NC STATE UNIVERSITY

Tacho Lycos

2025 NASA Student Launch

Preliminary Design Review

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

October 28, 2024

Common Abbreviations and Nomenclature

ADC	= Analog to Digital Converter
AGL	= Above Ground Level
AIOC	= Ham Radio All-in-one Cable
APCP	= Ammonium Perchlorate Composite Propellant
APRS	= Automatic Packet Reporting System
ARR	= Always Ready Rocketry
AV	= Avionics
AVAB	= Avionics and Air Brakes Bay
CAD	= Computer Aided Design
CATO	= Catastrophe At Take Off
CDR	= Critical Design Review
CG	= Center of Gravity
CNC	= Computer Numerical Control
CP	= Center of Pressure
CT	= Central Time
ECE	= Electrical and Computer Engineering
E Council	= Engineering Council
ETF	= Educational and Technology Fee
EYE	= Engineer Your own Experience
FAA	= Federal Aviation Administration
FM	= Frequency Modulation
FMEA	= Failure Modes and Effects Analysis
FRR	= Flight Readiness Review
FSM	= Finite State Machine
GPS	= Global Positioning System
HPRC	= High-Powered Rocketry Club
IMU	= Inertial Measurement Unit
IPL	= Inverted Pursuits Lab
LED	= Light-Emitting Diode
LiPo	= Lithium Polymer
LRR	= Lab Rat Rocketry
LRR	= Launch Readiness Review
LV	= Launch Vehicle
MAE	= Mechanical & Aerospace Engineering
MSFC	= Marshall Space Flight Center
N/A	= Not Applicable
NACA	= National Advisory Committee for Aeronautics
NAR	= National Association of Rocketry
NASA	= National Aeronautics and Space Administration
NCSG	= North Carolina Space Grant
NCSU	= North Carolina State University
PCB	= Printed Circuit Board
PDF	= Payload Demonstration Flight
PDR	= Preliminary Design Review
PETG	= Polyethylene Terephthalate Glycol
PH	= Performance Hobbies
PID	= Proportional-Integral-Derivative
PLA	= Polylactic Acid
PLAR	= Post-Launch Assessment Review
PPE	= Personal Protective Equipment
Q&A	= Questions and Answers
RMFS	= Removable Modular Fin System

RMS	= Removable Motor System
RTC	= Real Time Clock
RSO	= Range Safety Officer
SAIL	= STEMnaut Atmosphere Independent Lander
SDS	= Safety Data Sheets
SGA	= NC State Student Government
SGov	= Student Government
SL	= Student Launch
SPI	= Serial Peripheral Interface
SST	= Shear Stress Transport
STEM	= Science, Technology, Engineering, and Mathematics
STEMCRaFT	= STEMnaut Capsule Radio Frequency Transmitter
STL	= Stereolithography (File Format)
TAP	= Technical Advisory Panel (TRA)
TBD	= To Be Determined
TNC	= Terminal Node Controllers
TRA	= Tripoli Rocketry Association
TTS	= Text to Speech (TRA)
UART	= Universal Asynchronous Receiver/Transmitter
USLI	= University Student Launch Initiative
VDF	= Vehicle Demonstration Flight
VV&T	= Vehicle Verification and Testing

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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: Katelyn Yount, kvyount@ncsu.edu, (980) 258 - 2628

1.1.2 Team Mentor and Advisor

Name	Title	Email	Phone	TRA Certification	Flyer #
Jim Livingston	Mentor	livingston@ec.rr.com	(910)612-5858	Level 3	02204
Felix Ewere	Faculty Advisor	feewere@ncsu.edu	(919)515-8381	N/A	N/A

1.1.3 Competition Launch Plans

NC State University intends to launch in Huntsville, Alabama during launch week as the team's competition flight.

1.1.4 Time Spent on PDR Milestone

Approximately 1052 hours were spent on the PDR milestone between all members responsible for the project.

1.1.5 Social Media Accounts

Website	Instagram	Facebook	X	LinkedIn	Tiktok	Youtube
ncsurocketry.org	@ncsurocketry	/TachoLycos	@NCSURocketry	/tacholycos	@ncsurocketry	@tacholycos2206

1.2 Launch Vehicle Summary

1.2.1 Motor Selection

The primary motor choice is the AeroTech L1520T. The secondary motor choice is the AeroTech L1390G.

1.2.2 Official Target Altitude

The target apogee for the vehicle is 4800 ft. above ground level.

1.2.3 Vehicle Size and Mass

The leading launch vehicle design is 91.75 in. long, 6.17 in. in diameter, and has an overall mass of 35.78 lbs.

1.2.4 Recovery System

The leading recovery design is a dual deploy system with a Perfect Flite StratologgerCF primary altimeter, an Altus Metrum EasyMini secondary altimeter, and an Eggfinder Mini GPS tracker. A Fruity Chutes 18" Elliptical classic drogue parachute deploys at apogee and a Fruity Chutes Iris Ultra 96" compact main parachute deploys at 550 ft.

1.3 Payload Summary

The STEMCRaFT will record data for all 8 data points listed in NASA Requirement 4.2.1. The data will be recorded throughout the flight and processed upon landing. Using the APRS transmission method, the data will be encoded and transmitted on a specified frequency of the 2 meter band provided by NASA.

The launch vehicle will include Air Brakes that deploy after motor burnout, increasing the drag of the launch vehicle in a calculated manner to reduce it's predicted apogee to match the target apogee.

2 Changes Made Since Proposal

2.1 Changes Made to Vehicle Criteria

Table 2.1: Changes Made to Vehicle Criteria Since Proposal Submission.

Change Description	Justification	Affected Subsystem
Main Parachute Bay section length reduced from 30 in. to 24 in.	Reduction of excess volume and structural mass.	Structures
Motor retention changed from a commercial Aero Pack retainer to a custom made aluminum retainer plate.	Low cost retention system that will simplify thrust bulkhead fabrication and reduce part count.	Structures
Fin Can / Drogue Parachute Bay length reduced from 37 in. to 36 in.	Reduction of excess volume and structural mass.	Structures
Fin attachment method changed from 3D printed fin brackets to a through-wall aluminum runner system.	Improved structural interface between fins and airframe. More reliable aerodynamic simulations.	Aerodynamics, Structures
Fin geometry changed from trapezoidal to swept geometry.	Improved vehicle aerodynamics.	Aerodynamics, Structures
Fin thickness increased from 1/8 in. to 3/16 in.	Improved fin rigidity and strength.	Structures

2.2 Changes Made to Payload Criteria

Table 2.2: Changes Made to Payload

Change Description	Justification	Affected Subsystem(s)
The Air Brakes center gear ratio is set to 1:1 to maintain torque for deploying fins.	A 1:1 gear ratio allows for a balance between speed and torque, ensuring sufficient force is available to deploy the Air Brakes reliably without overloading the motor system.	Payload Structures
The payload will not be jettisoned due to the inclusion of Air Brakes and the limitation of not having more than two payloads.	The inclusion of Air Brakes necessitates that the payload remain onboard to meet NASA requirements. Incorporating more than two payloads would exceed the space and weight limitations.	Payload Systems, Structures
All eight data types will be transmitted.	The transmission of all data types will provide comprehensive flight information and maximize scoring.	Payload Electronics, Payload Systems
An XBee Pro S3B Transceiver will be used for remote override.	The XBee Pro S3B Transceiver provides remote override capabilities, offering an additional layer redundancy for stopping transmission.	Payload Systems, Payload Electronics

2.3 Changes Made to Project Plan

Table 2.3: Changes Made to Project Plan Since Proposal Submission.

Change Description	Justification	Affected Subsystem
Added structures subsystem build schedule for subscale and full-scale launch vehicles.	To ensure completion of the subscale and full-scale launch vehicles before CDR and FRR addendum.	Structures Subsystem
Added recovery subsystem deveopment schedule.	To ensure completion of a successful recovery system for subscale and full-scale launches.	Recovery Subsystem
Added aerodynamics development schedule.	To ensure completion of the rocket design, successful altitude prediction, and appropiate motor selection before competition milestones.	Aerodynamics Subsystem
Added payload development schedule, inclusive of experimental Air Brakes payload.	To ensure completion of a successful competition payload system and experimental payload system before the PDF milestone.	Payload Subsystem
Added project management development schedule.	To ensure the team completes all milestones and competition requirements.	Project Management Subsystem
Added backup subscale launch.	To ensure completion of the subscale launch before the CDR milestone.	Structures Subsystem, Project Management Subsystem
Changed subscale launch to two launches in the same day	To gather more Air Brakes data for accurate coefficient of drag.	All Subsystems
Added team derived requirements for project design and development.	As per Requirements Verification Section in NASA SL Handbook.	Integration Subsystem, Project Management Subsystem
Scheduled PDR presentation for November 8th at 12pm EST.	As per requirement in NASA SL Handbook.	All Subsystems
Started STEM Gateway registration.	To ensure all members are registered by the NASA deadline.	Project Management Subsystem
Added subscale painting schedule.	To ensure completion of the subscale paint design by the launch deadline.	All Subsystems
Added full-scale painting schedule.	To ensure completion of the full-scale paint design by the launch deadline.	All Subsystems
Extended time for subscale component testing.	To account for testing of the launch vehicle and recovery system.	Recovery Subsystem
Extended time for subscale manufacturing.	To account for construction of avionics bay and redesign of the RMFS.	Recovery Subsystem
Extended recovery system testing.	To account for design of avionics bay.	Recovery Subsystem

3 Vehicle Criteria

3.1 Launch Vehicle Mission Statement and Success Criteria

The launch vehicle's primary mission is to deliver the payload to the declared apogee and return it to the ground safely. A secondary objective of the launch vehicle is to carry the Air Brakes payload to improve accuracy in reaching the declared apogee. The overall design intent of the launch vehicle is to enable successful execution of the payload mission while being safe, reliable, and reusable. Criteria used to determine the level of mission success are listed in Table 3.1 below.

Table 3.1: Vehicle Success Criteria

Success Level	Vehicle Criteria
Success	· Nominal powered flight and coast phase · Nominal separation and deployment of recovery gear at intended altitudes · Launch vehicle achieves within 200 ft. of declared apogee · Launch vehicle lands within allotted time and recovery area. · No structural or electrical damage to Launch vehicle or payload · All sections of launch vehicle are recovered successfully · Launch vehicle can be relaunched the same day
Partial Success	· Nominal powered flight and coast phase · Nominal separation and deployment of recovery gear at intended altitudes · Launch vehicle achieves apogee within 4,000-6000 ft. · Launch vehicle sustains minor damage upon landing, is able to be repaired and re-flown in the same-day
Partial Failure	· Nominal powered flight and coast phase · Launch vehicle fails to achieve apogee within 4,000-6000 ft. · Partial deployment of recovery gear, recovery gear is tangled · Launch vehicle or payload sustains damage that prevents same-day re-flight. · Launch vehicle lands outside of recovery area or in a manner that precludes successful recovery (tree, water, power line, etc.)
Failure	· Launch vehicle fails to exit launch rail · Motor CATO · Premature separation during powered flight or coast phase · Launch hehicle fails to exceed 3,500 ft. altitude · Non-separation during recovery events · Any other mishap resulting in significant damage or total loss of Launch Vehicle or primary payload

3.2 Alternative Launch Vehicle Designs

3.2.1 Launch Vehicle Section Configurations

In addition to the motor and structural components, the launch vehicle must accommodate the primary payload, the secondary Air Brakes payload, the recovery system electronics, and the drogue and main recovery hardware. There are a variety of ways to effectively allocate space within the launch vehicle for these components. However, based on NASA and Senior Design Team requirements, the following configurations were considered.

Separate AV and Air Brakes Sections

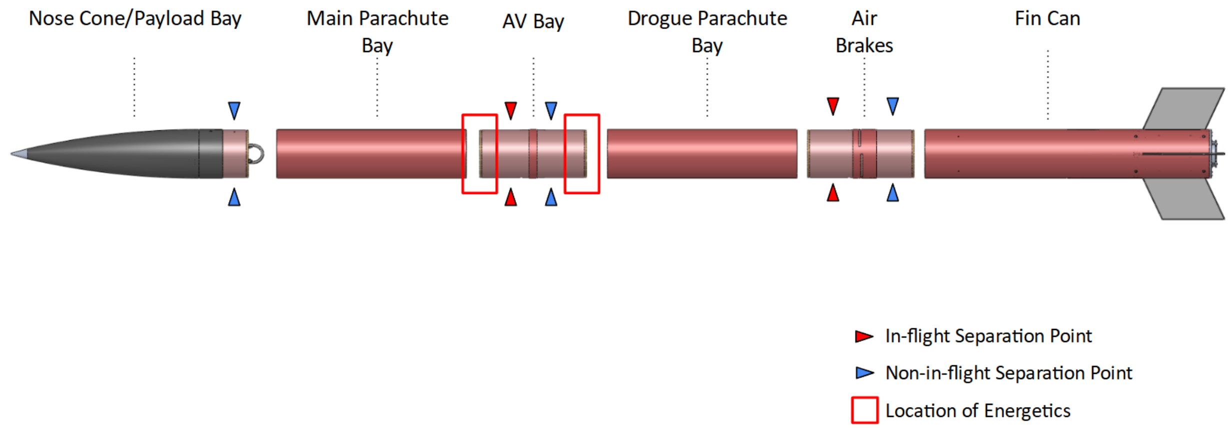


Figure 3.1: Separate AV and Air Brakes section concept.

A potential launch vehicle configuration is to use individual sections as bays for the primary payload, launch vehicle avionics, and the secondary Air Brakes payload. The primary payload would be positioned within the Nose Cone. The Main Parachute Bay would connect aft of the Nose Cone at an in-flight separation point. The AV bay for recovery electronics would connect aft of the Main Bay and would be followed by the Drogue Parachute Bay. The Air Brakes payload would be housed in another separate payload bay between the Drogue Parachute Bay and the Fin Can. This configuration would be easily feasible to manufacture, and has been used by previous Senior Design Teams [41]. However, this configuration increases overall vehicle length and requires additional structural mass in the form of airframe, coupler, bulkheads, and other components.

Air Brakes Integrated Into Fin Can

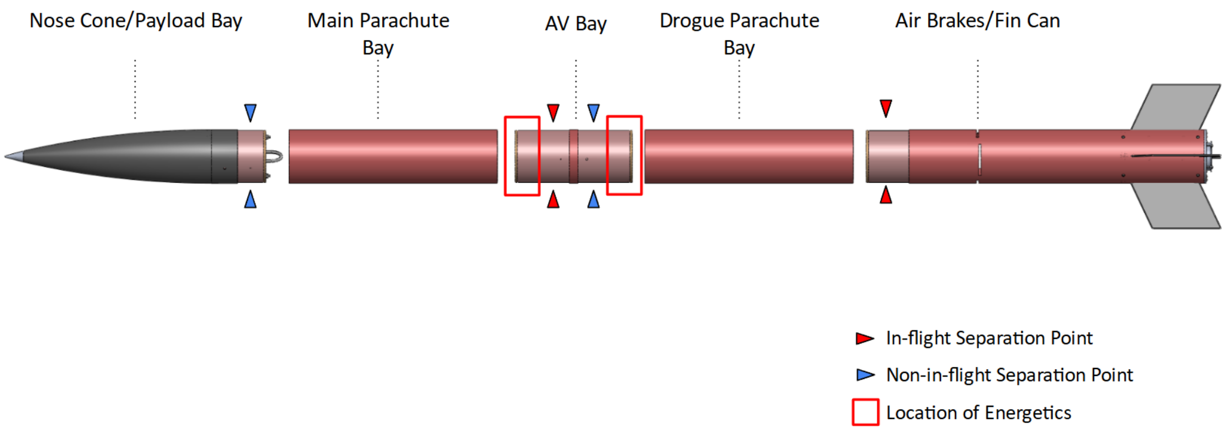


Figure 3.2: Air Brakes in Fin Can section concept.

A second configuration option is to maintain a separate section for the AV bay and to integrate the Air Brakes payload within the Fin Can. This would position the Air Brakes module well-aft of burnout CG, which satisfies NASA Requirement 2.15. This design also presents a number of technical challenges. Due to the design of the Air Brakes mechanism, slots for the drag fins must be cut through the airframe to allow the drag fins to extend into the airflow. These slots remove enough material to substantially weaken the airframe structure through a single-walled section such as the Fin Can. An internal coupler sleeve would be needed to reinforce the airframe strength. Additionally the Air Brakes mechanism requires at least two bulkheads to mount threaded rods which leads to potential access issues if a permanent bulkhead within the Fin Can was utilized. While feasible to fabricate, the technical challenges incurred make maintaining the Air Brakes payload within a separate section of the launch vehicle a more favorable option.

4 in. Diameter Airframe

The Senior Design Team briefly explored using a 4 in. diameter airframe for the full-scale launch vehicle. This option would be more cost effective and efficient from a launch vehicle sizing standpoint, however posed many technical challenges for integrating vehicle subsystems. Another concern was being able to scale down our experimental Air Brakes payload to fit into a 3 in. diameter subscale. While this is not a NASA requirement, the Senior Design Team placed a high priority on being able to fly a functional Air Brakes system as many times as possible prior to the competition flight. Ultimately, the team used a decision matrix to assess that a 6 in. diameter rocket was the better overall choice to meet NASA requirements and team goals.

Multi-Use Sections

The final and leading launch vehicle configuration maintains the primary payload within the Nose Cone and combines the AV and Air Brakes bays into a single section, the 'AVAB'. Furthermore, the forward portion of the Fin Can is able to serve as the Drogue Parachute Bay. The AVAB section is internally partitioned into the forward AV Bay and the aft Air Brakes Bay, with a sufficiently large switchband overlapping the two internal sections. This configuration allows for housing the AV and Air Brakes within a single coupler section. This configuration is highly feasible from a fabrication standpoint, and minimizes the total number of launch vehicle sections. Additionally, the Senior Design Team has successfully implemented this design on a separate launch vehicle of comparable size and performance. This configuration is further discussed in Section 3.3.

3.2.2 Airframe Material Selection

The airframe is the largest structural component of the launch vehicle and is subjected to substantial loading from thrust and aerodynamic forces. It must safely house the payloads and all launch vehicle subsystems, except for the fins. Because of this, sufficiently strong, lightweight, and resilient materials must be selected to satisfy the launch vehicle requirements. The following materials were assessed as potential airframe body tube and coupler material.

Blue Tube

Blue Tube 2.0™ is a spiral wound, high-density paper fiber tubing proprietary to Always Ready Rocketry, LLC [11]. It is specifically marketed for use as a high-power rocketry airframe material. It has more than sufficient compressive strength for use in the launch vehicle, and also is the lightest and least expensive of the materials considered. Additionally, it is easy to cut and does not create material hazards during fabrication. The primary disadvantage of this material is its vulnerability to water damage, which is a significant recovery hazard at our home launch field. An additional downside is potential material deformation around fastener holes from repeated use of shear pins. Both of these properties negatively affect the overall reusability of this material. It would be feasible to devise methods to make the tubes more resistant to water and shear loading, however, this would increase airframe fabrication complexity, workload, and cost. For these reasons it is disqualified for use on the full-scale launch vehicle.

Carbon Fiber

Carbon fiber resin composite tubing is the strongest, most durable, and most expensive of the airframe materials considered. Apart from cost, another significant downside of using the material is the hazards created during component fabrication. Debris generated during material removal poses significant inhalation, irritant, and abrasion hazards. These hazards can be mitigated through use of PPE and airborne debris management via ventilated booths. One major feasibility concern is the Senior Design team's limited access to a sufficiently large wet saw to cut the required diameters of carbon fiber tubing with the necessary precision. The dedicated carbon fiber cutting saw in the NC State Aerospace Design Lab is located in a small ventilated booth and is only intended for cutting smaller cross sections of carbon fiber tubing.

G12 Fiberglass

G12 fiberglass tubing is a composite material consisting of an epoxy resin matrix reinforced by 12 layers of wound glass fiber. Like carbon fiber composite, it is high strength while also being impact and water resistant. It is not as strong or lightweight as carbon fiber, yet it is much less expensive. Manufacturing airframe components out of G12 fiberglass poses similar hazards as carbon fiber, however are mitigated through similar protective measures. The feasibility of using G12 for airframe material has been long established. G12 fiberglass tubes commercially manufactured for high powered rocketry have been successfully used by multiple previous Senior Design Teams [41] [42]. This experience, combined with the satisfactory material properties and cost, makes G12 fiberglass composite the leading choice of airframe material.

3.2.3 Bulkhead Material Selection

Aviation Grade Plywood

Aviation or aircraft grade plywood and is high quality plywood manufactured to stringent standards. Previous Senior Design Teams have fabricated bulkheads using multiple plies of 1/8 in. aviation grade birch plywood adhered with epoxy in a layup process [41] [42]. Fabricating bulkheads using this material, however, has proven to be labor intensive. Additional costs are also incurred from consumables used during the many required layup processes such as nitrile gloves, peel-ply, and plastic vacuum bagging material. Furthermore, due to the thickness of each ply, many plies are required to make sufficiently thick bulkheads. Thicker sheets of the material are expensive and would still require multiple plies to achieve the desired bulkhead thickness.

Baltic Birch Plywood

Baltic Birch plywood is not as high grade as aviation grade plywood, however, is higher quality than standard construction grade plywood. It is made of solid birch plies without filler material or a softer wood core. Notably, it is void free which is highly desirable for ensuring consistent material strength. Some key benefits of Baltic Birch plywood are that it is much less expensive than aviation grade plywood and comes in much thicker sheets. By using this material, the bulkhead fabrication process will be greatly streamlined. Bulkheads can be precision milled directly from sheets of the desired final thickness using a ShopBot CNC router and only require light sanding to achieve final fit. This fabrication method is highly feasible and has been successfully tested by the Senior Design Team. For these reasons, Baltic Birch is the leading material choice for the manufacturing of the Nose Cone/Payload Bay and AVAB bulkheads.

6061-T6 Aluminum

6061-T6 aluminum alloy is a lightweight metal extensively used for aerospace applications. It is easily machined, provides greater strength and durability than wooden material, and can be threaded to directly accept removable fasteners. The T6 temper designation indicates a heat treating process which hardens the metal to provide the highest yield strength (35 ksi) out of the 6061 series of aluminum alloys. Previous Senior Design Teams have used a 6061-T6 aluminum plate in part of the thrust bulkhead to evenly distribute the thrust forces from the motor to the airframe [41] [42]. The current Senior Design Team intends to expand on this practice, using 6061-T6 aluminum to fabricate the rear thrust plate, forward centering ring, and the fin runners on the Removable Modular Fin System. This will enhance the strength and rigidity of the aft end of the Fin Can, where the maximum compressive forces will occur on the vehicle. Furthermore, this will improve the modularity of the system. The feasibility of using this material has already been successfully explored by the Senior Design Team via fabrication of similar components.

3.2.4 Nose Cone

Nose cones are used to reduce drag over the front of the vehicle in flight. Nose cones provide smooth contours to redirect the flow over the body of the vehicle. This reduces the dynamic pressure experienced by the launch vehicle. Commercially available nose cones have predetermined geometries that are optimized for drag reduction, such as an ogive profile. Team experience with ogive nose cones reduced selection options to two profiles; a 4:1 ogive or a 5:1 ogive.

4:1 Ogive

Ogive nose cones are defined by the ratio, length to diameter. A 4:1 ogive nose cone, for example, is four times as long as it's diameter. The nose cones are made from G12 fiberglass and feature a screw-on aluminum tip. Part of the consideration for this nose cone is that there is space for ballast and payload electronics to fit inside of it. The 4:1 nose cone also allows the overall vehicle length to be shorter, as well as reduces weight.

5:1 Ogive

The 5:1 ogive is a longer version of the 4:1 ogive nose cone. The choice to use the 4:1 as opposed to the 5:1 depends on the need for space. There is no need for the extra space a 5:1 ogive nose cone offers, and the length and weight is not desired.

Feasibility Evaluation

The use of the 4:1 Ogive is feasible because payload electronics can comfortably fit inside of the space provided, with room for ballast. This is shown in further detail as a part of the Payload Retention System Section (Section 4.5.4)y. Figure 4.27 pictures the payload inside of the 4:1 Ogive nose cone.

3.2.5 Nose Cone Bulkhead Retention

The decision to house the primary payload within the Nose Cone necessitates a removable bulkhead closure to install and remove the payload from the Nose Cone. Two main options were considered to accomplish this.

Central Rod

The fiberglass Nose Cone selected for the leading launch vehicle design features an anodized aluminum tip with a 1/4 in. threaded hole into the interior face. Typically, this is used along with a large washer and fastener to secure the aluminum tip to the fiberglass body of the Nose Cone. It is feasible to use a long 1/4 in. diameter threaded rod in lieu of the fastener, running the interior length of the Nose Cone and extending past the end of the Nose Cone. A removable bulkhead with a central hole would slide over the aft end of the rod and sit flush against the lip of the Nose Cone coupler section. This assembly would then be secured with a hex nut on the threaded rod.

This method would require the least amount of effort for fabrication, yet has a number of drawbacks. The rod creates a single point of failure for retention of the payload and Nose Cone assembly. The central placement of the rod means that the payload the system must be arranged around the rod, which could create issues accommodating larger components. Additionally, the payload system would need additional retention to prevent free rotation about the rod axis. Furthermore, the presence of a large metallic rod near the payload transmission antenna could create interference with the broadcast signal and hinder a primary payload function. For these reasons, an alternate design was considered.

Permanent Mounting Ring

For this system, the Nose Cone is enclosed on the aft end using a removable bulkhead. This closure is secured using a pair of 1/4 in. threaded rods that connect to an internal mounting ring made of 0.5 in. thick Baltic Birch plywood. This ring sits flush atop the forward edge of the coupler section. The bulkhead and Nose Cone coupler are both epoxied in place using West System 105 Epoxy Resin with West System 206 Slow Hardener curing agent. Additionally, the diameter of the mounting ring is larger than that of the coupler section. This leads to redundant structural connections; the epoxy bond between the ring and interior Nose Cone wall, the ring face and forward coupler lip, and the epoxy bond between the coupler and Nose Cone interior wall. The threaded rods are slightly offset from the Nose Cone wall and screw into threaded tee nut inserts pressed and epoxied into the forward face of the mounting ring.

A similar configuration has been successfully used in multiple previous vehicle designs and does not require complex fabrication [41] [42]. It provides ample structural support for mounting the payload system and accommodates larger payload component sizes. Additionally, it increases the internal volume which can be dedicated to the payload compared to other systems.

3.2.6 Fin Material Selection

Plywood / Sandwich Composite

Both all-plywood and plywood sandwich composite fins have been utilized by past Senior Design Teams for fin material. Sufficiently strong fins made solely of plywood must be thick to not risk breaking or cracking upon hard landings. Fins made using a sandwich composite can be lightweight, however have proven to be less durable than stronger composite materials such as G10 fiberglass. Additionally, sandwich composite fins require an involved fabrication process consisting of a composite layup followed by additional epoxy sealing of the fin edges, then final shaping. This process is feasible, however has proven to require more work and results in a less resilient fin structure than using other composites.

G10 Fiberglass

G10 fiberglass is manufactured as smooth, flat sheets which facilitates its use and popularity as a high-powered rocket fin material. It is heavier than plywood based materials, however the added durability is a worthwhile trade off to improve reusability. Additionally, fabrication is straightforward; the fin shape can be traced onto the material then cut out with an appropriate carbide bladed saw or rotary tool and sanded to the final dimensions. G10 fiberglass poses the same fabrication hazards as previously discussed G12 fiberglass tubing, therefore the same risk mitigation controls must be applied.

Recent and current Senior Design Teams have used G10 fiberglass fins with great success. The previous Senior Design Team incorporated tapered-swept 1/8 in. thick fins with beveled edges on the previous NASA SL launch vehicle [42]. The current Senior Design Team has conducted repeated, destructive structural testing of a 1/8 in. thick fin with geometry similar to the leading design. Testing consisted of repeated ground impacts of a fin mounted to a simulated Fin Can with 75 lbf-ft of impact energy. The highest impulse collision occurred during a simulated low-likelihood impact scenario where the fin planform area impacted at an oblique angle onto the edge of a cinder block. The fin suffered only light cosmetic scratches at the point of impact, shown in Figure 3.4. The leading launch vehicle design has fins extending beyond the end of the airframe, therefore the Senior Design Team will use 3/16 in. thick G10 fiberglass for even further stiffness and durability.

Figure 3.3: Example of fin system ground impact testing.

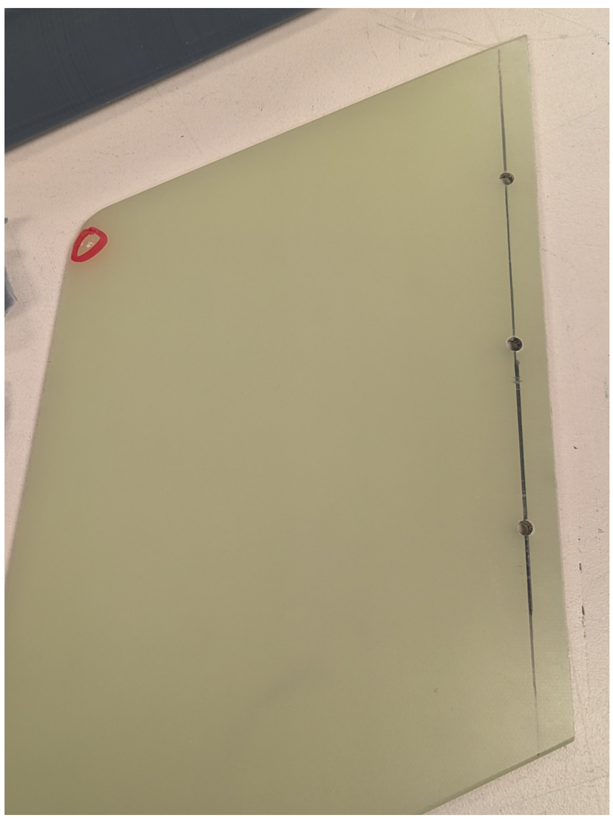


Figure 3.4: Slight cosmetic damage to G10 fiberglass fin after hard surface impact.

3.2.7 Fin Design

Fins have been designed with stability control and drag reduction in mind. The fins are able to shift stability by bringing the aerodynamic center of the vehicle aft of the center of gravity. Two main types of fins were considered, symmetric and swept fins. In accordance with Team-Derived requirement LVD.6, the four fins are identical and spaced evenly around the vehicle.

Symmetric Fins

The symmetric fin design is considered due to ease of fabrication and analysis. The design is mirrored across the center line, meaning it is bidirectional. Additionally, the center of pressure of the fin is easily determined. This fin is made of 3/16 in. thick G10 fiberglass and has a root chord of 8 in. with a tip chord of about 4.25 in. An aerodynamic simulation was conducted at 600 fps using the SST K- ω model in ANSYS Fluent. The velocity profile is shown below. This simulation also yielded a drag value of 1.92 lbf.

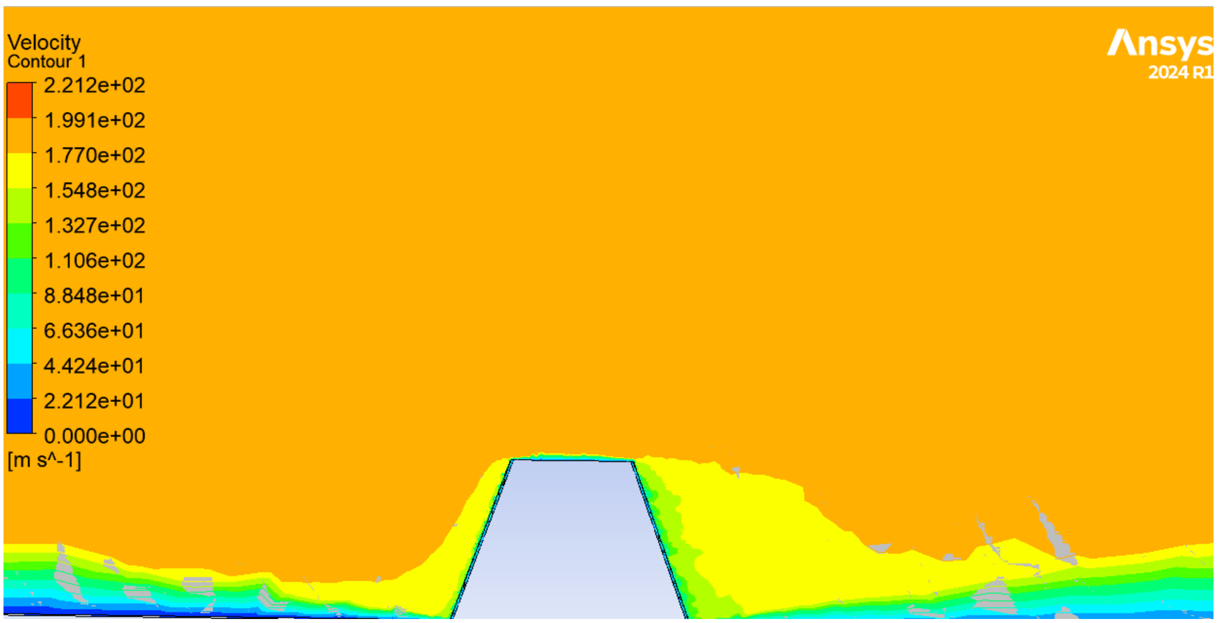


Figure 3.5: Velocity Profile of Symmetric Fin at 600 fps

Swept Fins

Swept fin designs are also considered for use on the launch vehicle. Swept fins generally lead to reduced drag. This is due to pressure distribution differences along the fins. There is generally a reduction in pressure along the leading edge of a swept fin. Additionally, pressure on the trailing edge is able to counteract the forces generated by the leading edge pressure, reducing drag. Two swept fin designs were created for analysis. Both are made from 3/16 in. thick G10 fiberglass and have a 8 in. root chord.

The first design, shown in Figure 3.6, featured a slanted tip chord. This appears to slightly round off the velocity losses on the aft end of the fin and reduce losses along the tip chord. Unfortunately, this design was not compatible with RASAero II and RocketPy, two of the three simulation suites, so it was not chosen. Therefore, a the second design was created as an iteration of the first. This maintained similar geometry, but with a flat tip chord that has the same length as the root chord. It can be seen in Figure 3.7 that the velocity losses are very similar to the slanted fin design. This design also shows significantly less losses when compared to the symmetric fin. When simulated at 600 fps, the drag calculated was 1.585 lbf, which is a 19% reduction in drag.

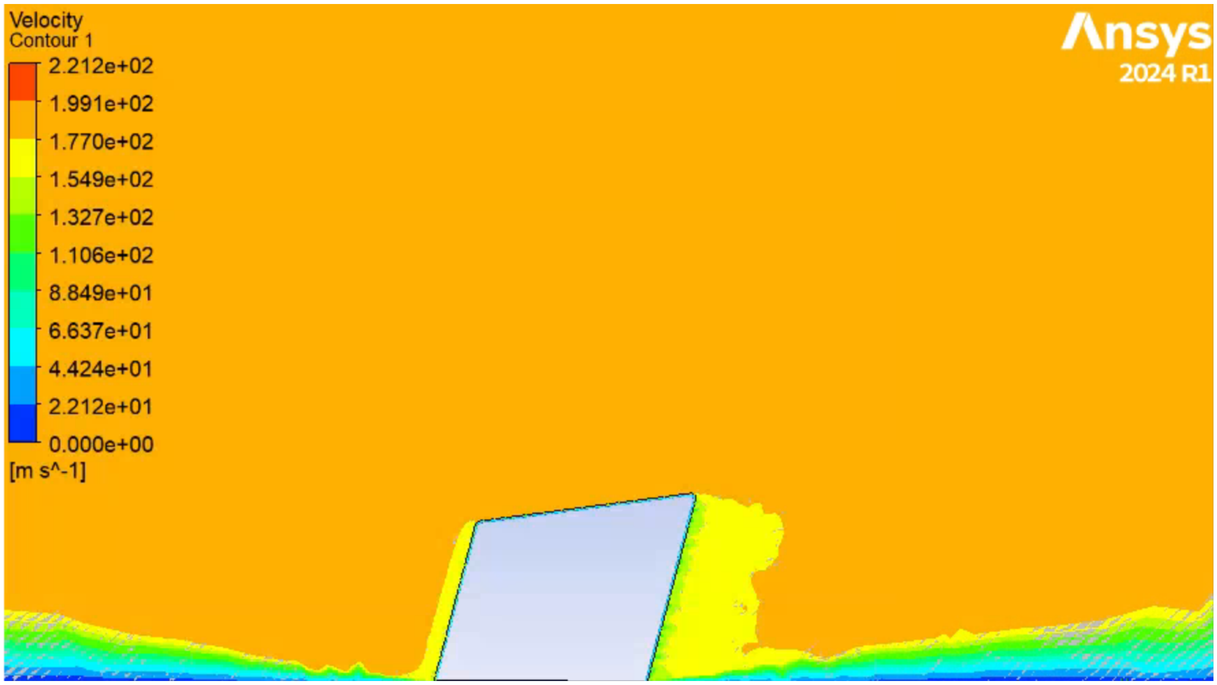


Figure 3.6: Velocity Profile of Swept Fin with Slanted Tip Chord at 600 fps

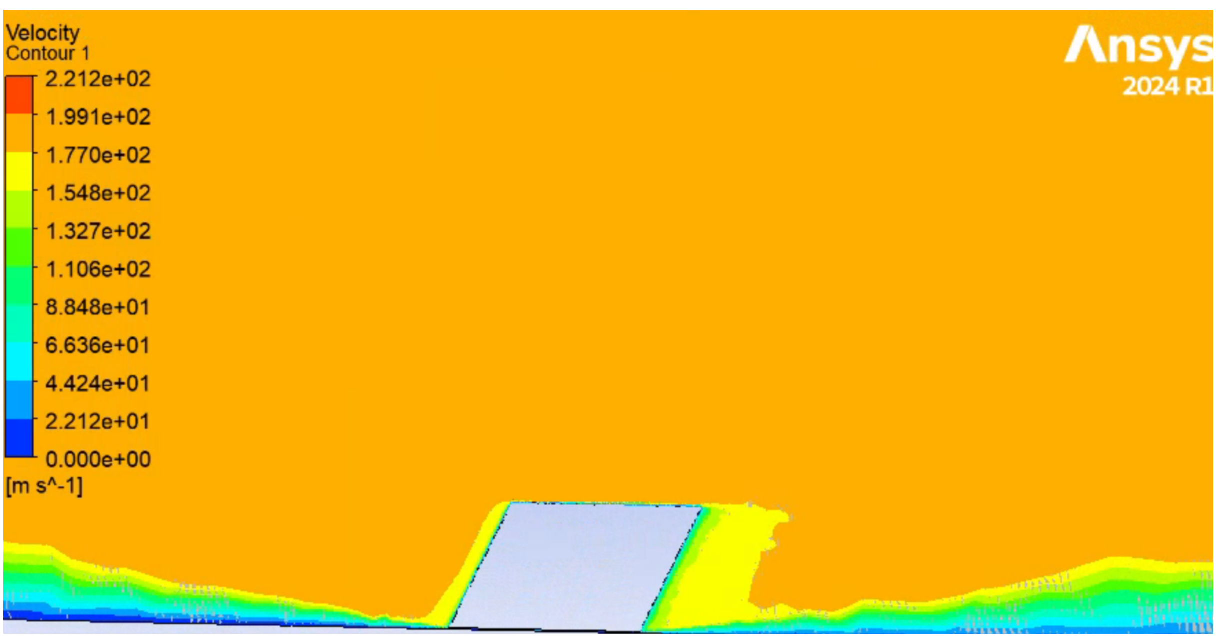


Figure 3.7: Velocity Profile of Swept Fin with Flat Tip Chord at 600 fps

Due to the reduction in velocity losses and drag, the second swept fin, shown in Figure 3.7, was selected as the fin design for the launch vehicle.

3.2.8 Fin Can Design

Fixed Fin Design

In a fixed-fin design, the fins are permanently bonded to the vehicle body via epoxy or other adhesives. This is typically done in a through-wall configuration where fin tabs extend through slots in the airframe to sit flush against a motor mount tube. Centering rings bracket the leading and trailing edge of the tabs, and all joints between the fins and other components can be reinforced with adhesive. Performed properly, this method results in a very strong and secure Fin Can assembly. The main drawback to this design is the lack of reusability in the event of damage to the Fin Can. Repair, replacement, or modification of components can become an involved and time consuming process. As reusability is a driving design criteria for the launch vehicle, a fixed-fin design should not be used.

Removable Fin Design

A removable fin design incorporates modular components in a system where the fins, centering rings, and motor mount can be easily removed from the launch vehicle. This is highly beneficial in the event of a broken fin, a design modification to the fins, or the use of removable ballast. It is a feasible and proven design implemented by previous Senior Design Teams [41] [42]. It requires slightly more fabrication work than a fixed fin design, however the potential labor and time savings in the event of a mishap are worth the trade off. For these reasons, a removable fin system design is the leading design choice.

3.2.9 Tail Cone Consideration

Tail Cone

Tail cones are used in vehicle design as a way to reduce the drag of the vehicle. This is done by adding a smooth contour on the end of the vehicle. Use of a tail cone is dependent upon design needs and drag concerns.

Flat Base

The launch vehicle utilizes a flat base as opposed to a tail cone for multiple reasons. First, drag savings at this level are not a design concern. Since the vehicle is utilizing Air Brakes to intentionally increase drag, the tail cone reductions would be counter-productive. Second, tail cones and their contours are difficult to manufacture. Overall, a tail cone is unnecessary for the design, which is why it is not utilized.

3.2.10 Motor Alternatives

Three motors are being considered for use in the launch vehicle. All motors are of the L class, and will reach an apogee between 4000 ft and 6000 ft, satisfying NASA Vehicle Requirements 2.1 and 2.12. AeroTech motors are exclusively considered due to positive team experience with the motors and their commercial availability. The three motors under consideration are the L1520T, the L1390G, and the L850W. More specific motor information can be found in the table below.

Table 3.2: Leading Motors for 2025 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)
L1520T	0.1270	0.2501	835.16	352.45	396.85	2.4	RMS-75/3840	20.39
L1390G	0.1351	0.2657	887.77	313.48	376.55	2.6	RMS-75/3840	20.86
L850W	0.1435	0.2564	819.69	191.09	419.54	4.4	RMS-75/3840	20.91

When deciding on a motor selection, the main factors under consideration are the altitude to which the motor can propel the vehicle, the thrust profile of the vehicle, and the time it takes for the motor to burn out. The first consideration is apogee range. A graph of each motor's altitude curve is shown below as Figure 3.8.

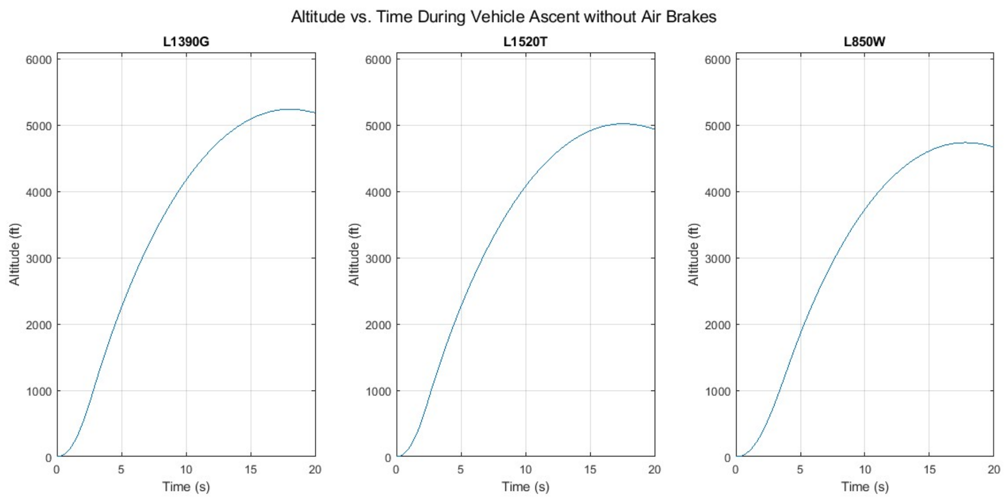


Figure 3.8: Altitude Curves for Motor Options

This graph shows that the L1390G has the highest apogee at around 5200 ft, the L1520T has the median altitude at around 5000 ft, and the L850W has the lowest altitude at around 4700 ft. These provide a range of options that could adjust as the mass of the rocket changes. Additionally, if the descent time is too high, it provides a lower altitude option. However, given the target apogee with Air Brakes of 4800 ft., the L1520T is the best choice in this category.

Next, the thrust profile and burnout time is considered. A steady thrust curve is better for accurate simulations and a shorter burn time is better for Air Brakes, because they will have more time to deploy during coast. A comparison of the thrust curves is shown below in Figure 3.9.

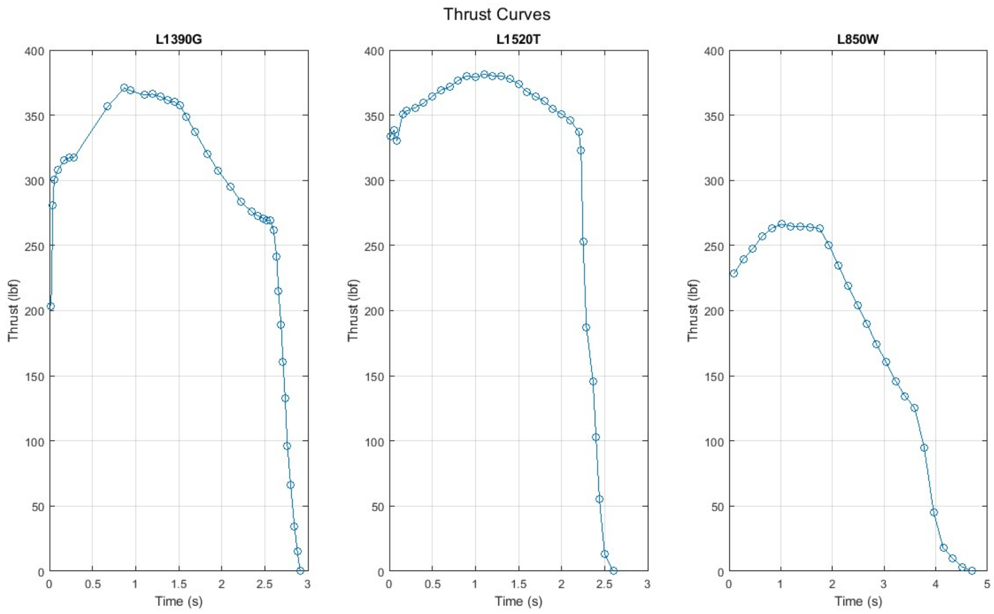


Figure 3.9: Thrust Curves for Motor Options

The graph shows that the L1520T has the most steady thrust curve and the lowest burn time. The L1390G is the least steady, but it has the second lowest burn time. The L850W has the longest burn time. Overall, these factors discussed indicate that the L1520T is the best motor for the vehicle parameters.

3.3 Leading Launch Vehicle Design

3.3.1 Launch Vehicle Overview

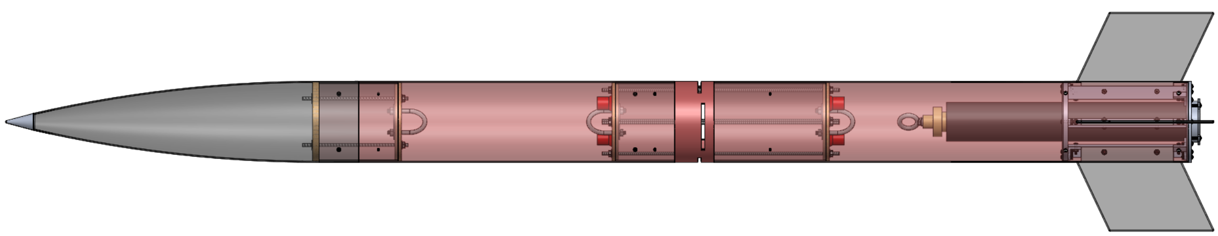


Figure 3.10: Launch vehicle internal structural view, including AeroTech RMS-75/3840 motor casing.

The leading launch vehicle design consists of four sections: the Nose Cone/Payload Bay, the Main Parachute Bay, the AVAB module, and the Drogue Parachute Bay/Fin Can. The launch vehicle overall length is 91.75 in. and the maximum airframe diameter is 6.17 in., resulting in an aspect ratio of 15:1. The fully integrated mass is estimated to be 35.78 lbs., with the AeroTech L1520T motor in an RMS-75/3840 casing. This launch vehicle section configuration was chosen to maximize the utility of each section, while keeping the required number of vehicle sections to a minimum.

3.3.2 Separation Points and Location of Energetics

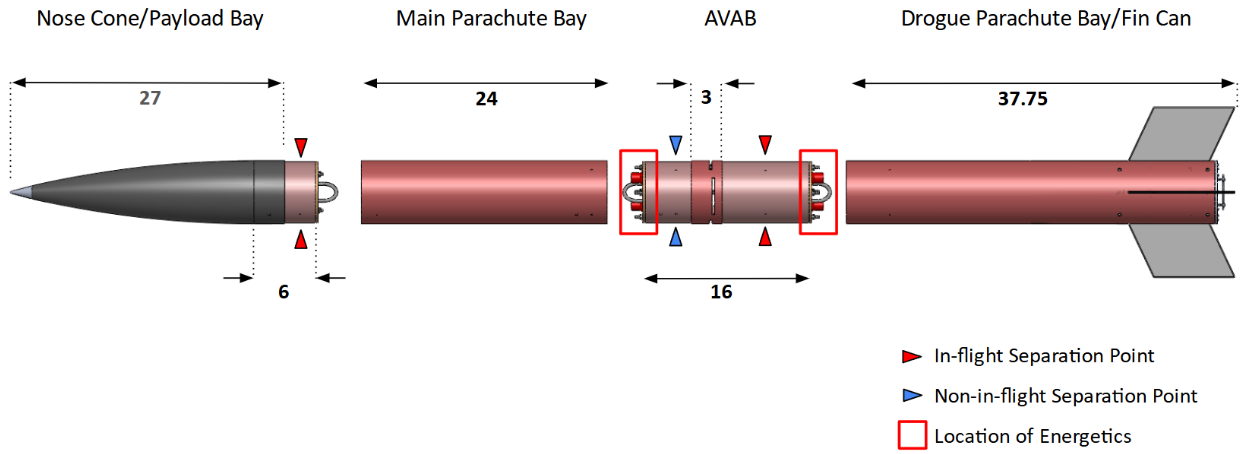


Figure 3.11: Launch vehicle section separation points and energetics location [in.]

