	$4,000
North Carolina Space Grant	$5,000	$0	$5,000
Sponsorship	$500	$500	$1,000
Total Funding:			**$22,000.00**
Total Expenses:			**$21,573.81**
Difference:			**$297.13**

6.5 Project Timelines

6.5.1 Competition Timeline

Table 6.29 lists the 2024 NASA SL Competition deliverable deadlines. The deadlines in gray have already passed as of the date of submission of this report. The deadlines in green are the next set of deadlines the team will be actively working under for the next deliverable, the Flight Readiness Review (FRR).

Figure 6.2 depicts the competition timeline in a Gantt chart for easy visualization. Tasks 4, 5, 6, 7, and 8 have been completed as of the date of submittal of this report. Between this report and the next, the team will be working on tasks 9, 10, 11, and 12.

Table 6.29: NASA SL Competition Dates and Deadlines

Date/Deadline	Event/Task
14 August 2023	Request for Proposal released
11 September 2023	Proposal due at 8am CST
4 October 2023	Awarded proposals announced
5 October 2023	PDR Q&A
26 October 2023	PDR packet due at 8am CST
9 November 2023	PDR video teleconference
7 December 2023	CDR Q&A
8 January 2023	subscale flight deadline
8 January 2023	CDR packet due at 8am CST
16 January - 6 February 2023	CDR video teleconferences
8 February 2023	FRR Q&A
4 March 2023	Vehicle Demonstration Flight deadline
4 March 2023	FRR packet due at 8am CST
11-19 March 2023	FRR video conferences
1 April 2023	Payload Demonstration Flight deadline
1 April 2023	Vehicle Demonstration Flight (reflights only)
1 April 2023	FRR Addendum due at 8am CDT
1 April 2023	Launch window opens for teams not traveling to Huntsville
4 April 2023	Launch Week Q&A
10 April 2023	Arrival in Huntsville
11-12 April 2023	Launch week events
13 April 2023	Launch day
14 April 2023	Backup launch day
23 April 2023	PLAR due at 8am CDT (Huntsville attendees)
30 April 2023	Launch window closes for teams not traveling to Huntsville

TACHO LYCOS

2023-24 NASA SL Competition Gantt Chart

				Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr			
Task Name	Task Number	Start Week	End Week	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36
Proposal	1	W02	W06		1	1	1	1	1																														
PDR Q&A	2	W10	W10										2																										
PDR	3	W07	W12							3	3	3	3	3	3																								
PDR Presentation	4	W13	W13													4																							
Subscale Launch	5	W14	W14														5																						
CDR Q&A	6	W17	W17																	6																			
Backup Subscale Launch	7	W18	W18																		7																		
CDR	8	W13	W21													8	8	8	8	8	8	8	8	8															
CDR Presentation Window	9	W22	W25																						9	9	9	9											
FRR Q&A	10	W25	W25																									10											
Vehicle Demonstration Flight	11	W27	W27																											11									
FRR	12	W22	W29																						12	12	12	12	12	12	12	12							
FRR Presentation Window	13	W30	W32																														13	13	13				
Payload Demonstration Flight	14	W27	W27																											14									
FRR Addendum	15	W29	W33																													15	15	15	15	15			
Launch Week Q&A	16	W33	W33																																	16			
Huntsville Launch Week	17	W34	W34																																		17		
Competition Launch	18	W34	W34																																		18		
PLAR	19	W34	W36																																		19	19	19

Figure 6.2: SL Competition Gantt chart.

6.5.2 Development Timelines

Figure 6.3 details the development plan for the 2024 NASA SL project. As of the submittal date of this report, the team has completed tasks 1-6 and is finishing tasks 7-8. Between the submission of this report and the following report, tasks 7-14 will be completed.

Figure 6.4 details the testing schedule for all the tests planned in Sections 6.1 and 6.2. Tests 1-3 have already been completed and all of the remaining tests are planned to be completed before March.

Table 6.30 contains the build schedule for the subscale launch vehicle. All items have been completed.

Table 6.31 contains the build schedule for the full-scale launch vehicle (items in blue) and the payload (items in orange). Construction and testing for both the full-scale launch vehicle and the payload is planned to be completed prior to February 24th, 2024 for the Vehicle Demonstration Launch. The Payload Demonstration Launch is planned to occur along with the Vehicle Demonstration Flight as of the date of submittal of this report, but if that were to change due to any payload construction delays, a backup Payload Demonstration Flight has been planned for March 23rd, 2024.

Table 6.32 contains HPRC's weekly lab meeting schedule. These are all of the times the team members are in the lab actively working on deliverables together.