The launch vehicle features two in-flight separation points; One between the Nose Cone/Payload Bay and the Main Bay, with the second between the AVAB and the Drogue Bay/Fin Can. During flight, these connections are secured with #4-40 nylon shear pins. A non-in-flight separation point exists between the aft section of the Main Parachute Bay and forward section of the AVAB, and is secured in flight with nylon push rivets. Energetics for separation and recovery system deployment are contained on the forward and aft AVAB bulkheads, as indicated in Figure 3.11 above. All launch vehicle sections are tethered together during recovery which is discussed further in Section 3.4.8. This configuration eliminates the necessity for having a separate tracking system for fully independent vehicle sections during recovery.

3.3.3 Airframe Material Selection

G12 fiberglass composite tubing will be used to fabricate the airframe and coupler sections as justified in Section 3.2.2. Permanent epoxy bonded connections between airframe and coupler sections will occur in two locations: the Nose Cone/Payload Bay coupler within the Nose Cone, and the AVAB switchband around the AVAB coupler tube. All airframe and coupler connections will satisfy NASA Requirement 2.4 for minimum coupler length between airframe sections.

To confirm suitability of G12 fiberglass tubing for airframe and coupler fabrication, preliminary analysis of the stresses induced on the launch vehicle airframe during flight was conducted.

Preliminary Force Analysis

When accelerating under thrust, a rocket body will experience an inertial force opposite the thrust vector. This force is a product of the vehicle mass and acceleration (Equation 1) and can be considered as a distributed load that runs along the longitudinal axis of the launch vehicle; the loading increases as the contributing mass increases. It follows that the maximum inertial loading will be experienced at the interface between the vehicle body and the thrust force. In the most simple case, when the vehicle is at a 0° angle of attack, this force results in pure compression of the airframe.

$$F_i = ma \qquad (1)$$

In atmospheric flight, aerodynamic drag adds additional loading to the vehicle opposite the velocity vector. Drag force is determined by fluid density, velocity, drag coefficient, and reference area, as shown in Equation 2.

$$F_D = \frac{1}{2}\rho v^2 C_D A \qquad (2)$$

By summing these loads, the total force of compression on the vehicle body can be determined, as in Equation 3.

$$F_C = F_i + F_D \tag{3}$$

Table 3.3: Force Calculation Variables.

Variable	Name	Value	Source
ρ	Air Density	0.00238 $slug/ft^3$	Standard Atmosphere at Sea Level
v	Maximum Velocity	653 fps	OpenRocket Simulation
A	Reference Area	0.208 ft^2	Calculated
C_D	Drag Coefficient	0.53	Aerodynamics Simulations
T_{max}	Peak Thrust Force	396.86 lbf	Motor Data Sheet

Finite element analysis using the inertial relief technique was conducted to determine material stresses under this linear compressive loading. First, drag force was calculated using the values in Table 3.3 and Equation 2, and determined to be approximately 55.9 lbf. Next, the sum of the drag force and peak motor thrust (Equation 3), 452.8 lbf., was applied to the aft circumference of the airframe at the thrust bulkhead interface. Figure 3.12 is the resulting equivalent stress contour along the airframe. A maximum stress of 848 psi. was located at the fastener holes near the aft end of the airframe (Figure 3.13). Lesser stress concentrations were noted on the AVAB switchband around the air brake slots (Figure 3.14). Given reported maximum compressive strength of over 25 ksi and maximum tensile strength of 17 ksi for G12 fiberglass [14][22], an approximate factor of safety of 20 was obtained.

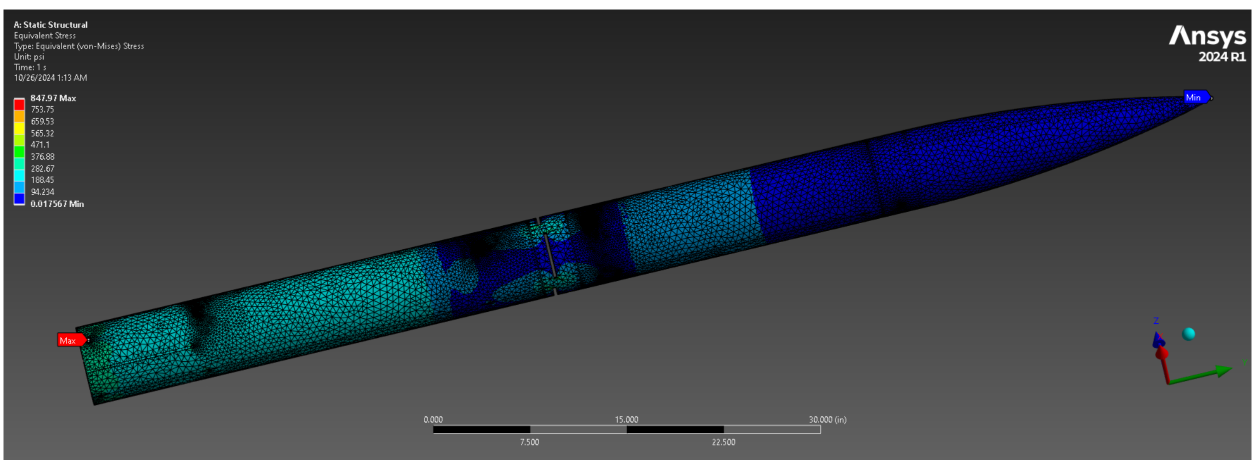


Figure 3.12: Launch vehicle airframe equivalent stress contour at peak thrust.

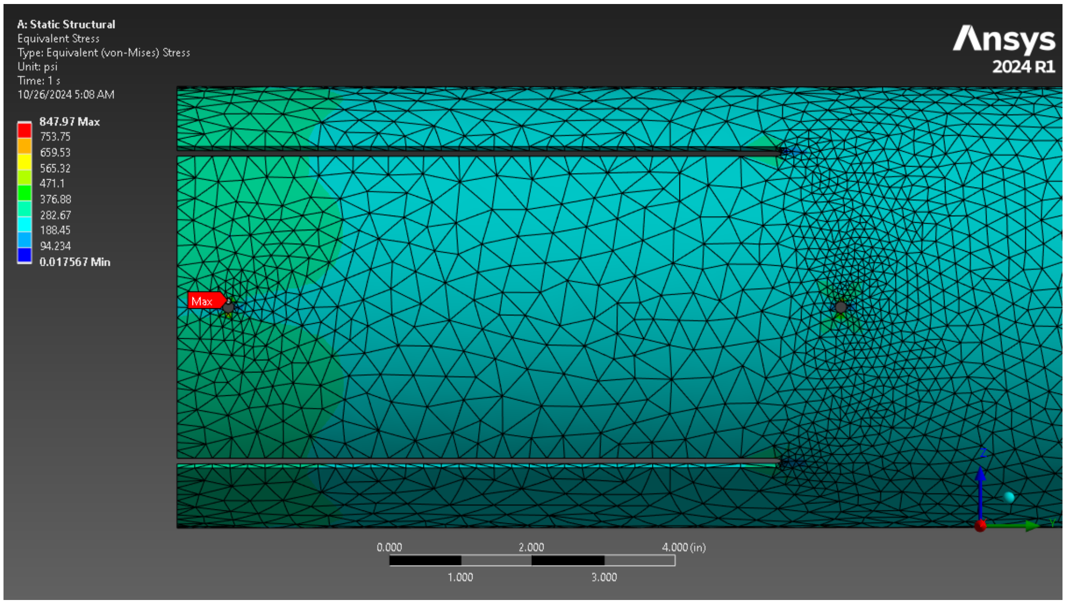


Figure 3.13: Fin Can stress contour detail.

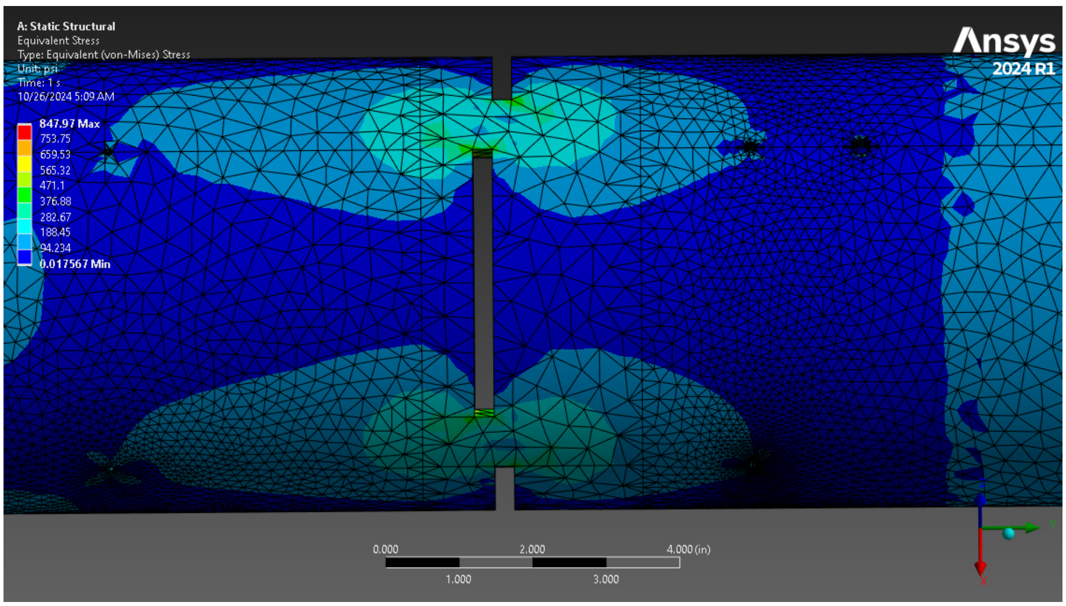


Figure 3.14: Switchband stress contour detail.

3.3.4 Nose Cone/Payload Bay

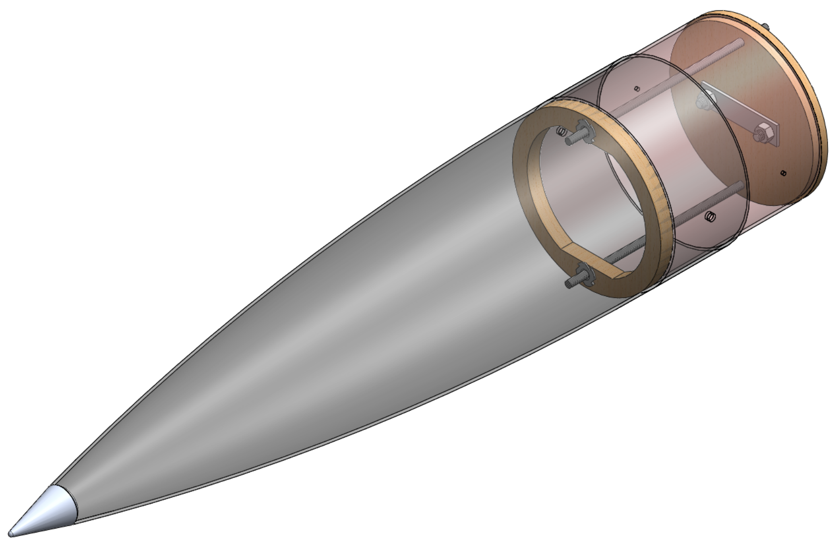


Figure 3.15: Nose Cone/Payload Bay assembly.

The Nose Cone/Payload Bay will be fabricated from a commercially available 4:1 tangent ogive G12 fiberglass nose cone with an anodized aluminum tip. This shape provides adequate balance between aerodynamics and interior volume for the primary payload. G12 fiberglass is RF transparent, which is a critical material property required for successful payload operation. The Nose Cone/Payload bay exterior is 27 in. long, with the forward 24 in. following a tangent ogive shape profile. The last 3 in. of the Nose Cone are a straight profile tangent to the end of the curve, which allows for a straight coupler section to be secured into the Nose Cone. The coupler section will be a 6 in. length of G12 fiberglass coupler material and will be epoxied 3 in. into the Nose Cone, along with a permanent ring mounting bulkhead, as described in Section 3.3.5. The exposed coupler section will form a 3 in. long shoulder extending from the Nose Cone, this will interface with the Main Payload Bay as an in-flight separation point, secured by #4-40 nylon shear pins. A removable bulkhead will form the aft closure of the Nose Cone/Payload Bay, and will be secured via two 1/4 in. threaded rods connecting to the permanent ring bulkhead.

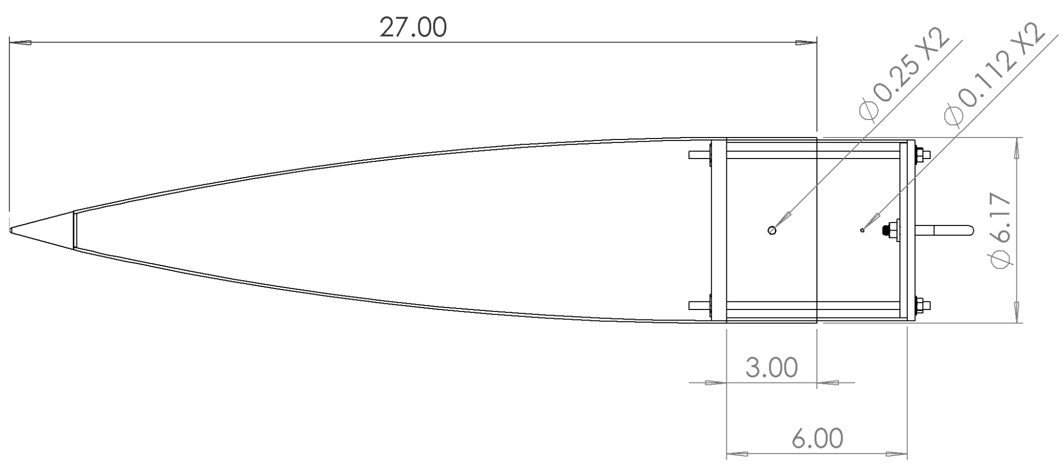


Figure 3.16: Nose Cone/Payload Bay assembly dimensions [in.]

Forward Ballast System

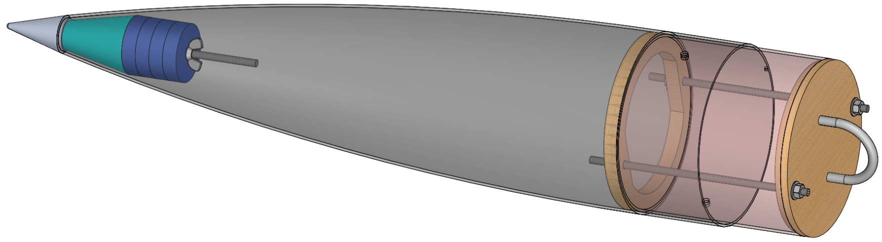


Figure 3.17: Forward ballast system concept.

The launch vehicle's stability is determined by the relative positions of the center of mass and center of pressure. The easiest method to adjust the stability is to shift the center of mass via the addition of ballast. Based on the current leading launch vehicle design, the Senior Design Team assesses that forward ballast may be required to tune stability margins. To minimize the mass of ballast required, it should be mounted as far forward on the vehicle as possible. A method to accomplish this is to use the threaded hole on the back of the aluminum Nose Cone tip. This configuration keeps ballast as far forward as possible from the payload. A threaded rod is fastened into the hole, and a ballast plug made of 3D-printed material or solid epoxy resin would sit flush against the retaining washer on the back side of the aluminum tip. Aft of the plug, rounds of sliced, solid epoxy resin are stacked and retained on the rod via a thumb-screw. For demonstration purposes only, the ballast configuration depicted in Figure 3.17 represents approximately 0.5 lbs. of added mass. For actual implementation of the system, various dimensions of the rounds would be sized to specific mass increments. The overall ballast mass would be adjusted via combinations of these individual rounds. The impact of specific ballast masses on mission performance is discussed in Section 3.6.6. For material, epoxy resin is a good choice as it is non-metallic and has a density of 0.043 lb/in^3 [43] which is greater than that of most wood. Furthermore, is it not granular like sand which would require more thorough containment.

3.3.5 Nose Cone/Payload Bay Bulkheads

The Nose Cone/Payload Bay features two bulkheads: a permanent ring mounting bulkhead and a removable aft bulkhead. Both bulkheads will be milled from a 0.5 in. thick sheet of Baltic Birch plywood. The ring mounting bulkhead will be situated forward of the Nose Cone coupler section and will be epoxied in place along with the coupler section as described in Section 3.3.4. Steel tee nut inserts will be pressed and epoxied into the forward face of the mounting ring to provide a connection point for two 0.25 in. threaded rods. These rods will run through and retain the solid removable bulkhead at the aft closure. The removable bulkhead will have a U-bolt for anchoring the Main Parachute recovery gear to the section.

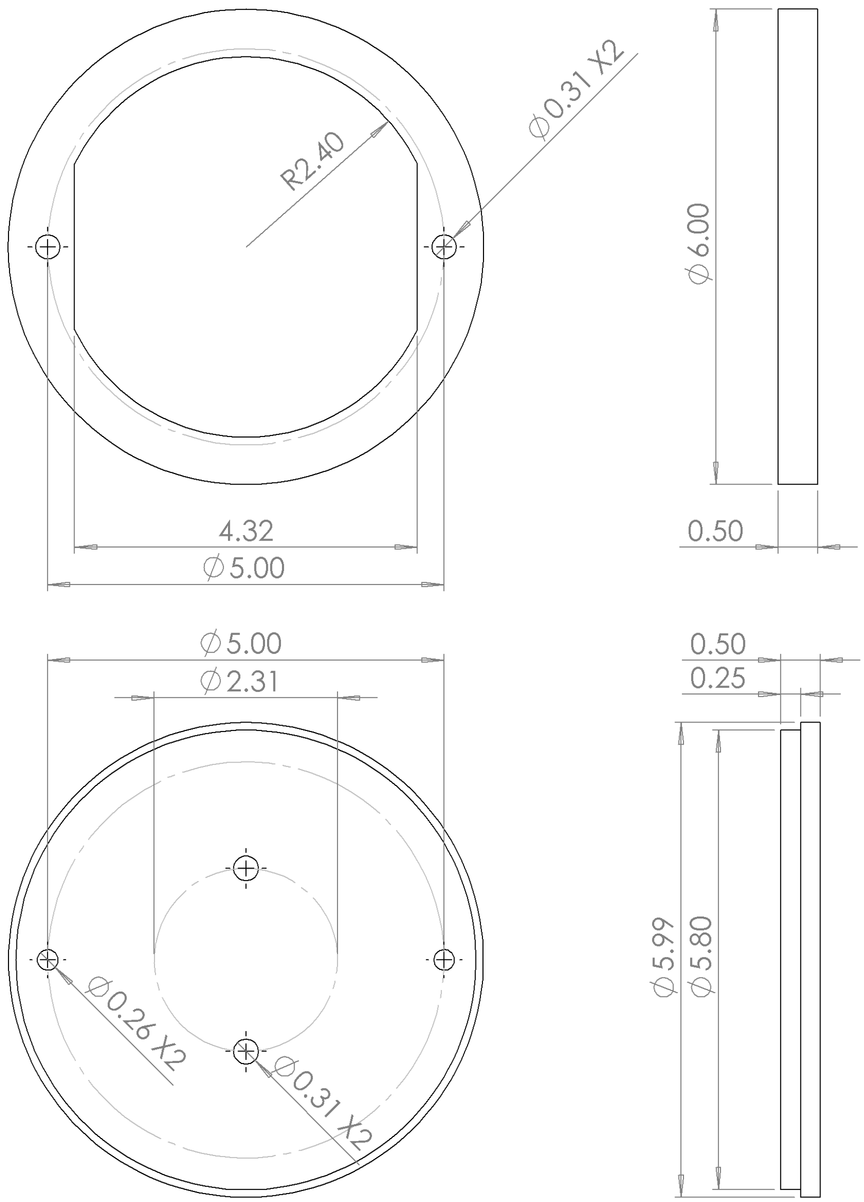


Figure 3.18: Nose Cone permanent ring bulkhead (top) and removable bulkhead (bottom) dimensions[in.]

Preliminary Force Analysis

The Nose Cone bulkheads and threaded rods form the structural connection securing the primary payload to the Nose Cone/Payload bay during flight. This system must withstand the shock force of Main Parachute deployment, calculated to be approximately 273 lbf. in Section 3.4.7. To ensure sufficient strength of this system, stresses from this loading were modeled using finite element analysis. Figures 3.19 and 3.20 predict that the system is sufficiently strong, with a minimum factor of safety of 1.76 noted at the interface between the threaded rod and removable bulkhead. This value exceeds the team derived requirements yet warrants further testing and validation.

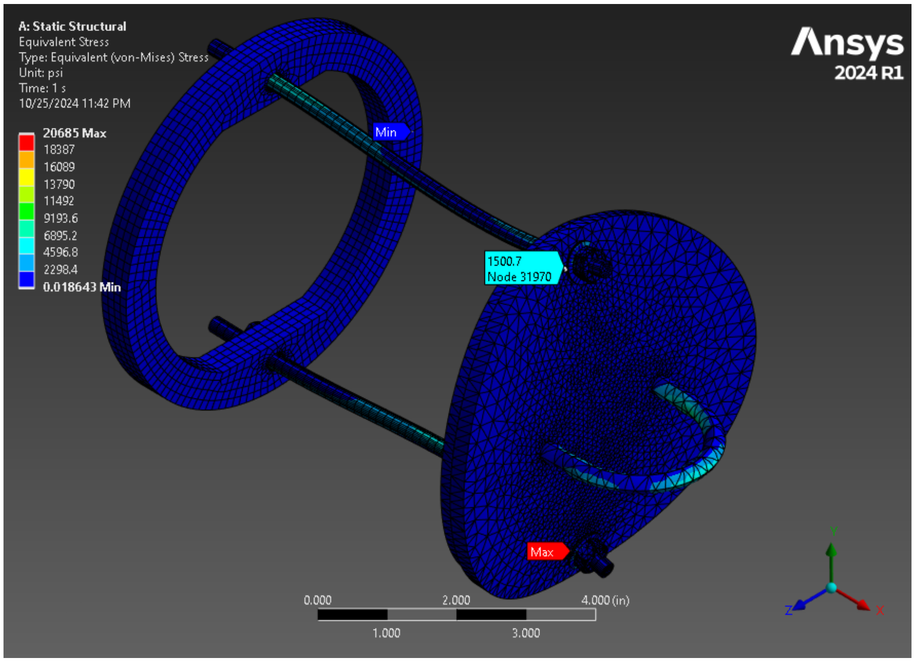


Figure 3.19: Nose Cone/Payload Bay bulkhead equivalent stress contour.

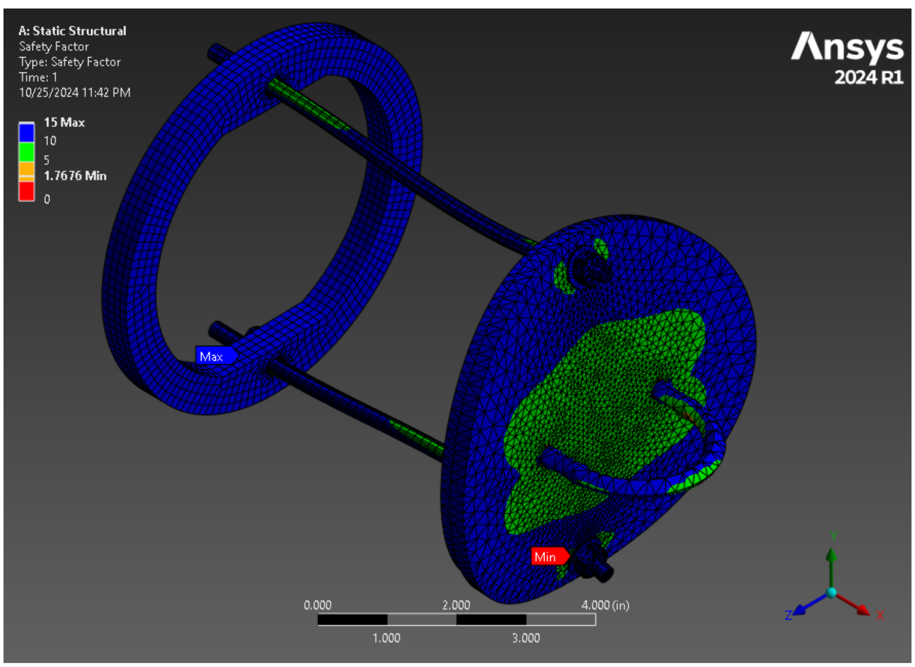


Figure 3.20: Nose Cone/Payload Bay bulkhead safety factor contour.

3.3.6 Main Parachute Bay

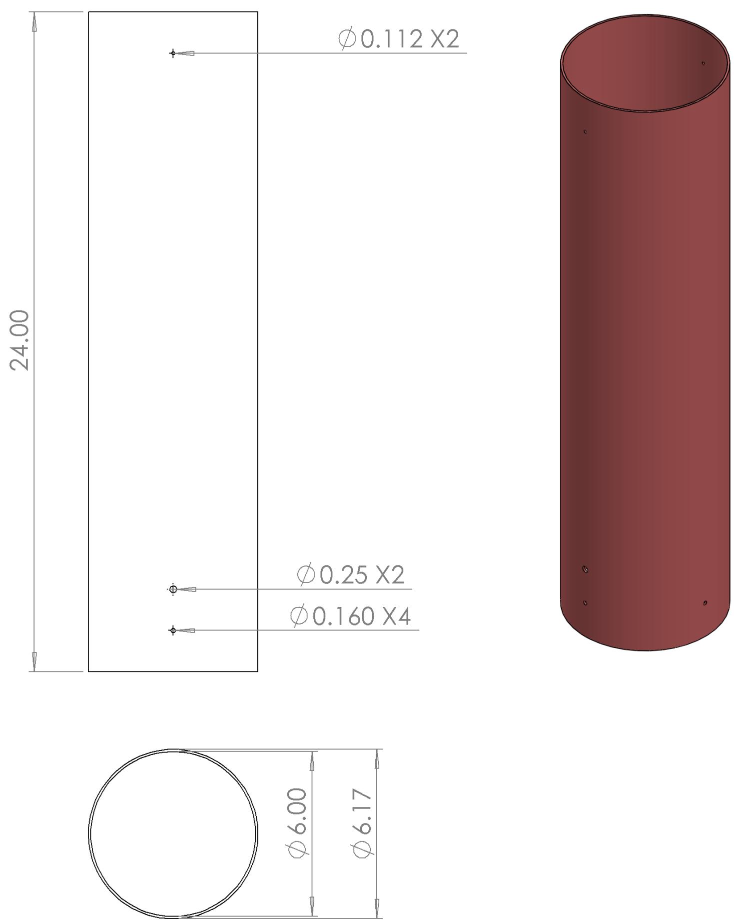


Figure 3.21: Main Parachute Bay dimensions [in.]

The Main Parachute Bay consists of a single 24 in. section of G12 fiberglass airframe. The forward end interfaces with the Nose Cone/Payload Bay coupler and is fastened with #4-40 nylon shear pins. The aft end of the section interfaces with the forward AVAB coupler section and is fastened with nylon push rivets. Two 0.25 in. pressure port holes are also present near the aft end. These holes line up with matching holes in the AVAB coupler wall to allow accurate atmospheric pressure data to the recovery altimeters.

3.3.7 Avionics/Air Brakes Bay (AVAB)

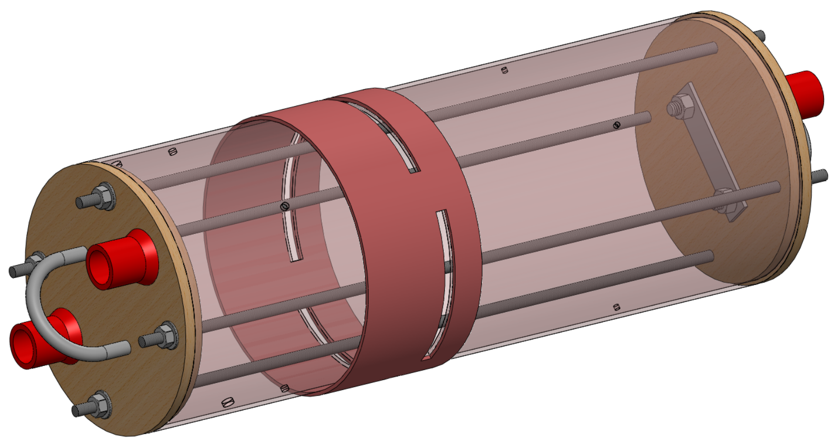


Figure 3.22: AVAB section without internal AV Bay or Air Brakes assembly.

The AVAB section consists of a contiguous 16 in. G12 fiberglass coupler section with a 3 in. long switchband located 4.5 in. from the forward edge of the coupler tube and 8.5 in. from the aft. These coupler lengths satisfy NASA Requirement 2.4 for separating and non-separating connections. Removable bulkheads will form the forward and aft closures of the AVAB, as seen in Section 3.3.8, and four 1/4" diameter threaded rods will mount to these bulkheads and run the length of the section. These rods will form the structural attachment points for the Air Brakes payload system and the recovery avionics sleds. Internally, the AVAB will be partitioned into a forward AV Bay and aft Air Brakes Bay. The 3 in. switchband is positioned to overlap a portion of both of these sections. This allows for a pull pin switch to run through the switchband for arming the recovery avionics as well as sufficient spacing and wall thickness for the Air Brakes drag fin slots. Pressure port holes for the recovery altimeters will run through the walls of the AV Bay and the Main Parachute Bay sufficiently far forward as to not be influenced by pressure gradients induced by the Air Brakes system.

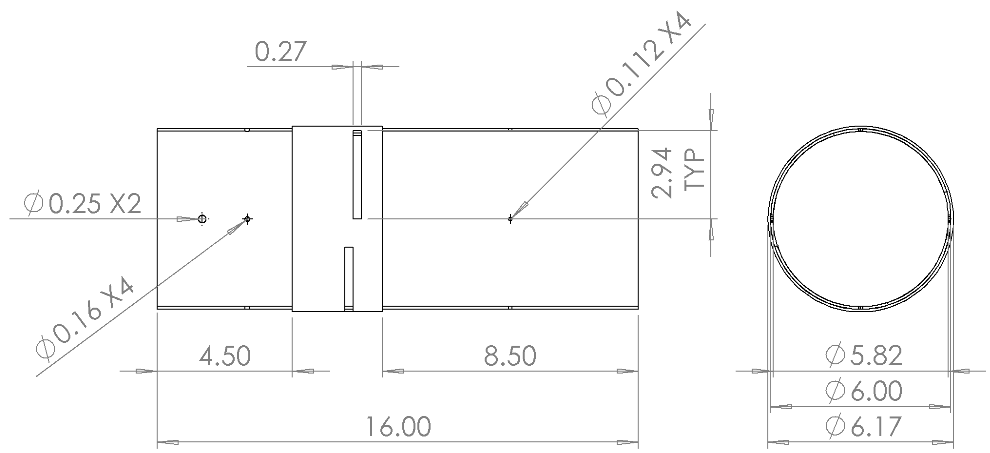


Figure 3.23: AVAB body dimensions [in.]

3.3.8 AVAB Bulkheads

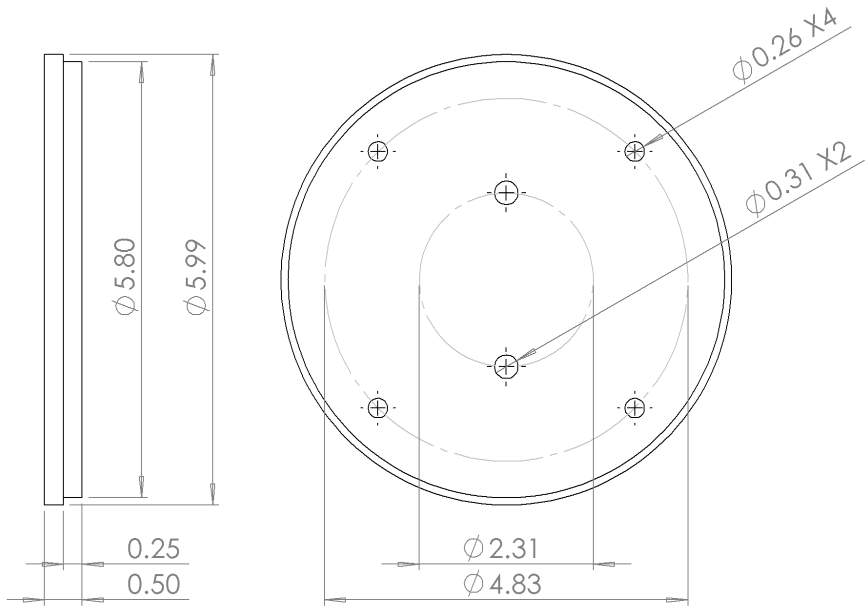


Figure 3.24: AVAB bulkhead dimensions [in.]

The AVAB bulkheads are fabricated from a 1/2 in. thick sheet of 9-ply Baltic Birch Plywood. They serve as the mounting point for U-bolts anchoring the recovery hardware, the four 1/4 in. threaded rods running through the AVAB, and the charge wells containing the recovery system energetics.

Preliminary Force Analysis

The AVAB is the central section between the Main and Drogue Parachute Bays. Shock forces from both recovery systems will be transmitted through the U-bolts, bulkheads, and threaded rods. As such, the interaction of these components must be evaluated to determine the stress response of the system under expected loading. As previously stated, a maximum estimated loading of 273 lbf. is expected during Main Parachute deployment and therefore was the force value applied for analysis. In Figures 3.25, and 3.26 the results of finite element analysis predict that the system is sufficiently strong, with a minimum factor of safety of approximately 4.5 on the U-bolt. This value exceeds team derived requirements.

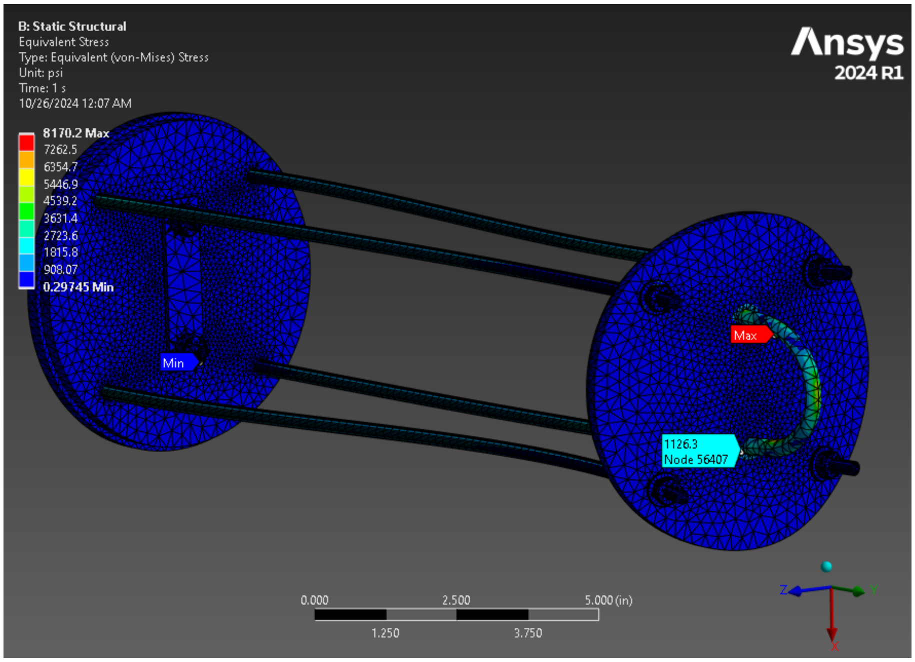


Figure 3.25: AVAB bulkhead equivalent stress contour.

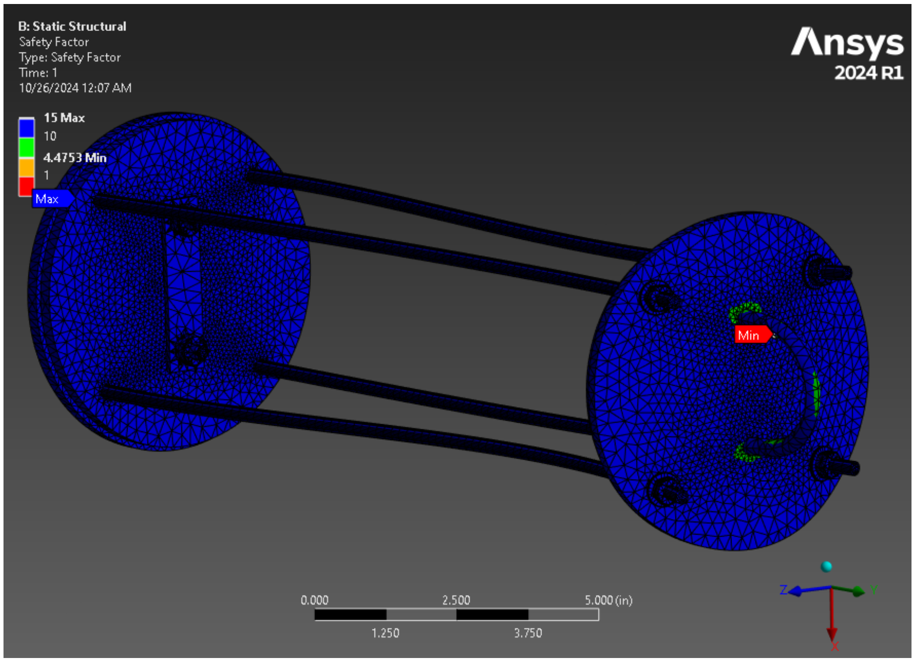


Figure 3.26: AVAB bulkhead safety factor contour.

3.3.9 Drogue Parachute Bay and Fin Can

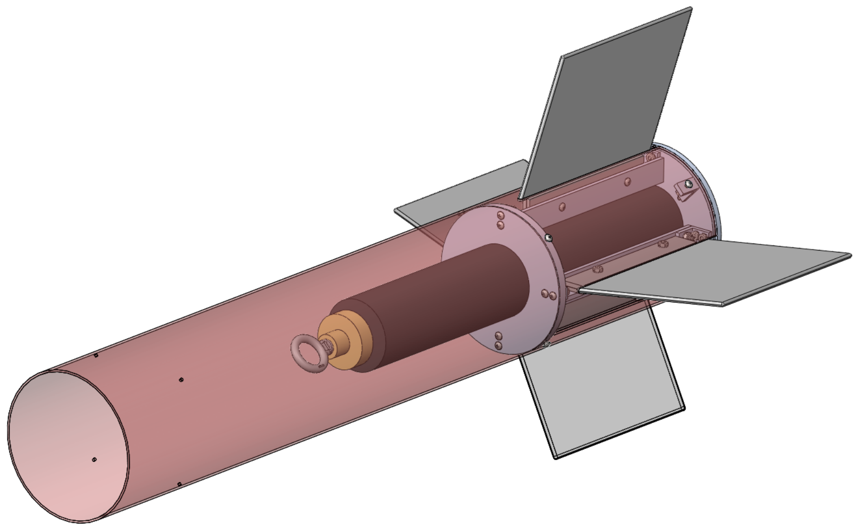


Figure 3.27: Drogue Parachute Bay/Fin Can assembly with inserted AeroTech RMS-75/3840 motor casing.

The Drogue Parachute Bay/Fin Can section is a 36 in. section of G12 fiberglass airframe. The forward end mates to the aft end of the AVAB section and forms an in-flight separation point. This connection is secured by #4-40 shear pins. The drogue parachute and associated recovery gear will occupy the forward volume of this section immediately aft of the AVAB aft bulkhead. The end of the drogue parachute system connects to a forged, lifting eye-bolt that threads directly into the forward closure of the AeroTech RMS-75/3840 motor casing. The motor casing and fins are affixed to the Fin Can via the Removable Modular Fin System, discussed in Section 3.3.10 below. Four 3/16 in. wide end-cut fin slots are located at the end of the Fin Can to accommodate the RMFS.

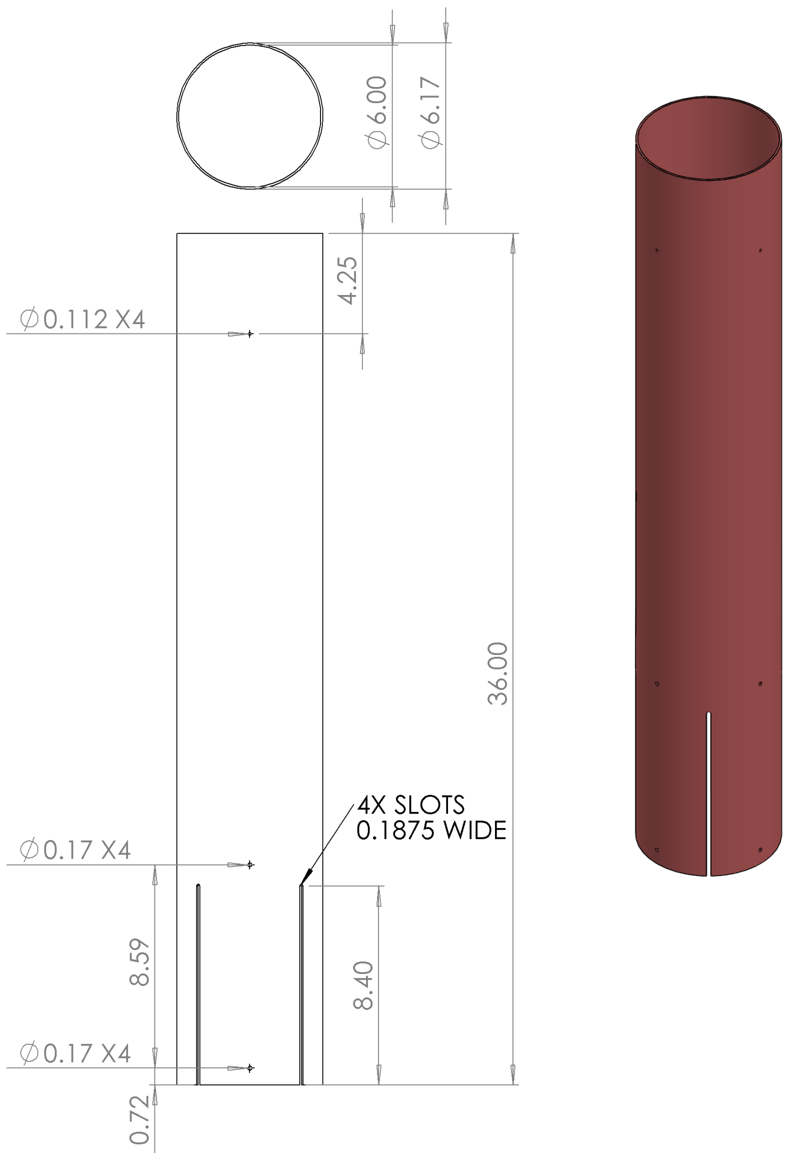


Figure 3.28: Drogue Parachute Bay/Fin Can airframe dimensions [in.]

3.3.10 Removable Modular Fin System (RMFS)

The Removable Modular Fin System (RMFS) is a multipurpose structural assembly within the aft end of the Fin Can that secures the fins and motor casing to the airframe. It is primarily made of 6061-T6 aluminum, and consists of a motor retainer, thrust bulkhead, fin mounting runners, forward centering ring, and a forward volume reduction bulkhead.

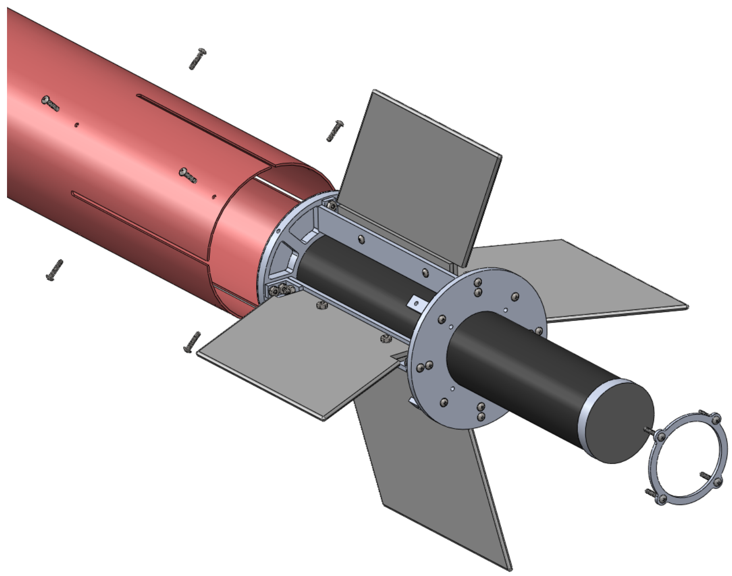


Figure 3.29: Exploded view of Fin Can with RMFS, motor casing, and motor retainer.

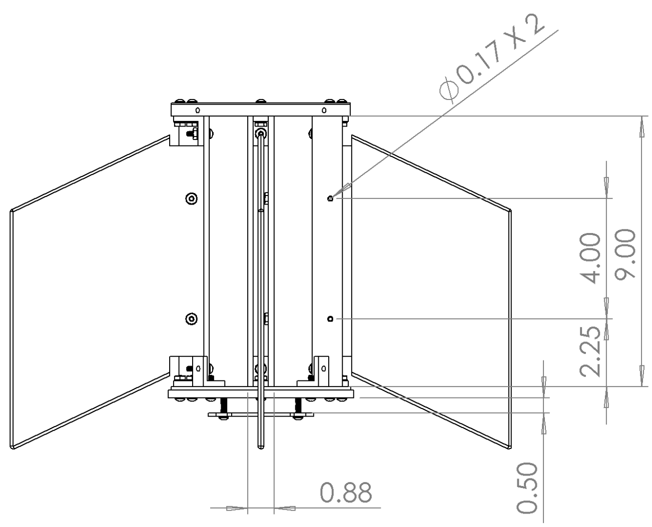


Figure 3.30: RMFS dimensions [in.]

The RMFS forgoes incorporation of a motor mount tube, instead using the thrust bulkhead and forward centering ring to center the AeroTech RMS-75/3840 motor casing. The aft lip of the motor casing is secured to the aft face of the thrust bulkhead using a 1/8 in. thick aluminum motor retainer plate fastened with four #8-32 machine screws. The thrust bulkhead is a 3/8 in. thick 6061-T6 aluminum plate that is flanged to sit securely against the outer circumference of the Fin Can airframe. The fin runners consist of four identical 9 in. long L-brackets of 3/16 in. thick 6061-T6 aluminum. These are fastened perpendicular to the thrust bulkhead and forward centering ring via smaller aluminum L-brackets. The fin tabs are secured against the runners using #8-32 machine screws, and spacers are used to align the fins with the airframe slots.

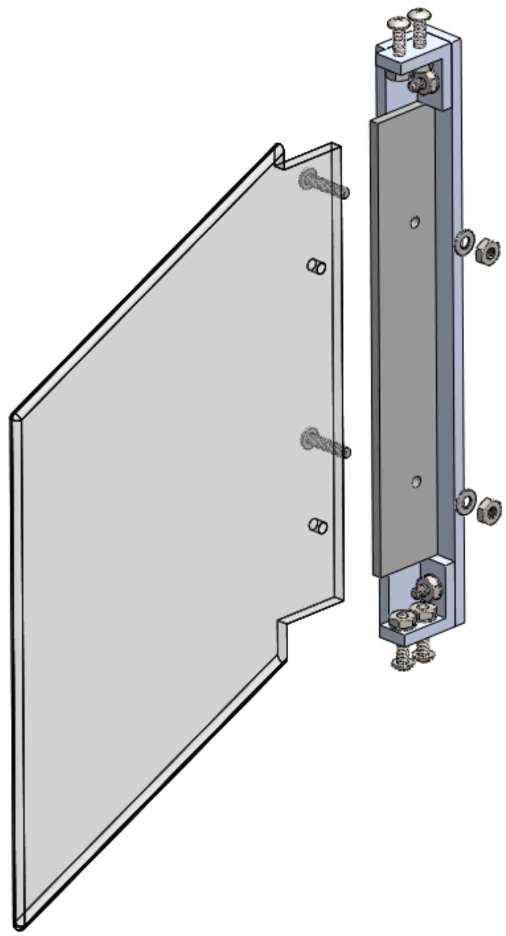


Figure 3.31: Exploded view of a fin runner with spacer and fin.

A thin bulkhead fabricated of 1/16 in.-thick aluminum sheet is secured to the front face of the forward centering ring using the fin runner fasteners. This serves to reduce the internal volume required to be pressurized during separation and Drogue Parachute deployment.

The entire assembly is fastened to the airframe using eight #8-32 machine screws through holes in the airframe wall. Four screws secure into radially positioned threaded holes within the forward centering ring. The remaining four secure to small L-brackets on the thrust bulkhead with hex nuts.

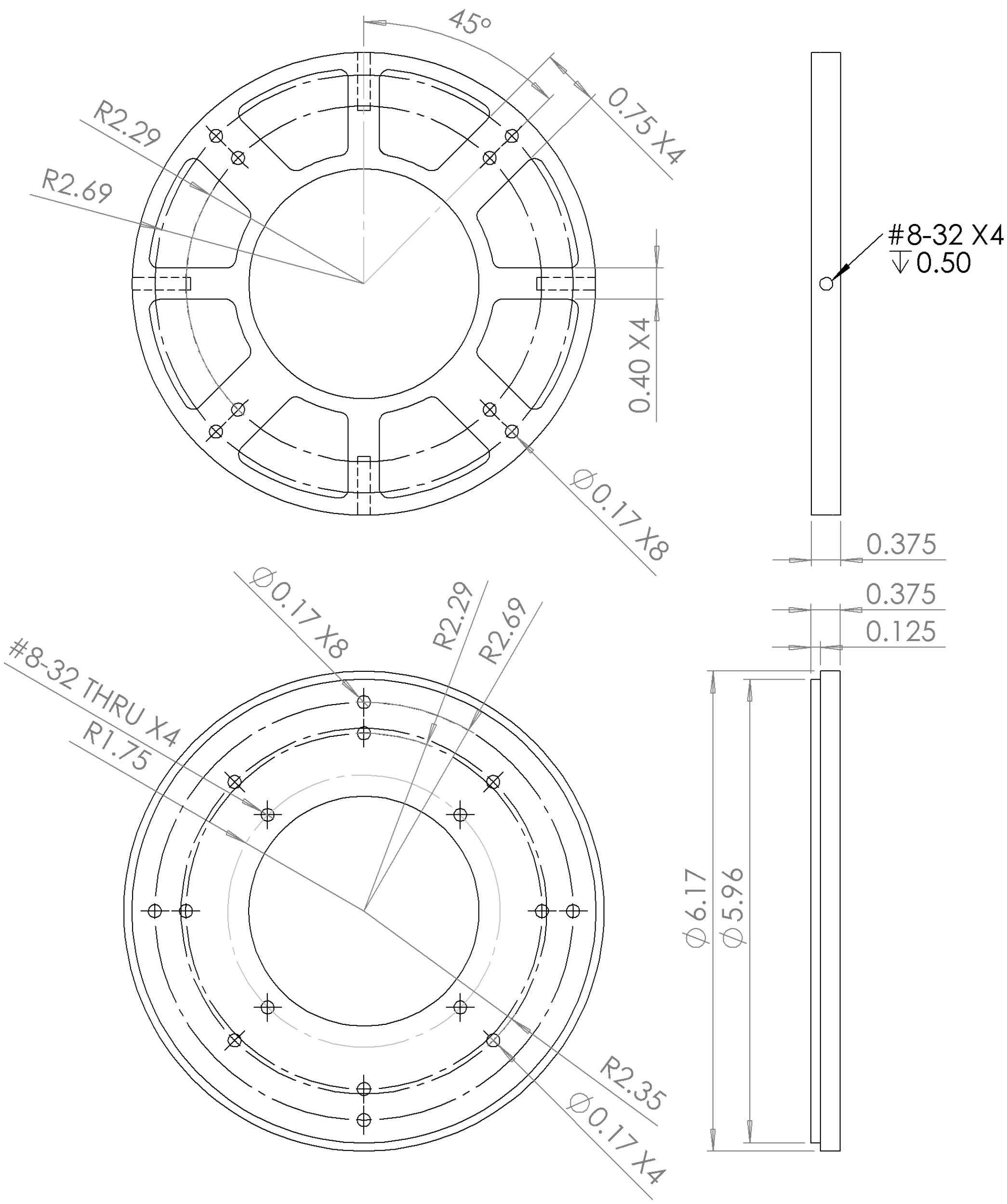


Figure 3.32: RMFS forward centering ring and thrust bulkhead dimensions [in.]

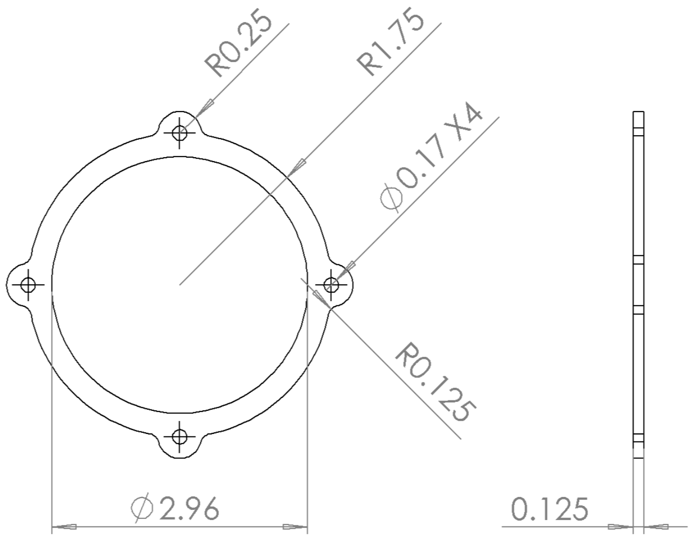


Figure 3.33: Motor retainer plate dimensions [in.]

Preliminary Force Analysis

The RMFS and the airframe are the key structural components of the launch vehicle. During powered flight, the motor pushes directly on the thrust bulkhead at the aft end of the vehicle, which distributes this thrust force through the RMFS and onto the Fin Can airframe. To ensure suitability of this system and materials, finite element analysis was conducted to predict material stress response. A loading of 400 lbf. was applied to the thrust bulkhead to simulate the approximate peak motor thrust. In Figures 3.34 and 3.35, maximum equivalent stress and minimum factor of safety of 10.6 occur at a fastener connection between the forward centering ring and the airframe. This value greatly exceeds team derived minimum safety requirements. Of note, the RMFS thrust plate will also be subjected to shock forces during parachute deployment, however these forces are much lower than the estimated maximum motor thrust.

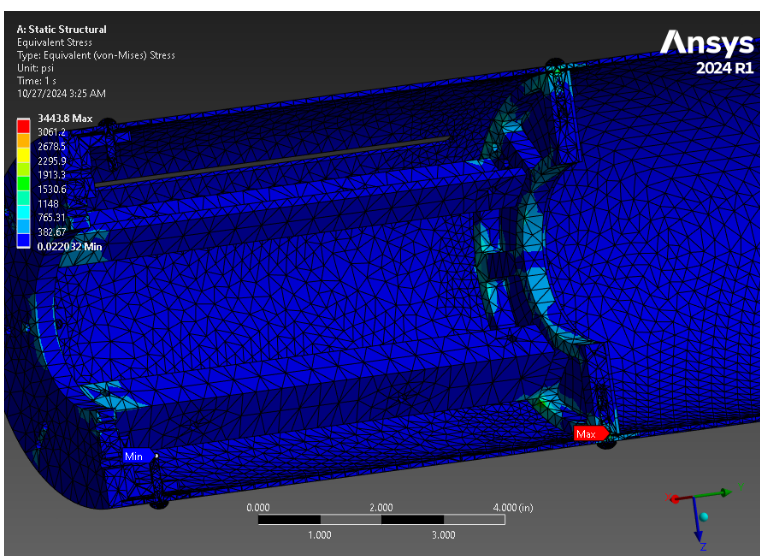


Figure 3.34: RMFS equivalent stress contour.

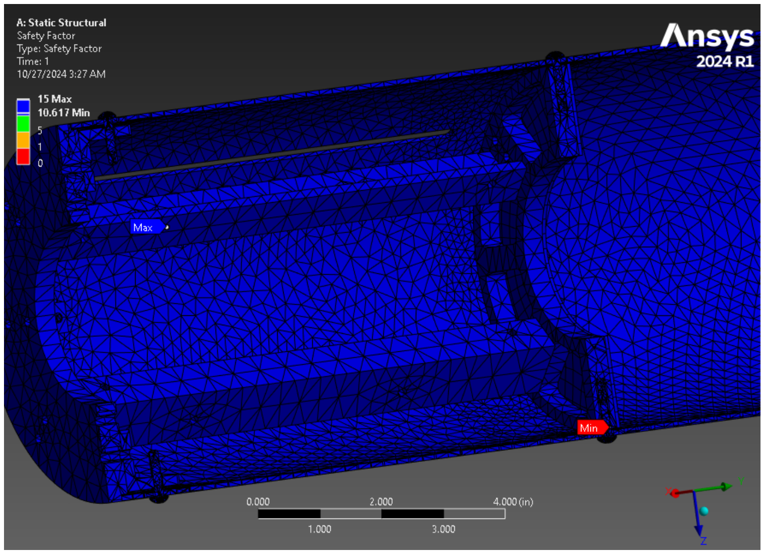


Figure 3.35: RMFS safety factor contour.

3.3.11 Fins

The launch vehicle features four identical fins, equally spaced at 90° increments about the long axis. They have a non-tapered swept geometry, with 8 in. root and tip chords and a 25.3°sweep angle. The fins are 3/16 in. thick, and have a tab along the root chord that extends 1.125 in. into the airframe and fastens to the RMFS fin runners. Rectangular spacers will be used to offset the fins from the runners to align them normal to the airframe circumference.

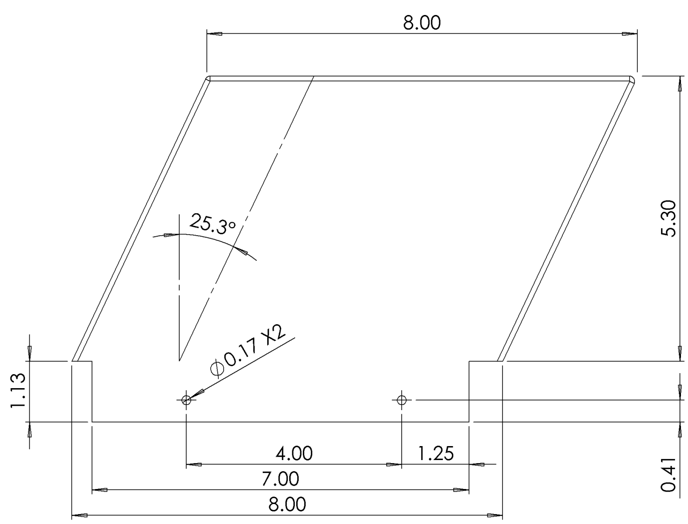


Figure 3.36: Swept fin dimensions [in.]

The fins will be fabricated from a G10 fiberglass sheet using a rotary cutting tool, then sanded to the final dimensions while utilizing proper PPE and hazard control measures. The exposed leading, trailing, and tip chord edges will be rounded off during the sanding process.

3.3.12 Launch Vehicle Weight Estimates

Table 3.4: Summary Weight Estimate

Section	Weight [lbs.]
Nose Cone/Payload Bay	7.02
Main Parachute Bay	4.69
AVAB	5.76
Drogue Parachute Bay/Fin Can	18.31
Launch Vehicle Total	**35.78**

Table 3.5: Section Weight Estimates

Nose Cone/Payload Bay	
Component	Weight [lbs.]
Nose Cone + Coupler	4.91
Permanent Bulkhead	0.11
STEMCRaFT	1.45
Threaded Rods	0.17
Removable Bulkhead	0.28
Hardware	0.10
Section Subtotal	**7.02**

Main Parachute Bay	
Component	Weight [lbs.]
Airframe	2.89
Main Parachute	0.84
Main Shock Cord	0.56
Deployment Bag	0.40
Section Subtotal	**4.69**

AVAB	
Component	Weight [lbs.]
Switchband	0.33
Coupler Tube	1.77
Bulkheads	0.56
Hardware	0.44
Air Brakes System	1.08
Threaded Rods	0.74
AV Sled	0.66
Quick Links	0.18
Section Subtotal	**5.76**

Drogue Parachute Bay/Fin Can	
Component	Weight [lbs.]
Airframe	4.33
Drogue Parachute	0.11
Drogue Shock Cord	0.63
Nomex	0.3
Quick Links	0.18
Thrust Bulkhead	0.8
Fins	2.27
Runners + Hardware	1.00
Volume Reduction Bulkhead	0.12
Centering Ring	0.38
Motor Retainer	0.04
Forged Eye Bolt	0.11
Motor w/ Casing	8.04
Section Subtotal	**18.31**

3.3.13 Motor Selection

The motor selection for the launch vehicle is the AeroTech L1520T due to factors such as predicted apogee, thrust curve stability, and burn time. A further analysis of this choice is outlined in Section 3.2.10.

3.4 Recovery Subsystem

The recovery system is designed with two recovery events, one for drogue parachute deployment and one for main parachute deployment. The first recovery event occurs at apogee when the primary altimeter ignites the primary drogue black powder charge on the aft end of the AVAB. One second later, the secondary altimeter will ignite the secondary drogue black powder charge on the aft end of the AVAB for redundancy. These black powder charges ignite and create a pressure buildup in the Drogue Bay, breaking the shear pins that connect the AVAB to the Drogue Bay, and separating the sections to deploy the drogue parachute. The launch vehicle then falls under the drogue parachute until the second recovery event.

The second recovery event occurs at 550 ft. when the primary altimeter ignites the primary main black powder charge on the forward end of the AVAB. At 500 ft, the secondary altimeter will ignite the secondary main black powder charge on the forward end of the AVAB for redundancy. These black powder charges ignite and create a pressure buildup in the Main Parachute Bay. This breaks the shear pins that connect the Main Parachute Bay to the Nose Cone and separates the sections to deploy the main parachute. The launch vehicle then falls under the main parachute for the remainder of the descent.

As a part of this design, the primary design considerations include: altimeters, trackers, batteries, switches, drogue parachute, main parachute, parachute protection and deployment, shock cord, AV sled material, ejection charge containment, and anchor point hardware. Since the AV Bay and the Air Brakes are contained within the AVAB, a primary goal for the AV Bay was to condense it down as much as possible in order to allow extra space for the Air Brakes system, without compromising performance. For more in depth information on the current complete recovery system, see Section 3.5.

3.4.1 Altimeters

Altimeters are the heart of the recovery system, measuring the altitude of the launch vehicle throughout the flight and triggering the deployment of the parachutes at designated recovery events. In order to ensure redundancy, two dual-deploy altimeters operating on independent circuits will be included in the recovery system.

As per NASA Requirement 3.4, all altimeters being considered are commercially available barometric altimeters specifically designed for initiation of rocketry recovery events. Also, all altimeters being considered are capable of recording and logging altitude, velocity, and time through the full duration of the flight.

The key factors the team used when considering an altimeter were: size, accuracy, reliability, power consumption, and cost. Table 3.6 below, summarizes some key factors the team used to make a decision.

Table 3.6: Altimeter Options

Altimeter	Altitude Logging Resolution	Size	Power	Cost	Owned
Altus Metrum EasyMini	1 ft	1.50” x 0.80”	3.7V - 12V	$80.00	No
Eggtimer Quantum	1 ft	2.60” x 0.90”	7.4V	$40.00	No
Eggtimer Quasar	1 ft	5.5” x 1.09”	7.4V	$100.00	Yes
PerfectFlite StratologgerCF	1 ft	2.00” x 0.84”	4V - 16V 9V Nominal	$69.95	Yes

Altus Metrum EasyMini

The Altus Metrum EasyMini is a great choice for a dual-deployment altimeter considering its small size, without a reduction in performance. In addition to its small size, it also only requires one single cell LiPo to be fully powered, allowing for a smaller battery to further reduce space. The largest drawback of this device is that the team does not currently own one, making it the most expensive option being considered. While an EasyMini has never been used by the North Carolina State University High-Powered Rocketry Team on a NASA SL competition launch vehicle, some members of the team have used EasyMini’s for their own personal launch vehicles and can vouch for their reliability.

Eggtimer Quantum

The Eggtimer Quantum is a WiFi-enabled flight computer, allowing the user to program, arm, disarm, and download flight data without any cables or an internet connection. The Quantum is still relatively small at 2.6” in length and can be powered using a single two cell LiPo battery. Like the EasyMini, the team does not currently own an Eggtimer

Quantum, however it is half the price of the Altus Metrum EasyMini at $40.00. Another drawback of the Eggtimer Quantum is that it does not come flight ready and several components need to be soldered onto the main board.

Eggtimer Quasar

The Eggtimer Quasar, like the Eggtimer Quantum, is also WiFi-enabled, allowing the user to program, arm, disarm, and download flight data without any cables or an internet connection. The main benefit of the Quasar is that it also acts as a GPS tracker, allowing the team to utilize the Quasar as a secondary altimeter and the flight tracker, without the need of another avionics device. The main drawback of the Eggtimer Quasar is its size; with an overall length of 5.5", it will not fit into the subscale launch vehicle horizontally along the cross section meaning that this device would require a minimum AV Bay length of approximately 5.5".

PerfectFlite StratologgerCF

The PerfectFlite StratologgerCF is well known in the hobby rocketry community for its small size, performance, and consistency for a reasonable price. The team has been using Stratologger's for years and can attest to their reliability. At 2.00" in length, these are the second smallest altimeters being considered by the team and the team already owns several of them, meaning they would be at no cost for this competition. One drawback of the Stratologger, as compared to the other altimeters on this list, is the manufacturer recommendation of a 9V Alkaline battery as opposed to a LiPo.

Leading Altimeters

The current leading design is to use one PerfectFlite StratologgerCF as the primary altimeter, with an Altus Metrum EasyMini acting as a secondary backup altimeter. With size being a major priority for this year's AV Bay components, these two altimeters offer outstanding performance relative to their size and fulfill all NASA and team derived requirements. While two EasyMini's would be ideal in order to minimize the space the altimeters take up within the AV Bay, the team decided the extra money required for a second EasyMini was not worth the minor reduction in size.

One benefit to using one EasyMini and one Stratologger, instead of two Stratologgers, is the ability to use a LiPo to power the EasyMini. This will allow the team to power the EasyMini, as well as the GPS tracker, with one battery. This allows the AV Bay to include one 9V battery powering the Stratologger and one LiPo powering the EasyMini and the GPS tracker. This is opposed to the two 9V batteries and one LiPo that would be required for a two Stratologger and one GPS configuration.

3.4.2 Tracking Devices

As per NASA Requirement 3.13, an electronics GPS tracking device must be included on all non-tethered independent sections of the launch vehicle. Since all the sections of the launch vehicle will remain tethered together for the duration of the flight, only one GPS will be used in order to track the position of the launch vehicle. Since the recovery area of the vehicle is limited to 2,500 ft., all GPS tracking devices being considered must be able to transmit to at least 5,000 ft.

The primary considerations for the GPS are size, range, cost, and transmitter frequency. Table 3.7 below, summarizes some key factors the team used to make a decision.

Table 3.7: Tracking Options

Tracker	Transmitter Frequency	Range	Size	Cost	Owned
Big Red Bee 900	900 MHz	6 miles	3.25" x 0.70"	$199.00	Yes
Eggfinder Mini	900 MHz	1.5 Miles	7.00" x 1.25"	$75.00	No
Eggtimer Quasar	900 MHz	2 Miles	5.5" x 1.09"	$100.00	Yes

Leading Tracker

All three GPS trackers being considered as a part of the recovery system transmit on the 900 MHz frequency band, meaning that they do not require a HAM radio license to operate. The biggest consideration for the team when choosing a GPS transmitter was the overall size. At 3.25” in length, including the antenna, the Eggfinder Mini is the only GPS tracker small enough, including the antenna, that can fit within the 3.9” subscale AV Bay horizontal across the cross section.

While the Eggfinder Mini’s overall range is lower than the Big Red Bee and the Eggtimer Quasar, 1.5 miles is still more than enough to fully encompass the entirety of the recovery area. Overall the team has decided that the benefits of using a much smaller GPS more than makes up for the reduced transmitting range of the device.

3.4.3 Switches

As per NASA Requirements 3.6 and 3.7, each altimeter shall be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket frame, and each arming switch shall be capable of being locked in the on position for the duration of the flight. The three main switches being considered for the altimeters are Lab Rat Rocket Double Pull Pin Switch, the Missile Works 6-32 Screw Switch, and the, and Featherweight Magnetic Switch.

Lab Rat Rocket Double Pull Pin Switch

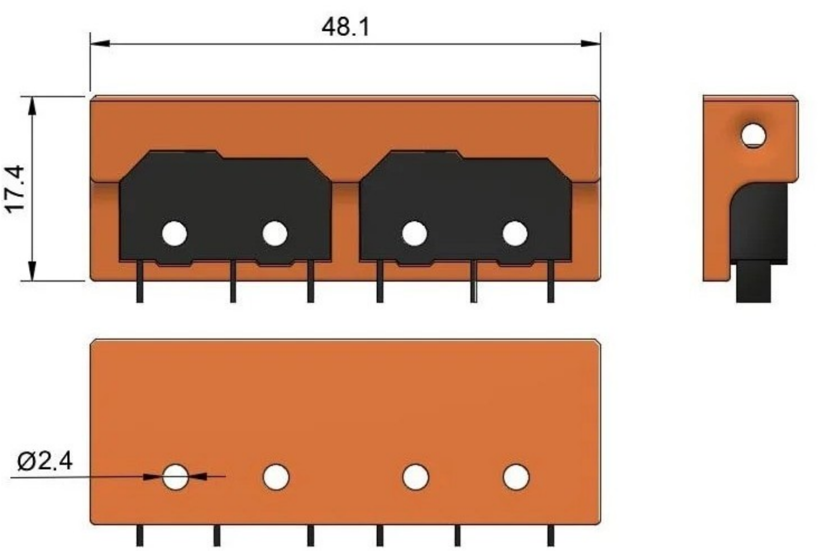


Figure 3.37: Lab Rat Rocketry Double Pull Pin Switch

As shown in Figure 3.37 above, the double pull pin switch consists of two micro switches, a pin guide, and a pin that is pushed against the active surface of the micro switches. When the pin is in, the button is compressed and the switch is configured to hold the circuit open. Once the pin is removed, the switch closes to close the circuit. With this double pull pin switch, the guide is lined up to allow a single pin to be used to control both circuits for both altimeters independently. The drawback of this pull pin switch is that the switch must sit inside of the launch vehicle in line with the switchband. If the pull pin was not on the switchband, it would be impossible to insert or remove with AV Bay from the launch vehicle without temporarily activating the altimeters by removing the pull pin. One benefit of the pull pin switch is that once the pull pin is inserted, it is extremely easy to remove on the launch pad in order to activate the altimeters.

Missile Works 6-32 Screw Switch

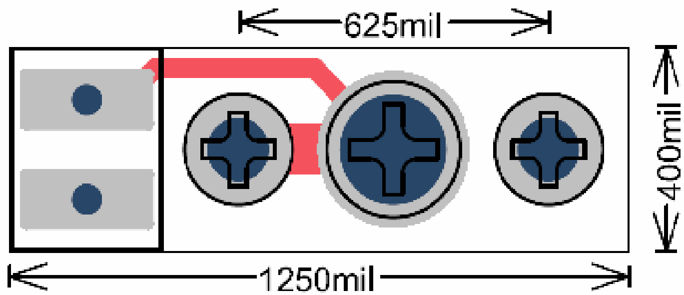


Figure 3.38: Missile Works 6-32 Screw Switch

As shown in Figure 3.38 above, the screw switch consists of a PCB with a nut on one side and a pad on the other. When the screw is tightened down, it makes electrical contact between the pad and the nut, completing the circuit. Once the screw is screwed into place, it cannot be unscrewed by forces seen during a typical flight. One benefit of screw switches over pull pin switches is that they do not need to be in line with the switchband on the launch vehicle since they can remain in an open circuit state while the AV Bay is inserted or removed from the launch vehicle. A disadvantage of the screw switches is that two holes need to be drilled into the exterior of the airframe in order to access them with a screwdriver and it can often be difficult to tighten the screws on the launch pad in order to activate the altimeters.

Featherweight Magnetic Switch

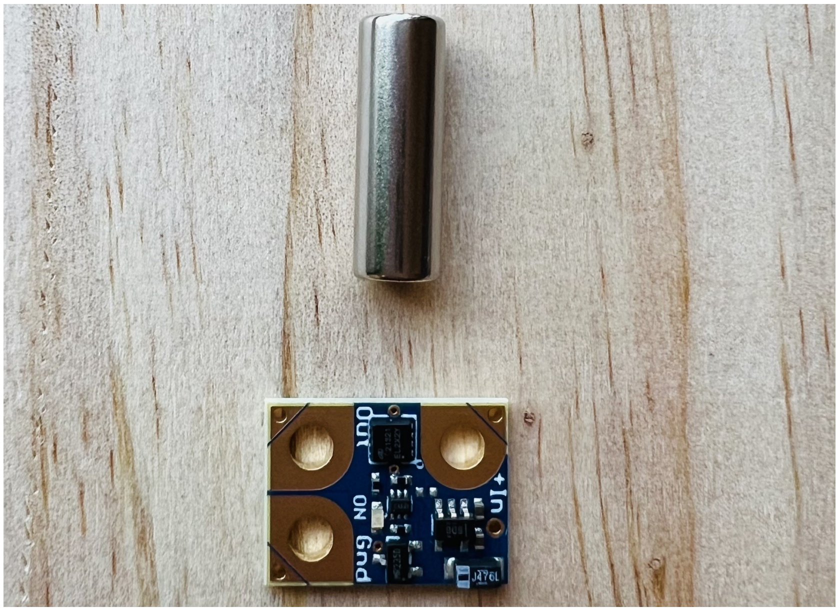


Figure 3.39: Featherweight Magnetic Switch

As shown in Figure 3.39, the Featherweight Magnetic Switch uses a magnet that can be swiped within the vicinity of the switch in order to turn it on and off. The switch is designed so that opposite magnetic polarities turn the switch on and off; that way one altimeter cannot accidentally be disarmed while attempting to arm a second altimeter. Magnetic switches are beneficial because they allow the team to arm and disarm altimeters from the exterior of the launch vehicle without having to drill any alignment holes for the switches. The student launch team does not have enough experience with these switches and would have to do further testing on them and their reliability before recommending them for something as important as the recovery avionics system.

Leading Switches

The current leading design is to use one Lab Rat Rocketry Double Pull Pin switch along the switchband in order to arm each of the altimeters. This design was chosen in large part due to the convenience of arming the altimeters on the launch pad and issues the team has run into with arming screw switches in the past. While the external frame of these switches makes them appear as one unit, each switch acts completely independently of the other, and each of the altimeters can be armed and disarmed independently using the single pull pin.

3.4.4 Batteries

As per NASA Requirement 2.6, the launch vehicle must be capable of remaining in launch-ready configuration for a minimum of 3 hours without losing the functionality of any critical on-board components. As per PerfectFlite recommendations, one single 9V battery will be used to power the primary StratologgerCF altimeter. With an average current draw of 1.5 mA, a single 9V battery can be used to power a PerfectFlite StratologgerCF for weeks.

One 7.4V 1000 mAh LiPo will be used to power both the Altus Metrum EasyMini and the Eggfinder Mini. The EasyMini has a nominal working current draw of 10 mA and the Eggfinder Mini has a nominal current draw of 70 mA. This will allow a 1000 mAh battery to power each of these devices for 12.5 hours.

3.4.5 AV Sled Material

All AV electronics will be secured to the AV Sled inside of the AV Bay. The primary considerations for the creation of the AV Sled are the overall cost, ease of manufacturing, and overall strength of the material used. In the past, the team has experimented with AV sleds made from birch plywood as well as various 3D printed filaments.

Birch Plywood

In order to create an AV Sled using birch plywood, each of the sides of the AV Sled would be laser cut with their edges designed like jigsaw shapes that fit together. These different sides would be epoxied together along these jigsaw edges. Some advantages to manufacturing the AV Sled out of birch plywood is that it is extremely strong and relatively quick to manufacture. The team has never had a plywood AV Sled break under even the most extreme forces produced during a launch. It is also extremely easy to drill into birch plywood in order to mount components onto the sled.

3D Printed Filaments

An alternative to using Birch Plywood would be to 3D print the AV Sled using a PETG or a PLA filament. The primary advantage of 3D printing the AV Sled is that it is extremely easy to model and print, without worrying about the complex jigsaw pattern required to ensure a strong birch plywood design. 3D printing also allows the team to consider more complex shapes and designs for the AV Sled that may be necessary in order to minimize space. One disadvantage of using 3D printed components is that any hardware mount points must be added to the design prior to printing because the infill of a 3D printed component is often too thin to properly hold screws needed to secure avionics hardware.

Leading AV Sled Material

The current leading design is to 3D print the AV Sled using PLA. PLA was chosen over PETG due to its increased overall strength, ease of printing, and consistent high-quality finish. PETG is generally more flexible than PLA, however the 32% increase in strength of PLA as well as the increased reliability in print quality are worth this reduction in flexibility.

3.4.6 Parachute Selection

As per NASA requirement 3.3, the maximum kinetic energy of the heaviest independent section of the launch vehicle must not exceed 75 ft-lbf at landing, and extra points will be awarded to teams that stay under 65 ft-lbf. As per NASA requirements 3.11 and 3.12, the rocket shall drift no more than 2,500 ft. from the launch pads and the overall descent time of the vehicle from apogee must be limited to 90 sec, with extra points awarded to teams who stay under 80 sec. For more information on how these values were determined, see Mission Performance Predictions: Section 3.6.7, Section 3.6.8, and Section 3.6.9.

These three requirements were the primary design criteria when choosing drogue and main parachutes for the launch vehicle. The next highest priority was the overall cost of the parachutes with priority given to parachutes that the team already owned. Other specifications taken into consideration were the parachute packing size and overall weight.

Drogue Parachute

The primary purpose of the drogue parachute is to slow the vehicle down to a velocity such that the impulse caused by main parachute deployment does not snap the shock cord and shroud lines, nor damage the launch vehicle's airframe. A secondary purpose of the drogue parachute is to help orient the vehicle properly on descent so that the main parachute deploys as expected. Table 3.8, shows a variety of parachutes as well as information used to help inform the drogue parachute selection.

Table 3.8: Drogue Parachute Options

Parachute	Drag Coefficient	Descent Velocity	Decent Time: Apogee to Main Deployment	Max Drift Distance: Apogee to Main Deployment	Owned
Fruity Chutes 15" Elliptical	0.8427	122.82 fps	34.60 s	1015.05 ft	Yes
Fruity Chutes 18" Elliptical	0.8427	102.35 fps	41.52 s	1218.06 ft	Yes
Fruity Chutes 24" Elliptical	0.8427	76.76 fps	55.37 s	1624.08 ft	Yes
Fruity Chutes 30" Elliptical	0.800	63.03 fps	67.43 s	1978.00 ft	No

The descent velocity is important in ensuring that the launch vehicle is descending fast enough to accommodate the descent time goals imposed by NASA Requirement 3.12. However, if the launch vehicle is descending too fast, the main parachute deployment may damage components in the launch vehicle. For this reason, Team Derived requirement [DR. 8] ensures that the launch vehicle will never exceed a descent velocity of 120 fps. For this reason, the 15" Fruity Chutes Elliptical parachute is not an option.

While the 30" Elliptical Parachute does not exceed the NASA Required descent time nor drift distance, the values are too large to combine with a main parachute that could be used to meet these requirements and keep the kinetic energy at landing below the required 75 ft-lbf.

This leaves the 18" and 24" parachutes as variable options for the drogue parachute with slight favor towards the 18" parachute since it stays well within our team derived maximum descent velocity while allowing more flexibility in main parachute selection.

Main Parachute

The primary purpose of the main parachute is to slow the launch vehicle's descent such that no damage is sustained during the impact with the ground and the launch vehicle can be fully recovered. Another primary consideration when selecting the main parachute is ensuring that, in tandem with the drogue parachute, the overall descent time and drift distance of the vehicle do not exceed NASA Requirements. Table 3.9 highlights all the parachutes in consideration.

Table 3.9: Main Parachute Options

Parachute	Descent Velocity	Kinetic Energy	Decent Time from Main Deployment	Max Drift Distance from Main Deployment	Owned
Fruity Chutes Iris Ultra 72" Compact	21.03 fps	97.72 ft-lbf	26.15 s	767.20 ft	No
Fruity Chutes Iris Ultra 84" Compact	18.02 fps	71.80 ft-lbf	30.51 s	895.07 ft	Yes
Fruity Chutes Iris Ultra 96" Compact	15.77 fps	54.97 ft-lbf	34.87 s	1022.93 ft	Yes
Fruity Chutes Iris Ultra 120" Compact	12.62 fps	35.18 ft-lbf	43.59 s	1278.67 ft	Yes

The 72" Iris Ultra parachute is not a viable option because it exceeds the competition required maximum kinetic energy of 75-ft lbs. All other parachutes are able to slow the descent of the vehicle enough to fulfill this requirement. The 120" Iris Ultra Parachute slows the vehicle down too much, pushing the descent time and maximum drift distance too high to be viable options.

The 84” and 96” Iris Ultra parachutes are both viable options in ensuring the vehicle is able to safely reach the ground in a timely manner. The 96” is a slightly favorable option ensuring that when used in tandem with an 18” Drogue parachute, the launch vehicle will remain under 65 ft-lbf of kinetic energy on landing and will still reach the ground under the 80 sec for bonus points on both requirements.

Leading Parachutes

The current leading design is to fly with a Fruity Chutes 18” Classic Elliptical as the drogue parachute and a Fruity Chutes Iris Ultra 96” Compact main parachute. This will give the launch vehicle a total descent time of 76.40 sec, a max drift distance of 2241.00 ft., and a landing kinetic energy of 54.97 ft-lbs. This parachute combination gives the team enough flexibility so that if there are minor mass changes, the vehicle is still well within all safety and competition requirements. This configuration also allows the team to achieve bonus points for the descent time and kinetic energy requirements.

3.4.7 Parachute Deployment and Protection

Another important consideration is what medium the team will use to protect and deploy the drogue and main parachutes. The two primary deployment mediums being considered are Parachute Deployment Bags and Nomex Blankets. The primary purpose of these mediums is to ensure that the parachutes deploy properly and are adequately protected from the ejection charges used to separate the vehicle during the recovery events.

Nomex Blanket

The simplest and easiest to use of these protection mediums is a protective Nomex blanket. A Nomex blanket is a flat Nomex cloth wrapped around a parachute primarily used to protect it from the ejection charges. This form of protection is what the team is most familiar with and has used for almost every parachute in the last few years.

Parachute Deployment Bags

Parachute deployment bags are helpful to ensure a successful parachute deployment by organizing and holding the canopy and shroud lines until the point of ejection. The shroud lines are z-folded and stowed within straps on the outside of the parachute deployment bags, allowing the lines to fully extend as the parachute is deployed, significantly reducing the chances of shroud line entanglement. Like Nomex blankets, parachute deployment bags also protect the parachutes from fire, heat, and abrasion. According to Fruity Chutes, parachute deployment bags are particularly beneficial for parachutes larger than 7 ft., but are often unnecessary for parachutes smaller than that.

Leading Parachute Deployment and Protection

The team currently intends to use a parachute deployment bag for the main parachute deployment and a Nomex blanket for the drogue parachute deployment.

3.4.8 Shock Cord Selection and Sizing

Shock cord is an important component in keeping all sections of the launch vehicle tethered together during the descent of the vehicle. Shock cord needs be strong enough to absorb the deployment forces caused by the rapid change in acceleration during parachute deployment and durable enough to endure the heat and forces caused by the ejection charges.

The length of the shock cord is important in ensuring that the sections of the launch vehicle do not collide during descent. A longer shock cord also allows for a more graduator absorptions of separation forces and reduces the probability of damages such as zippering during the separation events.

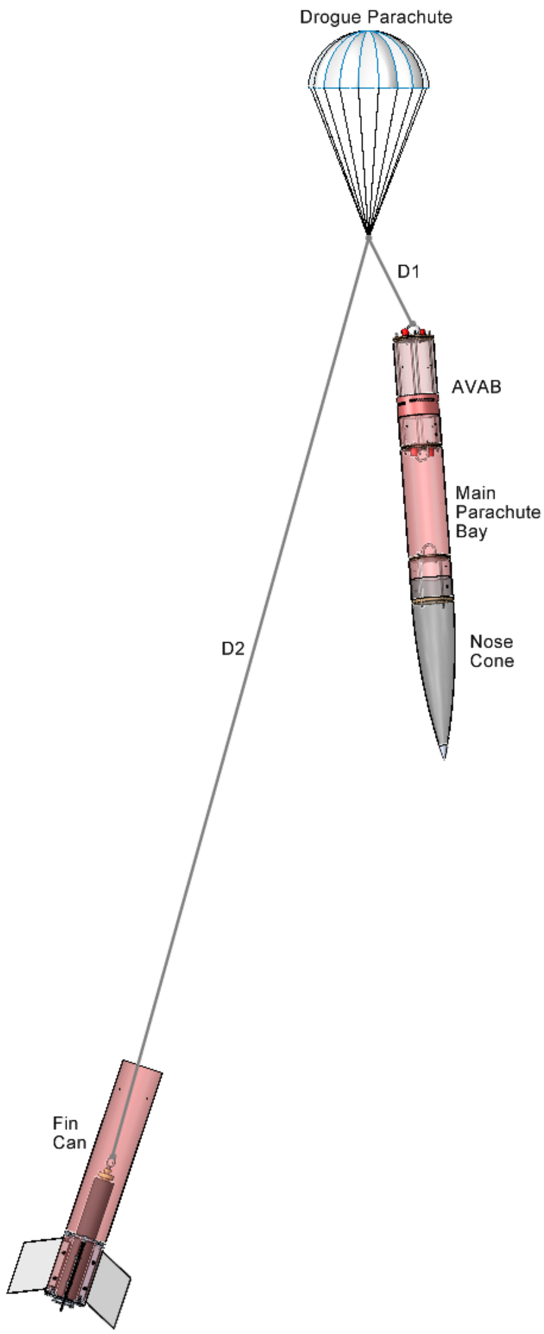


Figure 3.40: Drogue Deployment Configuration

Figure 3.40 to the left shows the descent configuration of the launch vehicle following the drogue parachute separation event. As per Team Derived Requirement RD.4, there must be at least 10 ft. between all independent sections during descent. This means that at there must be at least 10 ft. of separation between the fins on the Fin Can and the top U-bolt of the AVAB when the shock cord is fully extended.

For shock cord to launch vehicle connections, such as the connection point between D_1 and the AVAB, the shock cord is tied to quick links attached the launch vehicle U-bolt using a bowline knot. The parachute is tethered to the shock cord using a quick link attached to shock cord with an alpine butterfly knot.

On the diagram, D_1 represents the length between the AVAB U-bolt connection and the parachute connection and D_2 represent the length between the Fin Can U-bolt connection and the parachute connection point. This parachute connection point has been selected such that it is 20% of the way down the shock cord from the Fin Can connection. With these constraints in mind, the combines length of the forward sections of the launch vehicle, L_{fws}, and the length of drogue shock cord contained within the Fin Can, D_{fc}, the total drogue shock cord length, L_{drogue} can be calculated with the following system of equations.

$$L_{drogue} = D_1 + D_2 \tag{4}$$

$$D_2 = 4D_1 \tag{5}$$

$$D_2 - D_{fc} = D_1 + L_{fws} + 120in. \tag{6}$$

With a L_{fws} of 63.5 in. and 14 in. of D_2 contained within the Fin Can, the minimum required length of the drogue shock cord was calculated to be 329.16 in. The team will be using a drogue shock cord with a length of 330 in., or 27.5 ft.

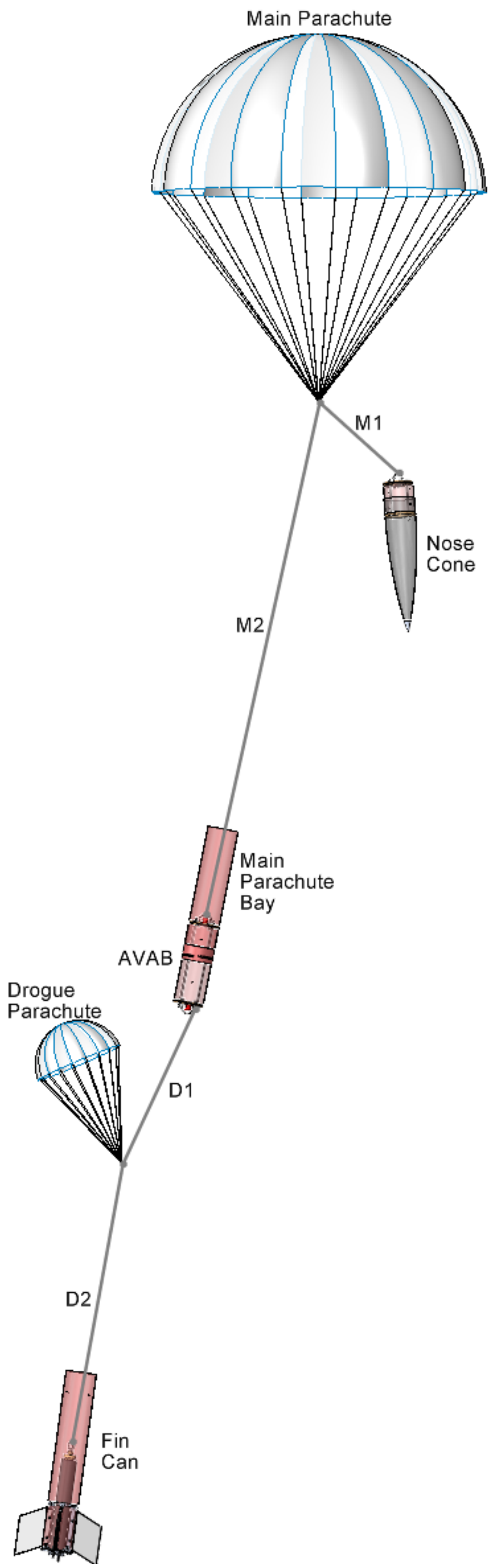


Figure 3.41: Main Deployment Configuration

Figure 3.41 to the left shows the descent configuration of the launch vehicle following the main parachute separation event. Similar to the descent under drogue parachute, all independent sections of the launch vehicle must be separated by at least 10 ft. during descent under main parachute. This means that at there must be at least 10 ft. of separation between the tip of the Nose Cone and the top of the Main Parachute Bay.

On the diagram, M_1 represents the length between the Nose Cone U-bolt connection and the parachute connection, and M_2 represents the length between the Main Parachute Bay U-bolt connection and the parachute connection point. Similar to the drogue parachute shock cord, this parachute point has been selected such that it is 20% of the way down the shock cord from the Nose Cone connection. With these constraints in mind, the Nose Cone length, L_{nc}, and the length of the main shock cord contained within the Main Parachute Bay, M_{mpb}, the total main shock cord length, L_{main}, can be calculated with the following system of equations.

$$L_{drogue} = M_1 + M_2 \tag{7}$$

$$M_2 = 4M_1 \tag{8}$$

$$M_2 - M_{mpb} = M_1 + L_{nc} + 120in. \tag{9}$$

With a Nose Cone length of 32 in. and 17.5 in. of M_2 contained within the Main Parachute Bay, the minimum required length of the main shock cord was calculated to be 282.5 in., or 23.54 ft.

Shock Cord Strength

The largest force that will act on the shock cord is caused by the main parachute deployment when the descent velocity decreases from 102.35 fps down to 15.77 fps. This change in velocity happens extremely quickly as a result of the main parachute deployment. The amount of time it takes to deploy the parachute can be calculated with the equation

$$t = \frac{8r}{v_d} \tag{10}$$

where t is the time it takes the main parachute to open, r is the radius of the parachute, and v_d is the descent velocity of the vehicle under drogue. For the 96" Iris parachute at a drogue descent rate of 102.35 fps, the main parachute deployment time was calculated to be 0.3126 sec. With the main parachute deployment time, the total shock force experienced by the shock cord can be calculated with the equation

$$F = \frac{m\Delta v}{t} 86.57 \tag{11}$$

Using 31.69 lbm for the vehicle descent mass mass, 86.58 fps for change in velocity, and 0.3127 sec for parachute deployment time, the maximum force the shock cords will experience is 272.74 lbf.

For the shock cords, the team will be using 5/8 in. Kevlar shock cord. Kevlar shock cord is a great option because it is extremely strong and heat resistant. The 5/8 in. shock cord has a maximum strength rating of 6600 lbs, providing a factor of safety of 24. While this is much higher than necessary considering the forces the shock cord will be under, the team already owns this shock cord so it will not require any additional cost.

For additional information on the overall strength of the shock cord connection points, see section 3.3.8.

3.4.9 Ejection Charge Sizing

Ejection charges are used in order separate the separate sections of the launch vehicle and deploy the parachutes. This process begins when the altimeters ignite the e-matches contained within the blast caps on either end of the AVAB. These e-matches ignite the black powder, which creates a high pressure environment within the parachute bays, and creates enough force to break the shear pins and separate the sections.

The mass of the black powder charges are calculated using the ideal gas law

$$m = \frac{PV}{RT} \tag{12}$$

where m is the mass of the black powder, P is the pressure required to separate the section, V is the volume of the section, R is the gas constant for black powder, and T is the temperature of the gas produced by the black powder combustion.

The ejection charges will be composed of 777 FFFg granular powder. This granular powder was chosen due to its finer grain size, allowing for quicker combustion, cleaner breaks, and less leftover black powder residue. The gas constant for black powder during combustion is 22.16 ft-lbf/lbm-°R and the combustion temperature is 3307°R. The empty volume of the main parachute bay with shock cord and the main parachute is estimated to be 277.28 in^3 and the empty volume of the drogue parachute bay with the shock cord and the drogue parachute is estimated to be 355.67 in^3.

A secondary ejection charge is also used as a backup for both the main and drogue separation events. As per Team Derived requirement RF.9, this secondary charge will be 0.5 grams larger than the primary charge to ensure separation in the event of a failure to separate from the primary charge. Table 3.10 below outlines the calculated primary and secondary charges for the main and drogue parachute deployment events.

Table 3.10: Ejection Charge Sizing

Separation Event	Volume of Section	Primary Charge Mass	Secondary Charge Mass
Drogue Parachute Deployment	355.67 in^3	2.75 g	3.25 g
Main Parachute Deployment	277.28 in^3	2.15 g	2.65 g

These ejection charge values were verified using Chuck Pierce's Black Powder Ejection Charge Calculator.

As per NASA Requirement 3.2, a ground ejection test is performed to confirm the sizing of the primary ejection charges prior to each launch. Each ejection test consists of configuring the rocket into its final launch day configuration and testing the separation events on the ground. In the event that the launch vehicle fails to separate from the calculated charges, an addition 0.2 grams are added to the ejection charges and the test is repeated until success.

3.5 Leading Recovery Design

3.5.1 Avionics Bay

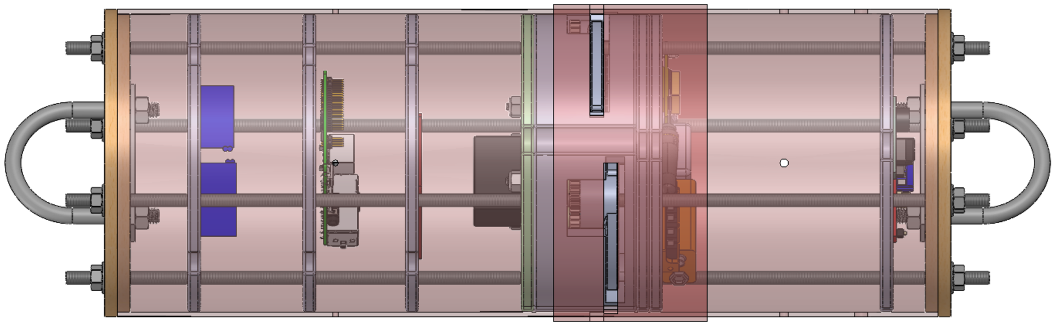


Figure 3.42: Full AVAB

As shown in Figure 3.42 above, the AVAB contains all the avionic electronics (right) integral to the recovery subsystem, as well as the full Air Brakes payload (left). More information on the Air Brakes system can be found in Section 5.

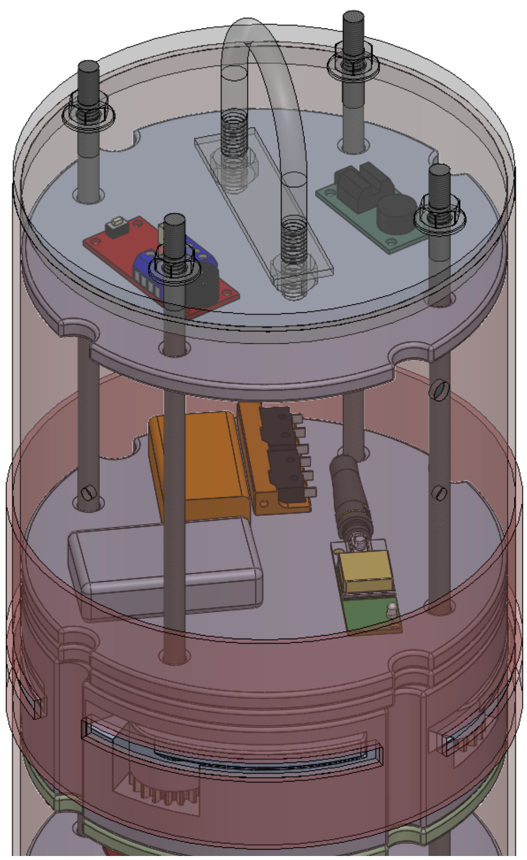


Figure 3.43: AV Bay

As pictured in Figure 3.43, the AV Bay is contained within the forward section of AVAB. Within the AV Bay is one Perfect Flite StratologgerCF acting as the primary altimeter, one Altus Metrum EasyMini acting as the secondary altimeter, one Lab Rat Rocketry Double Pull Pin Switch (which contains two micro switches), one Eggfinder Mini, one 9V Alkaline Battery and one 7.4V 1000 mAh LiPo Battery. Each of the altimeters are powered by separate batteries on independent circuits separated from all other payload and Air Brakes electronics.

The flat plate design allows 4 full in. of separation between the recovery altimeters and the Eggfinder Mini, which is the nearest frequency transmitting device. This flat plate design also allows for 6.68 in. of separation between the top of the Air Brakes servo and altimeters. The team also intends to cover the base of the top AV Bay plate with aluminum foil for further signal shielding.

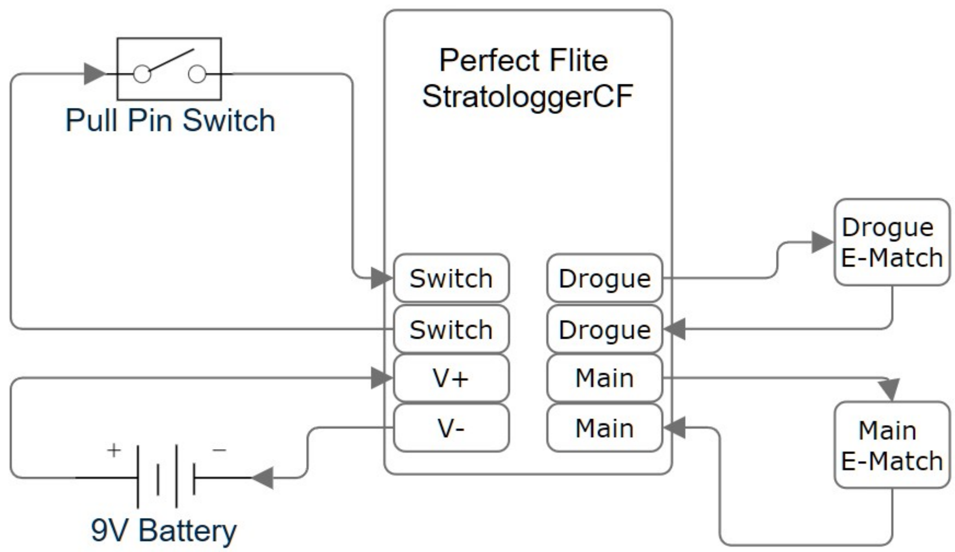


Figure 3.44: Primary Altimeter Wiring Diagram

Figure 3.44 above shows the wiring diagram for the primary altimeter. This circuit is independent from all other avionics electronics and is powered by a manufacturer recommended 9V battery. The StratologgerCF has two terminal blocks mounted on its PCB that threaded wire is clamped down into the make all the electrical connections to the altimeter. The board also has a built in switch that one of the micro switches is connected directly to as shown in the diagram.