Table 6.33 lists the outreach events that the team has already completed (in green) and the events planned after the date of submittal of this report (in yellow) along with the estimated number of participants total and for each event.

2023-24 NASA SL Project Development Gantt Chart

Task Name	Task Number	Start Week	End Week	Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr			
				W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36
Brainstorming	1	W02	W05		1	1	1	1																															
Vehicle Design	2	W05	W08					2	2	2	2																												
Payload Design	3	W05	W16					3	3	3	3	3	3	3	3	3	3	3	3																				
Subscale Parts Ordering	4	W08	W16								4	4	4	4	4	4	4	4	4																				
Subscale Manufacturing	5	W10	W14										5	5	5	5	5																						
Subscale Launch	6	W14	W14														6																						
Payload Parts Ordering	7	W20	W21																				7	7															
Fullscale Parts Ordering	8	W20	W21																				8	8															
Fullscale Manufacturing	9	W22	W25																						9	9	9	9											
Payload Manufacturing	10	W22	W28																						10	10	10	10	10	10	10								
Fullscale Components Testing	11	W22	W26																						11	11	11	11	11										
Recovery System Testing	12	W25	W26																									12	12										
Vehicle Demonstration Flight	13	W27	W27																											13									
Payload Testing	14	W23	W26																							14	14	14	14										
Payload Demonstration Flight	15	W27	W27																											15									
Competition Launch	16	W34	W34																																		16		

Figure 6.3: SL Development Gantt chart.

2023-24 NASA SL System & Component Testing Gantt Chart

Task Name	Task Number	Start Week	End Week	Nov				Dec				Jan				Feb				Mar			
				W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20
Subscale Ejection Test	1	W02	W02		1																		
Subscale Demo Flight	2	W03	W03			2																	
Subscale SAIL Deployment Test	3	W03	W03			3																	
Rivet Shear Loading Test	4	W10	W10										4										
Shear Pin Shear Loading Test	5	W10	W10										5										
Rotor Blade Adhesion Strength Test	6	W11	W11											6									
RF Signal Test	7	W11	W11											7									
G10 Fin Durability Test	8	W11	W11											8									
Rotor & Leg Deployment Test	9	W12	W12												9								
Latch Tensile Test	10	W12	W12												10								
Landing Leg Bend Test	11	W12	W12												11								
Nose Cone Bulkhead Tensile Test	12	W13	W13													12							
AV Bay Bulkhead Tensile Test	13	W13	W13													13							
Thrust Verification Test	14	W13	W13													14							
Full-scale Ejection Test	15	W14	W14														15						
GPS Operational Test	16	W14	W14														16						
Altimeter Testing	17	W14	W14														17						
Full-scale Demo Flight	18	W15	W15															18					
Payload Demo Flight	19	W15	W15															19					
Payload Demo Flight (Backup)	20	W19	W19																			20	

Figure 6.4: SL Development Gantt chart.

Table 6.30: Subscale Build Schedule

September						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
9/17	**9/18**	**9/19**	**9/20**	**9/21**	**9/22**	**9/23**
-	CAD bulkheads (fin can, AV bay)	Wellness Day	CAD RFS centering rings and runners	Laser cut bulkheads (fin can, AV bay)	-	-
9/24	**9/25**	**9/26**	**9/27**	**9/28**	**9/29**	**9/30**
-	Bulkhead layups (fin can, AV bay)	Laser cut RFS centering rings and runners	Sand bulkheads (FRS, AV bay, fin can); RFS bulkhead layups; Cut AV bay threaded rods	-	-	-
October						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
10/1	**10/2**	**10/3**	**10/4**	**10/5**	**10/6**	**10/7**
-	Cut body tubes; Cut nose cone shoulder; Epoxy AV bay coupler and body tube	CAD nose cone bulkhead; Laser cut a wood fin for reference; Laser cut new thrust bulkhead	Thrust bulkhead layups; Prep and assemble RFS; Cut threaded rods for RFS	-	-	-
10/8	**10/9**	**10/10**	**10/11**	**10/12**	**10/13**	**10/14**
-	Fall Break	Fall Break	Epoxy runners to RFS	Laser cut nose cone bulkhead and centering ring; Weld nuts to L-brackets	-	-
10/15	**10/16**	**10/17**	**10/18**	**10/19**	**10/20**	**10/21**
-	Cut fin slots into airframe; Assess fit of nose cone permanent and removable bulkheads; Assess placement of blast caps and termminal blocks; Cut and sand motor tube to attach retaining ring	-	Drill holes for blast caps and terminal blocks; Drill holes in airframe for RFS; Nose cone bulkhead layups	-	PDR soft deadline	-
10/22	**10/23**	**10/24**	**10/25**	**10/26**	**10/27**	**10/28**
-	-	Attach T-nuts to nose cone permanent ring; Cut threaded rods for nose cone sled; Epoxy nose cone permanent ring to nose cone; Epoxy motor tube to thrust plate	PDR due Epoxy motor retaining ring to thrust bulkhead; Trace fins geometry onto fiberglass; Start cutting fins out of fiberglass	-	-	-
10/29	**10/30**	**10/31**	-	-	-	-