3.5.2 Recovery Electronics

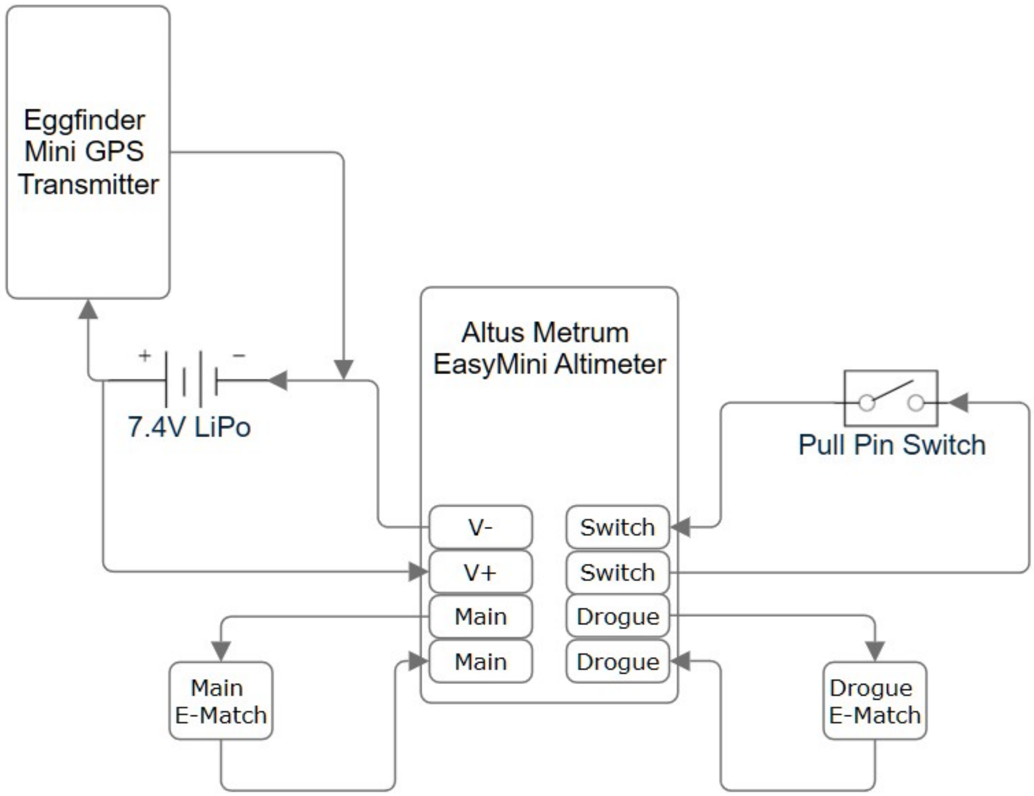


Figure 3.45: Secondary Altimeter & GPS Wiring Diagram

Figure 3.45 above shows the wiring diagram for the secondary altimeter as well as the tracking GPS. Both the Altus Metrum Altimeter and the Eggfinder Mini are powered, in parallel, by one 7.4V 1000 mAh LiPo battery. Like the StratologgerCF, the EasyMini has two terminal blocks mounted on its PCB that threaded wire is clamped down in to make all the electrical connection to the altimeter. One of the micro switches is connected to the built in switch on the EasyMini, meaning that the Eggfinder GPS is not controlled by this switch and will be turned on as soon as the battery is plugged in. The Eggfinder Mini is connected to the battery with a single terminal block that threaded wire is clamped down in.

3.5.3 Recovery Events

The first recovery event is triggered at apogee when the primary altimeter ignites a 2.75 g black powder charge in the drogue parachute bay. One second later, the secondary altimeter ignites a secondary 3.25 g black powder charge to ensure separation. This separation event causes the deployment of the Fruity Chutes 18" Elliptical drogue parachute. The drogue parachute is tethered to the Fin Can and AVAB with 240 in. of 5/8" Kevlar shock cord as shown in Figure 3.40.

The second recovery event is triggered at 550 ft. when the primary altimeter ignites a 2.15 g black powder charge in the main parachute bay. At 500 ft., the secondary altimeter ignites a secondary 2.65 g black powered charge to ensure separation. This separation event causes the deployment of the Fruity Chutes Iris Ultra 96" Compact main parachute. The main parachute is tethered to the Nose Cone and AVAB with 226 in. of 5/8" Kevlar shock cord as shown in Figure 3.41.

For the 41.52 sec from apogee at 4800 ft., until main parachute deployment at 550 ft., the 31.69 lbm launch vehicle is descending at 102.35 fps under the drogue parachute. This gives the heaviest section of the launch vehicle a kinetic energy of 2314.86 ft-lbf under drogue descent. For the 34.87 sec from main parachute deployment, to landing, the launch vehicle is descending at 15.77 fps under the main parachute. This gives the heaviest section of the launch vehicle a kinetic energy of 54.97 ft-lbf at landing.

3.5.4 Recovery Launch Preparation

Prior to every launch, all altimeters are tested to ensure they are functioning properly. To test the altimeters, an altimeter testing board is connected to the main and drogue output terminal blocks on each of the altimeters. The altimeter testing board houses two independent circuits with individual LEDs that serve as the simulated e-matches for the purpose of the altimeter tests. Since the team does not want to waste e-matches during testing, the LEDs will light up to simulate e-match ignition. The altimeter and testing board are placed in a pressure chamber created by the team. Pressure is removed from the chamber to simulate vehicle ascent and slowly added back in to simulate vehicle descent. Only after each of the altimeters are tested and verified to be functioning correctly, they are mounted to the AV Sled and inserted into the AVAB.

On launch day, the altimeters and tracker are not armed until the vehicle is standing upright on the launch pad immediately prior to launch. The altimeters must be armed prior to the insertion of the motor igniter to ensure the vehicle has an active recovery system in the event of premature motor ignition. The altimeters are armed one at a time so that the audible beep signals emitted by each altimeter are discernible from each other and proper arming of each altimeter can be verified. Once both altimeters are armed properly and the GPS has acquired signal, the recovery system is active and ready for launch. In the event there are any issues in the recovery activation procedure, the launch will be halted until the functionality of all recovery avionics systems can be confirmed.

3.6 Mission Performance Predictions

3.6.1 Launch Day Target Apogee and Flight Profile Simulations

The target apogee for the launch vehicle is 4800 ft. This is conditional upon the use of a L1520T Motor and Air Brakes deployment. Air Brakes will be discussed further in section 5.3.4. This calculation was completed using various simulations, following Team-Derived requirement LVF.10. The methodology of the analysis is detailed below in Figure 3.46.

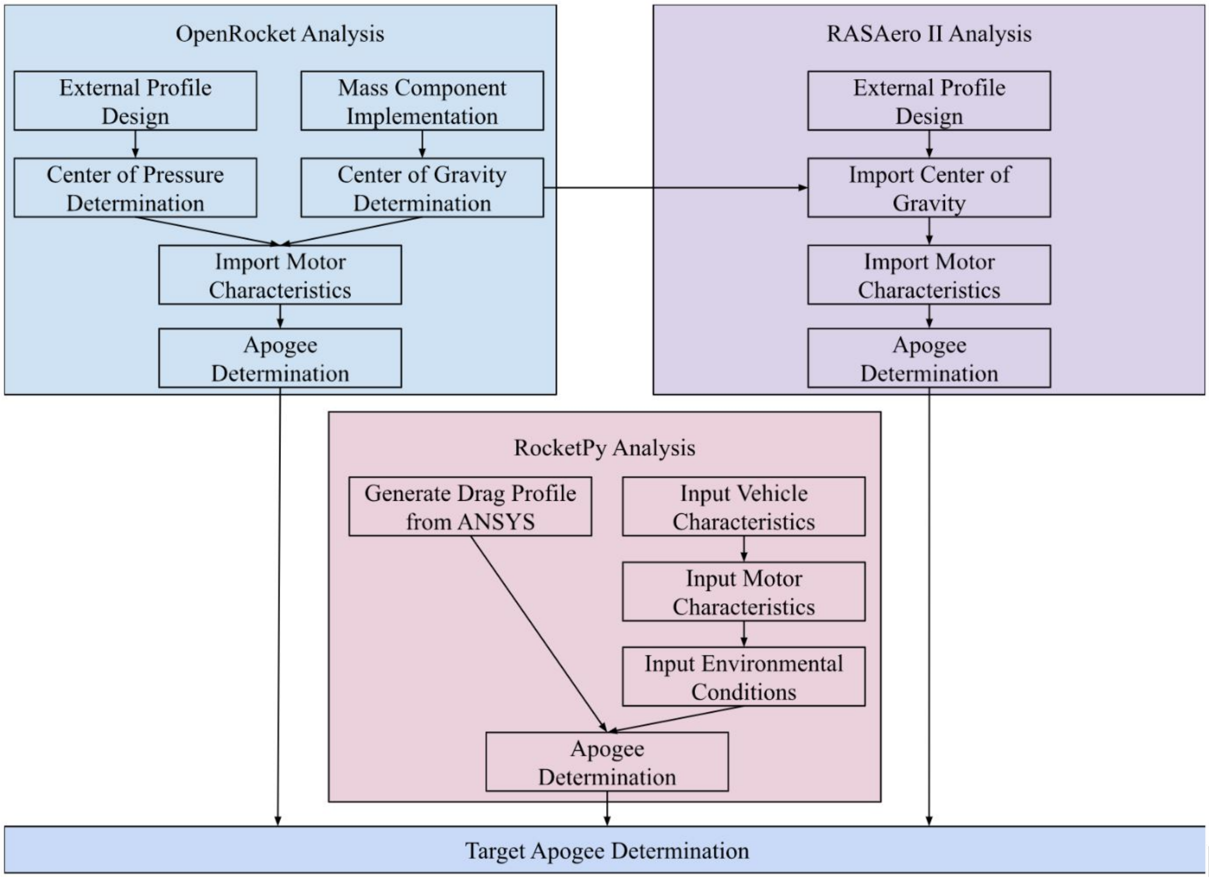


Figure 3.46: Methodology for launch vehicle Apogee Determination

The simulations run will use the conditions outlined in Table 3.11 for apogee calculations.

Table 3.11: Defined Launch Conditions

Parameter	Value	Justification
Wind Speed	10 mph.	Enveloping Value
Launch Rail Length	12 ft.	NASA 1.12
Launch Rail Cant	5°	NASA 1.12

OpenRocket Prediction

OpenRocket was used as a way to determine the Stability Margin of the launch vehicle based on the layout of the mass elements and payload. The mass elements of the vehicle were added into the correct location along the launch vehicle. Masses and locations were confirmed by the relevant subsystem members. Motor options were selected by utilizing the internal motor catalog in OpenRocket. Using these factors, center of gravity, center of pressure, stability margin, and apogee could be predicted for each motor. The motor chosen, the L1520T, was selected using this software along with other sources and factors. Motor selection is discussed further in Section 3.3.13. A model of the full scale launch vehicle from OpenRocket is shown below in Figure 3.47.

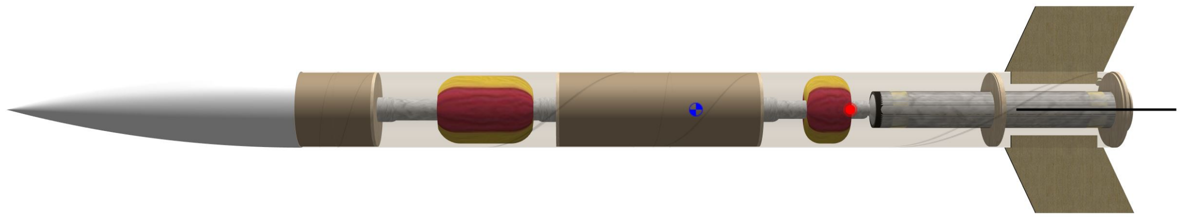


Figure 3.47: 3D Rendering of the launch vehicle in OpenRocket

Using the conditions listed in Table 3.11, the flight profile in Figure 3.48, shown below, was created using altitude, velocity, acceleration, and time data from OpenRocket.

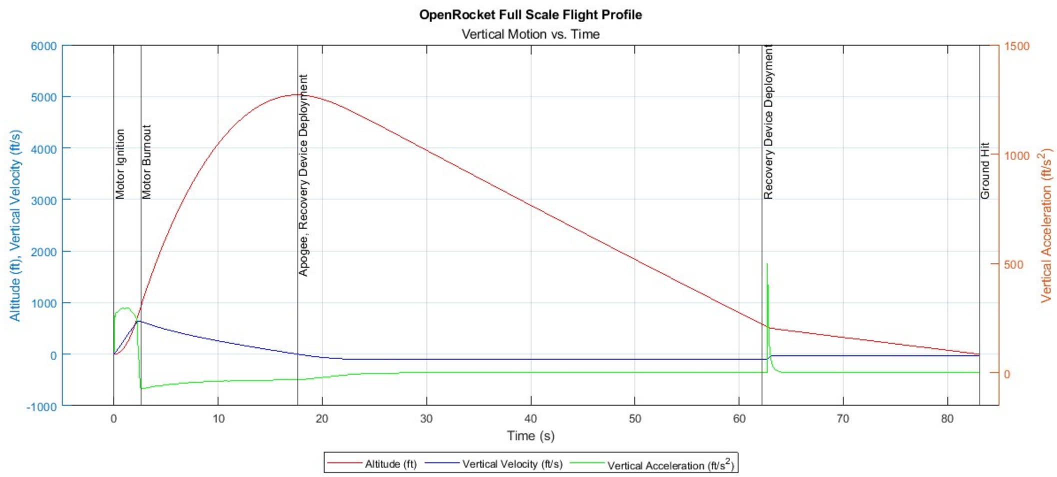


Figure 3.48: Flight Profile Generated from OpenRocket Data

According to this launch profile, the launch vehicle reaches an apogee of 5022 ft and has a maximum acceleration of 9.52 G's. The maximum velocity is 653 fps, or Mach 0.5734 at 80° Fahrenheit. This satisfies the Team Derived Requirement LVD.11.

RASAero II Prediction

RASAero II is used as a secondary flight prediction software. RASAero II is a compressible atmosphere model which is able to calculate coefficient of drag and center of pressure as the Mach number changes in simulated flight. The results from this software have been calibrated against NACA wind tunnel and NASA sounding rocket data, improving accuracy.

After designing the geometry and general flight profile in OpenRocket, it can be exported and loaded into RASAero II. RASAero II takes the external geometry from OpenRocket and determines the Center of Pressure. Center of Gravity is taken from OpenRocket mass simulations. After, the motor and launch conditions are defined. This results in the geometry shown below in Figure 3.49.

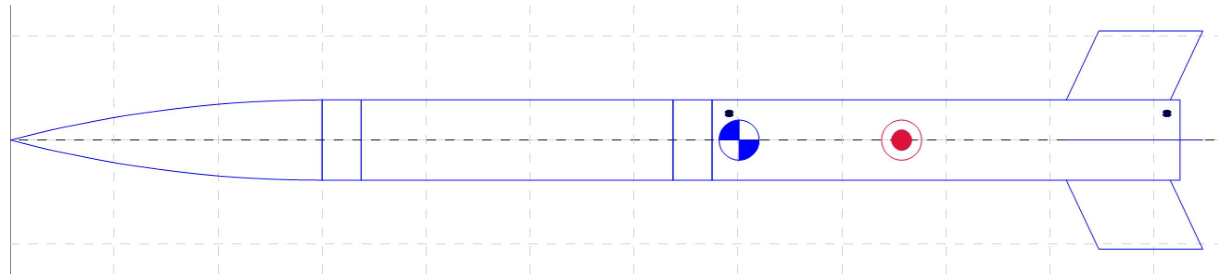


Figure 3.49: RASAero Rocket Geometry

Using the data generated in RASAero II, a flight profile may be generated. The results are shown below in Figure 3.50.

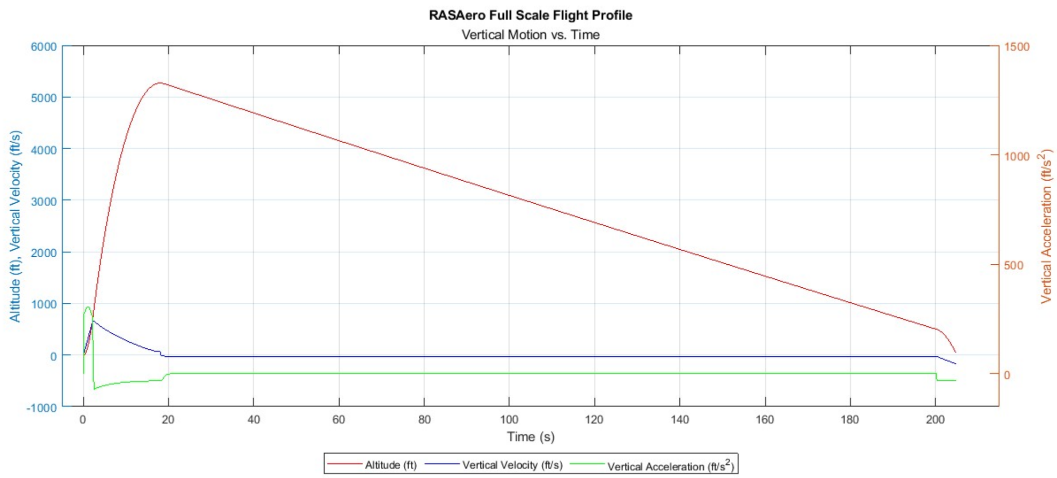


Figure 3.50: RASAero Flight Profile

According to this launch profile, the launch vehicle reaches an apogee of 5269 ft and has a maximum acceleration of 9.47 G's. The maximum velocity is 659.4 fps, or Mach 0.5791 at 80° Fahrenheit. This satisfies the Team Derived Requirement LVD.11.

RocketPy Prediction

RocketPy is an open source software that has been designed to model the flight of a launch vehicle. Unlike OpenRocket and RASAero II, values are manually inputted into the code, allowing for greater customization and control over the launch vehicle. The platform allows for 6 degree-of-freedom simulation, current weather data, and Monte-Carlo launch vehicle optimization. This provides for a higher fidelity prediction of flight trajectory and apogee.

In order to build the launch vehicle in RocketPy, multiple categories of information are required. The motor information is created by importing thrust curve data, defining grain geometry, and defining the nozzle profile. The launch vehicle is designed by inputting nose cone information, fin information, moment of inertia of the launch vehicle, and other geometry. Lastly, the atmospheric conditions are inputted or sourced for use in trajectory prediction. This allows for a prediction with a high level of accuracy, and the potential for day of adjustments for actual weather conditions. A diagram outlining the basic process is shown below as Figure 3.51.

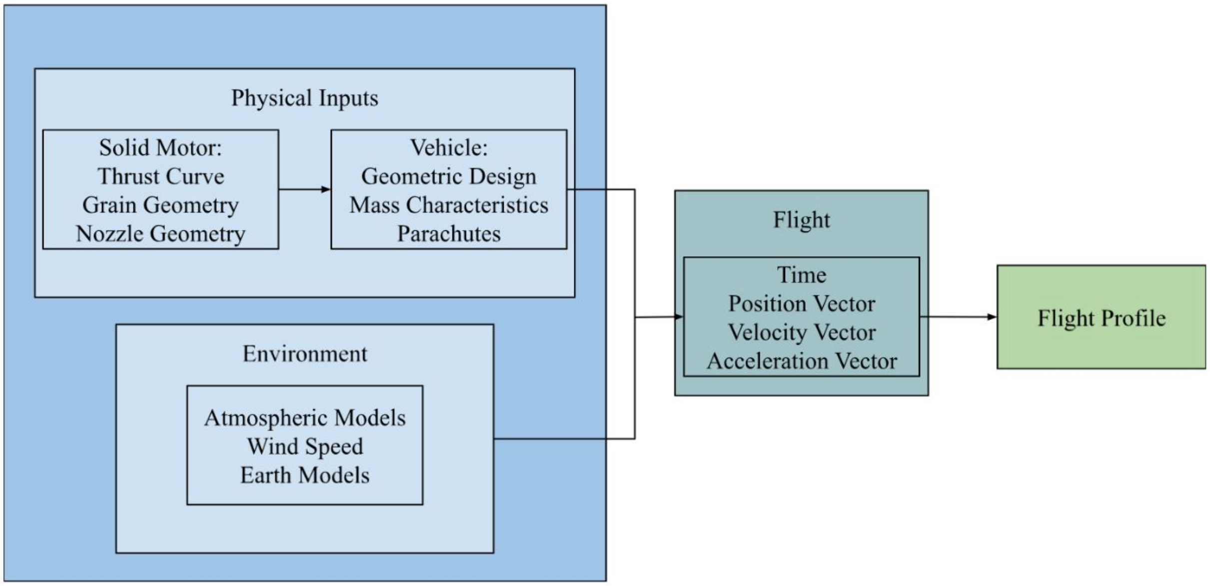


Figure 3.51: RocketPy Simulation Methodology

Another way to improve the accuracy of this simulation is to create a drag profile of the launch vehicle from a software such as ANSYS, as opposed to importing drag data from OpenRocket or RASAero II. Using the SST k-ω model, a drag calculation at various velocities was run in ANSYS Fluent. The velocity profile around the launch vehicle is shown below in Figure 3.52.

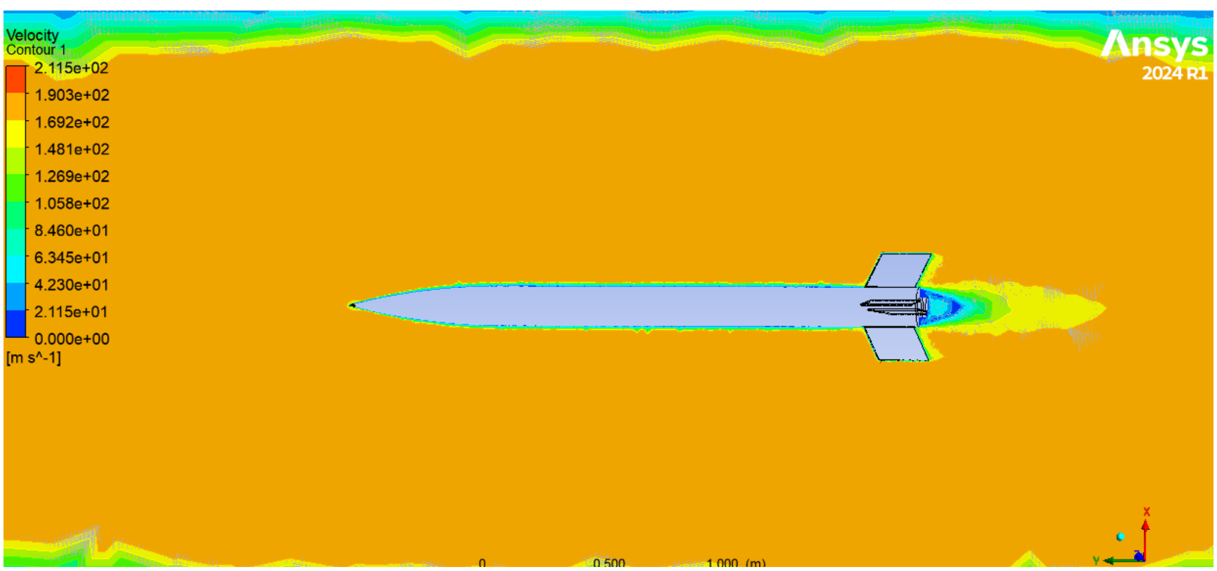


Figure 3.52: Velocity Profile of the launch vehicle at 600 fps

Figure 3.53, below, is a depiction of the iterative approach ANSYS Fluent exercises when determining drag force on the launch vehicle.

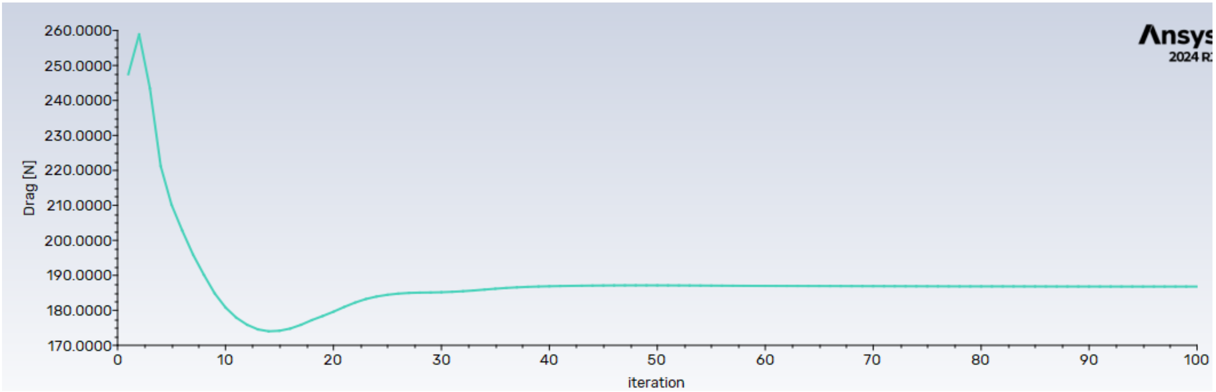


Figure 3.53: Iterative Process to Determine Drag

The drag results from ANSYS vary from those provided by OpenRocket and RASAero II. Figure 3.54, below, helps to illustrate the difference between the simulation suites. These differences can have significant effects on the apogee predictions, even if apogee is not primarily driven by drag influence.

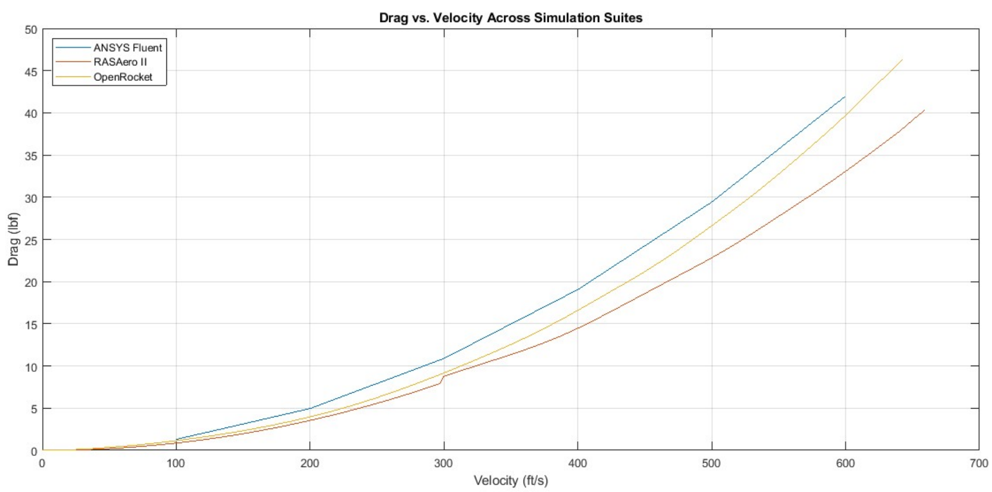


Figure 3.54: Drag vs Velocity for Simulation Suites

Once the drag calculations are complete, the Coefficient of Drag can be calculated against the Mach number using environmental conditions. These values were calculated at 80° Fahrenheit. Below is the resulting Coefficient of Drag Curve for the launch vehicle, Figure 3.55. This was implemented into the RocketPy for improved simulation accuracy.

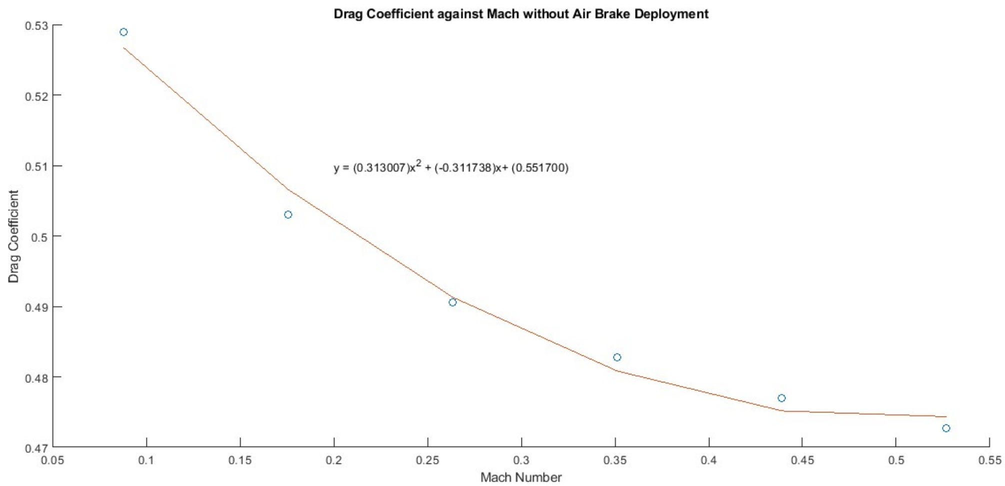


Figure 3.55: Coefficient of Drag Curve

Using this information and the aforementioned setup, RocketPy yields the following flight profiles. A 3D model is shown as Figure 3.56 and an analysis including velocity and acceleration is shown as Figure 3.57.

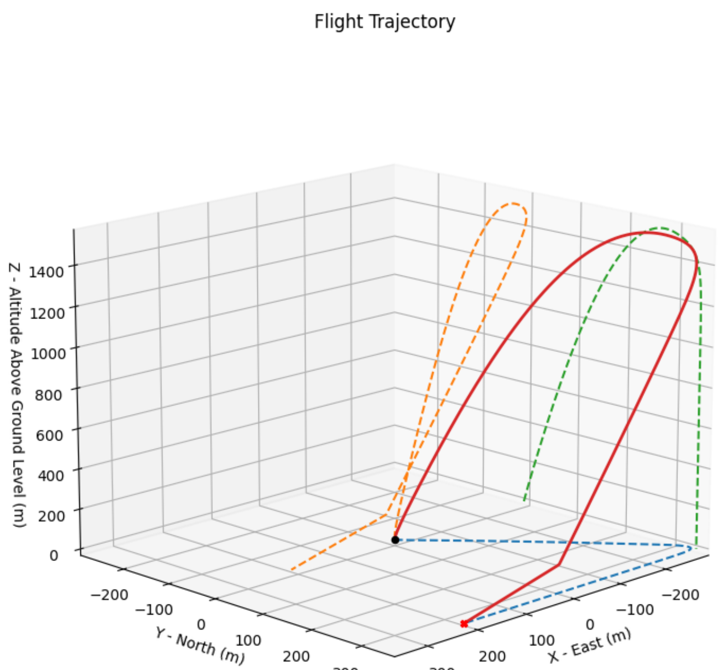


Figure 3.56: 3D Flight Profile

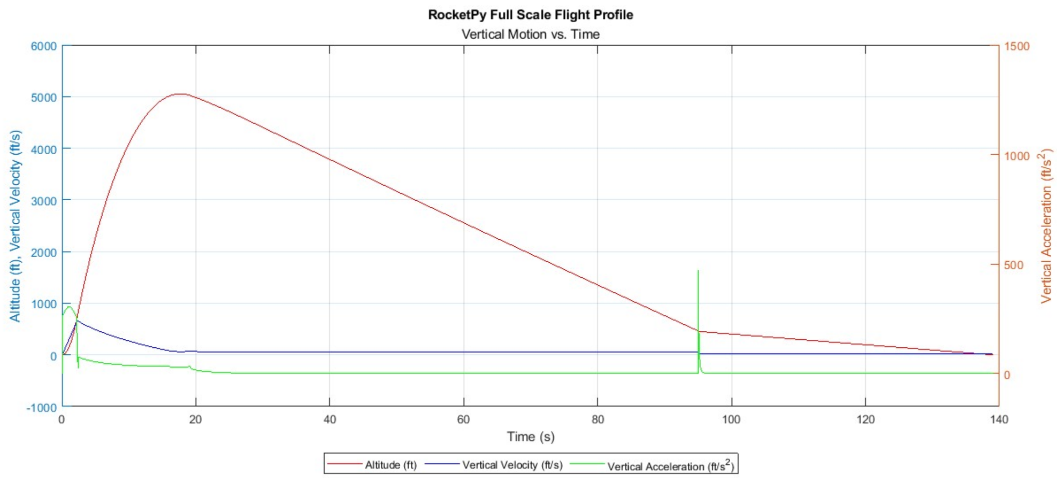


Figure 3.57: RocketPy Flight Profile

According to this launch profile, the launch vehicle reaches an apogee of 5054 ft and has a maximum acceleration of 9.52 G's. The maximum velocity is 653.75 fps, or Mach 0.5741 at 80°Fahrenheit. This satisfies the team derived requirement LVD.11.

Verification Calculations

In order to verify that the values provided by the simulation suites are reasonable, the Fehskens-Malewicki equations are utilized. The process and required equations are outlined below.

The drag force is expressed by the constant K:

$$k = \frac{1}{2}\rho C_d A \tag{13}$$

The relationship between the thrust, drag, and gravity, can be expressed as q:

$$q = \sqrt{\frac{T - Mg}{k}} \tag{14}$$

The relationship the drag force and q per unit mass, is expressed as:

$$x = \frac{2kq}{M} \tag{15}$$

By using Equations 14 and 15, the maximum velocity of the launch vehicle is found.

$$v_{max} = q\frac{1 - e^{-xt}}{1 + e^{-xt}} \tag{16}$$

The altitude of motor burnout, can be determined by Equation 17. This is where the force of drag and gravity start to be the main forces acting on the vehicle.

$$Z_{burnout} = -\frac{M}{2k}\ \mathrm{ln}\left(\frac{T - Mg - kv_{max}^2}{T - Mg}\right) \tag{17}$$

Equation 18 gives the total coast distance of the launch vehicle after burnout.

$$Z_{coast} = \frac{m \ln\left(\frac{mg+kv^2}{mg}\right)}{2k} \tag{18}$$

Last, apogee is determined by the sum of the coast distance and height of burnout.

$$Z_{apogee} = Z_{burnout} + Z_{coast} \tag{19}$$

Equations 13 through 19 are used to calculate the values found in Table 3.12 below.

Table 3.12: Apogee Calculation Constants and Results

Constant	Variable Name	Value	Units
M	Power On Average Mass	1.17486	Slug
m	Power Off Average Mass	0.9106718	Slug
g	Gravitational Acceleration	32.174	fps^2
t	Motor Burn Time	2.6	s
T	Average Thrust	352.46	lbf
ρ	Air Density	0.002377	$slug/ft^3$
A	Launch Vehicle Frontal Area	0.2076	ft^2
C_d	Drag Coefficent	0.53	NA
Equation	**Result**		**Units**
k	0.00013077		slug/ft
q	1551.208		ft^2/s^2
x	0.32344		fps^2
v_{max}	653.06		fps
$Z_{burnout}$	876.39		ft
Z_{coast}	3711.45		ft
Z_{apogee}	4587.84		ft

The analytical apogee analysis yields a value lower than that of all analyses. It yields a percent difference of 8.7 compared to that of the RocketPy analysis. These differences can be attributed to launch conditions, thrust timing, weight distribution, or other factors. However, this does show that the analyses are within a reasonable range of values when compared to the first order approximation.

3.6.2 Air Brakes Affect on Apogee Prediction

This launch vehicle is incorporating Air Brakes as a part of it's design and apogee determination. The target apogee for this vehicle is 4800 ft., and its apogee without Air Brakes is predicted to be 5054 ft. This implies that the Air Brakes system will need to take approximately 250 ft. off of the apogee of the rocket. In order to prove the feasibility of this value, a predictive algorithm was created in RocketPy. Similarly to that of the launch vehicle without Air Brakes, a drag curve was developed from ANSYS using a model where the Air Brakes were fully deployed. A velocity profile around the vehicle with Air Brakes deployed is shown below as Figure 3.58.

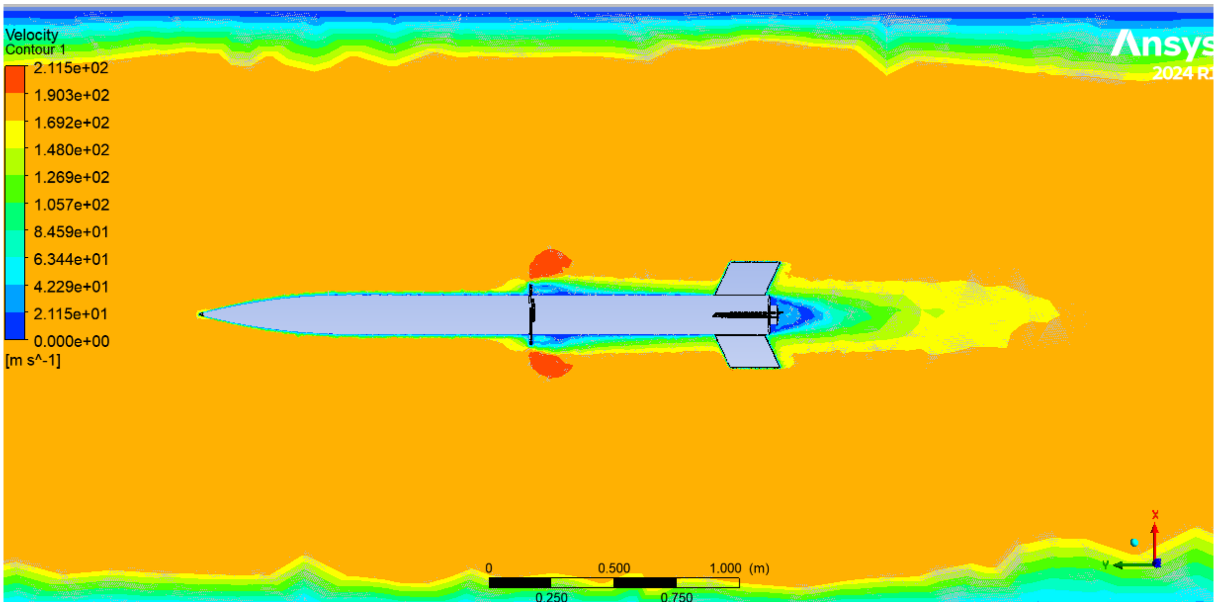


Figure 3.58: Velocity Profile of the Vehicle with Air Brakes Deployed

Drag calculations over the vehicle with Air Brakes deployed at various velocities were completed in ANSYS. A coefficient of drag against mach curve was created from this data, assuming a temperature of 80° Fahrenheit. The curve is shown below in Figure 3.59.

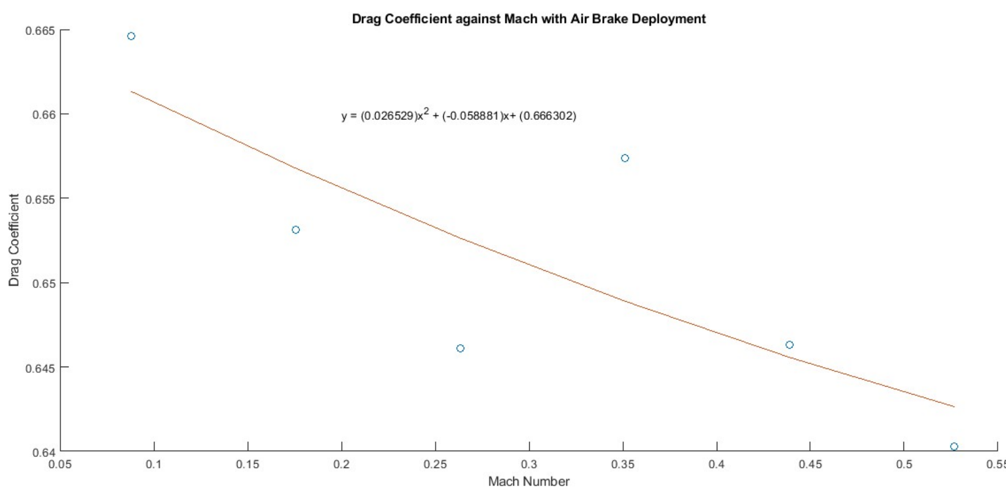


Figure 3.59: Coefficient of Drag Curve with Deployed Air Brakes

It should be noted that this curve does not fit the trend line as well as the previous drag curve for the vehicle without Air Brake deployment. As the design reaches CDR maturity, higher quality meshing and more iterations will yield a more trustworthy curve. However, it is shown that the deployment of the Air Brakes increases the coefficient of drag of the launch vehicle by around 0.1 consistently. The above drag curve was imported into RocketPy and used to predict apogee at different levels of deployment. The curve of deployment against apogee is shown as Figure 3.60 below.

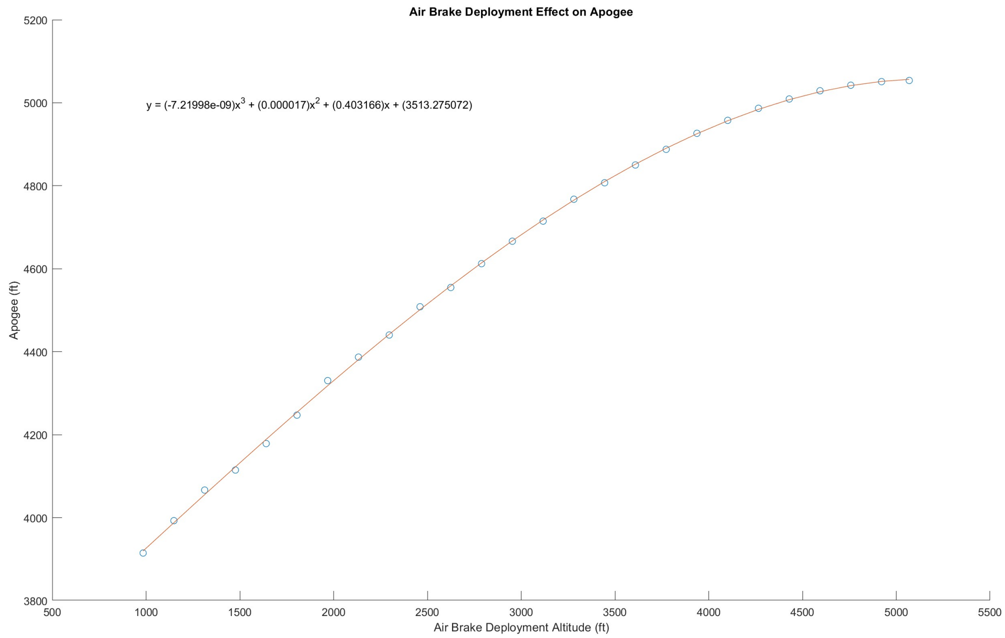


Figure 3.60: Apogee against Air Brake Deployment Level

This curve yields a line of best fit that can be used to estimate Air Brake deployment to reach a specific apogee. From this, it is estimated that deployment at 3407 ft. will yield the target apogee, 4800 ft.

3.6.3 Payload Weight Affect on Apogee Prediction

As a design is maturing, it is important to be aware of the impact different factors may have on the apogee of the launch vehicle. Payload mass can have a significant impact on the apogee of the vehicle, and can result in the need for more ballast to adjust the stability. The more these changes occur, the more the overall flight profile will be impacted. A study of payload masses from 0 lbs to 10 lbs was completed. The payload is currently predicted to be 2 lbs. and 10 lbs is the bounding value, as it would decrease apogee below 4000 ft, earning no apogee points. The impact on stability margin was also noted in this study, since the change in weight and moment of inertia would impact this. It should be noted that the center of gravity was modified as the mass was modified to ensure accurate predictions. The figure below displays the relationship between apogee, stability, and payload mass.

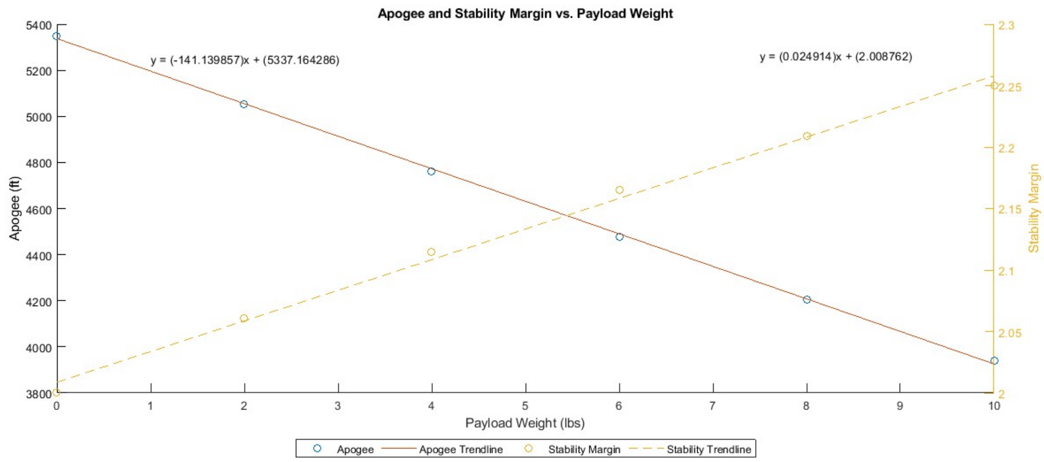


Figure 3.61: Apogee and Stability as a Function of Payload Mass

The trend yielded for apogee loss due to payload mass increase is a linear trend. This implies that for every pound of payload mass, apogee will decrease by 141.14 ft.

3.6.4 Wind Affect on Apogee Prediction

It is also important to analyze the impact of wind speed on the launch vehicle. The day of wind speed could drive the need for ballast adjustment on the day of launch, or a reduced apogee due to the wind impact. The figure below shows the relationship between apogee and wind speed.

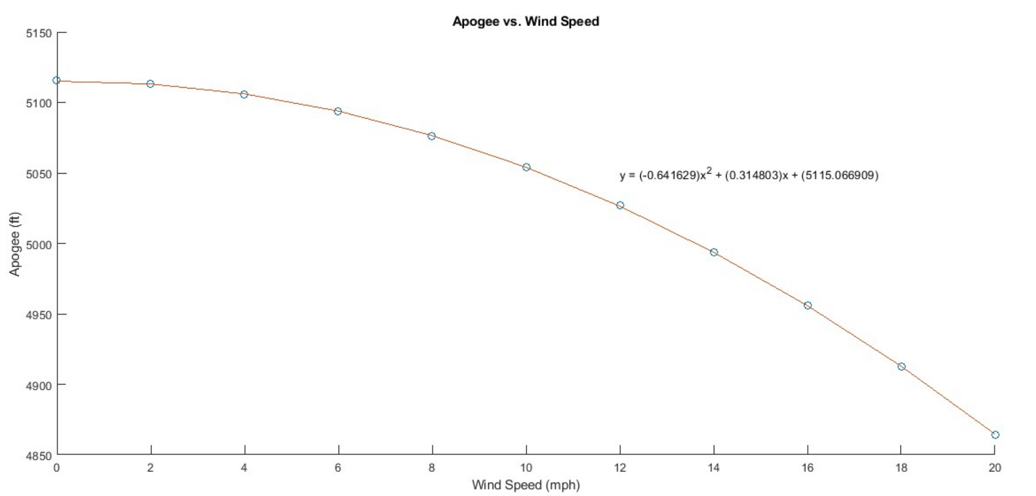


Figure 3.62: Apogee as a Function of Wind Speed

This curve follows a parabolic pattern. This is due to the fact that the pressure on the launch vehicle is related to the velocity squared. The optimal wind speed for apogee prediction is shown to be 10 mph. Depending on the conditions on the day of launch, ballasts may need to be added or removed to reach the targeted apogee.

3.6.5 Stability Margin

In order to predict apogee of the launch vehicle, each simulation suite calculates the center of pressure. This allows these simulations to predict the stability margin of the launch vehicle throughout the flight. OpenRocket, RASAero II, and RocketPy use external geometry inputs to measure Center of Pressure. OpenRocket generates the Center of Gravity and moment of inertia using mass component inputs. RASAero II directly uses OpenRocket Center of Gravity to compute Stability. RocketPy uses the moment of inertia from OpenRocket and user mass inputs to generate Center of Gravity, then computes Stability. The table below gives the calculated stability margin of the launch vehicle at liftoff from each simulation suite.

Table 3.13: Stability Margin Determination Across Software Suites

Software	Center of Pressure	Center of Gravity	Stability Margin
OpenRocket	68.68 in.	56.11 in.	2.04 Calibers
RocketPy	68.46 in.	55.75 in.	2.06 Calibers
RasAero II	68.58 in.	56.11 in.	2.02 Calibers

There is some variation in the values provided by each simulation suite. However, all are above the minimum stability margin outlined in NASA SL Requirement 2.14. The following diagrams are taken from those simulation suites and display their center of pressure and center of gravity placement.

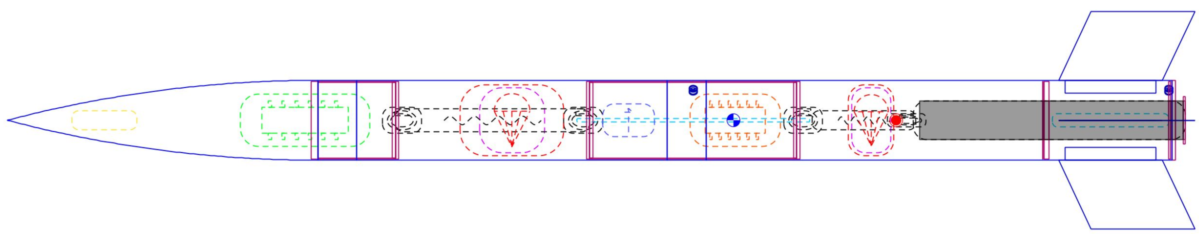


Figure 3.63: OpenRocket Stability Diagram

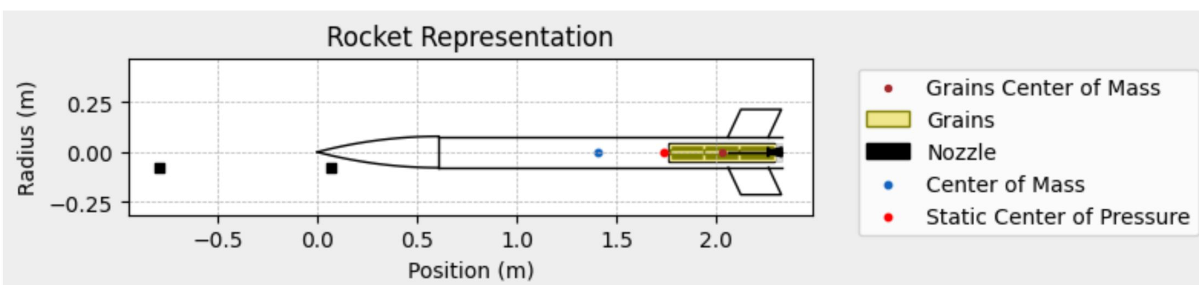


Figure 3.64: RocketPy Stability Diagram

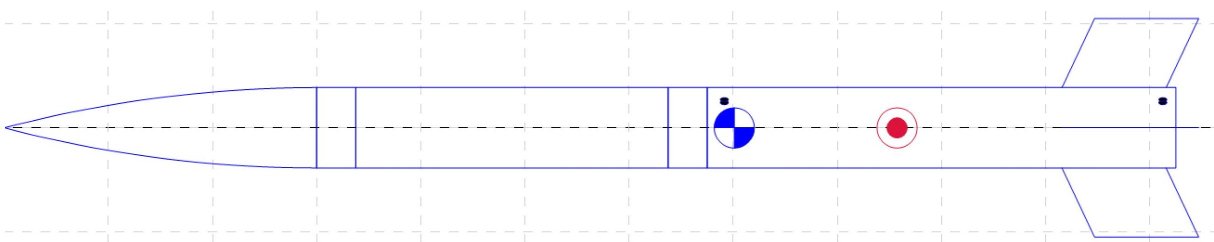


Figure 3.65: RASAero II Stability Diagram

Verification Calculation

In order to check the accuracy of the simulations, Barrowman equations can be used to analytically calculate stability. The relevant equations are shown below, along with the tabulated constants and results.

$$(C_{N_f}) = \left[1 + \frac{R}{S+R})\right] \left[\frac{4N(\frac{S}{d})^2}{1+\sqrt{1+(\frac{2L_F}{C_R+C_T})^2}}\right] \tag{20}$$

$$X_f = X_B + \frac{X_R(C_R + 2C_T)}{3(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T - \frac{C_R C_T}{C_R + C_T}\right] \tag{21}$$

$$X_{CP} = \frac{C_N X_N + C_F X_F}{C_N + C_F} \tag{22}$$

$$SM = \frac{X_{CP} - X_{CG}}{2R} \tag{23}$$

Table 3.14: Stability Margin Constants and Results

Constant	Variable Name	Value	Units
$(C_N)_N$	Nose Cone Coefficient	2	NA
X_N	Nose Cone Length Factor	11.184	in.
R	Body Radius	3.085	in.
S	Fin Span	5.3	in.
N	Number of Fins	4	NA
d	Base of Nose Diameter	6.17	in.
L_F	Fin Midchord Line Length	5.85	in.
C_R	Fin Root Chord Length	8	in.
C_T	Fin Tip Chord Length	8	in.
X_B	Nose to Root Chord LE length	83	in.
X_R	Tail to Root Chord LE length	2.5	in.
X_{CG}	Center of Gravity (RocketPy)	55.75	in.
Equation	**Result**		**Units**
$(C_N)_f$	7.2134		NA
X_f	86.25		in.
X_{CP}	69.96		in.
SM	2.3		Calibers

The Barrowman Equations estimate the center of pressure to be at 69.96 in. from the tip of the Nose Cone. This leads to a stability margin of 2.3 calibers, a percent difference of 11% compared to the RocketPy calculation of 2.06 calibers. This is similar to the predictions from OpenRocket and RocketPy, differing in calculated center of pressure by approximately one inch aft. This shows that the simulated values are reasonably accurate. These calculated margins are all above 2.0, satisfying NASA SL Requirement 2.14.

3.6.6 Addition of Ballast

The launch vehicle is designed such that ballast can be added if needed to maintain the stability of the vehicle if other mass components change in size. Since payload mass is estimated, it is important to leave room for ballast adjustment in the apogee prediction. Since predicted apogee without Air Brake deployment is 5054 ft and target apogee is 4800 ft, there is room to add ballast and still reach the target apogee. The ballast of the current configuration is 0.25 lbs in the Nose Cone in order to maintain stability. As shown in the table below, up to 2 lbs of ballast could be implemented in the Nose Cone before undershooting the target apogee.

Table 3.15: Ballast Impact on Apogee

Ballast Mass	Apogee
0.25 lb.	5054.07 ft.
0.50 lb.	5017.75 ft.
0.75 lb.	4981.54 ft.
1.00 lb.	4945.12 ft.
1.25 lb.	4908.97 ft.
1.50 lb.	4872.99 ft.
1.75 lb.	4836.72 ft.
2.00 lb.	4801.09 ft.

3.6.7 Kinetic Energy

The descent velocity of the launch vehicle was calculated using the equation

$$v_D = \sqrt{\frac{2mg}{\rho A C_d}} \tag{24}$$

where v_D is the descent velocity, m is the mass of the vehicle, ρ is air density, A is the canopy area of the parachute, and C_d is the drag coefficient of the parachute.

The drogue parachute selected for the launch vehicle is the Fruity Chutes 18" Elliptical Parachute. This parachute has an area canopy of 3.020 ft^2 and a coefficient of drag of 0.8427, resulting in a descent velocity of 102.348 fps under drogue. The main parachute selected for the launch vehicle is the Fruity Chutes Iris Ultra 96" Compact Parachute. This parachute has an area canopy of 86.701 ft^2 and a coefficient of drag of 1.236, resulting in a descent velocity of 15.772 fps.

With the descent velocity, the maximum kinetic energy at landing can be calculated with

$$K = \frac{1}{2} m {v_D}^2 \tag{25}$$

where K is the maximum kinetic energy.

Using the a descent velocity of 15.772 fps, Table 3.16 shows the kinetic energy for each of the independent sections of the launch vehicle.

Table 3.16: Kinetic Energy Calculations

Section	Mass (lbm)	Kinetic Energy (ft-lbf)
Nose Cone	7.02	27.137
AVAB + Main Parachute Bay	10.45	40.395
Fin Can + Drogue Parachute Bay	14.22	54.969

Since all sections of the launch vehicle are tethered together during descent, they all fall as the same velocity giving the Fin Can the highest kinetic energy at 54.969 ft-lbf, satisfying the bonus points as per NASA Requirement 3.3.

3.6.8 Descent Time

With descent velocity for the drogue and main parachutes, the total descent time was calculated using the equation

$$t_d = \frac{r_a - r_m}{v_d} + \frac{r_m}{v_m} \tag{26}$$

where t_d is the descent time, r_a is the apogee, r_m is the main parachute deployment altitude, v_d is the drogue descent velocity, and v_m is the main descent velocity.

Assuming a nominal drogue deployment at an apogee of 4800 ft, and a nominal main deployment at 550 ft, the total descent time was calculated to be 76.40 sec, satisfying the bonus points for NASA Requirement 3.12.

3.6.9 Drift Distance

With the total descent time and the wind speed, the total drift distance of the launch vehicle can be calculated with the equation

$$r_{drift} = t_d v_w \tag{27}$$

where r_{drift} is the total drift distance and v_w is the wind speed.

Table 3.17 shows how the drift distance of the launch vehicle from the launch pads will vary with wind speed up to a maximum of 20 mph.

Table 3.17: Wind Drift Distance

Wind Speed (mph)	Drift Distance (ft)
0	0
5	560.25
10	1120.50
15	1680.75
20	2241.00

These calculations assume that the launch vehicle will constantly drift with the wind and would reach apogee directly above the launch pad. Since the launch vehicle will fly into the wind and the wind will not be constantly blowing, these calculations are an upper bound for maximum drift distance, satisfying NASA Requirement 3.11.

4 Payload Criteria

4.1 Payload Objective

The primary objective of the STEMCRaFT payload is to safely house four STEMnauts while recording and processing various data points via external sensors. Upon landing, the STEMCRaFT must initialize a brief transmission that will relay the necessary data points to a NASA receiver. Transmission must end automatically after five minutes with the option for a remote override. Following the transmission, the STEMCRaFT must be recovered and all four STEMnauts must return home safely.

Throughout the launch vehicle's flight, the payload is tasked with recording and, upon landing, transmitting between 3 and 8 pieces of STEMCRaFT data along with landing coordinates. These data points, including the required landing coordinates are as follows:

- Approximate landing coordinates
- Temperature at the landing site
- Apogee of the rocket
- Payload battery or power status
- Orientation of the STEMnauts
- Time of landing
- Maximum velocity of the vehicle
- Landing velocity and G-forces sustained
- Calculated survivability of the STEMnauts

The payload uses five specialized sensors to capture the necessary data for transmission. An Inertial Measurement Unit (IMU) is used to gather data such as maximum velocity, landing velocity, and the orientation of the STEMnauts, while also providing data related to their survivability. A barometric pressure sensor measures the altitude and temperature, and provides the payload computer with real-time information about the launch vehicle's status throughout its flight. Additionally, a GPS module records the approximate landing coordinates of the vehicle for use in its transmission. A real-time clock (RTC) provides an accurate time throughout the flight, and a voltage sensor monitors the payload's power status throughout the flight. Together, these sensors provide the necessary data points in order to transmit all of the 8 possible data points.

4.2 Payload Success Criteria

Table 4.1: Payload Success Criteria

Success Level	Payload Aspect	Safety Aspect
Complete Success	The STEMCRaFT accurately collects all 9 pieces of data AND successfully transmits the data to the NASA receiver.	No one is harmed or injured during payload operations, with all risks effectively mitigated.
Partial Success	The STEMCRaFT collects less than 9 pieces of the data but still transmits at least 3 pieces of accurate data to the NASA receiver.	No one is harmed during payload operations, but there are moments that pose potential risks to individuals.
Partial Failure	The STEMCRaFT transmits less than 3 pieces of accurate data to the NASA receiver.	Some risks are not fully mitigated, leading to minor injuries to individuals during payload operations.

Total Failure	The STEMCRaFT does not transmit any data to the NASA receiver OR the STEMCRaFT transmission does not shut off.	Unmitigated risks result in major injuries to individuals during payload operations.

4.3 Potential Payload Designs

One of the primary decisions affecting the design of the payload is the number of pieces of data that the payload should aim to collect and transmit. For our primary design, the team has decided to pursue each of the 8 potential pieces of data that were provided as options. The primary justification for pursuing this goal is the desire for a comprehensive payload, and the belief that the benefit of collecting every piece of data outweighs the additional workload and risk. Additionally, many of the sensors being used are capable of providing data points relevant to multiple of the transmission options, resulting in minimal additional workload in achieving 8 data points as opposed to the minimum.

According to the team's understanding of the payload challenge scoring; recording, and transmitting the maximum pieces of data will result in a better scoring payload performance than recording and transmitting the minimum pieces of data. This is contingent on having no data points fail. If a data point fails to be recorded or transmitted, then the payload's score will be lower than a payload that transmits fewer pieces of data, but without failure. Despite the increased risk of attempting to record and transmit more pieces of data, a payload that successfully transmits more pieces of data, without failure, would be viewed as having a better payload objective performance.

Before deciding to design the payload to attempt to record the maximum number of data points, the alternative of recording fewer data points was considered. In comparison to recording and transmitting 8 pieces of data, this route would provide reduced risk for failure. However, due to the teams confidence in our leading payload design, discussed in Section 4.5, the team decided that this was not an optimal solution. This primarily came down to the reasoning that the risk of a single data point failing did not outweigh the benefit of transmitting all of the potential data points.

4.3.1 Antenna Type

Quarter-Wave Ground Plane Antenna

The quarter-wave ground plane antenna is a popular choice due to being cheap and simple to build. This makes it a great option for local communication. The benefit of this antenna is how easy it is to implement, because its compact size allows it to be used in more restrictive applications. A big downside of this antenna is the limited range due to a lower gain. This aspect, combined with the lower transmission power of 5 watts, makes this antenna less suitable for the 2025 NASA SL payload challenge. Another issue that makes this antenna less than ideal is that it requires a ground plane to function properly. This increases the complexity of shielding the electronics and creating a viable ground plane in the confines of the rocket.

J-Pole Antenna

The J-pole antenna is also a common choice for antenna, offering longer ranges than the quarter-wave antenna. The construction of the antenna can be a bit complicated, but its reliable performance more than makes up for this aspect. Standing at roughly 58 in., this antenna would provide a competitive gain and it is designed without a ground plane, further simplifying the integration into the payload system. The J-Pole falls short due to its sensitivity to orientation and bandwidth. The height of the antenna means that there will be complications with fitting it into the launch vehicle, which would require severe changes to the launch vehicle design to implement.

5/8 Wave Antenna

The 5/8 wave antenna is favored for its higher gain compared to quarter-wave models, offering better range and more effective communication over longer distances. The longer size of the antenna makes it more efficient at transmitting over a longer range due to a higher gain. However, the trade-off for this increased gain is the antenna's increased length which can make integration into the rocket more difficult. The 5/8 wave antenna often requires a loading coil to function correctly, adding to its complexity.

Yagi-Uda Antenna

The Yagi-Uda antenna is commonly known for its high gain and directivity, which makes it a powerful antenna for long-range communication. It is able to focus signals in a specific direction, increasing range and effectiveness. This makes it a popular choice for applications where distance is important such as in ham radio. However, the Yagi-Uda comes with significant trade offs. It is relatively large and heavy which can complicate installation, especially for portable or space-constrained setups. Additionally, the directionality of the antenna would require the ability to aim the antenna, further complicating the transmission process.

4.3.2 Transmission Methods

Text-to-Speech FM Modulation

Text-to-speech (TTS) is a one of the leading transmission formats under consideration for data transmission. This approach uses software-generated TTS audio to relay the payload data points, transmitted via the AIOC, as detailed in Section 4.3.3. The primary advantages of employing TTS (via FM modulation) include the relatively straightforward implementation, and broad compatibility across a wide range of devices.

APRS

APRS (Automatic Packet Reporting System) is a widely utilized method for transmitting real-time telemetry and positional data over amateur radio frequencies. Its capabilities are well suited for the data transmission requirements outlined within the payloads objective's. The primary benefits of utilizing APRS as a means of encoding data are its widespread amateur use, and its capabilities that closely align with the payload desired objective.

The widespread use of APRS within the amateur radio community means there are many libraries and public tools available for encoding and transmitting APRS signals. This includes support for software-based TNCs (Terminal Node Controllers), such as Direwolf, which allow standard transceivers to be used for APRS transmission. Additionally, many modern transceivers are equipped with built-in APRS tools, and the designated NASA transceiver, the FTM-300DR, is designed to receive APRS signals. This results in highly compatible transmission in terms of both reception and transmission.

4.3.3 Transmission Hardware

Through research, the team has found two leading candidates for transmitters that would encompass the hardware side of data transmission. The primary limitations in selecting the transmitter were the size, frequency range, price, and signal strength. Despite both of these options fitting within the limitations of the challenge, there are still distinct advantages and disadvantages between each of the options that were considered. The Si4464 Transceiver chip was selected to be used in the leading payload design.

Table 4.2: Transmission Specification Comparison

Specification	AIOC with 2M Handheld Radio	Si4464 Transceiver Chip
Frequency Range	144–148 MHz	119–1050 MHz
Modulation	FM, APRS	FSK, GFSK, OOK, 4GFSK, ASK, APRS
Power Output	5W	100 mW unamplified
Operating Voltage	7.2V–8.4V (battery powered)	1.8V–3.6V
Current Consumption	1.5A (transmitting at full power)	85 mA (for high-power transmission)
Communication Range	5–10 miles (depending on environment)	1 Mile (dependant on amplification)
Cost	$75-125	$15

The primary difference between the two options, discussed in greater detail below, are their physical footprint and implementation complexity. The 2M handheld offers a significantly more transmission-ready piece of hardware, but comes in a much bulkier form and relies on an external battery. Alternatively, the Si4464 provides a much smaller footprint but would significantly increase the complexity of both the hardware setup and software implementation.

AIOC (Ham Radio All-in-one-Cable.)

Figure 4.1: AIOC Ham Radio All-in-one-Cable

One of the leading transmission hardware solutions currently in use is the Ham Radio All-in-One Cable (AIOC). This cable provides a direct interface between the payload computer and a handheld radio. Through this direct connection, combined with software on the payload computer, the payload may convert audio files into radio transmissions. This hardware option offers a design that takes advantage of a handheld 2M radio, resulting in reduced complexity in terms of hardware.

To utilize the AIOC for transmission, the payload computer must generate an audio file that contains the necessary data. This process requires the audio file to follow specific formatting rules: it must start with a designated team member's call sign, include verbal callouts for each data point, and conclude with the call sign. This can be achieved through the use of software libraries capable of converting text to speech, and providing the required information to the text-to-speech program. Once the audio file is prepared, it can be transmitted by playing it through the handheld radio using the AIOC interface.

Effectively, the AIOC allows for the use of a handheld radio to use the payload computer's audio output as the input for the radio's microphone. By using this function, the system only requires the audio file to be played using a virtual sound card connected to the AIOC. This greatly reduces the hardware complexity and the encoding complexity required to transmit the required data points.

SI4464

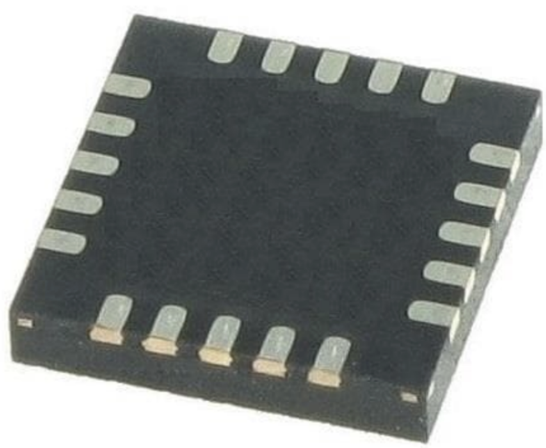


Figure 4.2: Silicon Labs Si4464 Transmission Chip

The Silicon Labs Si4464 is a sub-GHz transceiver chip that offers a versatile solution for RF transmission. It is designed for integration into embedded systems, making it an ideal choice for transmitting data on the 2M band, as per NASA Requirement 4.2.3. Key advantages of using the Si4464 include its low power consumption, enhanced transmission flexibility, and compact form factor, making it the preferred choice for a compact and optimized payload.

The Si4464 is a low active-power transmission chip, which is a significant advantage in the payload challenge. This reduced power draw helps minimize power complications prior to the payloads activation and while on the launch pad. By using the Si4464, the payload and transceiving hardware may also share the same power source, which eliminates the need for a separate battery in the case of a handheld radio. Due to its low signal strength, achieving transmission power levels comparable to conventional handheld radios (e.g., 5W) would also require the use of an external RF amplifier.

Despite its benefits, utilizing the Si4464 in transmission systems would significantly increase design complexity. On the hardware side, the transceiver must be integrated into a custom PCB or breakout board, which implements challenges due to the small size of the chip and the potential risk of damage during payload assembly and testing. Furthermore, the software becomes more challenging, requiring more low-level programming to properly configure the transceiver for the desired communication method in comparison to the AIOC. Overall, the Si4464 provides the option for a more efficient payload, at the expense of a more complex system.

4.3.4 Programming Languages

One of the primary software decisions being considered is the selection of a programming language for the payload's primary functionality. The main options being considered are Python and C. Each of these languages presents benefits and challenges that must be evaluated before making a final decision. Additionally, it is important to carefully consider this choice before development begins, as rewriting the code in another language later would require a significant amount of time.

Python

Figure 4.3: Python Programming Language Logo

The first language that is being considered, and currently utilized in our leading design, is Python. This language has been used frequently by hobbyists for creating code quickly, and with access to a large support base. Due to this language's popularity, it has a great number of publicly available libraries that may be utilized. The largest benefit of Python is its ease of use, as it is a relatively simple programming language, and is widely used. The primary downside of Python is it's performance in comparison to other lower level languages. While being simpler, Python often times performs worse, and could negatively impact payload performance due to its decreased efficiency.

C

Figure 4.4: C Programming Language Logo

The secondary language being considered is the C programming language. This language is incredibly well known with a large support base and has been one of the most popular programming languages for the last few decades. One of the primary benefits of utilizing C for the payload software is its increased performance. As a lower-level programming language, it is very explicit in what the code is performing and ends up providing very little software bloat, resulting in a much more efficient language. C is one of the most widely used languages and is compatible with a large number of devices, including the Raspberry Pi. The primary downsides of utilizing C include the massively increased development time and room for error. Since C has far fewer security features, it is much easier for a mistake in the code to occur and interfere with the payload's performance.

4.3.5 Direwolf

Direwolf is an open-source software designed for encoding and decoding data in multiple formats, and for the purposes of the payload, primarily the APRS (Automatic Packet Reporting System) format. By using this software on the payload computer to handle the encoding of the data prior to transmission, this eliminates the need for a hardware-based terminal node controller. With Direwolf, the payload is capable of converting digital data stored on a Raspberry Pi into an APRS signal suitable for reception from the NASA receiver.

One of the key advantages of Direwolf is its availability and compatibility with Linux-based systems. This allows the Raspberry Pi being used for data processing to also be capable of encoding data for transmission. In addition, Direwolf is extensively utilized within the amateur radio community for APRS data transmission, and has a large amount of public documentation available for use. Similarly, publicly available libraries will allow for more reliable and efficient implementation in the payload's software.

4.3.6 Electronics Board

For our primary electronics board, we plan to design and utilize custom printed circuit boards (PCBs). We've selected custom PCBs due to the payload's need for reliable connections between all of its components. Custom PCBs provide durable connections resilient to the high vibration environment of the STEMCRaFT's flight. The largest downside of a custom PCB is the difficulty in modification after manufacturing and the relatively high lead-time on production. However, these issues can be alleviated with rapid prototyping on CNC mills and the use of U.S. based manufacturers.

The team plans on using PCB manufacturer OSHPARK. As a U.S. based manufacturer, they allow for short lead times and lower shipping costs compared to overseas manufacturers like JLCPCB. For prototyping through the use of CNC PCB mills, we are utilizing the Othermill Pro PCB Maker. This allows for the rapid development and testing of 2-layer PCBs at a low cost. While the Othermill Pro PCB Maker is limited to single and double-sided PCBs, it is sufficient to allow for rough testing boards to be designed prior to committing to external providers for more complex PCBs.

PCB

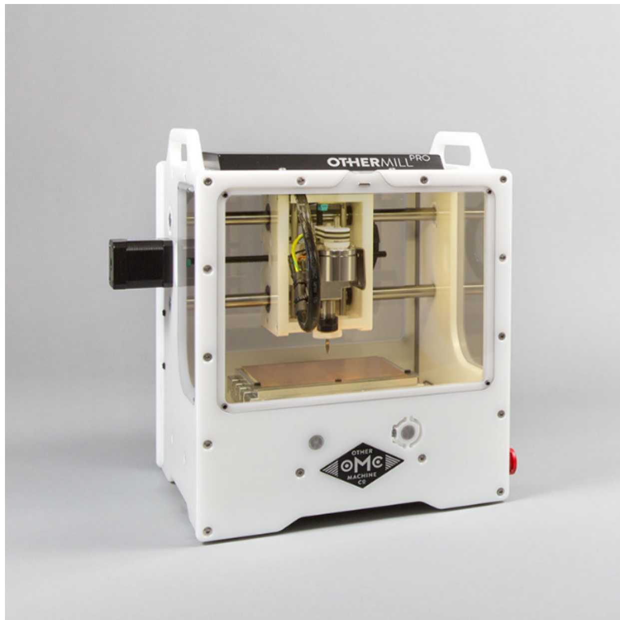


Figure 4.5: Othermill Pro PCB Maker

The benefits of a custom printed circuit board as the primary electronics board are primarily in its reliability and strength. In order to manufacture a proper PCB, the team is required to rely on external companies with setups designed to produce PCBs within proper tolerances. Manufacturing PCBs in this way can often lead to large shipping expenses and long lead times. In order to alleviate this issue, we aim to prototype PCB designs by using CNC PCB mills, which are limited in their abilities, but allow for rapid prototyping.

The benefits of a custom printed circuit board for our primary electronics board are primarily in its reliability and strength. To produce a custom PCB, we've decided to outsource the manufacturing to external companies once the teams designs have been finalized.

While CNC milled PCBs provide easy and quick access to prototype designs, they should not be used for our final design. The primary concern of using a CNC milled PCB board is its lack of connection security in comparison to a professionally manufactured PCB. Due to the human requirement of finishing the milled product, many connections may have loose connections or result in short circuits. In addition, the inaccuracy of many CNC PCB mills may lead to board areas that have sub-tolerable thicknesses, and may fracture throughout the STEMCRaFTs flight.

Proto-board

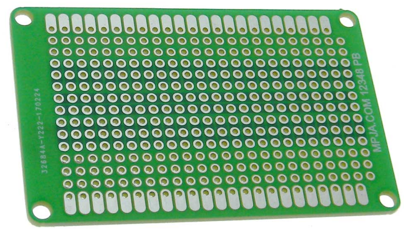


Figure 4.6: Commercially Available Proto-board

Proto-boards offer an in-between of PCBs and Breadboards in terms of benefits. They allow for the flexibility of a breadboard and allow for significantly stronger connections in comparison to those on a breadboard. The primary issue brought about by utilizing proto-boards is the risks of crossed connections via solder spillage, and connections being ripped out if mishandled. While soldering smaller components, it is common to short circuit devices, therefore requiring solder rework. Similarly, while a proto-board may hold up to launch and recovery conditions, frequent handling prior to the launch may result in connections being loosened.

Breadboard

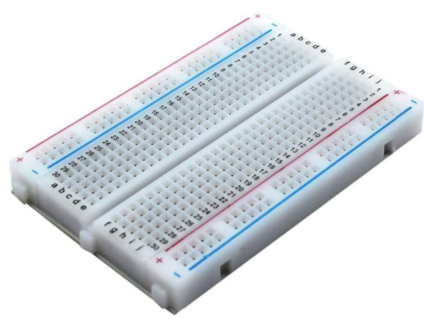


Figure 4.7: Commercially Available Breadboard

Breadboards represent the most rapid option available for prototyping systems. While breadboards are easy to work with and heavily modifiable, they are not able to be considered as a credible option for flight scenarios. Without further fastening, many pins are prone to falling loose throughout the rocket's flight, and many of the fastening methods are unreliable. Breadboards may be used for quickly testing designs, but will not be utilized in any capacity onboard the payload system.

4.3.7 Barometric Pressure Sensors

Barometric pressure sensors are primarily used for recording altitude and temperature at a point in time. For the purposes of the STEMCRaFT, these are both crucial data points that must be utilized in order to record the required data points for transmission. For this reason it is worth comparing and discussing the benefits and differences between many of the leading options for barometric pressure sensors.

Table 4.3: Pressure Sensor Comparison

Specification	BMP280	DPS310	MPL3115A2
Pressure Accuracy	±1 hPa	±0.005 hPa	±1 hPa
Temperature Accuracy	±1°C	±0.5°C	±1°C
Pressure Range	30 to 110 kPa	30 to 120 kPa	20 to 110 kPa
Power Consumption	Low power	Ultra-low power	Moderate power
Interface	I2C, SPI	I2C, SPI	I2C
Operating Voltage	1.71V - 3.6V	1.7V - 3.6V	1.95V - 3.6V

BMP280

Figure 4.8: Bosch BMP280 Barometric Pressure Sensor

The BMP280 is a widely utilized and commercially available barometric pressure sensor known for its high precision and reliability. As shown in Figure 4.8, the Adafruit BMP280 breakout board offers a easy integration into various systems. The BMP280 sensor allows relative altitude measurements with a relative accuracy of up to 1 meter, making it suitable for the purposes of measuring altitude. Additionally, the sensor is capable of measuring ambient temperature with an accuracy of up to ±1°C, providing reliable environmental monitoring capabilities.

NXP MPL3115A2

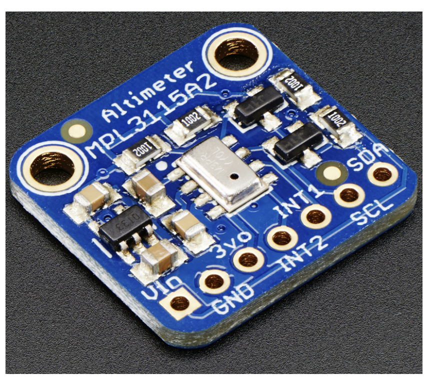


Figure 4.9: NXP MPL3115A2 Barometric Pressure Sensor

The MPL3115A2 is another widely used barometric pressure sensor with specifications comparable to the BMP280. It offers enhanced precision in altitude measurements, with a relative accuracy of up to 0.3 meters under optimal conditions. In addition, the MPL3115A2 provides ambient temperature measurements with an accuracy of ±1°C. Overall, the MPL3115A2 represents a viable alternative to the BMP280, delivering slightly improved accuracy in altitude readings, making it a strong contender for applications requiring high precision.

DPS310

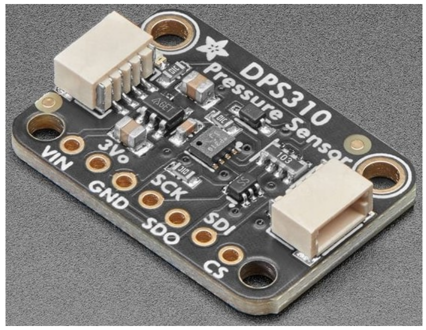


Figure 4.10: Infineon DPS310 Barometric Pressure Sensor

The DPS310 is the final barometric pressure sensor being discussed as a leading option and offers the highest precision among the listed options. It provides a relative altitude accuracy of up to 0.2 meters, making it the most accurate sensor in its category. Additionally, the DPS310 is capable of measuring atmospheric temperatures with an accuracy of ±0.5°C. When compared to other sensors, the DPS310 is the most accurate.

4.3.8 Inertial Measurement Unit

The Inertial Measurement Unit (IMU) is the sensor responsible for tracking the orientation, velocity, and acceleration of the launch vehicle throughout its flight. Selecting an IMU with sufficient accuracy and precision is critical to ensure reliable data for the STEMCRaFT. Furthermore, the IMU must be capable of operating effectively under the environmental conditions encountered during launch, including high accelerations, vibrations, and impacts.

Table 4.4: IMU Comparison

Specification	MPU9250	BMI160	LSM9DS1	BNO085
Accelerometer Range	±2g, ±4g, ±8g, ±16g	±2g, ±4g, ±8g, ±16g	±2g, ±4g, ±8g, ±16g	±2g, ±4g, ±8g, ±16g
Gyroscope Range	±250°/s, ±500°/s, ±1000°/s, ±2000°/s	±125°/s, ±250°/s, ±500°/s, ±1000°/s, ±2000°/s	±250°/s, ±500°/s, ±2000°/s	±250°/s, ±500°/s, ±2000°/s
Magnetometer Range	±48 gauss	N/A	±4, ±8, ±12, ±16 gauss	±4, ±8, ±12, ±16 gauss
Interface	I2C, SPI	I2C, SPI	I2C, SPI	I2C, SPI
Supply Voltage	2.4V to 3.6V	1.8V to 3.6V	1.9V to 3.6V	2.4V to 3.6V
Current Consumption	4mA	1mA	1.9mA	4mA
Temperature Range	-40°C to 85°C	-40°C to 85°C	-40°C to 85°C	-40°C to 85°C

MPU9250

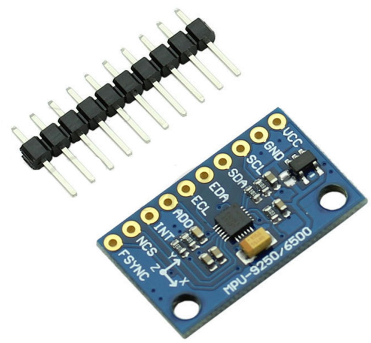


Figure 4.11: MPU9250 Inertial Measurement Unit

The MPU9250 is a widely-used IMU module, particularly among hobbyists for data collection applications. As outlined in Table 4.4, it can record accelerations up to 16g and angular velocities up to 2000°/s. These specifications make it well-suited for capturing the launch vehicles motion during flight. A key advantage of the MPU9250 is its integrated magnetometer, which offers an accuracy of ±48 gauss, the highest among the IMUs considered. This feature enables precise orientation tracking, which is critical for determining the orientation of onboard STEMnauts.

BMI160

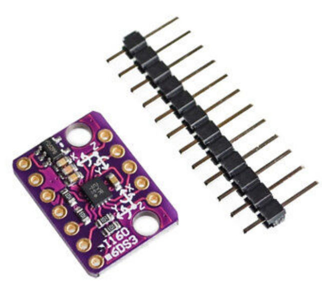


Figure 4.12: BMI160 Inertial Measurement Unit

The BMI160 is another leading IMU option under consideration, offering similar measurement ranges of up to 16g and 2000°/s. Its primary advantage lies in its lower power consumption relative to other sensors, making it an energy-efficient choice. However, this reduction in power draw comes at the cost of lacking a magnetometer, which may complicate accurate orientation determination for the STEMnauts.

LSM9DS1

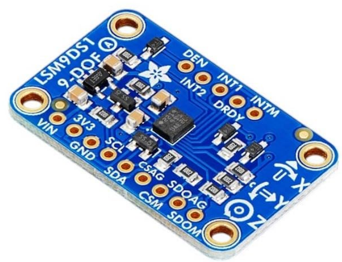


Figure 4.13: LSM9DS1 Inertial Measurement Unit

The LSM9DS1 is another IMU frequently used in hobbyist projects, featuring specifications comparable to the MPU9250. One of its key strengths is the extensive software support provided by its manufacturer, STMicroelectronics, which facilitates easier integration and data utilization. Additionally, the widespread use of this sensor and the availability of public documentation and libraries online contribute to its appeal as an option for the STEMCRaFT.

BNO085

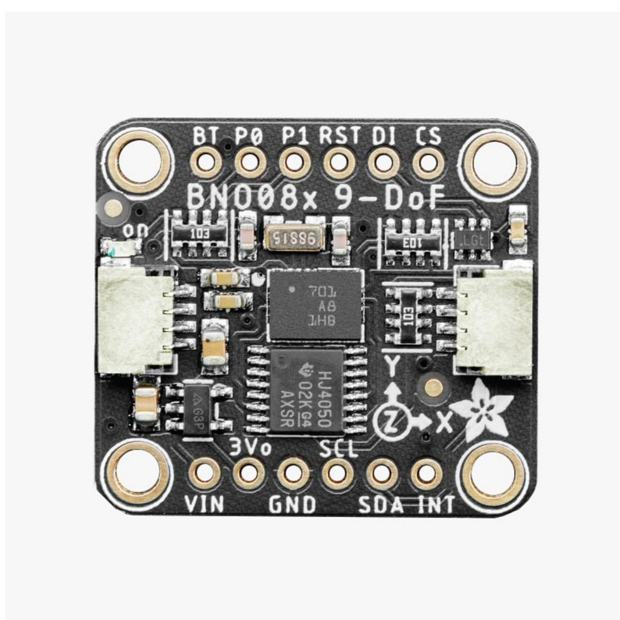


Figure 4.14: BNO085 Inertial Measurement Unit

Finally, the BNO085 is the most recently released IMU under evaluation. It stands out due to its chips embedded algorithms that enhance data accuracy and its ability to output quaternion data directly, eliminating the need for additional processing in the payload software. The BNO085 is commonly used in high-precision applications such as robotics, and it includes a magnetometer, which is essential for reliable orientation tracking of the STEMnauts.

4.3.9 GPS Module: SAM-M10Q Chip-Antenna Module

The SAM-M10Q Chip-Antenna Module is currently the leading candidate for the GPS module in the payload. This Chip-Antenna module integrates both a GPS chip and a built-in antenna, significantly simplifying the integration process. The SAM-M10Q is well known for its high accuracy, low power consumption, and fast time-to-fix capabilities, making it an ideal choice for providing precise GPS coordinates for the payload transmission while minimizing hardware complexity.

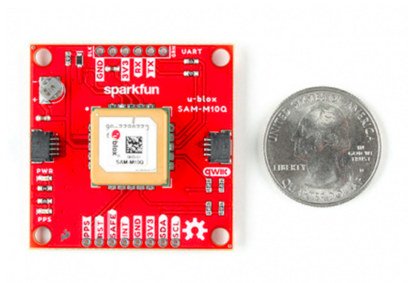


Figure 4.15: SAM-M10Q Chip-Antenna Module

The SAM-M10Q delivers positioning accuracy within ±1 meter, which is more than sufficient to determine the approximate landing coordinates of the STEMCRaFT after descent. Furthermore, the module boasts a cold start time of 23 sec and, in more likely operational scenarios, a hot start time of just 1 second if previously powered. The module can also supply up to 4 hours of backup power, enabling quick hot starts for sustained operation after short power interruptions.

Table 4.5: SAM-M10Q GPS Module Summary

Specification	SAM-M10Q
Positioning Accuracy	±1 meter
Time-to-First-Fix (TTFF)	23 sec (cold start), 1 second (hot start)
Power Backup	Up to 4 hours
Supply Voltage	1.8V to 3.6V
Current Consumption	18 mA (continuous tracking)
Temperature Range	-40°C to 85°C
Module Size	15.5 x 15.5 x 6.3 mm

In addition to its robust hardware capabilities, the module features multiple configurable parameters accessible through the dedicated software u-center2. This flexibility allows for further optimization of the GPS module's performance, ensuring it can be utilized in the method most beneficial to the payloads performance.

4.3.10 Voltage Sensor

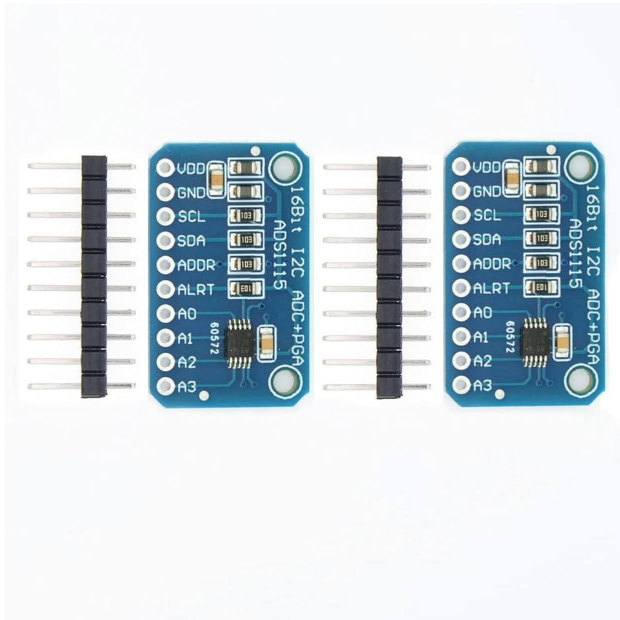


Figure 4.16: ADS1115 Voltage Sensor

Using an analog voltage sensor to measure the voltage of a 2S LiPo battery is a great way to monitor battery levels in systems like drones or portable devices. A typical analog voltage sensor takes the voltage of the 2S LiPo battery, which can range from 7.4V to 8.4V, and scales it down to a safe, readable range using a voltage divider. The scaled down voltage is then fed into an analog to digital Converter (ADC), such as the ADS1115, which converts the analog voltage signal into a digital value. The ADS1115 communicates with the main controller (like a Raspberry Pi) via the I2C bus, sending the digital representation of the battery voltage for further processing or display. The controller can then interpret this data to monitor the battery's charge status and trigger warnings if the voltage falls below a critical threshold. This setup is highly flexible and provides accurate real-time monitoring, essential for ensuring the safe operation of devices powered by a 2S LiPo battery.

4.3.11 Voltage Regulator

Figure 4.17: LM2596 Buck Converter

There are two main types of voltage regulators; Linear and switching. Linear regulators are more simple and have low noise. They provide a stable output voltage by converting excess energy as heat which reduces efficiency when dealing with a large difference in the input and output voltages. Switching regulators describes the family of buck, boost, and buck-boost converters. These are much more efficient because they use inductors and capacitors instead of disposing the extra voltage as heat. The downside of switching regulators is that they generate much more noise in the output voltage which sometimes needs to be filtered when dealing with sensitive components.

4.3.12 Redundancy

Sensor Redundancy

To mitigate the risk of not collecting data due to a sensor failure during flight, the team has decided to implement two of each sensor where applicable. There will be duplicate IMU and Pressure sensors meaning there will be 2 lines for each data point they record (acceleration, gyroscope, magnetometer, altitude, pressure, temperature). This setup provides flexibility in case one of the sensors fails or loses connection, ensuring data can still be collected without interruption. An additional benefit to having duplicate sensors is being able to minimize noise in the data collected by combining and filtering the data provided by each sensor.

In addition to improving reliability, having redundant sensors will also enhance data quality. By utilizing the outputs from both sensors, the system can provide more accurate and consistent measurements. The onboard computer will process the data to identify and filter out any outliers, further improving the precision of the collected data.

Antenna Redundancy

Due to the nature of how the launch vehicles are recovered, it's difficult to predict the physical landing orientation of the STEMCRaFT. In an effort to minimize risk of landing in an awkward way that could potentially limit the payloads ability to transmit, it is necessary to attempt to add some redundancy to our antenna configurations. Thorough testing is required to ensure that a horizontally polarized antenna close to the ground can effectively communicate with a vertically polarized receiver. While efficiency is significantly decreased in this configuration, there is research that supports the notion that there will be enough power to overcome these inefficiencies.

Transmission Shut-off

Another feature of the redundancy strategy the team plans to implement is a remote override system for starting and stopping the payload's transmission. While the payload software will automatically initiate and terminate transmission after a predefined duration, a command can also be sent to initialize the transmission as well as shut it down. This will serve as a backup in the event of a software failure, ensuring the transmission can be safely started upon landing and stopped within the allotted transmission time.

The determined method for accomplishing a remote override is having a separate receiver operating on a higher band interfaced to thepayload controller. The controller software will be configured to accept commands from the receiver to either start or stop the transmission which makes the transmission system more robust. These commands will be transmitted by a remote system, where they will be received by an onboard XBee Pro S3B Transceiver, discussed further in 4.5, and relayed to the Raspberry Pi.

4.4 Feasibility Study

To select the final payload design, a feasibility study was performed to evaluate the pros and cons of each design component. Pugh matrices were utilized to carry out these assessments. In each matrix, the key elements of each design component are identified, their impacts are rated on a scale of 1 to 5 (with 1 being the least impactful and 5 the most impactful). The ratings for each design option are displayed accordingly.

Strong Negative Impact	Little to No Impact	Strong Positive Impact
-1	0	+1

Criteria	Weight	AIOC (Handheld)	Si4464
Power Consumption	5	-1	1
Ease of Integration	3	1	-1
Design Complexity	2	1	-1
Size	4	-1	1
Transmission Flexibility	5	0	1
Transmission Strength	3	1	-1
Cost	2	0	1
RAW TOTALS		1	1
WEIGHTED TOTALS		-1	8

Table 4.6: Pugh Matrix of Transmission Hardware

Criteria	Weight	Python	C Programming Language
Ease of Use	5	1	-1
Performance	5	-1	1
Library Availability	4	1	0
Development Time	4	1	-1
Error Susceptibility	3	0	-1
Compatibility	4	1	1
Resource Efficiency	3	-1	1
RAW TOTALS		2	0
WEIGHTED TOTALS		9	0

Table 4.7: Pugh Matrix of Programming Language

Criteria	Weight	Quarter Wave	J-Pole	5/8 Wave	Yagi-Uda
Ease of Integration	4	1	-1	1	-1
Cost	2	1	0	0	0
Compliance with Size Constraints	3	1	-1	-1	-1
Gain	5	-1	1	1	0
Complexity	3	1	-1	-1	-1
RAW TOTALS		3	-2	0	-3
WEIGHTED TOTALS		7	-5	3	-10

Table 4.8: Pugh Matrix of Antenna Design Options

Criteria	Weight	DPS310	MPL3115A2	BMP280
Altitude Accuracy	5	1	0	-1
Temperature Accuracy	4	1	0	0
Power Consumption	3	0	-1	1
Cost	2	-1	0	1
Durability	3	1	0	0
Weight	2	1	0	-1
RAW TOTALS		3	-1	0
WEIGHTED TOTALS		12	-3	-2

Table 4.9: Pugh Matrix of Pressure Sensors

Criteria	Weight	MPU9250	LSM9DS1	BMI160	BNO085
Accuracy	5	-1	0	-1	1
Power Consumption	4	0	0	1	0
Durability	3	0	1	0	1
Magnetometer	2	1	0	-1	0
Ease of Integration	3	1	1	0	1
RAW TOTALS		1	2	-1	3
WEIGHTED TOTALS		0	6	-3	11

Table 4.10: Pugh Matrix of IMUs

Criteria	Weight	TTS FM Modulation	APRS
Integration Complexity	4	1	0
Transmission Capability	5	1	1
Power Consumption	3	-1	1
Transmission Flexibility	4	0	1
Compatibility	3	1	1
RAW TOTALS		2	4
WEIGHTED TOTALS		9	15

Table 4.11: Pugh Matrix of Transmission Methods

Criteria	Weight	Proto-board	PCB	Breadboard
Ease of Access/Modification	2	0	-1	1
Longevity and Reliability	5	-1	1	-1
Prototyping Flexibility	3	1	0	1
Manufacturing Complexity	3	0	-1	1
Size	4	0	1	-1
Cost	2	1	0	1
RAW TOTALS		1	0	2
WEIGHTED TOTALS		0	4	1

Table 4.12: Pugh Matrix of Electronics Boards

4.5 Leading Payload Design

The leading payload design has been developed based on the component selections identified through feasibility studies conducted in Section 4.4. After evaluating and determining the most suitable options for each individual subsystem, the leading payload design was assembled.

At a high level, the design consists of a central computer interfacing with the necessary sensors to process and record data. This data is used to maintain a finite state machine (FSM) that controls the detection and progression through the various phases of the launch. The FSM advances states based on predefined criteria, ensuring that the system correctly identifies each phase of the flight. When conditions for transitioning between states are met, the state machine progresses, updating the payload functionality and conditions required for subsequent phases. This mechanism ensures that data points are recorded properly at the appropriate times and that transmission is initiated only upon reaching the final ”landing” state.

Upon activation of the landing state, the system processes the necessary data and compiles it into packets for transmission. Using onboard encoding software, the payload formats the data according to the transmission system's expected data format. Once the data packets are generated, the transmission system will initiate periodic broadcasts, transmitting the designated NASA data points as a beacon over the allocated period. Additionally, a fail-safe system has been implemented to ensure redundancy and reliability in the event of a system failure during transmission.

Figure 4.19: STEMCRaFT Front and Back Views

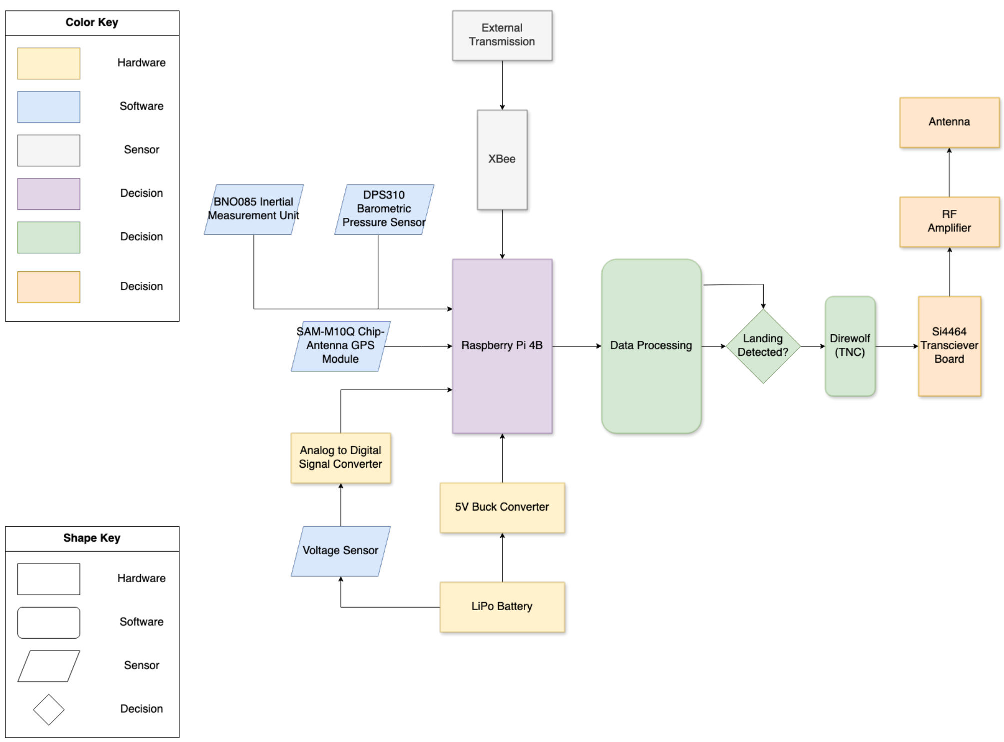


Figure 4.18: Payload Operational Flowchart

4.5.1 Major Components

In the following section the major electrical components of the leading payload design are discussed in further detail. Figure 4.18 illustrates the general overview of how the payload will operate.