-	Sand and bevel fiberglass fins; Fill ridges of airframe with spackle to prepare for paint; Drill shear pin and rivet holes into airframe	-	-	-	-	-
November						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
-	-	-	**11/1**	**11/2**	**11/3**	**11/4**
-	-	-	Sand airframe to prepare for paint; Drill pressure port holes; Drill switchband hole for pull pin; Prime airframe, fins, and nose cone	-	-	-
11/5	**11/6**	**11/7**	**11/8**	**11/9**	**11/10**	**11/11**
-	Paint airframe, fins, and nose cone	-	Clear coat airframe, fins, and nose cone	-	Dry run 1	-
11/12	**11/13**	**11/14**	**11/15**	**11/16**	**11/17**	**11/18**
-	-	-	-	Ejection testing	Dry run 2; Packing for launch day	Launch day

Table 6.31: Full-scale & Payload Build Schedule

January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1/7	**1/8**	**1/9**	**1/10**	**1/11**	**1/12**	**1/13**
-	CDR Due Laser cut bulkheads (fin can, AV bay); Bulkhead layups (fin can , AV bay)	-	Order all components; Print all 3D parts; Cut bulkheads	Laser cut RFS bulkheads and runners; Sand bulkheads (fin can, AV bay); Cut AV bay threaded rods; Attach hardware to bulkheads (fin can, AV bay)	Cut G12 fiberglass tubes to design lengths	-
1/14	**1/15**	**1/16**	**1/17**	**1/18**	**1/19**	**1/20**
-	Sand RFS blukheads and runners; Bulkhead layups (RFS); Sand edges of fiberglass tubes; Epoxy AV switchband in place	Structural testing at 3pm	Rotor blade fabrication (CF layup); Bulkhead fabrication for deployment bay; Solder SAIL electronics breadboard	Laser cut thrust bulkhead and one fin; Sand bulkhead (RFS); Epoxy runners in place; Epoxy fin can bulkhead to DP bay/fin can	Water jet aluminum thrust plate	-
1/21	**1/22**	**1/23**	**1/24**	**1/25**	**1/26**	**1/27**
-	Bulkhead layups (thrust bulkhead); Trace fins onto sheet of G10 fiberglass; Attach blast caps and terminal blocks to AV bay bulkheads	Laser cut nose cone centering ring and removable bulkhead	Weld nuts to L-brackets for RFS; Cut all parts (legs, body tube, hubs); Assemble gear box; Test electronics function (motor, ESC); Rotor blade adhesion test	Sand thrust bulkhead; Bulkhead layups (nose cone centering ring, removable bulkhead)	-	RF signal test
1/28	**1/29**	**1/30**	**1/31**	-	-	-
-	Cut threaded rods for RFS; Sand bulkheads (nose cone centering ring, removable bulkhead); Attach hardware to nose cone centering ring and removable bulkhead	-	Assemble landing legs; Final assembly; Test rotor and leg deployment time; Latch tensile test; Landing leg bend test	-	-	-
February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
-	-	-	-	**2/1**	**2/2**	**2/3**

-	-	-	-	Epoxy nose cone centering ring inside nose cone; Begin cutting G10 fiberglass fins; Attach motor retainer to thrust bulkhead with included hardware; Add all hardware to RFS	-	-
2/4	**2/5**	**2/6**	**2/7**	**2/8**	**2/9**	**2/10**
-	Finish cutting and bevel G10 fiberglass fins; Cut threaded rods for nose cone; Drill holes for shear pins and rivets into airframe; Drill holes for AV bay switchband; Drill screw holes for RFS into airframe	-	Thrust verification test	Begin priming airframe	-	-
2/11	**2/12**	**2/13**	**2/14**	**2/15**	**2/16**	**2/17**
-	Finish priming airframe; Sand primer	-	Payload drop/deployment test with ARC	Ejection testing	-	-
2/18	**2/19**	**2/20**	**2/21**	**2/22**	**2/23**	**2/24**
-	-	-	-	-	Dry run and packing	**Vehicle Demonstration Flight**