Raspberry Pi

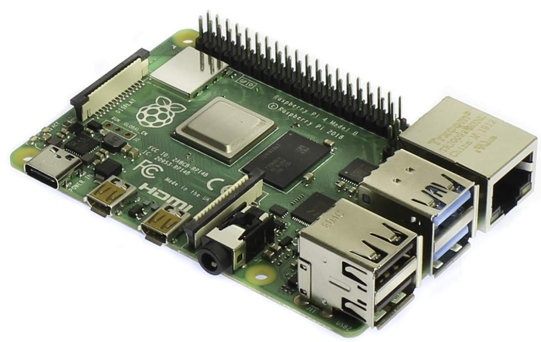


Figure 4.20: Raspberry Pi 4B

The leading payload design utilizes a Raspberry Pi as the primary payload computer. The Raspberry PI is responsible for communication with the onboard sensors, transmission system, recording data, and any necessary computations. In this design, the Raspberry PI provides the necessary flexibility and infrastructure to utilize a number of widely available public libraries and tools on the Linux OS. Using these tools, the payloads software is primarily coded in Python, which allows for easy interfacing with the various sensors and modules utilized by the payload.

In addition to acquiring external data from the onboard sensors, the Raspberry Pi will integrate a real-time clock (RTC) to monitor the time throughout the launch. This ensures that the payload can accurately record the STEMCRaFT's landing time, which is essential for transmission requirements. The timing data, along with other critical pieces of data, will subsequently be relayed to the Si4464 transceiver for broadcast once the STEMCRaFT has landed.

As previously mentioned The Raspberry PI primarily relies on a finite state machine to determine the necessary function that it must perform in order for the payload to operate. These states begin with the payload being armed before takeoff, and progress until the payload has detected a landing through the use of the onboard sensors. By using a finite state machine, the payload is able to control key factors such as the data logging rate, and the transmission state with minimal risk of payload failures.

BNO085

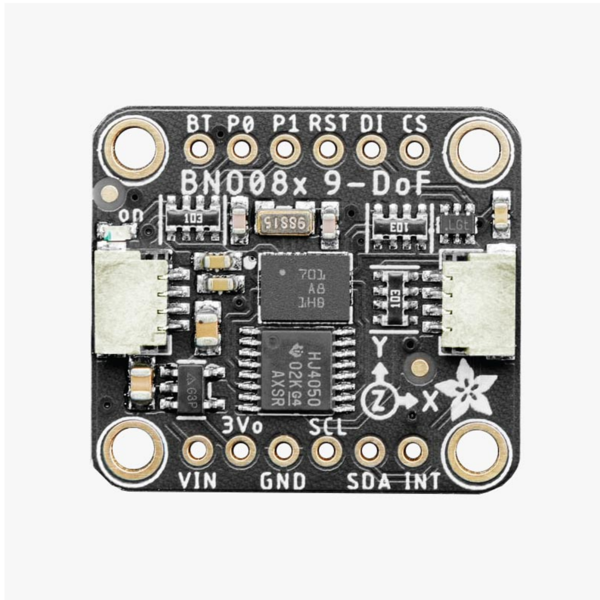


Figure 4.21: BNO085 Inertial Measurement Unit

The payload will use the BNO085 inertial measurement unit (IMU) as its sensor for motion and orientation tracking. This IMU was selected based on its precision, reliability, and capability to meet the requirements of the payload's operational environment. The BNO085 provides high-fidelity data that is important for producing accurate data for transmission and future analysis.

The BNO085 provides data from its onboard accelerometer, gyroscope, and magnetometer. These sensors collectively allow the payload to accurately determine essential metrics outlined in the payload challenge, including the orientation of the onboard STEMnauts, peak flight velocity, landing velocity, and the overall survivability of the crew. This allows for precise data throughout the entire flight, from launch through transmission.

Power

The primary power source for the payload system is a 2-cell Lithium Polymer (LiPo) battery. This type of battery was chosen for its flexibility in capacity, allowing for adaptability should the payloads power requirements change, as well as its proven reliability in maintaining charge stability prior to launch. The power generated by the LiPo battery is sent to a buck converter, which steps down the voltage to a 5V output. This ensures that the voltage supplied is safe for powering the Raspberry Pi and other electronics on board.

Once the Raspberry Pi receives power from the regulated 5V line, it acts as the central power hub for the entire payload. The Raspberry Pi is responsible for allocating power to each component, delivering either 3.3V or 5V depending on the specific requirements of each sensor or subsystem. All electronics in the payload design have been selected to operate within this voltage range in order to avoid the requirement for multiple power sources. This centralized power simplifies wiring and power management, but also enhances the reliability of the payload system.

In addition to powering the Raspberry Pi and the payload's electronic systems, the LiPo battery is connected to a voltage sensor. This sensor tracks the battery's voltage levels throughout the flight, providing data on the remaining power capacity. This voltage sensor records analog data which must then be converted to digital data before being processed by the Raspberry PI. This voltage information is a necessary data point as defined in the payload objectives, as the payload must transmit its power status upon landing.

DPS310

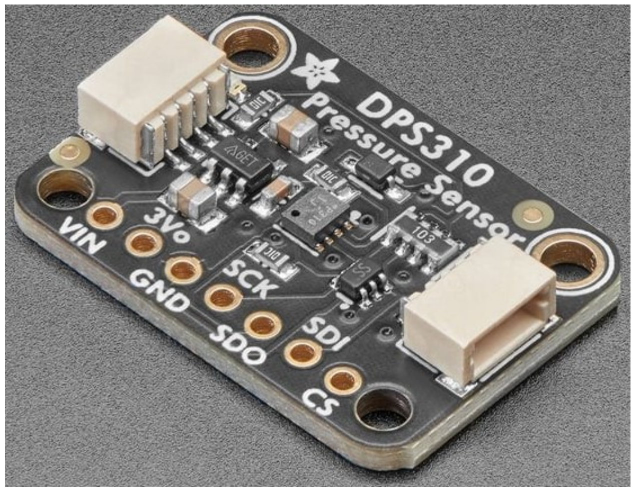


Figure 4.22: DPS310 Barometric Pressure Sensor

The DPS310 barometric pressure sensor is used to record pressure and temperature data for the payload which is utilized by the Raspberry PI. The sensor provides pressure and temperature data, which is processed by the Raspberry PI to create altitude and temperature data. This data is then utilized by the Raspberry PI for use in controlling the payloads state, and for later transmission after landing.

One of the ways this sensor's data is used is in controlling the state of the payloads finite state machine. The DPS310's pressure and temperature data, in conjunction with data from the inertial measurement unit, are used for driving the finite state machine that governs the payload's operations. The finite state machine relies on these inputs to control the payload's behavior during different flight phases, ensuring that data is being recorded throughout the flight, and that transmission does not begin prior to landing.

Additionally, the DPS310 is essential for calculating the maximum apogee and the temperature at the landing site. These are necessary data points that must be included in the payloads transmission in order for the payload to successfully transmit the data points declared in the payload objective.

SAM-M10Q Chip-Antenna Module

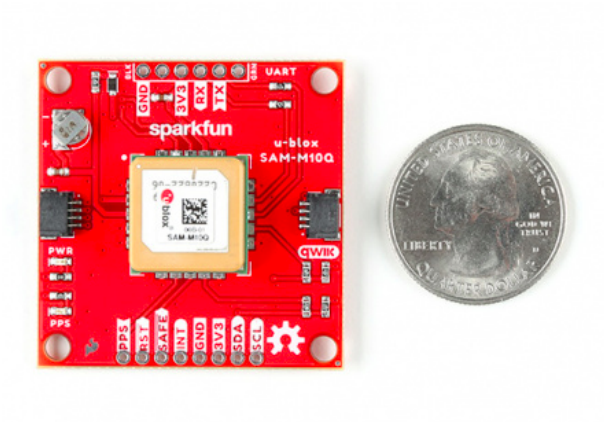


Figure 4.23: SAM-M10Q Chip-Antenna Module

The SAM-M10Q Chip-Antenna Module is used in the payload system to obtain approximate coordinates for the location of the STEMCRaFT. This module sends positional information to the Raspberry Pi, where it is processed. The SAM-M10Q module is critical in fulfilling the payload's mission requirement of transmitting approximate landing coordinates. After landing, the coordinates taken from the SAM-M10Q are included in the payload's transmission, providing approximate coordinates of the landing position.

Further technical details about this component are discussed further in 4.3.9.

XBee Pro S3B Transceiver

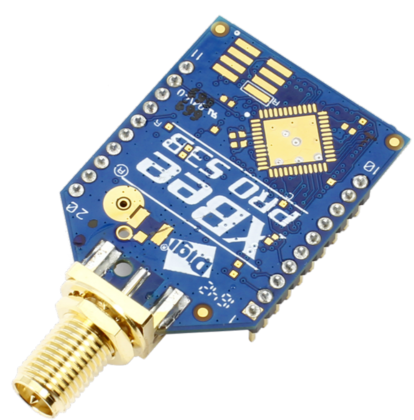


Figure 4.24: XBee Pro S3B Transceiver

The XBee Pro S3B Transceiver is integrated into the payload system to allow for the reception of manual commands from the team, enabling remote control of the STEMCRaFT's functionality should it become necessary. The primary role of the XBee Pro is to provide a communication channel outside of the 2M band, allowing the team to send control signals without interfering with the payload's designated transmission frequency. This capability is useful for controlling the STEMCRaFT remotely without transmitting non-payload data on the 2M band.

By transmitting commands, the team can remotely control key functions, such as initiating or halting data transmission. Upon receiving a command through the XBee Pro, the Raspberry Pi overrides the payload's normal finite state machine behavior. Depending on the command received, the FSM is set to either the pre-transmission or post-transmission state.

This remote capability introduces redundancy into the payload's transmission protocol, allowing the team to manually start and stop the transmissions. This enhances the reliability of the system by ensuring the transmission does not exceed the allotted time and reducing the risk of operational issues that would result in a lack of transmission. The XBee Pro provides a likely unnecessary, but useful method of avoiding errors that could result in a payload failure.

Si4464

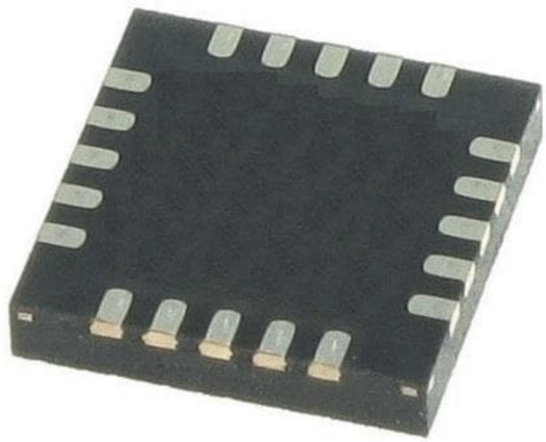


Figure 4.25: Si4464 Transceiver Chip

The Si4464 transceiver is responsible for transmitting the payloads data after the STEMCRaFT has landed. To facilitate this process, the Raspberry Pi uses the Direwolf software described in Section 4.3.5 to encode the data into an APRS signal. Once encoded, the data is sent to the Si4464 transceiver, which will be configured to transmit APRS signal. The payload will continue to broadcast this signal at regular intervals within the allocated broadcast period, allowing multiple opportunities for the NASA ground station to successfully receive the data.

To increase base transmission strength, the Si4464 transceiver uses an RF amplifier, which boosts the signal power to the maximum permissible limit of 5 watts, as per NASA Requirement 4.2.6. This amplification ensures the signal is strong enough to be reliably received by the NASA ground station, even in the presence of interference from the STEMCRaFT's landing environment. The increased transmission power helps to mitigate potential signal interference from obstructions or environmental factors.

Following amplification, the signal is then sent to the payload's antenna for broadcast. The periodic transmission schedule is designed to increase the likelihood of successful reception by the NASA receiver.

4.5.2 Electrical Schematic

Figure 4.26 presents the wiring schematic anticipated for the payload. The diagram emphasizes the communication protocols employed by each device to interface with the Raspberry Pi and other components. This layout was also used to verify that the Raspberry Pi has sufficient GPIO pins to interface with all necessary peripherals.

While the diagram depicts power delivery to the Raspberry Pi and voltage sensor, it omits the Raspberry Pi's relaying of power to the other connected hardware for clarity and to reduce visual clutter. It should be noted that all external devices interfacing with the Raspberry Pi can be powered via the available 5V and 3.3V output pins. Additionally, passive components that do not require power connections, such as the antenna, are excluded from the figure for simplicity.

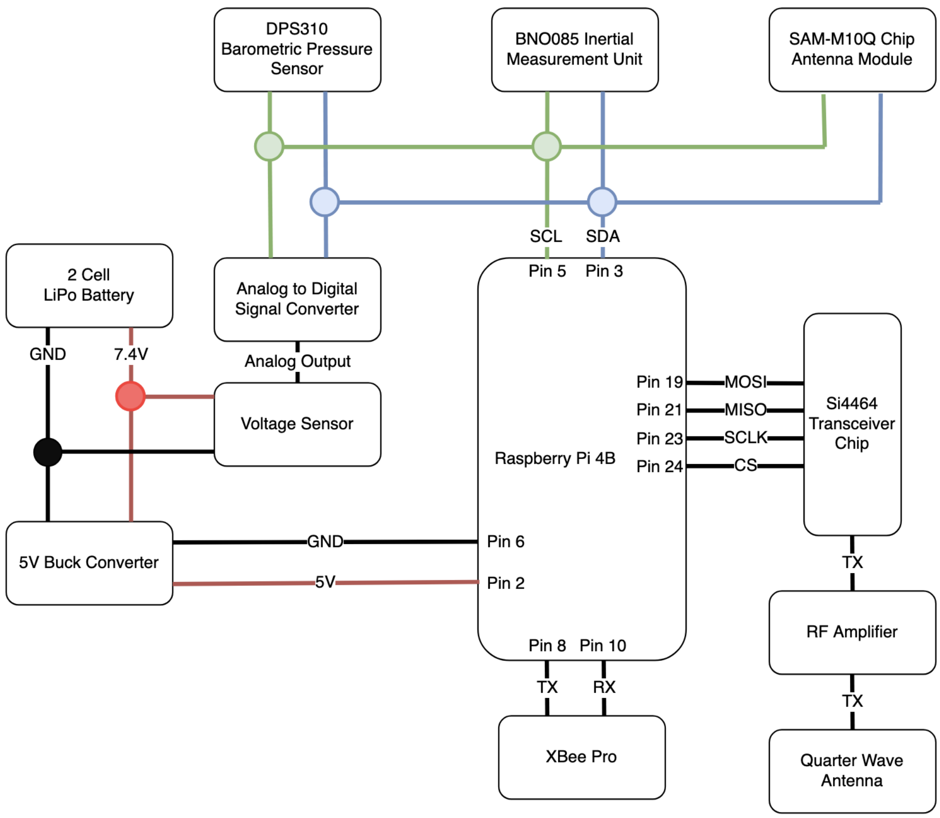


Figure 4.26: Payload Electric Diagram

As shown in Figure 4.26, all data sensors utilize the I2C communication protocol, allowing multiple sensors to share the same communication bus while being differentiated by individual device addresses. The Raspberry Pi is capable of accessing each device by its address as needed to read data. Specifically, the analog-to-digital converter, barometric pressure sensor, and inertial measurement unit all communicate via I2C, allowing for the same data line to be shared among them.

In the lower section of the diagram, the XBee Pro module is shown interfacing with the Raspberry Pi. This is accomplished through the Raspberry Pi's Universal Asynchronous Receiver/Transmitter (UART) interface, using the RX and TX pins. This setup enables the XBee Pro to receive wireless signals and relay data to the Raspberry Pi. This allows both the XBee Pro and Raspberry Pi to communicate with eachother, and allows for the team to remotely control the payload should it be required.

On the right side of the diagram, the Si4464 transceiver and its associated data transmission connections are shown. The Serial Peripheral Interface (SPI) protocol is employed to facilitate communication between the Si4464 and the Raspberry Pi. The SPI protocal allows for increased data transfer rates to be utilized in transmission. Once the Si4464 has received the necessary data via SPI, it generates the transmission signal, which is subsequently amplified by an RF amplifier. This amplifier boosts the signal strength to the maximum allowable limit, as specified in SL Handbook section 4.2.6. Finally, the amplified signal is routed through a coaxial cable to a quarter-wave antenna for wireless transmission.

4.5.3 Radio Communication

The transmission setup for the payload primarily involves the use of the Direwolf software, an Si4464 Transceiver, an RF amplifier, and a quarter-wave antenna. These components allow for the encoding, transmission, and amplification of the necessary data within the APRS format. This allows for the payload to achieve the necessary signal strength and data format to be received by the designated FTM-300DR transceiver that will be used by NASA on launch day.

Using the Automatic Packet Reporting System (APRS) transmission method with the Direwolf software on a Raspberry Pi is an efficient way to encode data. Direwolf functions as the APRS encoder that runs on the Raspberry Pi, allowing it to handle APRS transmissions without the need for dedicated hardware TNCs (Terminal Node Controllers). Using a virtual soundcard on the Raspberry Pi, Direwolf can generate APRS packets. This setup allows APRS data to be transmitted over radio frequency on the 2 meter band to the NASA reciever.

After this data is encoded within the APRS format, the transmission is directed onto the onboard Si4464 transceiver, which generates the final signal ready for broadcast. While the STEMCRaFT is in the proper state to be transmitting, this data will continue to be encoded and sent to the Si4464 for broadcast. After the transmission is created, it is then amplified up to 5W in order to create the strongest signal possible. Finally, this strengthened signal is sent to the antenna where it is broadcast for reception by the NASA transceiver.

4.5.4 STEMCRaFT Retention System

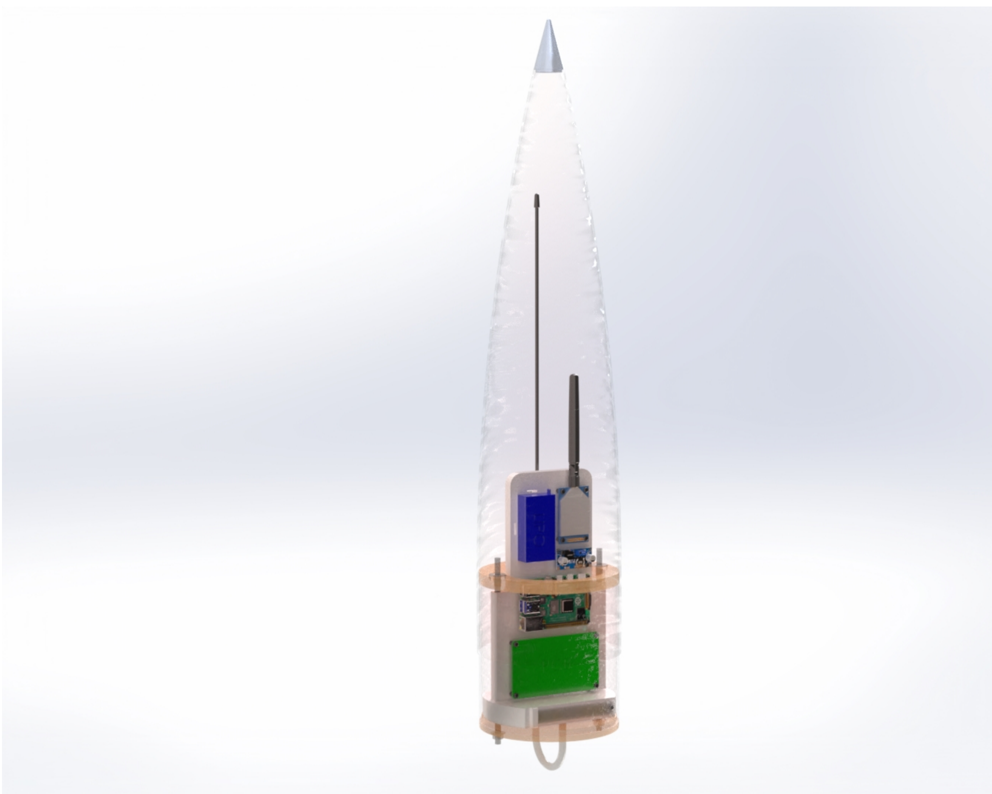


Figure 4.27: STEMCRaFT in Nose Cone

The STEMCRaFT will be housed inside the Nose Cone and will interface with two threaded rods attached to the permanent ring bulkhead. Two holes along the length of the STEMCRaFT body will allow the entire capsule to slide onto the threaded rods. The main body of the STEMCRaFT will sit between the permanent ring bulkhead and the removable bulkhead located at the aft portion of the Nose Cone. The clearance in this area will be small to prevent any movement of the STEMCRaFT during flight. The STEMCRaFT will be secured with two nuts on the threaded rods aft of the removable bulkhead. This retention method allows for easy installation and removal of the STEMCRaFT before and after the flight.

4.5.5 STEMnaut Choice and Housing

The duck figurine STEMnauts that flew on the team's SAIL in the 2023-2024 launch competition will be used again this year for the STEMCRaFT. There will be a total of four STEMnauts flying on the STEMCRaFT.

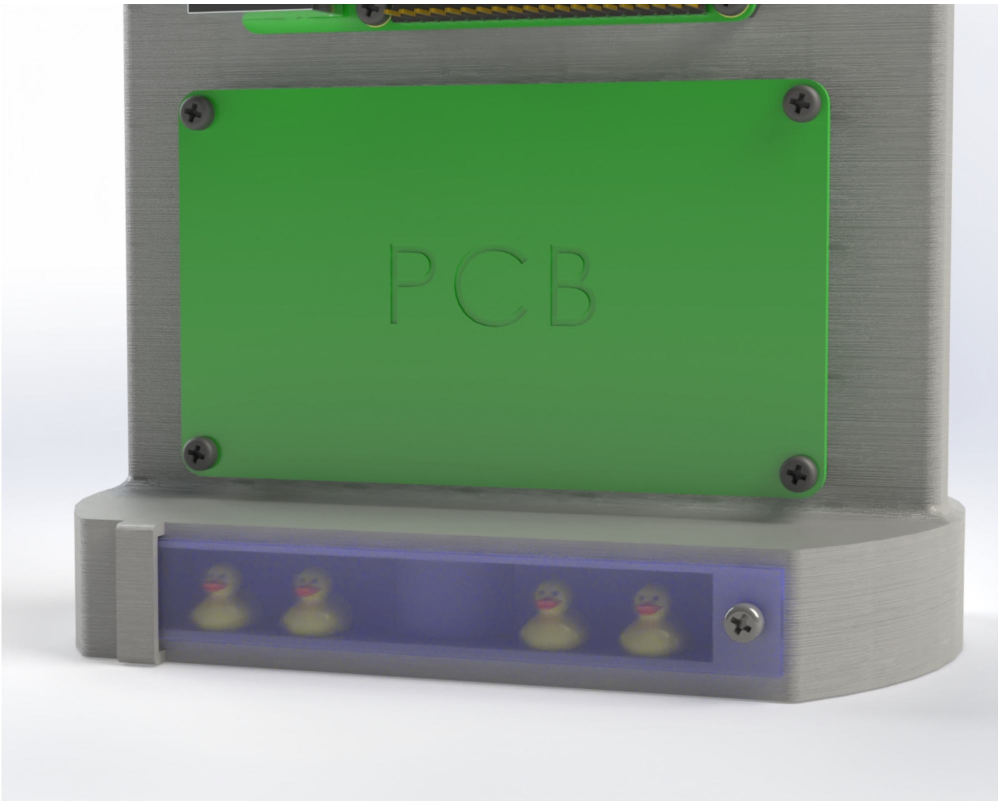


Figure 4.28: STEMnaut Housing

The STEMnauts will be housed in the aft portion of the STEMCRaFT inside of a small compartment. Each STEMnaut will be secured to the STEMCRaFT using a small piece of Velcro. A clear piece of acrylic will be used as a window and a door to seal the STEMnauts inside of the STEMCRaFT. The acrylic piece will slot into the STEMCRaFT on one side and be secured with a screw on the other side.

4.5.6 Manufacturing Methods

3D Printing

The STEMCRaFT body will be created using 3D printing due to its ability to produce custom geometries and rapidly iterate designs. 3D printing will allow holes for mounting the electronics to be modeled directly into the part, enabling the spacing to be determined before the part is printed. 3D printing can also use supports to create complex geometries, such as the slot for the STEMnaut to sit in. The sled will be printed using PETG filament, as it is both strong and flexible. This slight flexibility will help absorb some of the shock experienced during landing. PETG has a higher melting point than another common filament material, PLA, which will help prevent any thermal damage to the STEMCRaFT from the electronics, which may heat up during operation.

Mounting and Securing Electronics

The payload electronics will be mounted to the sled using heat-set inserts. Heat-set inserts are cylindrical metal parts with internal threads and a textured exterior to grip the plastic part they are melted into. These inserts provide a stronger connection than threading a screw directly into the plastic. Nylon standoffs will be used between the heat-set inserts and the electronics to protect the components and connections on the underside of the electronic boards. Retention methods will also be in place to ensure the wires do not get caught on any part of the vehicle when the payload is being loaded into the Nose Cone. Any slack in the wires will be secured close to the payload sled body using Velcro straps and electrical tape. This will also help alleviate some stress on the wires during the flight, preventing any disconnections.

PCB Manufacturing

Manufacturing PCBs is a cheap and easy solution for getting custom circuit boards. This allows for a more compact design when finalizing the electronics which also makes integration into the rocket a lot easier. This can be accomplished by using a CNC to cut away layers of copper from a substrate, commonly done using desktop milling machines. In the ECE MakerSpace at NCSU, two PCB milling machines are available: the Bantam Tools and OtherMill Pro. These machines use drill bits to mill single or double-sided FR1 boards, which are a common material due to their flexibility and low heat tolerance. PCB milling will allow for the ability to customize the layout of the sensors in the most economical way to conserve space on the STEMCRaFT, while also simplifying the wiring and construction.

Soldering

Soldering is an important process in electronics for creating conductive and strong connections between components. It involves melting a metal alloy, commonly tin-lead or lead-free alternatives, to bond the leads of components to copper pads on the PCB. This technique is used in both surface-mount and through-hole assembly, where it provides good electrical conductivity and reliable mechanical connections. Soldering is relatively easy to learn and a cost effective way to make electrical system more robust.

Soldering also has some limitations. Poor technique can lead to what is referred to as cold joints, which may cause weak connections ultimately causing defective circuits. Traditional tin-lead solder poses environmental and health risks so it is common to use lead-free alternatives. However, these lead-free solders require higher temperatures and can be more difficult to work with. Even though there are some challenges with soldering, it remains the primary method for joining electronic components together due to its precision, ease of use, and the durable electrical connections it provides

4.5.7 Estimated Payload Weight

Component	Unit Weight (lb)	Quantity	Net Weight (lb)
Raspberry Pi	0.1013	1	0.1013
BNO085	0.0063	2	0.0125
DPS310	0.0088	2	0.0175
Voltage Sensor	0.0063	1	0.0063
GPS	0.0125	1	0.0125
PCB	0.0156	1	0.0156
Voltage Regulator	0.0250	1	0.0250
Antenna	0.0881	1	0.0881
Antenna Bracket	0.1169	1	0.1169
Xbee with Duck Antenna	0.0703	1	0.0703
Wires	0.0313	1	0.0313
LiPo Battery	0.2109	1	0.2109
Pull Pin Switch	0.0078	1	0.0078
3D Printed Sled	0.4063	1	0.4063
Heat-set inserts	0.0113	19	0.2138
Nylon standoffs	0.0006	14	0.0088
Screws	0.0006	19	0.0119
STEMnauts	0.0031	4	0.0125
Miscellaneous	0.0625	1	0.0625
		Total Weight (lb)	1.4315

Table 4.13: Component Weight Estimates

5 Air Brakes

5.1 Air Brakes Objective

The objective of the Air Brakes system is to control the drag of the rocket during its ascent and guide the rocket to a target apogee. This will be accomplished by deploying Air Brakes fins to alter the reference area of the rocket which subsequently changes the force of drag experienced throughout the flight.

5.2 Air Brakes Success Criteria

Table 5.1: Air Brakes Success Criteria

Level of Success	Payload Criteria
Complete Success	Apogee prediction algorithm generates a flight profile that allows the control system to deploy Air Brakes and retract Air Brakes to reach an altitude within 4% of the target height.
Partial Success	Apogee prediction algorithm generates a flight profile that allows the control system to deploy Air Brakes and retract Air Brakes to reach an altitude within 10% of the target height.
Partial Failure	Apogee prediction algorithm generates a flight profile that allows the control system to deploy Air Brakes and retract Air Brakes to reach an altitude within 30% of the target height.
Complete Failure	Apogee prediction algorithm fails to generate a flight profile in time OR the Air Brakes control system fails to deploy Air Brakes OR the altitude reached is further than 50% of the target height.

5.3 Air Brakes Design

5.3.1 System Overview

The purpose of the Air Brakes system is to control the rocket's ascent to get 4% within a target height . The two main ways to control the ascent of the rocket is to add kinetic energy or remove it from the system. Since the rocket uses a solid fuel, it is unable to add any significant thrust after launch. The other option is to reduce the kinetic energy of the rocket during the flight. An elegant way of achieving this is through an Air Brakes system which increases the force of drag experienced by the rocket. The force of drag can be calculated from the following equation:

$$F_d = \frac{1}{2}\rho C_d A v^2 \tag{28}$$

where F_d is the force of drag, ρ is density, C_d is the coefficient of drag, A is the reference area, and v is velocity.

The variable from the drag equation that the Air Brakes system has control over is the reference area A. Increasing the reference area of the rocket directly increases the force of drag experienced by the rocket and subsequently increases the rocket's deceleration.

5.3.2 Major Components

The Air Brakes mechanism is made up by a housing, a central gear system, and four fins with embedded gears that mate to the central gear system. The design is intended to deploy the four fins rotationally about the longitudinal axis of the rocket. This deployment increases the area perpendicular to the freestream velocity, directly increasing the reference area of the rocket.

The primary components of the Air Brakes control system include a Raspberry Pi 4B serving as the central controller, and an HS-7950TH servo motor which is responsible for actuating the central gear system. To make sure the controller is receiving accurate data, a 3DM-CX5-AR IMU from Parker is used to deliver measurements of altitude, acceleration, and rotational acceleration at a high sampling rate of 500 Hz directly to the Raspberry Pi. The IMU is a critical component for giving the control system accurate information about the flight. A LM2596 buck converter is used to regulate the voltage coming from the LiPo battery.

5.3.3 Electrical Schematics

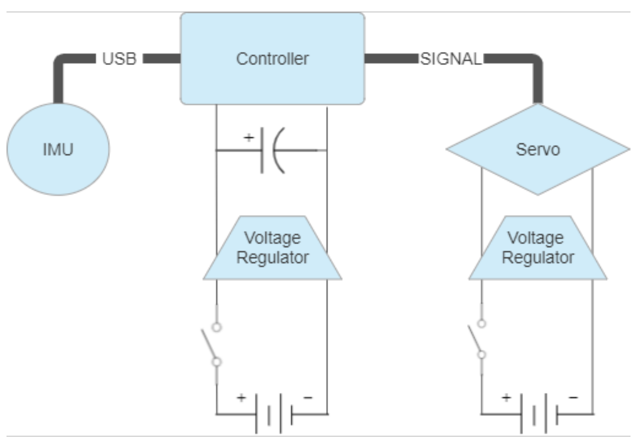


Figure 5.1: Wiring Diagram for Air Brakes Control System

For power, the system has two separate circuits charged by two 2200 mAh LiPo batteries which individually power the servo and Raspberry Pi respectively. These batteries provide the necessary capacity to sustain the high power demands of the servo while also allowing the Raspberry Pi to remain on an independent power circuit. A capacitor is placed in parallel to the output of the voltage regulator to smooth out the fluctuations of the input voltage as well as provide a source of brownout protection. This design choice eliminates the possibility of browning out the Raspberry Pi when the servo stalls which would be a possibility if they were wired in parallel. Both circuits utilize voltage regulation which is managed by LM2596 buck converters. These Voltage Regulators stabilize the power supply to the various components, allowing for the safe and reliable function of the Air Brakes control system. Additionally, 2 pull-pin switches are used to arm the Air Brake system while the rocket is positioned on the launch rail. This configuration ensures the Air Brakes system starts in an upright position in standby state, preventing accidental deployment while also conserving power prior to launch.

5.3.4 Air Brakes Software

The Air Brakes control system's software is written in Python and consists of a finite state machine structure which keeps track of the various stages of flight. The software follows a sequence of states to manage the deployment of the Air Brakes system and ensure they are only used when the rocket is coasting. This system implements checks for reliable transition between different phases of the flight, making the system less prone to failure.

Standby State

The software starts in a standby state, which prepares the system by zeroing out necessary data features such as pressure +altitude and acceleration. In this state, a rolling buffer window is used to eliminate unnecessary data, ensuring that only 6 sec of data before launch is logged. This state continues until the checks pass for transition to the Motor Burn State.

Motor Burn State

The system transitions to the motor burn state when the speed of the rocket exceeds 10m/s or the altitude records above 10m. During this state, the data is very noisy and unreliable to use for apogee prediction. Data is logged and the conditions are monitored for transition to the Coast State.

Coast State

As the rocket reaches the end of the motor burn, the acceleration decreases significantly, and the rocket starts to coast upwards. The system transitions to the coast state when it detects that the current speed of the rocket is less than the maximum speed. Another check to trigger the system to transition is to code a time delay after launch is detected that is based on the data sheet for the motor burn time of the specific motor being launched. During this state, the software utilizes an apogee prediction algorithm to predict the rocket's apogee and flight path. If it determines that deploying the Air Brakes can lower the flight path to reach the desired apogee, the system uses the servo motor to deploy the Air Brakes fins. This phase is crucial for slowing the rocket's ascent and preventing it from overshooting the apogee.

Free Fall State

Once the rocket reaches its apogee, the system transitions into the free fall state. This occurs when the detected altitude is 1% (approximately 10m) below the maximum altitude reached. In this state, the software commands the Air Brakes to retract if they are still deployed.

Landing State

Finally, the landing state starts when the altitude reaches close to zero, indicating that the rocket has landed. During this state, another buffer window is used to confirm that all motion has ceased. The software then ends the logging process after 10 sec and shuts down the program. This ensures that no unnecessary power is consumed post landing and that all relevant flight data is saved for post-analysis.

Apogee Prediction Algorithm

The apogee prediction algorithm is the heart of the Air Brakes control system. It's inputs consist of quaternions, XYZ accelerations, pressure altitude, current rocket state, and timesteps. While the rocket is in the standby state, the apogee prediction algorithm uses Earth's gravity as a reference vector in addition to the quaternions to get the current orientation of the rocket. It then rotates the frame of reference from the IMU onboard the rocket, which will have an initial state angles while on the rail, to a global setting with the Z-axis perpendicular to the Earth. At the start of the coast phase of the flight, the XYZ acceleration data is rotated from the IMU frame to the global frame and the Z-axis acceleration is extracted for further use. For simplicity and further processing, the gravity vector is subtracted out of the acceleration. A curve fit following the equation $A(1 - Bt)^4$ is used to extrapolate the Z-axis acceleration until it reaches close to zero. Apogee is indicated from the z-axis acceleration curve fit when the acceleration value reaches zero. As seen in Figure 5.2 the curve fit is inaccurate during the start of the coast phase as there is not enough data to create a strong correlation.

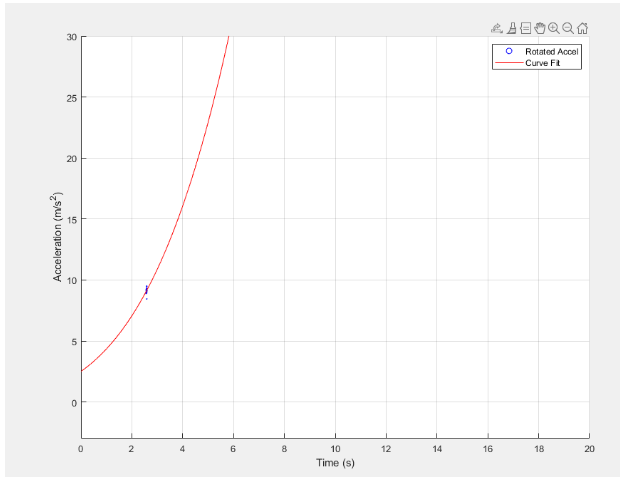


Figure 5.2: Curve fit Function at the start of the coast phase.

After 2 sec of flight data in the coast state, the curve fit settles close to a final equation as seen in Figure 5.3. From 2 to 3 sec after motor burnout, the curve fit changes are minuscule in that the resulting predicted apogee only changed by 5 meters.

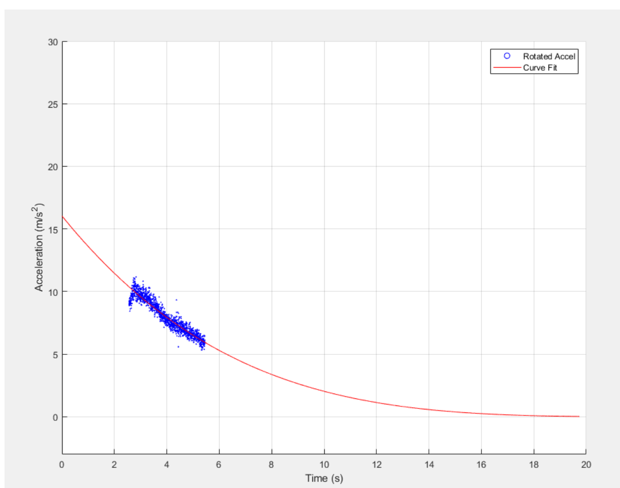


Figure 5.3: Curve fit equation settled after 2 sec of flight data.

Figure 5.4 shows the z-axis accelerations of the coasting phase overlayed on the predicted curve fit. The resulting difference between the actual acceleration curve to the predicted acceleration curve is less than 1%.

The height is then integrated from the predicted acceleration curve to output a predicted apogee as well as a velocity profile for the flight.

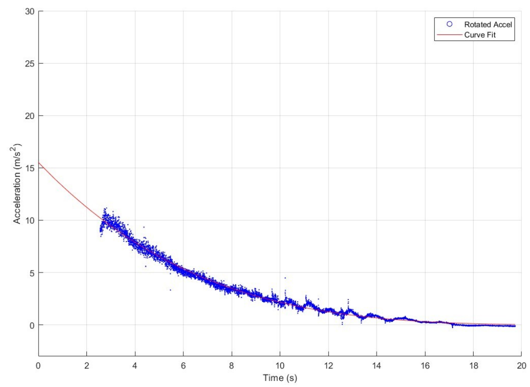


Figure 5.4: Acceleration data plotted with curve fit.

Control Scheme

The bang-bang controller was chosen over the PID controller for a few reasons. The tuning process would be difficult due to the issue that it would require a complete simulation of the Air Brakes and its aerodynamic effects on the rocket at various deployment amounts. Also, the PID controller would need to be tuned for different rocket sizes, further increasing complexity. The PID controller would require an active apogee prediction throughout the flight, which adds to the computational power needed. The bang-bang controller simplifies the control scheme by being independent of the aerodynamics of the Air Brakes which means it is not sensitive to different rocket sizes. It also does not require any tuning and is overall a simple solution for controlling the Air Brakes.

From the flight profile derived from the Apogee Prediction algorithm, a function-based lookup table is made that has the velocity as an input and the ΔH as an output, where ΔH is the difference in height between the apogee of the predicted flight curve and the current height. If the apogee prediction algorithm predicts that the current flight path results in a higher apogee than the target apogee, the Air Brakes control mechanism deploys the Air Brakes. Because the ΔH is based on the predicted flight curve, only one flight prediction is required which allows for fewer calculations and a more reliable system.

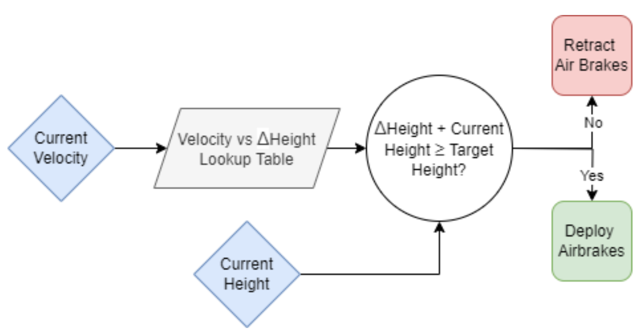


Figure 5.5: Flow diagram of control process.

As seen in Figure 5.5, the controller uses the current velocity to find the difference between the predicted apogee height and the current height which is analogous to the remaining height the rocket will travel with Air Brakes retracted. This can be added to the current height which, with Air Brakes deployed, will have deviated from the predicted flight path and be lower than the original flight path. If the current height + ΔH is higher than the height of the target apogee, then the Air Brakes control system deploys the fins. If the current height + ΔH is lower than the height of the target apogee, then the Air Brakes control system will retract the Air Brakes.

Processing

The Raspberry Pi 4B offers a 4-core processor which is useful for running different processes simultaneously. There are four processes that are each dedicated to a core: Main process, IMU process, Logger Process, and Apogee Prediction Process. The main process, retrieves data packets from the IMU process and the Apogee Prediction process and performs data processing on the packets. The IMU process fetches data packets from the IMU and sends them to the Main process. The Logger process fetches the data packets from the Main process and writes them to a file for later review. The Apogee Prediction process takes packets from the Main process and performs calculations to provide the Main process with the necessary data of the flight prediction.

5.3.5 System Verification

The Air Brakes system will have the ability to use previous flight data as a means of simulating a realistic flight of the rocket. These simulations will allow the Apogee Prediction System to be tested across a plurality of previous flights to verify the accuracy of the predicted flight path as well as the functionality of the finite state machine. The simulated flight will also allow the controller to verify the functionality of deploying and retracting the Air Brakes fins, ensuring the system is fully functional.

5.4 Manufacturing Methods & Assembly

Due to the complex geometry of the Air Brakes mechanism, the current method for construction is using additive manufacturing techniques for the housing and fins via 3D Printing with PLA. The housing includes 4 through-holes which allow threaded rods to pass through and act as hinges for the Air Brakes' Fins.

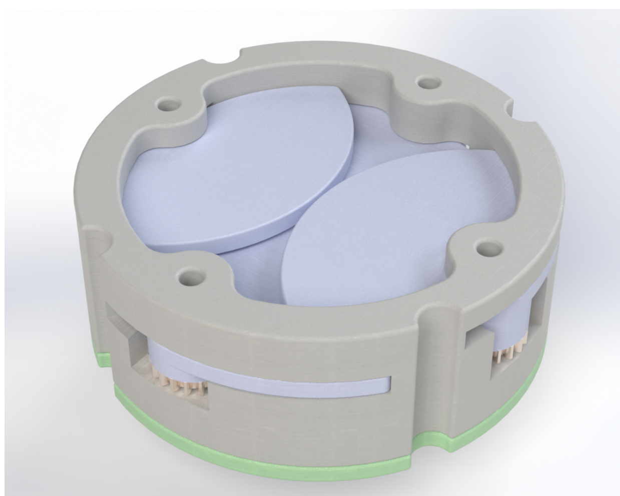


Figure 5.6: CAD of Air Brakes mechanism with fins retracted.

As seen in Figure 5.6, 2 sets of opposing fins are used, where 1 set is above the other and offset by 90 °. This design maximizes the area of each Air Brake Fin and is an efficient use of the cross-sectional area of the rocket. There are 4 half-cylinder channels which allow wire and cable to pass from one side of the housing to the other.

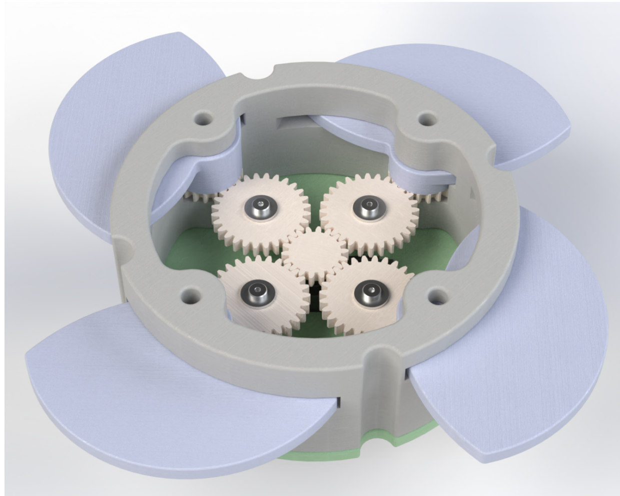


Figure 5.7: CAD of Air Brakes mechanism with fins deployed.

Figure 5.7 shows the Air Brake mechanism deployed. The internal area of the rocket is roughly $21.5in^2$ and each Fin has an exposed area of $7in^2$. This means that deploying the Air Brakes will result in the reference area nearly doubling which can for better control authority at slower speeds.

Central Gear System

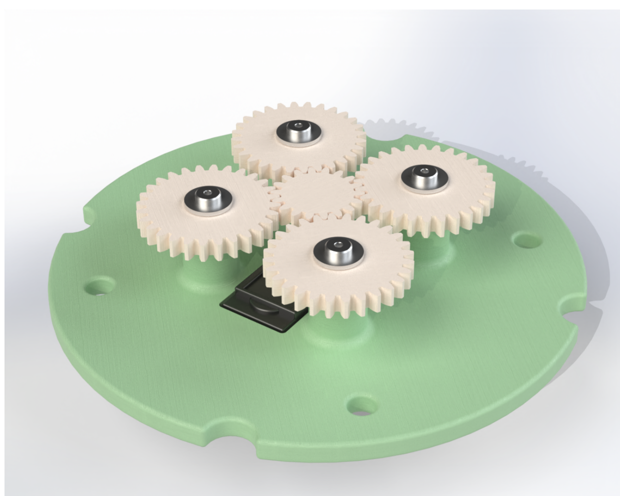


Figure 5.8: CAD of central gear system.

The central gear system is used over a single gear due to the torque requirements of deploying the fins. With each fin having an area of $7in^2$ and traveling at speeds greater than 300fps, the system experiences large aerodynamic forces that can lead to binding in the system. Through testing various designs, a central gear system allows the Servo to transfer torque to the fins on a 1:1 ratio. This preserves torque at the cost of speed within the Air Brakes mechanism.

5.5 Estimated Masses:

Table 5.2: Item Weight and Quantity

Item	Weight	Quantity
Servo	2.25 oz	1
Raspberry Pi	3.25 oz	1
IMU with cable	3.25 oz	1
Housing	4.25 oz	1
Central gear system	5.63 oz	1
Fin	0.75 oz	4

6 Safety

6.1 Necessary Components

Successfully completing the 2024-2025 NASA Student Launch Competition requires several key components that are broken down into subsystems, including launch vehicle design, recovery design, payload development, integration, and launch operations. Each subsystem must undergo hazard analysis to identify risks related to design, testing, and functionality so that mitigation procedures can be implemented. Personnel and environmental hazards also emerge as the project develops into the construction and testing phases, necessitating safety procedures. Risk management for mitigating project risks such as budget constrains, time constraints, and dependency delays must also be evaluated to ensure completion of the project by set milestones.

6.2 Safety Documentation Methods

The methodology used for hazard analysis begins with defining the analysis scope, including specifying the system, process, or product to be analyzed, its functional boundaries, and objectives. Pertinent data is collected, including historical performance metrics, industry standards, and prior failure records, to provide a comprehensive understanding of risk factors. Next, potential failure modes are identified by breaking down the system or process into components and evaluating possible risks due to physical, operational, or environmental factors. Probable failure causes are identified and any existing controls intended to prevent or detect these failure modes are evaluated. For each identified failure mode, its potential effects on overall safety, system functionality, and personnel impact are analyzed. Potential mitigating actions and controls are identified for each hazard, focusing on mitigating risk by reducing the likelihood of failure and minimizing its impact. Severity and likelihood ratings are assigned to each hazard based on a standardized scale both before and after mitigatory actions are taken.

6.3 Safety Documentation Methods

Failure Mode Effects Analysis (FMEA) in tandem with Risk Assessment Matrices are the primary method of analysis for safety risks and hazards for all competition-related systems. Additional methods of safety documentation and hazard analysis will be included in subsequent design reviews as appropriate.