Table 6.32: HPRC Spring Semester Lab Meeting Times

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Launch Day (Select Weekends)	**SL Vehicle Meeting** (6-7pm)	**Experimental Meeting** (6:30-8pm)	**SL Payload Meeting** (6-7:30pm)	**SL Integration Meeting** (3-5:30pm); **Safety Meeting** (5:30-6pm); **SL Vehicle Meeting** (6-7pm); **General Body Meetings** (7:30-8:30pm)	**Experimental Meeting** (11am-12:30pm)	**Launch Day** (Select Weekends)

Table 6.33: Outreach Events and Estimated Participants

Event Name	Date	Estimated Participants
Brentwood Elementary	October 17th, 2023	84
Christina Koch Bottle Rockets	October 24th, 2023	50
Fred Old's Elementary	October 27th, 2023	45
Joyner Science Go Rounds	November 8th, 2023	83
Apex Friendship High School	December 5th, 2023	70
Lacy Elementary STEM Night	January 25th, 2024	150
Astronomy Days	February 3rd-4th, 2024	500
Washington Elementary Math and Science Night	March 7th, 2024	80
	TOTAL:	1062

References

[1] 106 Series Stainless Steel REX™ Shaft (8mm Diameter, 264mm Length). URL: https://www.gobilda.com/2106-series-stainless-steel-rex-shaft-8mm-diameter-264mm-length/.

[2] 1120 Series U-Channel (1 Hole, 48mm Length). URL: https://www.gobilda.com/1120-series-u-channel-1-hole-48mm-length/.

[3] 1121 Series Low-Side U-Channel (2 Hole, 72mm Length). URL: https://www.gobilda.com/1121-series-low-side-u-channel-2-hole-72mm-length/.

[4] 1309 Series Sonic Hub (6mm Bore). URL: https://www.google.com/url?q=https://www.gobilda.com/1309-series-sonic-hub-6mm-bore/&sa=D&source=editors&ust=1704593405469053&usg=AOvVaw2vAXjFwSatXtsox4EeTBiu.

[5] 1309 Series Sonic Hub (8mm REX™ Bore). URL: https://www.gobilda.com/1309-series-sonic-hub-8mm-rex-bore/.

[6] 1611 Series Flanged Ball Bearing (8mm REX™ ID x 14mm OD, 5mm Thickness). URL: https://www.gobilda.com/1611-series-flanged-ball-bearing-8mm-rex-id-x-14mm-od-5mm-thickness-2-pack/.

[7] 2:1 Ratio Bevel Gear Set (8mm REX™ Bore Pinion Gear). URL: https://www.gobilda.com/2-1-ratio-bevel-gear-set-8mm-rex-bore-pinion-gear/.

[8] 2106 Series Stainless Steel REX™ Shaft (8mm Diameter, 24mm Length). URL: https://www.gobilda.com/2106-series-stainless-steel-rex-shaft-8mm-diameter-24mm-length/.

[9] 32mm Bore 2-Side, 2-Post Pillow Block (43mm Width). URL: https://www.gobilda.com/32mm-bore-2-side-2-post-pillow-block-43mm-width/.

[10] 4103 Series goTUBE (43mm Length). URL: https://www.gobilda.com/4103-series-gotube-43mm-length/.

[11] 516 Series 8mm REX Standoff (M4 x 0.7mm Threads, 48mm Length). URL: https://www.gobilda.com/1516-series-8mm-rex-standoff-m4-x-0-7mm-threads-48mm-length-4-pack/.

[12] 8mm REX™ Bore 2-Side, 1-Post Pillow Block (43mm Width). URL: https://www.gobilda.com/8mm-rex-bore-2-side-1-post-pillow-block-43mm-width/.

[13] A technique for the calculation of the opening-shock forces for several types of solid cloth parachutes. URL: https://doi.org/10.2514/6.1973-477.

[14] Adafruit 9-DOF Absolute Orientation IMU Fusion Breakout - BNO055. URL: https://www.adafruit.com/product/2472.

[15] Adafruit Feather M0 Adalogger. URL: https://www.adafruit.com/product/2796.

[16] Aeropak 75mm Retainer (Flanged). URL: https://www.apogeerockets.com/Building_Supplies/Motor_Retainers_Hooks/Screw-On_Retainers/75mm_AeroPack_Retainer_Flanged.

[17] AeroTech L1940X. URL: https://www.thrustcurve.org/motors/AeroTech/L1940X/.

[18] McDaniel et al. Tacho Lycos 2024 NASA Student Launch Preliminary Design Review. 2024. URL: https://ncsurocketry.org/reports-2023-2024/.