Table 6.1: FMEA LS Matrix

		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

Table 6.2: FMEA Severity Key

Level of Severity			
1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Negligible damage to vehicle, personnel and environment unharmed, does not impact development	Minimal damage to vehicle, personnel can be easily treated with first aid, environment is minimally harmed, minimal impact on development	Moderate damage to vehicle, personnel require intensive first aid or eventual treatment by a medical professional, environment has moderate damage, significant impact on development	Irreparable damage to vehicle, personnel require immediate medical attention, personnel death, environment is destroyed, incomplete project, missed milestone

Table 6.3: FMEA Likelihood Key

Likelihood of Occurrence			
A Very Unlikely	B Unlikely	C Likely	D Very Likely
1-10% Occurrence	11-25% Occurrence	26-65% Occurrence	66-100% Occurrence

6.4 Personnel Hazard FMEA

6.4.1 Hazards to Personnel

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards Encountered in Designated Lab Space							
TL.1	Slips, trips, falls	(1) Material spills (2) Cluttered work environment	Injury requiring first aid, bone break/fracture	2C	(1) Lab floors are cleaned and inspected after handling of construction materials (2) Lab is organized and construction materials are put away after every meeting	2A	TBD
TL.2	Exposure to fumes	Handling uncured epoxy, paints, and chemicals	Respiratory irritation/ difficulty breathing	2D	Personnel are provided with and are required to use N95 masks or respirators when handing epoxy, paint, or other vaporous chemicals	2A	TBD

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
TL.3	Fingers or other appendages caught in bandsaw	(1) Misuse of equipment (2) Blade is caught on clothes, jewelry, or gloves	Loss of appendage, severe damage to muscle or soft tissue, bone break	4C	(1) Personnel must be trained on operation of the bandsaw before use (2) Personnel are required to not wear loose clothing, gloves, or jewelry when using the bandsaw	4A	TBD
TL.4	Fingers or other appendages caught in drill press	(1) Misuse of equipment (2) Drill bit is caught on clothes, jewelry, or gloves	Loss of appendage, severe damage to muscle or soft tissue	4C	(1) Personnel must be trained on operation of the drill press before use (2) Personnel are required to not wear loose clothing, gloves, or jewelry when using the drill press	4A	TBD
TL.5	Exposure to uncured epoxy	Working with epoxy	(1) Skin rash or irritation/ eye irritation (2) Difficulty breathing/ respiratory irritation	2D	(1) Personnel are provided with and are required to use gloves and to limit skin contact with epoxy (2) Personnel are required to wear a N95 mask or respirator when working with epoxy	1B	TBD
TL.6	Personnel contact with hot components of soldering iron	Misuse of equipment	Mild to potentially severe burns	3D	Personnel must be trained on operation of the soldering iron and proper use of PPE	2B	TBD
TL.7	Personnel contact with ejection charges	Inadvertent contact with blown ejection charges during ejection testing	Mild to potentially severe burns, respiratory inflammation	4B	Only trained personnel are authorized to conduct ejection testing, trained safety personnel are required to be present for all ejection tests	3A	TBD

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
TL.9	Exposure to loud noises	Personnel work with/around power tools	Temporary or permanent hearing loss	1D	Ear plugs and other hearing protection is provided to personnel when working with power tools	1B	TBD
TL.10	Exposure to carcinogenic particles	(1) Working with colloidal silica (2) Working with fiberglass	Respiratory irritation, difficulty breathing, cancer	4C	(1) Personnel are required to wear N95 particle masks (2) Personnel are required to wear particle masks	3A	TBD
TL.11	Inhalation of spray paint fumes	Working with spray paint for rocket aesthetics	Respiratory irritation/ infection	2D	(1) Spray painting is required to occur outside or in a designated indoor paint booth equipped with ventilation (2)Personnel are required to wear masks when using spray paint	2A	TBD
Hazards Encountered at Launch Sites							
TF.1	Slips, trips, falls	Uneven launch field conditions	Bruising, bone break, concussion, mild injury requiring first aid	3C	(1) Only designated personnel are permitted to recover the LV (2) Personnel are required to wear closed-toe shoes	2B	TBD
TF.2	LV collides with personnel	(1) Launch rail tips (2) LV is propelled sideway (3) LV lands in close proximity to spectators	Skin abrasion, bruising, bone fracture, concussion, mild to severe burns	2B	(1) Launch rails are provided and managed by TRA/NAR personnel (2) LV is securely attached to launch rail and motor is not installed into the LV until it is vertical on the launch rail (3) Launch rail is angled away from spectators, spectators are instructed to keep eyes on the LV during flight and not try to catch the LV	1A	TBD

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
TF.3	Excessive load placed on personnel muscles	Personnel lift heavy LV components	Muscle strain or tear	2C	At least two personnel are required to carry the LV while it is fully configured	1A	TBD
TF.4	Insect sting/bite	Exposure to outdoors for prolonged periods of time during launch day activities	Skin itchiness, rash, mild allergic reaction, anaphylaxis	2C	Bug repellent is kept in launch day safety box at all times and is readily available to personnel, personnel who have allergies make the Safety Officer aware before launch day activities	1B	TBD
TF.5	Allergic reaction	(1) Personnel with outdoor allergies are exposed to wildlife for prolonged periods of time (2) Personnel are allergic to the crops grown at launch site	Runny nose, sinus pressure, mild allergic symptoms, swelling, rash, hives, anaphylaxis	3C	Emergency antihistamine is kept in launch day safety box at all times and is readily available to personnel, Safety Officer is made aware of any severe allergies before launch day activities, if it is found that a designated recovery personnel is allergic to vegetation or crops where an LV is to be recovered, a suitable replacement for the personnel will be found	1B	TBD
TF.6	Personnel contact with ejection charges	Contact with unblown black powder after touchdown, battery short during avionics installa-tion/arming procedures	Mild to severe burns, bruising, skin abrasions	4B	Personnel inspecting LV after flight must wear fire proof gloves, LV inspected for unblown charges prior to the handling of recovery procedures	3A	TBD

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
TF.7	Excessive amount of walking	LV lands far from launch site, personnel not allowed to drive during recovery	Shin splints, muscle sprain, tendinitis, stress fracture	2D	Personnel are driven a portion of the recovery distance if allowed, all sections of LV required to be equipped with a functional GPS tracker to reduce walking in searching for the LV	1C	TBD
TF.8	Excessive exposure to sunlight or UV rays	Long duration of time spent in the sun during launch day activities	Sunburn, sun poisoning, heat stroke, cancer	2D	Personnel are required to dress appropriately for the weather, Personnel are required to use and reapply sunscreen during launch day activities	1B	TBD
TF.9	Inhalation of combustion reactants	Close proximity to motors and ejection charges	Respiratory irritation, difficulty breathing	2B	(1) Personnel in close proximity to combustion are provided with N95 masks (2) Personnel stand a minimum distance away from burning motors as determined by NAR/ Tripoli code	1B	TBD
TF.10	Inhalation of smoke	Launch field fire	Respiratory irritation, difficulty breathing	2D	(1) Personnel in close proximity to launch field fire are provided with N95 masks (2) Sparky motors are not used at launch fields	1B	TBD
TF.11	Contact with airborne shrapnel	CATO	Concussion, head trauma, skin abrasion, mild to severe burns, bruising, bone fracture	4B	Personnel and spectators are instructed to maintain a minimum distance from LVs in flight by RSO according to NAR/ Tripoli code	3A	TBD

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
TF.12	Eyes have prolonged exposure to the sun	Maintaining vision of a descending LV on a bright/sunny day	Permanent blindness, temporary blindness, cataracts, solar retinoscopy, macular degeneration	3C	Personnel are encouraged to wear sunglasses or shield their eyes from direct solar contact	1C	TBD
TF.13	Personnel become severely dehydrated	Extended time at the launch field without drinking water	Muscle cramps, kidney damage, drop in blood volume, headache, dizziness	3C	Personnel are instructed to pack ample water, water is provided if necessary	2B	TBD
TF.14	Personnel experience heat stroke	Personnel overheats due to prolonged exposure to high temper-atures	Dehydration, organ damage, heart and kidney stress, nausea, headache, confusion	3C	Personnel provided with water and a tent is used during launch day activities	2B	TBD
TF.15	Personnel contact with high kinetic energy LV components	(1) Components disconnect from LV during flight (2) Improper sizing of parachutes (3) Failure of parachutes to deploy	Head injury, skin abrasion, bone fracture	3B	(1) Components connections checked by Safety Officer during launch day assembly (2) Parachutes sized for 75 ft-lbs maximum kinetic energy at landing (3) Parachutes and shock cord Z-folded, altimeters tested prior to launch	2A	TBD

6.4.2 Project Schedule Analysis

Table 6.5: Project Schedule Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Project Schedule							
PS.1	Subsystem leads cannot travel to Huntsville	Interference of senior graduation with Huntsville trip	Seniors cannot travel to Huntsville	1C	(1) Seniors request NASA management team to allow them to arrive one day late to Huntsville (2) Current subsystem leads train future subsystem leads to replace them at Huntsville.	1A	(1) Currently in communication with Allison Chouinard about Huntsville attendance (2) N/A
PS.2	Inadequate Huntsville attendance	Incorrect completion of Gateway registration	Members cannot travel to Huntsville	3C	Attend Gateway registration help sessions	1B	Attended STEM Gateway Open Office Hours on: 10/15/2024 at 1:00pm CT
PS.3	Fatigue and burnout	Heavy workload, long working hours	Increased risk of accidents, reduced focus, lower quality of work	3C	(1) Monitor workload (2) Limit procrastination (3) Plan group activities	2B	(1) Team lead divides workload for each milestone document. (2) Team lead sets soft deadlines (Table 7.18). (3) Group activities are held on NCSU mandated wellness days.
PS.4	Mental health stress	Unpredictable schedules, tight deadlines	Reduced productivity	3C	(1) Provide information about NCSU Mental Health resources in weekly General Body Meetings. (2) Develop comprehensive and detailed schedules	2B	(1) General Body Meeting Slide in the Appendix (2) See Table 7.18

Table 6.5: Project Schedule Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
PS.5	Reduced team coordination	Conflicting subsystem schedules	Miscommunication	3B	(1) When2meet.com to schedule group meetings outside of subsystem meetings (2) Integration Lead attends all meetings and coordinates information via notes and messages	2A	(1) N/A (2) TBD
PS.6	Dependency delays	Interconnected tasks, miscommunication, resource allocations	Timeline delays	3C	(1) Create detailed subsystem schedules with adequate buffer time (2) Integration lead keeps track of upcoming interconnected tasks	2B	(1) See Table 7.18 (2) TBD

6.4.3 Personnel Availability Analysis

Table 6.6: Personnel Availability Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Personnel Availability							
PA.1	Team Lead becomes unavailable	Unforeseen circumstances, travel	Project communication and coordination challenges	4B	Integration Lead takes over position	2B	N/A
PA.2	Integration Lead becomes unavailable	Unforeseen circumstances, club rugby, health	Decreased subsystem communication, incomplete requirement verification	4B	Team Lead takes over position	2B	N/A
PA.3	Structures Lead becomes unavailable	Unforeseen circumstances, family	Incomplete launch vehicle	4B	Recovery Lead takes over position	2B	N/A
PA.4	Recovery Lead becomes unavailable	Unforeseen circumstances, work schedule, required travel for courses	Incomplete recovery system	4B	Aerodynamics Lead takes over position	2B	N/A

Table 6.6: Personnel Availability Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
PA.5	Aerodynamics Lead becomes unavailable	Unforeseen circumstances, graduation, travel	Decreased apogee prediction accuracy, inefficient launch vehicle design	4B	Structures Lead takes over position	2B	N/A
PA.6	A Payload Lead becomes unavailable	Unforeseen circumstances, travel, family, holidays	Incomplete payload design	4B	Other Payload Leads take over position	2B	N/A
PA.7	Treasurer becomes unavailable	Unforeseen circumstances, other club activities	Decrease in project funding	2B	New Treasurer elected	1B	Club constitution
PA.8	Safety Officer becomes unavailable	Unforeseen circumstances, family	Decrease in project safety	3B	New Safety Officer elected	2B	Club constitution
PA.9	Outreach Lead becomes unavailable	Unforeseen circumstances, overlap of outreach event scheduling	Decrease in STEM engagement activities	2B	New Outreach Lead elected	1B	Club constitution
PA.10	Necessary members absent for NASA design review presentations	Scheduling conflicts	Incomplete presentation requirement	4B	Plan availability with scheduling software (when2meet.com)	2A	N/A
PA.11	Necessary members absent for Huntsville launch	Scheduling conflicts, graduation ceremony	Decreased team productivity, failed launch criteria	4D	(1) Follow designations above for absent personnel (2) Train another member to take the absent member's place (3) If necessary, launch at home field	2C	(1) See PA.1-PA.6

Table 6.6: Personnel Availability Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
PA.12	Necessary members absent for milestone launch	Scheduling conflicts	Decreased team productivity and efficiency, failed launch criteria	2B	Follow designations above for absent personnel	1A	See PA.1-PA.6

6.5 Failure Mode and Effects Analysis

6.5.1 Launch Vehicle FMEA

Table 6.7: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Fin System							
VF.1	Fin bracket breaks	(1) Fin flexing during flight (2) Landing impact force (3) Excessive heat from motor	Loss of fin, non-reusable LV	4B	(1) Design fin brackets to be rigid (2) Design fin brackets to survive drop tests for landing at the maximum kinetic energy of 75 ft-lbs (3) Design fin brackets out of aluminum to withstand high temperature (Section 3.2.6). Thermal analysis on motor tube.	1B	TBD
VF.2	Fin fracture	Impact force and impact angle	Non-reusable LV	2B	Design fin such that it passes impact testing at 75 ft-lbs	2A	TBD
VF.3	Separation of fin from LV	Stripped fastener connecting fin to RMFS	LV does not fly straight, inability to launch LV	3B	Do not over-tighten fasteners when installing fins into RMFS	1A	TBD
VF.4	RMFS loses functionality	Motor CATO	RMFS deformation	4A	Inspect motor grains and motor casing prior to launch	2A	TBD

Table 6.7: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Motor							
VM.1	Motor retainer failure	(1) Motor retainer attached incorrectly (2) Ejection charge too large	Motor ejection	3A	(1) Motor retainer secured with 4 screws (2) Ejection testing prior to every launch (Requirement RF.23)	1A	TBD
VM.2	Cracks or voids in propellant grain	Manufac-turer error	CATO	4B	Inspection prior to launch will determine if a motor is viable to launch on	4A	TBD
VM.3	Premature ignition of motor	(1) Excessive heat exposure during handline (2) Contact with electrical connections	Injury to personnel/ LV, flight without recovery system, expenditure of motor	4B	(1) Storage of motor in flame cabinet prior to launch, storage of motor in shade at launch field (2) Storage of motor in flame-proof explosive containment box	4A	TBD
VM.4	Thrust plate failure	Excessive compressive stresses	RMFS destroyed, jettison of motor	4B	Conduct force analysis on the thrust plate and select materials with a 1.5 or greater factor of safety	3A	TBD
Hazards to Airframe							
VAF.1	Airframe cracking	Hoop stress from internal pressure from ejection charges, excessive landing force	Separation of RMFS from Fin Can, non-reusable LV	3B	Calculate black powder ejection charge size empirically (Section 3.4.9) Size parachutes for a landing kinetic energy of less than 75 ft-lbf (Section 3.4.6)	1B	TBD
VAF.2	Airframe zippering	Excessive force from deployment of parachutes	Airframe rupture, non-reusable LV	3B	(1) Use of fiberglass and blue tube airframe that can withstand excessive force (2) Calculations to properly size main and drogue parachute for descent velocity (Section 3.6.7, 3.6.8)	1B	TBD

Table 6.7: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
VRF.3	Stripped fastener	Excessive forces when installing or during flight	Separation of fin from vehicle	3A	Follow checklist procedures to not over-tighten fasteners during assembly	2A	TBD
VRF.4	Deforma-tion of RFS	Motor CATO	Fin loses functionality	4A	Material reduced, minimization of stress concentrations	2A	TBD
VAF.5	High energy impact with ground	Late/no parachute deployment	Airframe ruptures	3B	Parachute selection based on calculations of LV kinetic energy at landing	2A	TBD
VAF.6	Airframe exposed to flame/burn-ing ejection charges	Excessive amount black powder used in ejection charge	Airframe dis-integration/ rupture	2C	Ejection charges are calculated and tested prior to launch, LV airframe constructed from flame-resistant fiberglass and blue tube	1A	TBD
VAF.7	Airframe exposed to water	(1) LV lands in water (2) Wet weather conditions (3) LV pulled into water by parachute	Airframe disintegration	2D	(2) Do not launch LV in rain (3) Do not launch LV in high wind, recover LV quickly and retain parachute	1C	TBD
VAF.8	Airframe exposed to motor exhaust gases	(1) Motor sealed incorrectly (2) CATO	Airframe rupture	2B	(1) Construct motor under the supervision of personnel possessing a L2 Certification or higher (2) Inspect motor grains and motor casing prior to launch	2A	TBD
Hazards to Bulkheads							
VB.1	Avionics bulkhead detached	(1) Excessive stress from recovery hardware (2) Bulkhead retained incorrectly	Recovery hardware detached in flight, recovery failure	4C	Tensile testing of bulkheads, bulkhead material chosen according to force analysis, bulkhead retained with two points of contact	4A	TBD

Table 6.7: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
VB.2	Nose Cone bulkhead detached	Excessive forces	Payload exposed to the elements	3C	Bulkhead is epoxied and retained by the Nose Cone shoulder	3A	TBD
VB.3	Bulkhead crack	Excessive stress concentrations on bulkhead from parachute deployment	Disconnection of parachutes from LV, ballistic descent	3B	(1) Design bulkheads to be made of a material with no/little voids that could cause stress concentrations (2) Inspect bulkhead structure prior to launch	3A	TBD
VB.4	Burns into bulkhead	(1) Excessive use of black powder in ejection charges (2) Black powder contained incorrectly	Bulkhead damage, bulkhead unable to withstand flight forces	2B	(1) Calculate size of ejection charges empirically with formulas in Section 3.4.9 (2) Test correct containment of black powder in blast caps after construction to ensure no leaks	1A	TBD
Hazards to Aerodynamics							
VA.1	Motor CATO	(1) Voids in motors (2) Cracks/deformation in motor casing	Complete mission failure	4B	(1) Motor grains inspected prior to launch (2) Motor casing inspected for defects or inconsistencies during motor assembly	4A	TBD
VA.2	LV is over-stable	CG is too far forward	weather cocking	1C	Vehicle CG location is measured prior to launch as a part of checklist, Vehicle is designed to include removable ballast in Fin Can and Nose Cone	1B	TBD

Table 6.7: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
VA.3	LV over/under expected weight	(1) Payload is over-weight/un-derweight (2) Material mass differs from aerodynamic simulations	LV fails to meet predicted apogee, LV fails to meet NASA apogee range, LV stability is too high/low, stability is not between 2 and 2.7, incorrect Air Brakes location	2C	(1) Integration Lead holds weekly LV and payload integration meetings (1) Vehicle is designed to include removable ballast in Fin Can and Nose Cone (2) Team measures all material components and records results on a shared document	2A	TBD
Hazards to/from Recovery System							
VR.1	Nomex detaches from parachute	(1) Rips/tears in nomex (2) Breakage in nomex connection	Parachute catches on fire, permanent loss of nomex and parachute	3B	(1) Nomex is inspected prior to launch vehicle assembly for rips, tears, and inconsistencies (2) Nomex is connected to shock cord with threaded quick links	2A	TBD
VR.2	Parachute detaches from launch vehicle	(1) Shroud lines tear (2) Quick-link fails during flight	LV kinetic energy is over 75 ft-lbs. at touchdown, ballistic landing of LV, damage to LV body	3D	(1) Parachute and shroud lines are inspected for thinning, tears, and knots prior to launch vehicle assembly (2) Threaded quick-link attached to parachute is secured with tape	3B	TBD
VR.3	Main parachute deploys at apogee	(1) Drag separation of main parachute bay (2) Altimeter failure (3) Ematches are wired to the opposite bay	LV potentially lands in an inaccessible area, potential loss of LV and Payload	2B	(1) 4-40 shear pins are used (2) Altimeter testing is performed at least once leading up to launch day (3) Recovery Lead oversees the assembly of the recovery avionics bay.	1A	TBD

Table 6.7: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
VR.4	No/ partial parachute deployment	(1) Insufficient separation charges (2) Insufficient altimeter batteries (3) Shear pins don't break (4) Rubber bands aren't removed from parachute during assembly (5) Parachutes are not packed incorrectly	Ballistic descent, kinetic energy requirement failure, complete mission failure	4C	(1) Black powder calculations are made according to Requirements RF.9 and RF.11. Calculations are verified with an ejection test prior to launch day (2) Altimeters are powered with a 9V battery whose power is verified with a multimeter prior to AV assembly. (3) 4-40 shear pins are used (4) Added as a seperate checklist item (5) Parachutes are folded using the "Z-fold"	4A	TBD
VR.5	Shock cord rip/tear	(1) Late parachute deployment (2) Excessive force on shock cord	Ballistic descent of LV, complete mission failure	4B	(1) Altimeters are tested prior to launch day (2) Parachutes are sized according to Section 3.4.6 to accommodate expected drag forces	1B	TBD
VR.6	LV sections collide	(1) Insufficient length of shock cord (2) Shock cord entan-glement	Damage to LV by collision or landing velocity	2C	Allotted more than 5 ft separation between falling sections under parachute	1B	TBD
VR.7	Late section separation	Incorrect timing of black powder detonation	Ballistic landing, excessive force on shock cord connections and shock cord, flight failure	4B	Recovery altimeters are programmed appropriately and tested at least once prior to launch day (Requirement RF.13)	4A	TBD

Table 6.7: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
VR.8	Shock cord tangled during deployment	Shock cord is not packed appropriately	Parachute is partially deployed, LV fails kinetic energy landing requirement	3D	Shock cords are z-folded and secured with rubber bands prior to launch vehicle integration	2B	TBD
VR.9	Altimeter malfunction	Improper sizing of pressure port holes	Parachutes are deployed incorrectly, ballistic landing	3C	Pressure port holes are sized according to altimeter handbooks	3A	TBD

6.5.2 Payload FMEA

Table 6.8: Payload Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Transmitters							
PT.1	Transmission failure	(1) Landscape interferes with transmission (2) Error in code (3) Electronics interfere with antenna	NASA doesn't receive collected data points	4B	(1) VV&T on payload system to ensure transmission design is resistant to minor landscape interferences that may occur at the launch field (people, tents, trees, etc.) (2) Test transmission code prior to launch day (3) Shield antenna from other electronics, test transmission set-up prior to launch day	4A	TBD
PT.2	Overlap of transmission with another team	(1) Data is transmitted on the wrong frequency (2) Faulty encoder	NASA doesn't receive collected data point	2B	(1) Develop code to have transmission frequency as an input variable. Frequency assigned by NASA on launch day is then entered correctly (2) Test encoder prior to launch	1A	TBD

Table 6.8: Payload Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
PT.3	Early trans-mission	Software detects landing at wrong time	Payload challenge fails, failure to meet NASA Requirement 4.2.6	4C	Robust state based model to detect landing	4A	TBD
PT.4	Transmis-sion exceeds allotted time	Error in software code	Failure to adhere to NASA requirements	2B	(1) A hard-coded stop time is included in software code as a backup to timer stop. (2) Manual shut-off with XBee	1B	TBD
PT.5	Electronics hardware disconnec-tion	(1) Flight forces (2) Accidental detachment during assembly	Payload data collection and transmission failure	3B	(1) Test electronics under anticipated flight forces prior to launch (2) Ensure proper connections on launch day with checklist, adhere to Team Derived Requirement PF.8	3A	TBD
PT.6	Data formatted improperly	Mistake in payload software	Failure to adhere to NASA specifi-cations, payload failure	3A	(1) Verify expected data format (2) Perform test transmissions using the desired data format prior to launch day	1A	TBD
Hazards to Receivers							
PR.1	Mismatched XBee trans-mission and receiving frequencies	Improper frequency/ channel setup	Payload unable to receive manual shut off signal	1B	Verify correct frequency with checklist, test receiver on specified channel prior to launch	1A	TBD
PR.2	Transmis-sion goes over allotted time	Software issue/ improper XBee configuration	Failure to adhere to NASA requirements	1B	(1) Ensure automatic transmission shutoff software is tested (2) Ensure XBee manual shutoff is configured to receive signal	1A	TBD

Table 6.8: Payload Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
PR.3	Noise/ feedback	Hardware interference	Inability of payload to transmit/re-ceive information	1C	(1) Test receivers in payload bay prior to launch (2) Test transmission systems for interference prior to launch day	1A	TBD
Hazards to Wiring Connections							
PW.1	Lack of com-munication between components	(1) Wires improperly secured (2) Soldering disconnec-tion	Wire disconnection	3C	Include a checklist item to ensure wires are secured, adhere to Team Derived Requirement PF.8	2A	TBD
PW.2	Data not collected, received, and/or transmitted	Excessive forces in launch/ preparation	Pin headers disconnected from electronics	4B	Ensure proper connections on launch day with checklist, adhere to Team Derived Requirement PF.8	4A	TBD
Payload Electronics							
PE.1	Loss of critical data	Defective sensor reports incorrect data	Sensor failure	2B	Sensors tested under launch conditions prior to flight and after previous flights	1A	TBD
PE.2	Electronic lose power	(1) Loose connection (2) Impact forces	Voltage regulator failure	4B	(1) Ensure proper connections and solder joints to voltage regulator (2) Test connections after simulated impact	4A	TBD
PE.3	Damage to Raspberry Pi	Voltage regulator failure	Under-voltage resulting in Pi failing to stay powered (which powers other electronics), over-voltage resulting in damage to the board	3B	(1) Verify configuration of voltage regulator prior to launch (2) Ensure working solder connections	3A	TBD

Table 6.8: Payload Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
PE.4	Electronics not receiving sufficient power	Batteries uncharged/ bad	Insufficient power to payload	2B	(1) Check battery power is within specification in checklist prior to launch (2) Bring spare batteries	2A	TBD
Hazards to Air Brakes							
PA.1	Air Brakes failure	(1) Faulty manufacturing/ printing (2) Excessive aerodynamic forces during launch	Broken Air Brakes fin	2B	(1) Increase infill on 3D printed materials (2) Calculate aerodynamics forces in fins and conduct tests	2A	TBD
PA.2	Failed Air Brakes deployment/retraction	(1) Friction in the Air Brakes mechanism (2) Inadequate servo strength (3) Incorrect assembly	Air Brakes fins stuck in LV	2B	(1) Reduce friction in mechanism (2) Verify servo deployment strength under highest aerodynamic loading (3) Assemble air brakes according to checklist	2A	TBD
PA.3	Melted Air Brakes components	Over-amperage of servo	Air Brakes exposed to excessive heat	2B	(1) Ensure servo angles set in the Air Brakes software prevent over-amping (2) Shield Air Brakes from heat effects of the servo	2A	TBD
PA.5	Air Brakes contact with water	Air Brakes land in/ are dragged into water on the launch field	Air Brakes electronics waterlogged/ damaged	3A	(1) Recover Air Brakes in a timely manner to avoid contact with water (2) Shield Air Brakes electronics from the external environment	2A	TBD
Hazards to Payload Structure							
PS.1	Structural failure of payload sled	In-flight/ landing forces	Sled material weakens/breaks	2B	Conduct structural testing on payload sled prior to flight	2A	TBD

Table 6.8: Payload Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
PS.2	Loss of flight data points	(1) In-flight/ landing forces (2) Improper adhesion/ connection	Damage to payload electronics,	2B	Ensure proper connection of payload electronics to sled and test connections under similar conditions to in flight forces	2A	TBD

6.5.3 Integration FMEA

Table 6.9: Integration Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Integration System							
IS.1	Recovery connection points for shock cord improperly sized	Calculation error, wrong parts are ordered	Quick links with attached shock cord cannot attach to bulkheads	4B	Sizes are verified by Integration Lead before purchases are made	2A	TBD
IS.2	Threaded rods for sleds improperly sized	Measure-ment miscommu-nication, unit conversion error	Sleds do not fit on threaded rods	3B	Sizes are verified by Integration Lead before purchases are made	2B	TBD
IS.3	Payload doesn't fit in Nose Cone	Miscommu-nication between subsystems, lack of test fitting	Payload cannot be included in LV, payload failure	4C	Sizes verified by Integration Lead before construction	3A	TBD
IS.4	Payload too heavy	Miscommu-nication, improper calculations of weight	Stability margin outside of defined range of 2.0-2.7, apogee lower than predicted 4800 ft	3D	Measurements and calculations verified by Payload Leads and communicated to the Structures Lead	2A	TBD

Table 6.9: Integration Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
IS.5	Drogue recovery system doesn't fit	(1) Miscommunication in dimensions between subsystems (2) lack of testing	Failed recovery system	4C	(1) Communal dimensions document that is checked weekly (2) Test fit recovery system and design the system to have additional breadth (Requirement LVF.7).	3B	TBD
IS.6	Main recovery system doesn't fit	Miscommunication in dimensions between subsystems, lack of testing	Failed recovery system	4B	Test fit recovery system and design system to have an additional breadth	3A	TBD
IS.7	Inability to use Air Brakes to control launch apogee	Incorrect tolerancing, miscommunication	Air Brakes do not fit in LV	2D	Model Air Brakes and LV together in CAD to determine proper sizing	1B	TBD
IS.8	LV components do not connect properly	Misaligned marking/ measurements for hole placement	Misalignment of hoes for fasteners	3D	3D print alignment and marking devices before drilling	1A	TBD
IS.9	Improper LV assembly	Lack of knowledge, fatigue, stress, inadequate checklists	LV recovery failure, failure to launch	4B	Team Lead creates checklist for every launch that are followed and signed on launch day	2A	TBD
IS.10	Improper recovery system assembly	Lack of knowledge, fatigue, stress, inadequate checklists	Parachutes do not deploy, parachutes collapse during flight	4C	Follow checklist for recovery procedures at every launch	2A	TBD

6.5.4 Launch Support Equipment FMEA

Table 6.10: Launch Support Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Launch Support Equipment							
SL.1	Damage to launch vehicle at launch pad	(1) High winds at launch site (2) Uneven ground at launch pad	Launch rail falls over after LV is attached	2B	(1) Launches will not be conducted in winds over 20mph (2) Launch pad stability inspected prior to attaching LV to launch rail	2A	TBD
SL.2	Shade tent flies away	(1) High winds (2) Improper anchoring to ground	Potential damage to cars or LV components, tent breaks, personnel sunburn	2D	(1) Launches will not be conducted in high winds (2) Use of stakes to keep tent grounded	1B	TBD
SL.3	LV prematurely detaches from launch rail	Improper connection of rail button to LV	Rail button stripped out of launch vehicle on launch pad	3B	Load testing of connection of rail button to LV prior to launch	2A	TBD
SL.4	Motor doesn't ignite	(1) Ignitor is not in direct contact with motor grains (2) Bad ignitor	Ignitor fails to ignite motor	1D	(1) Igniters are installed under the guidance of NAR/TRA L3 personnel (2) Redundant igniters brought to launch	1A	TBD
SL.5	Damage to launch vehicle during launch day assembly	(1) High winds (2) Uneven landscape	Table falls/collapses during LV construction, LV rolls off table	2C	(1) Launches will not be conducted in winds over 20 mph, (2) Team will set up tables for assembly on flat/even ground, team will use stands to prevent rolling	2B	TBD
SL.6	Shear pin failure	Shear pins unable to withstand LV weight when fully configured	Flight readiness review failure	3C	Shear testing of shear pins to a factor of safety of 1.5	2A	TBD

Table 6.10: Launch Support Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
SL.7	Ignition system failure	Powering of ignition system insufficient/ wire shortage	Inability to launch	2A	Ignition system operated by NAR/TRA personnel	1A	TBD

6.5.5 Launch Operations FMEA

Table 6.11: Launch Operations Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Launch Day Operations							
OL.1	Aircraft flies into FAA designated airspace	Pilot disobeys FAA guidance	All launches halted until aircraft exits airspace	4B	RSO is in contact with air traffic control	1A	TBD
OL.2	LV collides with personnel or vehicle	Launch rail is not angled away from personnel	Injury to personnel, severe damage to vehicle	4B	RSO ensures launch rail is appropriately angles to avoid flights over spectators and vehicles	3A	TBD
OL.3	Ejection charges detonate prematurely	Short in wire connection	Injury to personnel, severe damage to vehicles or property	4B	Antistatic bags utilized during transportation of energetics	3A	TBD
OL.4	Personnel harmed by motor ignition	Personnel or spectators close to LV flight	Injury to personnel or spectators	4C	Abide by Tripoli/NAR standards on distance from launch pad	3A	TBD
OL.5	Black powder spills during assembly	(1) Rushed assembly (2) Improper technique	Improper detonation of ejection charges	3C	(1) Black powder assembly conducted prior to launch day (2) Checklist followed to prevent spillage of black powder for ejection charges	2B	TBD
OL.6	LV components accidentally left in lab	Components over-looked/missed during packing	Missing necessary components for launch	4C	Follow prewritten checklist/packing list	2A	TBD

Table 6.11: Launch Operations Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
OL.7	Motor detonates prematurely	(1) Sparks or open flame (2) Static discharge	Loss of motor	4C	Motor transported in a flame-proof explosive containment box and handled with care	3A	TBD
OL.8	Car troubles	Vehicle transporting LV to launch field gets speeding ticket or breaks down	Inability to fly	2C	Team travels in convoy to launch field in order to provide assistance if necessary	2A	TBD
OL.9	Bird Strike	Flock of birds fly into LV flight path	Damage to and potential loss of LV	4B	RSO verifies that range and sky are clear before commencing with launch	2A	TBD
OL.10	Personal stuck in inclement weather	Sudden change in weather while at launch field	Hazardous weather conditions	3A	Weather is monitored during launch day activities	1A	TBD
OL.11	Lack of qualified person-nel/prefects to manage launch day operations	Unforeseen circum-stances	Launch canceled/ delayed	4B	Team moves launch to another date/location, team uses backup launch	2A	TBD
OL.12	LV does not exit launch rail	Friction on launch rail	LV gets stuck on launch rail	4B	Lubricant for launch rail is packed and used if lv does not easily slide onto launch rail	3A	TBD

6.5.6 Environmental Concerns FMEA

Table 6.12: Environmental Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Land/Vegetation at Launch Sites							
EL.1	Fire on launch field	(1) Motor ignition (2) Premature ejection charge detonation (3) CATO	Tree/shrub-bery damage, damage to farmland	4B	(1) Use of blast plates on launch rails provided by NAR/TRA (2) Altimeters aren't armed until launch pad (3) Ensure presence of fire extinguisher at launch field	3A	TBD
EL.2	Compro-mised battery	(1) Battery punctured (2) Battery exposed to high temperature	Fire on launch field, hazmat leakage	3B	(1) Design electronics bays such that batteries are not close to sharp components (2) Electronics bay kept in shade prior to launch	2A	TBD
EL.3	LV impacts into ground with high kinetic energy	Late/par-tial/no parachute deployment	Permanent ruts or damage to launch field, LV is buried into launch field and is unable to be located, field is unable to be used for crops	4A	See VR.4 Mitigation	3A	See VR.4 Verification
EL.4	LV lands in tree	Parachute deploys at apogee and drifts	Tree dam-age/death, LV is left behind in tree	4B	(1) Launch sites are selected by NAR/TRA personnel to be far from trees or other hazards (2) See VR.3 Mitigation	2A	(1) NASA Requirement 1.12 (2) See VR.3 Mitigation
EL.5	Soil becomes contami-nated from fiberglass, carbon fiber, or other contami-nants	(1) CATO (2) Black powder is released at landing (3) HazMat littering	Soil is unusable, wildlife injury/death	4A	(1) See VA.1 Mitigation (2) See Requirement RS.2 (3) Trash Bags are brought to launch field	3A	(1) See VA.1 Mitigation (2) See Requirement RS.2 Verification (3) TBD

Table 6.12: Environmental Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
EL.6	Hazmat deposit in irrigation ditch	(1) Battery explosion (2) Explosion byproducts	Toxins remain in food crops and could be consumed by humans or wildlife	3A	(1) Utilized packing insulation is biodegradable (See Requirement RE.1) (2) Batteries are insulated and protected from impact	2A	(1) See Requirement RE.1 Verification (2) See NASA Requirement 2.22 Verification
EL.7	Littering of launch field	(1) Discon-nection of parachutes/ Nomex (2) Discon-nection of rubber bands from shock cord (3) Spillage of wadding	Environmen-tal contamina-tion	2C	(1) See VR.1 and VR.2 Mitigations (2) Adhere to Requirement RE.2 (3) Adhere to Requirement RE.1	1A	(1) See VR.1 and VR.2 Verifications (2) See Requirement RE.2 Verification (3) See Requirement RE.1 Verification
Hazards to Air/Water at Launch Sites							
EA.1	Microplastic emission	Excessive use of single-use plastics in LV design	(1) Microplastics are released into local watershed (2) Wildlife bodily harm/death	3A	LV design minimizes use of single-use plastics	1A	TBD
EA.2	Chemical off-gassing	Motor ignition, CATO	Air pollution	3B	AeroTech motors are selected for their high safety factor	2A	Verification pending
EA.3	Emission of smoke	(1) CATO (2) Motor ignition (3) Ejection charge detonation (4) Fire on launch field	Air pollution	2C	(1) Only AeroTech motors due to their good performance statistics (2) & (3) LV operation produces minimal combustion products (4) See EL.1 Mitigation	1C	TBD
EA.4	Greenhouse gas emissions	(1) Trans-portation to/from launch field and Huntsville (2) Combustion by-products	Air pollution, contribution to global warming	2C	(1) Team carpools to and from launch sites (2) See EA.3 Mitigation	1C	See EA.3 Verification

Table 6.12: Environmental Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Wildlife							
EW.1	Fire on launch field	motor ignition, premature ejection charge detonation, battery fire, CATO	Wildlife injury, habitat loss, crop damage, team member injury	4B	See EL.1 Mitigation	3A	See EL.1 Verification
EW.2	LV collides with birds in flight	Birds fly into clear airspace	Wildlife injury or death	4A	RSO confirms that range and sky are clear ahead of launch	3A	TBD
EW.3	Wildlife consumes toxins	Solid or liquid waste littering at launch site	Wildlife injury or death	4B	(1) Littering by personnel is prohibited, team follows leave no trace principles (2) Trash Bags are brought to launch field	2A	TBD
EW.4	LV lands in tree	Premature parachute deployment, strong wind drift	Habitat loss, wildlife injury or death	2B	See EL.4 Mitigation	1A	See EL.4 Verification
EW.5	Permanent jettison of Nomex sheet	(1) Rips and tears in Nomex (2) Breakage at Nomex connection	Contamination of wildlife food/water supply, wildlife injury/death	3B	See VR.1 Mitigation	2A	See VR.1 Verification
EW.6	Motor CATO	(1) Voids in motors (2) Cracks/deformation in motor casing	Wildlife injury or death, contamination of wildlife food/water supply	4B	See VA.1 Mitigation	3A	See VA.1 Verification

6.5.7 Project Risks FMEA

Table 6.13: Project Risks

Label	Risk	Effect	Likelihood	Impact	Mitigation	Quantified Impact of Mitigation
Time Risks						
TR.1	Incomplete/ rushed PDR, CDR, FRR, PLAR	Reduced scores on documenta-tion	Medium	High	Soft deadlines 1 week before due date, peer review 2 weeks before due date	A 1 week soft deadline allows the project management team to review the entire document after it's written.
TR.2	Delayed arrival of subscale components	Failure to construct subscale launch vehicle on time	Medium	High	Order components in September for November launch	Mitigation reduces need for backup launch dates. If not followed, a 2 week delay in component delivery would result in backup subscale launch needing to be used
TR.3	Delayed arrival of full-scale components	Failure to construct full-scale launch vehicle on time	Low	High	Order components in December for February launch	N/A, waiting for 2025 launch dates
TR.4	Subscale construction takes longer than anticipated	Failed subscale launch criterion	High	Medium	Schedule a 2 week buffer into subscale timeline.	A 2 week buffer allows time for launch vehicle mistakes to be corrected without using the backup subscale launch date.
TR.5	Full-scale construction takes longer than anticipated	Failed VDF	High	Medium	Schedule a 3 week buffer into full-scale timeline.	A 3 week buffer allows time for launch vehicle mistakes to be corrected without rescheduling VDF.
TR.6	Payload construction takes longer than anticipated	Failed PDF	Low	Medium	Schedule a 2 week buffer into payload construction timeline.	Creates a 2 week buffer period to fix/update payload if required.

Table 6.13: Project Risks

Label	Risk	Effect	Likelihood	Impact	Mitigation	Quantified Impact of Mitigation
TR.7	Rain on scheduled launches	Failed milestone	Medium	Low	Plan backup launch days, identify backup launch fields	Backup launch days allow the team to still complete the launch milestone with undesired weather conditions
TR.8	Interference of finals with Huntsville trip	Individuals cannot attend the Huntsville launch	High	Low	Reschedule finals	Rescheduling finals at the earliest time possible allows members to attend Huntsville. It would also decrease the amount of time available to take final exams by 20%.
TR.9	Failed ejection test	Failure to complete milestone launches	Medium	Medium	Plan to do ejection testing 2 weeks before PDF	Creates a 2 week buffer period to fix/update recovery system if required.
TR.10	Failed payload testing	Payload challenge failure	Medium	Medium	Allow time for retesting by starting payload testing 2 weeks before PDF	Creates a 2 week buffer period to fix/update payload if required.
TR.11	Failed vehicle testing	Rebuild launch vehicle, failure to complete milestone launches	Low	Medium	Test components before verification flights of the launch vehicle	According to timelines in Section 7.4, failed testing results in 3 weeks buffer to rebuild the launch vehicle between the last verification testing and vehicle flight testing.
TR.12	Failed subscale launch	Failure to complete milestone	Low	High	Refly at next launch, allow time for backup launches	Creates a buffer of 2 weeks.
TR.13	Failed VDF	Failure to complete milestone	Low	High	Refly at next launch, allow time for backup launches	N/A, waiting on 2025 launch dates.

Table 6.13: Project Risks

Label	Risk	Effect	Likelihood	Impact	Mitigation	Quantified Impact of Mitigation
TR.14	Failed PDF	Failure to complete milestone	Low	High	Refly at next launch, allow time for backup launches	N/A, waiting on 2025 launch dates.
			Resource Risks			
RR.1	Motor shortage	Failure to complete milestone launches	Low	Medium	Use backup motors, purchase motors early	Backup motors are identified in PDR and will be used if necessary
RR.2	No launches in April at home launch field	Missed PDF	High	Medium	Plan to do PDF in March, identify backup launch fields	Creates a month buffer to find another launch field if needed.
RR.3	Machine shop closed	Cannot manufacture aluminum parts	Low	Medium	Schedule machining at times the machine shop is open, use alternate materials such as wood	Using wood in place of aluminum components for RMS and thrust plate (see Section 3.2.3) results in a significant decrease in strength
RR.4	Fiberglass shortage	Cannot use fiberglass material for full-scale launch vehicle	Low	Medium	Utilize blue tube for full-scale design	(1) Increases budget cost by at least $300 (2) Increases risk of water logging the rocket during field recovery and failing NASA Requirement 2.3.
RR.5	Antenna unavailability	Can no longer use proposed payload design	Low	Medium	Redesign payload to use a different antenna, order antenna at earliest possible time	Redesigning the payload would negatively impact the payload timeline (Table 7.17), possibly resulting in moving PDF

Table 6.13: Project Risks

Label	Risk	Effect	Likelihood	Impact	Mitigation	Quantified Impact of Mitigation
Budget Risks						
BR.1	Any funding sources are eliminated entirely	Significant reduction in project budget	Low	High	Request funding from MAE department, contact funding source, request limited funding	Despite emergency funding, the team would lose approximately 800−8,000 according to Table 7.11.
BR.2	SGov funding is reduced	Subscale launch vehicle construction is delayed/ compromised	Medium	High	Fill out SGov application for an appeal of the allocated funding amount	If 25% of funding is still lost this results in a loss of $398 per Table 7.11.
BR.3	E Council funding is reduced	WolfWorks Experimental project funding is reduced/ compromised. Reduction in funding to SL competition project	Low	High	Fill out E Council funding sheet on time and prepare for the presentation necessary to request funding	Gain an additional $100-200 dollars from the appeal process.
BR.4	Space Grant funding is reduced	Full scale launch vehicle and payload development are compromised	Low	High	Rely on Student Government funding and include this information in the presentation for the next funding cycle	If 25% of funding is still lost this results in a loss of $1,250 per Table 7.11.
BR.5	EYE funding is reduced	Team is not able to travel to Huntsville or the number of students who can attend the Huntsville launch is reduced	Low	High	Contact EYE and appeal for more funding. Allow only necessary personnel to travel to Huntsville.	If 25% of funding is still lost this results in a loss of $2,000 per Table 7.11.

Table 6.13: Project Risks

Label	Risk	Effect	Likelihood	Impact	Mitigation	Quantified Impact of Mitigation
BR.6	ETF funding is reduced	Mentors funding is reduced and mentors cannot attend Huntsville launch	Low	High	Contact ETF and request additional funding, use mentor travel stipend from NASA, request that additional mentors pay for thier own travel	If 25% of funding is still lost this results in a loss of $625 per Table 7.11.
BR.7	High-Powered Rocketry Club credit card is declined or information is stolen	Cannot purchase items listed	Low	High	Replace card with new card, inform Wells Fargo of the stolen card immediately	Adds increased budget cost to replace card and adds more required time to the Treasurer.
BR.8	Receipt is not properly documented	Cannot receive payment from funding sources	Low	Medium	Attempt to locate receipt or request an online copy of the receipt, use money from club savings if necessary	Adds several hours of work to Treasurer to track down reciepts.
BR.9	Member fails to pay for t-shirt	Overstock of club merchandise. Reduction in club funds for competition purposes.	Low	Low	Only give t-shirts to members after payment is received	Financial gain is stagnant.
BR.10	Student steals/ takes money from club	Reduction in funding/ resources for club projects	Low	Medium	Remove student from the club, contct university code of conduct	Improves quality of team members.
BR.11	Club does not register as a nonprofit	Cannot receive payment from funding sources, team fined	Low	Low	Re-register club each year and fill out forms to submit to IRS	Adds approximately 30 minutes of paperwork.

Table 6.13: Project Risks

Label	Risk	Effect	Likelihood	Impact	Mitigation	Quantified Impact of Mitigation
BR.12	Missed deadline for funding	Delayed or reduced funding amount	Low	Medium	Contact funding source and explain situation, ask for late funding	Increases odds for at least some percentage of offered funding. Still would not result in the total amount requested.
Scope/ Functionality Risks						
SFR.1	Limited drogue recovery space	Failure to complete subscale, VDF, and PDF milestone launches	Low	High	Change drogue packing arrangement	Redo ejection testing protocols and delays project by at least 1 day. Increases the posibility of still launching on time.
SFR.2	Limited main recovery space	Failure to complete subscale, VDF, and PDF milestone launches	Low	Medium	Change main packing arrangement	Redo ejection testing protocols and delays project by at least 1 day. Increases the posibility of still launching on time.
SFR.3	Vehicle overweight/ underweight	Inaccurate apogee prediction	Medium	Medium	(1) Use Air Brakes to control apogee (2) Add/remove ballast to launch vehicle	(1) Have to update Air Brake software (2) Increases time of launch day assembly
SFR.4	Experimental payload complications	Loss of resources for payload challenge	Medium	High	Shift in resources away from experimental payload and toward competition payload	Results in loss of experimental payload (air brakes) and a less accurate apogee prediction
SFR.5	Air Brakes fail approval from NASA SL management team	Loss of Air Brakes on full-scale launch vehicle	Low	Medium	Include thorough and detailed Air Brakes docu-mentaiton in milestone documents	Requires time spent on Air Brakes documentation in all milestone documents. Reduction in resources allocated to competition payload.

Table 6.13: Project Risks

Label	Risk	Effect	Likelihood	Impact	Mitigation	Quantified Impact of Mitigation
SFR.6	Misinterpretation of payload challenge and requirements	Failure to complete payload challenge, disqualification	Low	High	Attend Q&A sessions, contact management team with clarifying questions	Informed team members and subsystem leads. Reduces points lost in documentation scoring. Avoids team disqualification.
SFR.7	Non-compliance to launch vehicle requirements	Failed milestones, disqualification	Low	High	Attend Q&A sessions, contact management team with clarifying questions	Informed team members and subsystem leads. Reduces points lost in documentation scoring. Avoids team disqualification.
SFR.8	Incorrect completion of STEM Engagement Activity Reports	Reduction in STEM Engagement score	Low	Medium	Attend STEM Engagement Webinar, contact management team with clarifying questions	Informed Officer Team and Outreach Lead. Results in an increase in quality of STEM Engagement reports and higher outeach score.