[19] Arduino Nano Every. URL: https://store.arduino.cc/products/arduino-nano-every.

[20] Barrowman Equations. URL: https://www.rocketmime.com/rockets/Barrowman.html.

[21] Blue Tube. URL: https://alwaysreadyrocketry.com/product/1-15-29mm-x-062-wall-x-48-airframe-mmt/.

[22] BRB900 GPS Telemetry System. URL: http://old.bigredbee.com/docs/BLGPS/brb_lcd6.pdf.

[23] Cobra Motor USA. URL: https://www.cobramotorsusa.com/esc-150amp.html.

[24] Digi XBee-PRO XSC. URL: https://www.digi.com/products/embedded-systems/digi-xbee/rf-modules/sub-1-ghz-rf-modules/xbee-pro-xsc.

[25] Eggtime Quasar FAQ's. URL: https://eggtimerrocketry.com/quasar/.

[26] External Retaining Ring for 3 mm OD, Black-Phosphate 1060-1090 Spring Steel. URL: https://www.mcmaster.com/98541A111/.

[27] FAA AC No. 91-57A. URL: https://www.faa.gov/documenTLibrary/media/Advisory_Circular/AC_91-57A_Ch_1.pdf.

[28] Gikfun Solder-able Breadboard. URL: https://www.amazon.com/Gikfun-Solder-able-Breadboard-Plated-Arduino/dp/B071R3BFNL/ref=sr_1_5?crid=TSAE17CAJQF7&keywords=solder-able+breadboard+with+power+rail&qid=1704384050&sprefix=solder-able+breadboard+with+power+rail%2Caps%2C70&sr=8-5.

[29] High Torque Servo. URL: https://hitecrcd.com/products/servos/digital/coreless/hs-7950th/product.

[30] HRB 4S Lipo Battery XT60. URL: https://www.amazon.com/HRB-Connector-Multirotors-Hexacopter-Octacopters/dp/B07HQRMWW2/ref=sr_1_50?crid=25NHX6M7AJVT2&keywords=4s+lipo+battery&qid=1701360706&sprefix=4s+lipo+battery+%2Caps%2C91&sr=8-50.

[31] Mini Spy Camera with Trigger for Photo or Video. URL: https://www.adafruit.com/product/3202.

[32] MPL3115A2 - I2C Barometric Pressure/Altitude/Temperature Sensor. URL: https://www.adafruit.com/product/1893?gad_source=1.

[33] Pull Pin Switch Kit. URL: https://www.labratrocketry.com/product-page/pull-pin-switch-kit.

[34] Release Buck Converter. URL: https://www.addicore.com/products/lm2596-step-down-adjustable-dc-dc-switching-buck-converter.

[35] Release Li-Po Image. URL: https://hobbykoo.com/produit/zeee-batterie-lipo-7-4v-1500mah-50c-wltoys/.

[36] Rocket Equations. URL: https://www.rocketmime.com/rockets/rckt_eqn.html.

[37] RocketPy's User Guide. Version 1.0.1. URL: https://docs.rocketpy.org/en/latest/user/index.html.

[38] RRC3 Altimeter System. URL: https://www.missileworks.com/rrc3.

[39] Scorpion HKIV-4035. URL: https://www.scorpionsystem.com/catalog/helicopter/motors_4/hkiv-40/HKIV_4035_330/.

[40] Scorpion HKIV-4035. URL: https://www.scorpionsystem.com/files/i3,477_full_dimension.pdf.

[41] Southco Latch. URL: https://southco.com/en_us_int/r4-05-22-505-10.

[42] SparkFun XBee Explorer USB. URL: https://www.sparkfun.com/products/11812.

[43] Spring Hinge Self-Closing, Steel, 1-1/4" x 3/8" Door Leaf. URL: https://www.mcmaster.com/15205A32/.

[44] Spring Hinge with Holes, Self-Opening, 304 Stainless Steel, 2" x 1/2" Door Leaf. URL: https://www.mcmaster.com/15205A83/.

[45] StratoLoggerCF Altimeter. URL: http://www.perfectflite.com/SLCF.html.

[46] Unidirectional Carbon Fabric (4.0 oz). URL: https://www.fibreglast.com/product/Unidirectional_Carbon_Fabric_40_oz_2585.

[47] XBee Pro S3B. URL: https://www.mouser.com/new/digi-international/digi-xbee-pro-xsc-s3-s3b-modules/.

[48] XTend 900 1W RPSMA - 40 Mile Range. URL: https://www.sparkfun.com/products/retired/9411.