7 Project Plan

7.1 Requirements Verification

Table 7.1: 2024-2025 General Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
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). Student team members SHALL only be a part of one team in any capacity. Teams SHALL submit new work. Excessive use of past work SHALL merit penalties.	The team members of the NC State's High-Powered Rocketry Club will design, build, and document a completely original work as a solution to the challenge and vehicle requirements outlined in the NASA SL Handbook.	Inspection of launch vehicle and payload designs.	TBD	Project Management	In Progress
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 Team Lead, Vice President, Outreach Officer, Safety Officer, Treasurer, and Webmaster will develop a project plan and adhere to it. This plan will include deadlines and expectations for project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	Inspection of project timelines.	TBD	Project Management	In Progress
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 will ensure all team members who shall travel to the Huntsville Launch have completed in the NASA Gateway system before the roster deadline or by Nov. 29th, 2024.	Inspection of NASA Gateway profile.	TBD	Project Management	In Progress
1.3.1	Team members who will travel to the Huntsville Launch SHALL include students actively engaged in the project throughout the entire year.	The Team Lead will only select team members who have actively engaged in the project throughout the year to travel to the Huntsville Launch.	Inspection of member participation.	TBD	Project Management	Not Verified

Table 7.1: 2024-2025 General Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
1.3.2	Team members who will travel to the Huntsville Launch SHALL include one mentor (see Requirement 1.13).	The Team Lead will invite the mentor identified in Section 1.1.2 to the Huntsville Launch competition. A notice of the Huntsville Launch dates will be sent to the mentor(s) once NCSU HPRC is officially accepted into the competition.	Inspection of mentor stipend.	TBD	Project Management	Not Verified
1.3.3	Team members who will travel to the Huntsville Launch SHALL include no more than two adult educators.	The Team Lead will invite the adult educator identified in Section 1.1.2 to the Huntsville Launch competition. A notice of the Huntsville Launch dates will be sent to the adult educator once NCSU HPRC is officially accepted into the competition.	Inspection of Huntsville group members.	TBD	Project Management	Not Verified
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 40 – 43.	The Outreach Lead, identified in Section 1.6 of the proposal, will organize multiple events across the fall and spring semesters at local schools, organizations, etc. The Outreach Lead will keep a tally of all participants and a record of proof, consisting of photos and email confirmations. All information will be shared with the Team Lead before and after the event.	Inspection of STEM outreach activities.	TBD	Project Management	In Progress
1.5	The team SHALL establish and maintain a social media presence to inform the public about team activities.	The Social Media Officer, identified in Section 1.6 of the proposal, will document club progress and events across multiple social media platforms. Platforms consist of Instagram, Facebook, X, TikTok, YouTube, and LinkedIn (Section 1.1.5.	Inspection of team social media accounts.	TBD	Project Management	In Progress

Table 7.1: 2024-2025 General Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
1.6	Teams SHALL email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file SHALL be sufficient. Late submissions of PDR, CDR, or FRR milestone documents will NOT be accepted. Teams that fail to submit the PDR, CDR, or FRR milestone documents SHALL be eliminated from the project.	The Team Lead will email all deliverables to the NASA project management team by the deadline specified in the NASA SL handbook. The Webmaster, identified in Section 1.6 of the proposal, will receive the deliverables and upload it to the NCSU HPRC's website by the specified deadline.	Inspection of project deliverable submissions.	TBD	Project Management	In Progress
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 will meet to determine the teams' status in the program, and the teams SHALL be notified shortly thereafter.	Team members will complete all milestone review documents and submit before the provided deadline. In the event that NASA determines a document is not satisfactorily completed, the team will address the action items in a delta review session.	N/A	TBD	Project Management	Not Verified
1.8	All deliverables SHALL be in PDF format.	The Team Lead will send all deliverables to the NASA project management team in PDF format.	Inspection of project deliverable submissions.	TBD	Project Management	In Progress
1.9	In every report, teams SHALL provide a table of contents, including major sections and their respective subsections.	The Team Lead will organize the report documents to include and follow a table of contents.	Inspection of report submissions.	TBD	Project Management	In Progress
1.10	In every report, the team SHALL include the page number at the bottom of the page.	The Team Lead will ensure that a page number is included at the bottom of every page in the report document.	Inspection or report submissions.	TBD	Project Management	In Progress

Table 7.1: 2024-2025 General Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
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 Lead will provide and set-up all computer equipment necessary for video teleconference presentations/meetings in advance. The Team Lead will only use cellular phones for meetings and presentations as a last resort after all other avenues have been attempted.	Inspection of teleconference equipment.	TBD	Project Management	In Progress
1.12	All teams attending Launch Week SHALL be required to use the launch pads provided by Student Launch's launch services provider. No custom pads SHALL be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails SHALL be canted 5 – 10° away from the crowd on Launch Day. The exact can't SHALL depend on Launch Day wind conditions.	The Aerodynamics Lead and Structures Lead will ensure and construct a launch vehicle that can use the launch pads provided by the NASA SLs launch services provider. The Aerodynamics Lead and Structures Lead will consider the launch rail cant and dimensions when designing/constructing the launch vehicle.	Demonstration with subscale, VDF, and PDF.	TBD	Aerodynamics & Structures	Not Verified

Table 7.1: 2024-2025 General Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
1.13	Each team SHALL identify a “mentor.” A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The team mentor SHALL not be a student team member. The mentor SHALL maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of two flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend 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 Lead will identify a mentor according to NASA Regulation 1.13 and include the mentors information in all NASA documentation. The Treasurer and Team Lead will provide a travel stipend to the mentor(s) to travel to the Huntsville Launch.	Inspection of mentor information in milestone reports.	See Section 1.1.2 for mentor contact information	Project Management	Verified
1.14	Teams SHALL track and report the number of hours spent working on each milestone.	The Team Lead and Integration Lead will record the hours worked by all sub-teams at the end of every week. The Team Lead will ensure the number of hours spent working on each milestone is compiled for each milestone and is included in the respective document.	Inspection of milestone reports for team member hours.	TBD	Integration & Project Management	In Progress

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
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 SHALL receive zero altitude points towards their overall project score and SHALL not be eligible for the Altitude Award.	The Aerodynamics Lead will design a launch vehicle that reaches an apogee between 4,000 and 6,000 ft. AGL. The Structures Lead will organize and facilitate the construction of the launch vehicle with the rest of the team.	(1) Analysis of rocket using OpenRocket, RASAero II, and RocketPy. (2) Flight data from subscale launch, VDF, and PDF.	TBD	Aerodynamics & Structures	In Progress
2.2	Teams SHALL declare their target altitude goal at the CDR milestone. The declared target altitude SHALL be used to determine the team's altitude score.	The Aerodynamics Lead will perform multiple simulations to determine the approximate apogee for the full-scale rocket and include the target altitude in the CDR milestone.	Inspect CDR report for target altitude.	TBD	Aerodynamics	Not Verified
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 Structures Lead and Recovery Lead will design a recovery system that allows the launch vehicle to be recovered and re-used upon ground impact. The rocket will sustain minimal damage and have the ability to launch twice in the same day without repairs or needed modifications.	Document minimal launch vehicle damage after field recovery.	TBD	Recovery & Structures	In Progress
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 Lead and Recovery Lead will design a launch vehicle and recovery system that has a maximum of four independent sections.	Inspect separation points and recovery system.	TBD	Aerodynamics & Recovery	In Progress
2.4.1	Coupler/airframe shoulders which are located at in-flight separation points SHALL be at least two airframe diameters in length. (One body diameter of surface contact with each airframe section).	The Aerodynamics Lead will design the coupler/airframe shoulders to be at least 2 airframe diameters in length. The Structures lead shall build the coupler/airframe shoulders per the Aerodynamics Leads design.	Inspect coupler/airframe shoulders at separation points with a measurement device.	TBD	Aerodynamics & Structures	In Progress

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
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 will design the coupler/airframe shoulders to be at least 1.5 airframe diameters in length. The Structures lead shall build the coupler/airframe shoulders per the Aerodynamics Leads design.	Inspect coupler/airframe shoulders at non-in-flight separation points with a measurement device.	TBD	Aerodynamics & Structures	In Progress
2.4.3	Nosecone shoulders which are located at in-flight separation points SHALL be at least ½ body diameter in length.	The Aerodynamics Lead will design the nosecone shoulders to be at least 0.5 body diameter in length. The Structures Lead will construct the nosecone shoulders per the Aerodynamics Leads design.	Inspect Nose Cone shoulders with a measurement device.	TBD	Aerodynamics & Structures	In Progress
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 Team Lead, Integration Lead, and Safety Officer will develop launch day checklists that can be performed within 2 hours of the time the FAA flight waiver opens.	Time launch day assembly for subscale, VDF, and PDF.	TBD	Integration & Project Management & Safety	Not Verified
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 Team Lead, Integration Lead, and Safety Officer will monitor and ensure that the launch vehicle is able to remain in launch-ready configuration on the launch pad for a minimum of 3 hours without losing any critical components. The Team Lead and Safety Officer will ensure the safety of the launch vehicle during this time.	(1) Demonstrate with subscale, VDF, and PDF. OR (2) Demonstrate with electronic selection and electronic properties.	TBD	Project Management & Safety	Not Verified
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 Team Lead and Structures Lead will select a motor igniter that is capable of being launched by a 12-volt direct current firing system.	Demonstrate with subscale, VDF, and PDF.	TBD	Project Management & Structures	Not Verified
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 Team Lead and Structures Lead will select a motor igniter that is capable of being launched by a 12-volt direct current firing system.	Demonstrate with subscale, VDF, and PDF.	TBD	Project Management & Structures	Not Verified

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
2.9	Each team SHALL use commercially available ematches or igniters. Hand-dipped igniters SHALL not be permitted.	The Team Lead and Safety Officer will ensure that all emaches and igniters used are commercially available and that the launch vehicle does not use hand-dipped igniters.	Inspect ematches and/or ignitors prior to use.	TBD	Project Management & Safety	In Progress
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 will select a commercially available solid motor propulsion system that uses APCP and is approved by NAR, TRA, and/or CAR for the launch vehicle. The Team Lead will verify the motor selection.	Inspect propulsion system prior to rocket construction.	TBD	Aerodynamics & Project Management	In Progress
2.10.1	Final motor choice SHALL be declared by the Preliminary Design Review (PDR) milestone.	The Aerodynamics Lead will declare the final motor choice in the PDR milestone.	Inspect PDF report for motor selection.	See Section 1.2.1 for final full-scale motor choice	Aerodynamics	Verified
2.10.2	Any motor change after PDR SHALL be approved by the NASA management team or NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment SHALL not be approved. A scoring adjustment against the team's overall score SHALL be incurred when a motor change is made after the PDR milestone. The only exception is teams switching to their secondary motor choice provided the primary motor choice is unavailable due to a motor shortage.	The Team Lead will request the NASA management team or NASA RSO for approval for motor changes following the PDR milestone.	N/A	TBD	Project Management	Not Verified
2.11	The launch vehicle SHALL be limited to a single motor propulsion system.	The Aerodynamics Lead will design the launch vehicle to be a single motor propulsion vehicle.	Inspect propulsion system and vehicle configuration prior to construction.	TBD	Aerodynamics	In Progress
2.12	The total impulse provided by a College or University launch vehicle SHALL not exceed 5,120 Newton sec (L-class).	The Aerodynamics Lead will select a motor for the launch vehicle that will not exceed a total impulse of 5,120 Newton sec.	Inspect motor impulse for motor selection.	TBD	Aerodynamics	In Progress
2.13	Pressure vessels on the vehicle SHALL be approved by the RSO.	The Structures Lead will not include a pressure vessel in the launch vehicle design.	Pressure vessels are not included in launch vehicle design.	See Section 3.3 for current vehicle design	Structures	Verified

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
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 will not include a pressure vessel in the launch vehicle design.	Pressure vessels are not included in launch vehicle design.	See Section 3.3 for current vehicle design	Structures	Verified
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 will not include a pressure vessel in the launch vehicle design.	Pressure vessels are not included in launch vehicle design.	See Section 3.3 for current vehicle design	Structures	Verified
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 SHALL 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 will not include a pressure vessel in the launch vehicle design.	Pressure vessels are not included in launch vehicle design.	See Section 3.3 for current vehicle design	Structures	Verified
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 will design the launch vehicle to have a minimum static stability margin of 2.0 at the point of rail exit.	Analysis of rocket stability on OpenRocket, RASAero II, and RocketPy.	TBD	Aerodynamics	In Progress
2.15	The launch vehicle SHALL have a minimum thrust to weight ratio of 5.0:1.0.	The Aerodynamics Lead will design the launch vehicle to have a minimum thrust to weight ratio of 5.0:1.0.	(1) Analysis using OpenRocket, RASAero II, and RocketPy. (2) Inspection of thrust to weight calculations.	TBD	Aerodynamics	In Progress
2.16	Any structural protuberance on the rocket SHALL be located aft of the burnout center of gravity. Camera housings SHALL be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	The Aerodynamics Lead will design the launch vehicle to only have structural protuberance aft of the burnout center of gravity on the rocket.	Calculations of rocket burnout CG and Air Brake location.	TBD	Aerodynamics	In Progress
2.17	The launch vehicle SHALL accelerate to a minimum velocity of 52 fps at rail exit.	The Aerodynamics Lead will design the launch vehicle and select the appropriate motor to have a minimum velocity of 52 fps at rail exit.	Analysis of motor selection.	TBD	Aerodynamics	In Progress

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
2.18	All teams SHALL successfully launch and recover a subscale model of their rocket. Success of the subscale is at the sole discretion of the NASA review panel. The subscale flight may be conducted at any time between 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 team will successfully launch and recover a subscale model of their intended launch vehicle. The Team Lead will ensure that the subscale flight data is reported and presented in the CDR milestone. The Aerodynamics Lead will ensure that the subscale uses a minimum motor impulse class of E.	Demonstrate with subscale launch.	TBD	Aerodynamics & Project Management	Not Verified
2.18.1	The subscale model SHALL 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 and Structures Lead will design and construct a subscale launch vehicle that will resemble and perform, as similarly as possible to the full-scale launch vehicle. The full-scale model will not be used as the subscale model.	Analysis and inspection of subscale rocket.	TBD	Aerodynamics & Structures	In Progress
2.18.2	The subscale model SHALL carry an altimeter capable of recording the model's apogee altitude.	The Recovery Lead will install an altimeter capable of recording the subscale model's apogee altitude into the launch vehicle.	Inspection of subscale Avionics Bay.	TBD	Recovery	In Progress
2.18.3	The subscale rocket SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The Aerodynamics Lead and Structures Lead will facilitate the design and construction of a unique subscale rocket, built for the purpose of this years NASA SL challenge.	Verification of purchased subscale construction parts.	TBD	Aerodynamics & Structures	In Progress
2.18.4	Proof of a successful flight SHALL be supplied in the CDR report.	The team will include proof of a successful flight in the CDR report. The Team Lead will verify this information and formatting.	Inspection of CDR report for proof of successful subscale flight.	TBD	Project Management	Not Verified

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
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 will process altimeter flight data and include altimeter flight profile graphs in the CDR report. If altimieter flight profile graphs are not avialable, the Recovery Lead will submit a quality photo showing successful launch, recovery events, and landing events as proof for a successful flight.	Analysis of flight profile graphs for subscale, PDF, and VDF.	TBD	Recovery	Not Verified
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: nosecone, recovery system, airframe, and booster.	The Recovery Lead will take quality photos of all sections of the launch vehicle in its landed configuration. The Team Lead will include the photos in the CDR report.	Inspection of CDR report for quality pictures of post-launch launch vehicle.	TBD	Project Management & Recovery	Not Verified
2.18.5	The subscale rocket SHALL not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4" diameter, 100" length rocket, your subscale SHALL not exceed 3" diameter and 75" in length.	The Aerodynamics Lead and Structures Lead will design and construct a subscale rocket that does not exceed 75% of the dimensions for the designed full-scale rocket.	Inspection of subscale launch vehicle design.	TBD	Structures	In Progress
2.19.1	Vehicle Demonstration Flight— All teams SHALL successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown SHALL be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). Requirements 2.19.1.1-9 SHALL be met during the full-scale demonstration flight:	The team will successfully launch and recover their designed full-scale launch vehicle prior to FRR in its final flight configuration. The team will validate all aspects of the launch vehicle during this flight and meet NASA requirements 2.19.1.1-9.	Demonstrate successful VDF and completed flysheet.	TBD	Project Management	Not Verified

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
2.19.1.1	The vehicle and recovery system SHALL have functioned as designed.	The Integration Lead and Team Lead will verify that the vehicle and payload system functioned as it was designed.	Demonstration with subscale, VDR, and PDF.	TBD	Integration & Project Management	Not Verified
2.19.1.2	The full-scale rocket SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The Aerodynamics Lead and Structures Lead will facilitate the design and construction of a new full-scale rocket, built for the purpose of this years NASA SL challenge.	Verification of purchased full-scale construction parts.	TBD	Aerodynamics & Structures	Not Verified
2.19.1.3.1	During Vehicle Demonstration Flight - If the payload is not flown, mass simulators SHALL be used to simulate the payload mass.	The Payload Team and Structures Lead will use a mass simulator to simulate the payload mass if the payload is not flown during the vehicle demonstration flight.	Inspection of full-scale launch vehicle during VDF.	TBD	Payload & Structures	Not Verified
2.19.1.3.2	The mass simulators SHALL be located in the same approximate location on the rocket as the missing payload mass.	The Structures lead will place the mass simulators in the same approximate location in the launch vehicle as the missing payload mass.	Inspection of full-scale launch vehicle during VDF.	TBD	Structures	Not Verified
2.19.1.4	If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems SHALL be active during the full-scale Vehicle Demonstration Flight.	Payload Team and Team Lead ensure that Air Brakes is on the full-scale rocket and is functioning during VDF.	Inspection of full-scale launch vehicle and Air Brakes during VDF.	TBD	Payload & Project Management	Not Verified
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 and Team Lead will ensure that the competition launch motor is used for the Vehicle Demonstration Flight. If unable, the Team Lead will request a waiver for the use of an alternative motor from NASA in advance.	Inspection of motor and propulsion system prior to VDF.	TBD	Aerodynamics & Project Management	Not Verified

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
2.19.1.6	The vehicle SHALL be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast SHALL not be added without a re-flight of the full-scale launch vehicle.	The Aerodynamics Lead and Team Lead will ensure that the full-scale launch vehicle is flown in its fully ballasted configuration during the vehicle demonstration flight. The Aerodynamics Lead will not add additional ballast without a re-flight of the full-scale launch vehicle.	Inspection of vehicle ballast prior to VDF.	TBD	Aerodynamics & Project Management	Not Verified
2.19.1.7	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components SHALL not be modified without the concurrence of the NASA management team or Range Safety Officer (RSO).	The team will not modify the launch vehicle or any of its components after completing the full-scale demonstration flight without the approval of the NASA management team or RSO.	Inspection of launch vehicle design post VDF.	TBD	Project Management	Not Verified
2.19.1.8	Proof of a successful flight SHALL be supplied in the FRR report.	The Team Lead will ensure that proof of a successful full-scale demonstration flight is supplied in the FRR report.	Inspection of FRR report for proof of successful flight.	TBD	Project Management	Not Verified
2.19.1.8.1	Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet Requirement 2.19.8. Altimeter flight profile graph(s) that are not complete (liftoff through landing) SHALL not be accepted.	The Recovery Lead will include altimeter flight profile data with accompanying altitude and velocity versus time plots in the FRR report for the full-scale launch vehicle.	Inspection of FRR report for altimeter flight profile data and graphs.	TBD	Recovery	Not Verified
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: nosecone, recovery system, airframe, and booster.	The Recovery Lead and Team Lead will include quality photos of the landing configurations for all parts of the launch vehicle in the FRR report.	Inspection of FRR report for quality pictures of launch vehicle post-landing.	TBD	Project Management & Recovery	Not Verified
2.19.1.8.3	Raw altimeter data SHALL be submitted in .csv or .xlsx format.	The Recovery and Team Lead will submit all raw altimeter data in .csv or .xlsx format.	Inspection of FRR report for raw altimeter data.	TBD	Project Management & Recovery	Not Verified

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
2.19.1.9	Vehicle Demonstration flights 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. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight SHALL submit an FRR Addendum by the FRR Addendum deadline.	The team will complete the Vehicle Demonstration flights by the FRR submission deadline.	VDF flysheet and proof submission by deadline.	TBD	Project Management	Not Verified
2.19.2	Payload Demonstration Flight— All teams SHALL successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown SHALL be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. Requirements 2.19.2.1-4 SHALL be met during the Payload Demonstration Flight.	The team will launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The Payload Team and Structures Team will ensure that the launch vehicle and payload flown are to be flown the exact same as the competition launch.	PDF flysheet and proof submission by deadline.	TBD	Payload & Project Management & Structures	Not Verified
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 Payload Team does not design a jettisoning payload.	The payload design does not jettison.	TBD	Integration & Payload	Not Verified

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
2.19.2.2	The payload flown shall be the final, active version.	The Payload Team and Team Lead will ensure that the payload flown during the payload demonstration flight is the final, active version of the payload.	Inspection of payload design prior to PDF.	TBD	Payload & Project Management	Not Verified
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 team will adhere to and meet NASA Requirements 2.19.2.1-2. The Team Lead will ensure all criteria for the VDF are complete and submitted before the FRR deadline. If the criteria is not properly met, the team will submit an additional flight and an FRR Addendum.	Verification of Requirements 2.19.2.1-2	TBD	Project Management	Not Verified
2.19.2.4	Payload Demonstration Flights SHALL be completed by the FRR Addendum deadline. NO EXTENSIONS SHALL BE GRANTED.	The team will complete the payload demonstration flights by the FRR Addendum deadline.	PDF submitted by FRR addendum deadline.	TBD	Project Management	Not Verified
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 Report.	The team will submit an FRR Addendum if the team needs to complete a Payload Demonstration Flight or a NASA required Vehicle Demonstration Re-flight after the FRR Report.	Submitted FRR addendum if required.	TBD	Project Management	Not Verified
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 team will complete a Vehicle Demonstration Re-Flight, if required, and submit it by the FRR Addendum deadline.	Submitted VDF re-flight if required.	TBD	Project Management	Not Verified
2.20.2	Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload during launch week. Permission SHALL not be granted if the RSO or the Review Panel have any safety concerns.	The team will petition the NASA RSO for permission to fly the payload during launch week if the Payload Demonstration Flight is not fully successful.	N/A	TBD	Project Management	Not Verified

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
2.21	The team's name and Launch Day contact information SHALL be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information SHALL be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	The Team Lead will verify that the team's name and contact information is in the rocket airframe and any section of the launch vehicle that separates during flight and is not tethered to the main airframe.	Inspection of internal launch vehicle air frame for contact information.	TBD	Project Management	Not Verified
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 Team Lead and Safety Officer will ensure that all Lithium Polymer batteries are sufficiently protected from impact with the ground. All Lithium Polymer batteries will be brightly colored and clearly marked to make it distinguishable from other payload hardware.	Inspection of all LiPo batteries for protection and labels.	TBD	Project Management & Safety	In Progress
2.23.1	The launch vehicle SHALL not utilize forward firing motors.	The Aerodynamics Lead will design the launch vehicle to not utilize forward firing motors.	Inspection of launch vehicle motor.	TBD	Aerodynamics	In Progress
2.23.2	The launch vehicle SHALL not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The Aerodynamics Lead will design the launch vehicle to not utilize motors that expel titanium sponges.	Inspection of launch vehicle motor.	TBD	Aerodynamics	In Progress
2.23.3	The launch vehicle SHALL not utilize hybrid motors.	The Aerodynamics Lead will design the launch vehicle to not utilize hybrid motors.	Inspection of launch vehicle motor.	TBD	Aerodynamics	In Progress
2.23.4	The launch vehicle SHALL not utilize a cluster of motors.	The Aerodynamics Lead will design the launch vehicle to not use a cluster of motors.	Inspection of launch vehicle motor.	TBD	Aerodynamics	In Progress
2.23.5	The launch vehicle SHALL not utilize friction fitting for motors.	The Structures Lead will construct the launch vehicle to not utilize friction fitting for motors. A reusable casing mechanism will be designed to house a motor.	Inspection of launch vehicle motor retention.	TBD	Structures	In Progress
2.23.6	The launch vehicle SHALL not exceed Mach 1 at any point during flight.	The Aerodynamics Lead will design the launch vehicle and select a motor such that Mach 1 is not exceeded at any point during the flight.	(1) Analysis of launch vehicle in OpenRocket, RASAero II, and RocketPy. (2) Demonstration with subscale, VDF, and PDF.	TBD	Aerodynamics	In Progress

Table 7.2: 2024-2025 Launch Vehicle Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
2.23.7	Vehicle ballast SHALL not exceed 10% of the total un-ballasted weight of the rocket, as it would sit on the pad (i.e., a rocket with an un-ballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).	The Aerodynamics Lead will design the launch vehicle such that the vehicle ballast does not exceed 10% of the total un-ballasted weight of the rocket.	Analysis and calculations of vehicle ballast.	TBD	Aerodynamics	In Progress
2.23.8	Transmissions from on-board transmitters, which are active at any point prior to landing, SHALL not exceed 250 mW of power (per transmitter).	The Payload Team and Recovery Lead will verify that any transmission from on-board transmitters will not exceed 250 mW of power (per transmitter) prior to the landing of the launch vehicle.	Inspection and analysis of electronic properties.	TBD	Payload & Recovery	In Progress
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 Payload Team and Recovery Lead will verify that all transmitters used will not create excessive interference. All information being transmitted shall use unique frequencies, passcode systems, or other relevant systems to reduce interference.	(1) Analysis of electronic properties. (2) Demonstration with subscale and PDF.	TBD	Payload & Recovery	In Progress
2.23.10	Excessive and/or dense metal SHALL not be utilized in the construction of the 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 will not use excessive and/or dense metal in the construction of the launch vehicle. Only the use of lightweight metal will be allowed into the design and construction of the launch vehicle.	Inspect launch vehicle design and construction for dense metal.	TBD	Structures	In Progress

Table 7.3: 2024-2025 Recovery Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
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 Lead will design a dual deploy recovery system using two altimeters, one serving as a primary altimeter and one serving as a secondary backup altimeter. The drogue shoot will be deployed at apogee and the main parachute deployed above 500 ft.	Demonstrate with subscale, VDF, and PDF.	TBD	Recovery	In Progress
3.1.1	The main parachute SHALL be deployed no lower than 500 ft.	The Recovery Lead will program the primary altimeter to deploy the main parachute at 550 ft. and the secondary altimeter to deploy the main parachute at 500 ft.	(1) Demonstrate with subscale, VDF, and PDF. (2) Analysis of Avionics Bay electronics and flight data.	TBD	Recovery	Not Verified
3.1.2	The apogee event SHALL contain a delay of no more than 2 sec.	The Recovery Lead will program the primary altimeter to deploy the drogue parachute with a 0 second delay from apogee. Similarly, the secondary altimeter will be programmed to deploy the drogue parachute 1 second after apogee.	(1) Demonstrate with subscale, VDF, and PDF. (2) Analysis of altimeter flight data.	TBD	Recovery	Not Verified
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.	The Recovery Lead will design a dual deploy recovery system controlled by two altimeters, not motor ejection.	Inspection of launch vehicle motor retention.	TBD	Recovery	In Progress
3.2	Each team shall perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale vehicles.	The Recovery Lead will perform ground ejection tests prior to every vehicle launch.	Demonstrate and record successful ground ejection test in CDR and FRR milestone.	TBD	Recovery	Not Verified
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 Lead will design a recovery system to use parachutes large enough such that the heaviest section of the launch vehicle's kinetic energy does not exceed 75 ft-lbf.	Analysis of kinetic energy calculations.	TBD	Recovery	In Progress

Table 7.3: 2024-2025 Recovery Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
3.4	The recovery system SHALL contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	The Recovery Lead will design a recovery system that uses two separate commercially available barometric altimeters designed for rocketry recovery events that function on two separate electronic circuits.	Inspection of recovery system design prior to construction.	TBD	Recovery	In Progress
3.5	Each altimeter SHALL have a dedicated power supply, and all recovery electronics SHALL be powered by commercially available batteries.	The Recovery Lead will design the recovery system such that each of the altimeters have their own independent commercially available batteries that function on separate circuits.	Inspection of Avionics Bay power source design.	TBD	Recovery	In Progress
3.6	Each altimeter SHALL be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	The Recovery Lead will design the recovery system such that each of the altimeters are armed using pull pin switches that can be accessed from the exterior of the launch vehicle's airframe.	Inspection of launch vehicle switchband.	TBD	Recovery	In Progress
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 Lead will choose arming switches that can lock in the ON position for the entirety of the flight.	Inspection of launch vehicle switchband and arming switch.	TBD	Recovery	In Progress
3.8	The recovery system, GPS and altimeters, and electrical circuits SHALL be completely independent of any payload electrical circuits.	The Recovery Lead will design the recovery system such that both altimeters and the GPS function on circuits independent from any payload electrical circuits.	Inspection of Avionics Bay GPS and altimeter circuits.	TBD	Recovery	In Progress
3.9	Removable shear pins SHALL be used for both the main parachute compartment and the drogue parachute compartment.	The Recovery Lead will design the recovery system to utilize shear pins on the connection points for the main parachute compartment and the drogue parachute compartment.	Inspection of launch vehicle separation point pins.	TBD	Recovery	In Progress
3.10	Bent eye bolts SHALL not be permitted in the recovery subsystem.	The Recovery Lead shall confirm that no bent eye bolts are utilized anywhere within the recovery subsystem.	Inspection of eye bolts prior to installation.	TBD	Recovery	Not Verified

Table 7.3: 2024-2025 Recovery Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
3.11	The recovery area SHALL be limited to a 2,500 ft. radius from the launch pads.	The Recovery Lead will design the recovery system to utilize parachutes appropriately sized to ensure that the launch vehicle does not drift more than 2,500 ft. from the launch pads during descent.	Analysis of drift distance calculations.	TBD	Recovery	In Progress
3.12	Descent time of the launch vehicle SHALL be limited to 90 sec (apogee to touch down). Teams whose launch vehicle descent, as verified by vehicle demonstration flight data, stays under 80 sec will be awarded bonus points.	The Recovery Lead will design the recovery system to utilize parachutes appropriately sized to ensure that the launch vehicle descends to the ground in under 90 sec.	(1) Analysis of parachute calculations. (2) Demonstration of subscale, VDF, and PDF.	TBD	Recovery	In Progress
3.13	An electronic GPS tracking device SHALL be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	The Recovery Lead will design the recovery system to utilize an electronic GPS in each separating section of the launch vehicle.	Inspection of Avionics Bay for GPS.	TBD	Recovery	In Progress
3.13.1	Any rocket section or payload component, which lands untethered to the launch vehicle, SHALL contain an active electronic GPS tracking device.	The Recovery Lead will utilize an electronic GPS in each separation section of the launch vehicle.	Inspection of separated independent sections for GPS device.	See Section 4.5 for current non-jettison payload design.	Recovery	Verified
3.13.2	The electronic GPS tracking device(s) SHALL be fully functional during the official competition launch.	The Recovery Lead will test all electronic GPS tracking device(s) after the vehicle is fully assembled before every launch.	Demonstration with subscale, VDF, and PDF.	TBD	Recovery	Not Verified
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 Lead will design the recovery system such that none of the recovery system electronics are influenced by other on-board electronic devices.	Demonstration with subscale, VDF, and PDF.	TBD	Recovery	Not Verified
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 Lead will design the recovery system such that all altimeters are physically located in a separate compartment from all other non-recovery on-board electronics.	Inspection of recovery altimeters and Avionics Bay.	TBD	Recovery	In Progress

Table 7.3: 2024-2025 Recovery Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
3.14.2	The recovery system electronics SHALL be shielded from all on-board transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The Recovery Lead will design the recovery system such that the recovery system electronics are shielded from all on-board transmitting devices.	Inspection of Avionics Bay.	TBD	Recovery	In Progress
3.14.3	The recovery system electronics SHALL be shielded from all on-board devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The Recovery Lead will design the recovery system such that the recovery system electronics are shielded from all on-board magnetic wave generating devices.	Inspection of Avionics Bay.	TBD	Recovery	In Progress
3.14.4	The recovery system electronics SHALL be shielded from any other on-board devices which may adversely affect the proper operation of the recovery system electronics.	The Recovery Lead will design the recovery system such that the recovery system electronics are shielded from all on-board devices which may adversely affect the proper operation of the recovery system electronics.	Inspection of Avionics Bay.	TBD	Recovery	In Progress

Table 7.4: 2024-2025 Payload Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
4.1	USLI PAYLOAD MISSION OBJECTIVE- College/University Division teams SHALL design, build, and fly a STEMnaut flight capsule capable of safely retaining four STEMnauts and transmitting, via radio frequency, relevant rocket and STEMnaut landing site data to a NASA-owned receiver located at the launch site. STEMnauts SHALL be physical representations of the crew onboard the rocket. The method(s) and design(s) utilized to complete the payload mission SHALL be at the team's discretion, permitted so long as the designs are deemed safe, comply with FAA and legal requirements, and adhere to the intent of the challenge. NASA reserves the right to require modifications to any proposed payload.	The team will design a flight capsule that meets size, weight, and structural requirements to safely house four STEMnauts, physical models that represent a crew. A microcontroller with sensors will collect and store data for transmission upon landing. The design process will adhere to all FAA and NAR rules. Safety reviews will be conducted, and any necessary modifications will be implemented according to feedback from NASA.	Demonstration with subscale and PDF.	TBD	Payload Team	In Progress
4.2.1	Teams SHALL choose a minimum of 3 pieces of data from the below list to a maximum of 8 to transmit to the NASA receiver. • Time of landing • Maximum velocity • Landing velocity, G-forces sustained • Calculated STEMnaut crew survivability • Temperature of landing site • Apogee reached • Battery check/power status • Orientation of on-board STEMnauts	The team will transmit the following data: • Time of landing • Maximum velocity • Landing velocity, G-forces sustained • Calculated STEMnaut crew survivability • Temperature of landing site • Apogee reached • Battery check/power status • Orientation of on-board STEMnauts Sensors and data logging systems will be installed in the capsule to measure these parameters. All data will be transmitted to the NASA receiver upon landing.	Demonstration with subscale and PDF.	TBD	Payload Team	In Progress

Table 7.4: 2024-2025 Payload Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
4.2.2	The payload SHALL not have any protrusions from the vehicle prior to apogee that extend beyond a quarter inch exterior to the airframe.	The Payload Structural Integration Lead will design the STEMCRaFT such that it does not have any protrusions extending beyond a quarter inch of the airframe prior to apogee.	Inspection of payload design and construction.	TBD	Payload Structural Integration	In Progress
4.2.3	Payload SHALL transmit on the 2-M band. A specific frequency SHALL be given to the teams later. NASA SHALL use the FTM-300DR transceiver.	The Payload Team will design the STEMCRaFT such that transmissions will be sent to the FTM-300DR receiver on the 2-M band using a specific frequency stated by NASA.	Inspection of payload design and construction.	TBD	Payload Team	Not Verified
4.2.4	All transmissions SHALL start and stop with team member call sign.	The transmission system will be programmed to initiate and terminate all transmissions with the designated team member call sign, ensuring compliance with communication protocol.	(1) Inspection of payload software (2) Demonstration with subscale and PDF.	TBD	Payload Systems	Not Verified
4.2.5	Teams SHALL submit a list of what data they will attempt to transmit by NASA receiver by March 17.	The team will prepare and submit a list of selected data points to NASA before the March 17 deadline.	Submission of data points by deadline.	TBD	Payload Team	Not Verified
4.2.6	Teams SHALL transmit with a maximum of 5W and transmissions SHALL not occur prior to landing.	The Payload Team ensures that no transmissions begin prior to the launch vehicle landing, and that the transmission does not exceed 5W of power.	(1) Demonstration with subscale and PDF (2) Analysis of flight data and electronic properties	TBD	Payload Electronics & Payload Systems	Not Verified
4.2.6.1	Teams SHALL not transmit on the specified NASA frequency on launch day prior to landing.	The Payload Team ensures that no transmission is sent on the NASA specified frequency prior to the launch vehicle landing.	Demonstration with subscale and PDF.	TBD	Payload Electronics & Payload Systems	Not Verified
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 Team will not jettison the payload.	The payload design does not jettison.	See Section 4.5 for the current non-jettison payload design.	Payload Team & Safety	Verified
4.3.2	Teams SHALL abide by all FAA and NAR rules and regulations.	The Safety Team reviews all payload systems to ensure that the payload is compliant with all FAA and NAR regulations.	Inspection of payload design and construction.	TBD	Safety	In Progress

Table 7.4: 2024-2025 Payload Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
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 Team does not design and construct a jettisoning payload.	Payload does not jettison.	See Section 4.5 for the current non-jettison payload design.	Payload Systems & Safety	Verified
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 Team does not design or construct a UAS or a jettisoning payload.	Payload does not jettison.	See Section 4.5 for the current non-jettison payload design.	Payload Systems & Safety	Verified
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 Team does not design or construct a UAS or a jettisoning payload.	Payload does not jettison.	See Section 4.5 for the current non-jettison payload design.	Safety	Verified
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 Team does not design or construct a UAS or a jettisoning payload.	Paylod does not jettison.	See Section 4.5 for the current non-jettison payload design.	Payload Team	Verified

Table 7.5: 2024-2025 Safety Requirements

NASA Req. No	Requirement Statement	Planned Action	Verification Method	Verification	Subsystem Allocation	Status
5.1	Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	The Team Lead will create a launch and safety checklist. All team members will use this checklist during launch day activities and rocket/payload construction. The final checklist will be included in the FRR report and used during LRR.	Validation of launch and safety checklist.	TBD	All Subsystems	Not Verified
5.2	Each team shall identify a student safety officer who will be responsible for all items in Section 5.3.	The team will democratically nominate a student safety officer who will be responsible for all items in NASA Requirement 5.3. The designated Safety Officer is identified in Section 1.4 of the proposal document.	Inspection of milestone documentation.	N/A	Safety	Verified
5.3.1.1	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during design of vehicle and payload.	The Safety Officer will attend team activities that focus on the design of vehicle and payload to enforce proper safety protocols.	Demonstration during subsystem meetings and launch day activities.	TBD	Safety	In Progress
5.3.1.2	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during the construction of vehicle and payload components.	The Safety Officer will attend team activities that focus on the construction of vehicle and payload components to enforce proper safety protocols.	Demonstration during subsystem meetings and launch day activities.	TBD	Safety	In Progress
5.3.1.3	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during the assembly of vehicle and payload	The Safety Officer will enforce proper safety protocols during the assembly of the vehicle and payload.	Demonstration during subsystem meetings and launch day activities.	TBD	Safety	In Progress
5.3.1.4	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during the ground testing of vehicle and payload.	The Safety Officer will attend and enforce proper safety protocols during the ground testing of vehicle and payload.	Demonstration during subsystem meetings and launch day activities.	TBD	Safety	Not Verified
5.3.1.5	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during the subscale launch test(s).	The Safety Officer will attend the subscale launch test(s) and ensure that the team follows the written safety protocols and checklists.	Demonstration during subsystem meetings and launch day activities.	TBD	Safety	Not Verified
5.3.1.6	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during the full-scale launch test(s).	The Safety Officer will attend the full-scale launch test(s) and ensure that the team follows the written safety protocols and checklists.	Demonstration during subsystem meetings and launch day activities.	TBD	Safety	Not Verified

5.3.1.7	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during the competition launch.	The Safety Officer will attend the competition launch and ensure that the team follows the written safety protocols and checklists.	Demonstration during subsystem meetings and launch day activities.	TBD	Safety	Not Verified
5.3.1.8	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during recovery activities.	The Safety Officer will be present and enforce safety protocols during launch vehicle recovery activities.	Demonstration during subsystem meetings and launch day activities.	TBD	Safety	Not Verified
5.3.1.9	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during STEM engagement activities.	The Safety Officer will attend STEM engagement activities and ensure all participants are following propery safety protocols.	Demonstration during subsystem meetings and launch day activities.	TBD	Safety	In Progress
5.3.2	The designated Safety Officer SHALL implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The Safety Officer will implement and verify all procedures developed by the team for construction, assembly, launch, and recovery activities.	Demonstration in milestone reports.	TBD	Safety	In Progress
5.3.3	The designated Safety Officer SHALL manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and SDS/chemical inventory data.	The Safety Officer will manage and maintain the team's hazard analyses, failure modes analyses, procedures, and SDS/chemical inventory data.	Inspection	TBD	Safety	In Progress
5.3.4	The designated Safety Officer SHALL assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	The Safety Officer will assist the team in the creation of the team's hazard analyses, failure modes analyses, and procedures to maintain a safe laboratory space.	Demonstration in milestone reports.	TBD	Safety	In Progress
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 Officer will verify that the team abides by all local rocketry club rules and regulations.	Demonstration during launch day activities and in milestone reports.	TBD	Safety	Not Verified

5.5	Teams SHALL abide by all rules set forth by the FAA.	The Safety Officer will train the team on all appropriate safety protocols and rules. The Safety Officer will ensure that the team follows all rules set forth by the FAA.	Inspection of milestone documentation.	TBD	All Subsystems	In Progress

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
Functional Requirements							
LVF.1	When performing cuts or drilling holes into a fiberglass tube, pilot holes SHALL be drilled before making the final hole. Additionally, blue masking tape SHALL be applied to the underside of the fiberglass tube at the location of the future hole.	Physical stress to the fiberglass during cutting or drilling procedures increases the risk of delamination and splintering in the material. Drilling a pilot hole reduces stress in the concentrated region and blue tape reinforces the outermost layer of the material. These procedures reduce the risk of damaging the material on the opposite end that the drilling is occuring. As referenced in Section 3.3.3, the full-scale launch vehicle will be composed of primarily fiberglass. This requirement must be followed when drilling the shear pin holes, pressure port holes, rivet holes, and switchband holes.	TBD	Section 3.3.3	Structures	Not Verified	Fiberglass tubing has yet to be purchased
LVF.2	Prior to the launch day of any version of the NASA SL competition rocket, the NC State HPRC team members SHALL perform a “dry run” of launch day assembly. Dry run includes the set-up and installation of all parts of the rocket, except motor install and black powder charges.	A dry run is required before launch day to verify that the launch vehicle and payload integrate correctly, without requiring extra materials on the day of launch. This is crucial because the nearest launch site is at least two hours away, and any missing components would prevent the launch from proceeding. Thus resulting in failed milestones.	TBD	N/A	Structures, Team Management	Not Verified	First subscale ejection test and launch has yet to occur

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
LVF.3	The team members of the NC State HPRC, SHALL perform test fitting procedures during every main construction phase of any version of a NASA SL competition rocket. Test fitting procedures are necessary for any semi or fully built assembly of the launch vehicle.	Test fitting is necessary to verify that all components of the launch vehicle are sized and spaced correctly. This ensures that new materials do not need to be purchased and component tolerancing is correct. Additionally, the team has a fixed budget and cannot purchase unnecessary or repetitive materials frequently. The teams budget and purchasing allowances can be found in Table 7.10.	TBD	Table 7.10	Integration, Structures	Not Verified	Subscale components are under construction and component fitting has began (not official)
LVF.4	Anytime West Systems epoxy is used on any version of the NASA SL competition rocket, the particular area SHALL undergo a curing process of 24 hours.	West Systems epoxy requires 24 hours to fully cure. This ensures the epoxy achieves it's full strength.	TBD	West Systems Epoxy cure instructions	Structures	Not Verified	Epoxy has yet to be used
LVF.5	When performing cuts into the circular tubing of any version of the NASA SL competition launch vehicle, a jig SHALL be used to make sure the object does not roll.	Due to budgeting of materials, correct measurements and accurate cuts are required for the body tube of the rocket. A jig or clamp allows for the material to be steady during manipulation and result in clean and precise cuts. As seen in Section 3.3, the dimensions of the rocket are fixed to allow adequate spacing for challenge payload, experimental payload, and recovery systems.	TBD	Section 3.3	Structures	Not Verified	Subscale body tube has been cut
LVF.6	When using a drill press, the relevant team member SHALL ensure that the part is properly clamped down to prevent misalignment and shifting during the drilling process.	Securing materials with clamps while using the drill press ensures that the component does not shift under the drill bit force, preventing hole misalignment that could necessitate component replacement. Component replacement is an expense beyond the budget outlined in Section 7.2.	TBD	Section 7.2	Structures	Not Verified	Subscale rivet and shear pin holes have been drilled

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
LVF.7	Prior to the cutting of any body tube of any version of the NASA SL competition rocket, the Integration Lead (or Team Lead) and the Structures Lead SHALL approve the measurement individually.	Implementing a two-factor verification process minimizes the risk of making incorrect measurements for materials with limited availability.	TBD	N/A	Integration, Structures	Not Verified	All measurements have been doubly verified so far
LVF.8	All ballast installed in the NASA SL competition launch vehicle SHALL be removable.	Due to the long timeline of payload design outlined in Section 7.4.2, the payload mass may change after vehicle dimensions are defined. This may result in changes in stability margin of the launch vehicle beyond the margins defined in Requirement LVD.10. To maintain the desired stability margin throughout the project, removable ballast is required to adjust the rocket's stability margin as needed.	TBD	Requirement LVD.10 Section Section 7.4.2	Structures	Not Verified	Design confirmed
LVF.9	Fasteners attached to the RMFS SHALL only be tightened by hand or by screwdriver. No torque or torque multiplying devices SHALL be used.	Over tightening the 8-32 machine screws into the 6061-T6 aluminum RMFS would result in stripping of the threads in the RMFS. This would result in loss of the RMFS centering ring. Component replacement is an expense beyond the budget outlined in Section 7.2.	TBD	Section 3.3.10 Section 7.2	Structures	Not Verified	Subscale RMFS has yet to start construction

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
LVF.10	The apogee of the full-scale NASA SL competition launch vehicle SHALL be determined and verified by at least three separate analysis programs.	Using three different analysis programs allows the team to cross-analyze results and reduces the likelihood of systematic errors. Additionally, these programs provide advanced initial conditions that can capture a wider range of performance scenarios. This expanded data pool enhances the team's ability to accurately predict the apogee, as required by NASA Requirement 2.1, and optimize altitude points. Furthermore, the results from the analysis programs, as detailed in Section 3.6.1, also support the performance and coding software for the Air Brakes payload discussed in Section 5.3.4.	Simulations: See Section 3.6.1 for current rocket analysis in 3 separate programs.	NASA Requirement 2.1 Section 3.6.1 Section 5.3.4	Aerodynam-ics	In Progress	Aerodynamic simulations in progress
Design Requirements							
LVD.1	Prior to integrating new systems into a NASA SL rocket, Ansys/CAD, numerical calculations, or structural testing SHALL be required and produce results with a positive margin, given a factor of safety value of 1.5.	Verifying Ansys/CAD results with "real-life" data minimizes the risk of material failure during flights. The 1.5 factor provides a buffer against unforeseen stresses and design uncertainties. Early identification of potential issues allows for the necessary modifications, enhancing safety and contributing to overall mission success.	TBD	N/A	Aerodynam-ics	In Progress	Air Brake system is currently being designed and in the early simulation stage; yet to enter VV&T stage

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
LVD.2	All materials used for the tubing of a NASA SL competition rocket SHALL be from a reputable supplier in hobby rocketry.	This requirement is necessary to ensure that all tubing materials meet established safety, quality, and performance standards. This also ensures that there are no inconsistencies in the tubing that may increase the risk of material failure during flight. Given the strict build schedule and launch dates outlined in Table 7.14, there is no time allotted for rebuilding airframes in the case of material failure.	Subscale Materials: See Table 7.10 for budget and subscale material purchases Full-scale: TBD	Table 7.14 Table 7.10	Structures	In Progress	Subscale materials have arrived
LVD.3	The subscale version of the NASA SL competition rocket SHALL be constructed using Blue Tube.	Due to budget constraints outlined in Section 7.2, blue tube is the most cost effective material for subscale launch vehicle body tube.	Subscale Materials: See Section 7.2 for budget and subscale material purchases	Section 7.2	Structures	Verified	Subscale materials have arrived
LVD.4	The full-scale version of the NASA SL competition rocket SHALL be constructed using fiberglass tubing.	As outline in Section 3.2.2, fiberglass is used as the full-scale rocket material due to its longevity and material strength. Additionally, the payload challenge and recovery system requires that the material be RF transparent. Thus, we use fiberglass instead of carbon fiber for the launch vehicle body.	TBD	Section 3.2.2	Structures	Not Verified	Full-scale materials are preliminarily selected
LVD.5	The subscale and full-scale nosecone material SHALL be RF transparent.	The payload challenge requires the use of a radio antenna to transmit data to a NASA transceiver and is outlined in Section 4.5.1. Due to the estimated length of the antenna, the payload needs to be in the Nose Cone of the rocket. This can be seen in Figure 4.27. Thus, the Nose Cone needs to be made of radio-transparent material to not hinder RF transmissions.	Subscale: Blue Tube is confirmed RF transparent Full-scale: Fiberglass is confirmed RF transparent in Section 4.5.1	Section 4.5.1 Figure 4.27	Structures	In Progress	Subscale construction in progress

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
LVD.6	The launch vehicle design for any version of the NASA SL competition rocket SHALL have four identical fins, evenly spaced around the rocket tube.	Four identical and evenly spaced fins provides aerodynamic stability, redundancy in error, and helps distribute the aerodynamic forces equally. This allows the rocket to clear the launch rail evenly and cleanly. Air Brakes, Section 5, uses these aerodynamic forces to predict relative and future apogee.	Design: See Section 3.3.11 and Section 5	Section 3.3.11 Section 5	Structures	In Progress	Subscale fins are fabricated, full-scale fins are selected (Section 3.3.11)
LVD.7	The launch vehicle design for any version of the NASA SL competition rocket SHALL have the center of gravity forward of the center of pressure.	Handbook Requirement 2.14 states that the launch vehicle must have a static stability margin of 2.0 at rail exit. Due to static stability margin calculated in Section 3.6.5, the center of gravity of the launch vehicle must be forward of the center of pressure to ensure a positive static stability margin.	Aerodynamic Simulations: Full-scale CG and CP calculations are seen in Section 3.6.5	NASA Requirement 2.4 Section 3.6.5	Aerodynam-ics	In Progress	Multiple aerodynamic simulations
LVD.8	The full-scale version of the NASA SL competition rocket SHALL include a 6061 Aluminum thrust plate between the motor retainer and the airframe body.	A 6061 Aluminum thrust plate is necessary to distribute the motor's thrust evenly across the rocket's airframe, preventing localized stress that could damage the launch vehicle components. Such components include the RMFS to which the thrust plate is attached. This ensures structural integrity during launch, minimizing the risk of failure and enhancing the rocket's reliability under high loads. 6061 Aluminum is necessary for the thrust bulkhead as determined in Section 3.2.3.	Design: See Section 3.2.3 for confirmation Construction: TBD	Section 3.2.3	Structures	In Progress	Subscale thrust plate fabricated

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
LVD.9	The NASA SL competition rocket SHALL utilize at least two centering rings to support the motor casing.	Two centering rings are necessary to ensure that the motor casing is straight and centered in the launch vehicle, which aligns the thrust of the motor with the center of gravity of the launch vehicle. This prevents instability and ensures the accuracy of the mission performance predictions in Section 3.3.10.	Design: See Section 3.3.10 for confirmation Construction: TBD	Section 3.3.10	Structures	In Progress	Subscale motor retention in construction
LVD.10	The full-scale NASA SL competition rocket SHALL have a stability margin between 2 and 2.7 at rail exit.	Handbook Requirement 2.14 states that the launch vehicle must have a minimum stability margin of 2.0. A maximum stability margin of 2.7 reduces the likelihood of undesired weather cocking which would decrease the accuracy of the mission performance predictions in Section 3.6.	Simulation: See Section 3.6 for maximum full-scale rocket velocity	Section 3.6	Aerodynam-ics	In Progress	Multiple aerodynamic simulations
LVD.11	The subscale and full-scale NASA SL competition rocket SHALL have a maximum velocity at or below Mach 0.75.	At Mach 0.75 the launch vehicle may start to experience transonic effects, which typically begin to occur around Mach 0.8. These effects, such as increased aerodynamic drag, shock wave formation, and instability, could compromise the rocket's structural integrity and apogee prediction. Thus decreasing accuracy of the predicted mission performance predictions in Section 3.6.1.	Simulation: See Section 3.6.1 for maximum full-scale rocket velocity Flight Data: TBD	Section 3.6.1	Aerodynam-ics	In Progress	Multiple aerodynamic simulations
LVD.12	All materials used for any version of the NASA SL competition launch vehicle SHALL have known properties and reactions.	To accurately perform stress and strain analysis' on online software, the material properties must be known to set accurate initial conditions. These software simulations allow for the launch vehicle structure to be analyzed and for Requirement LVD.1 to be met.	TBD	Requirement LVD.1	Structures	In Progress	Subscale materials have arrived

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
Safety Requirements							
LVS.1	Any club member who wishes to participate in the construction of any part of a NASA SL rocket or club rocket SHALL score a 100% on a lab safety quiz created by the Safety Officer. No member SHALL be allowed to interact with any tool in the NC State HPRC lab prior to taking the safety quiz. Previous year members SHALL not be exempt from the rules established above.	Understanding the safety procedures and proper PPE for each lab tool decreases the number of lab related incidents. Additionally, it establishes early expectations on lab procedures and reinforces the importance of safety education. The safety quiz requirement makes sure that all team members are fully aware of current safety standards and practices.	See Safety Quiz in the Appendix	The Appendix	Safety Team, Structures	In Progress	Safe construction practices are maintained daily
LVS.2	During all phases of construction of the launch vehicle or payload, the elected safety officer or a member of the safety team SHALL be present to enforce safety procedures and proper PPE. Every member participating or in the proximity of tool use SHALL wear the proper PPE associated with the task.	Proper PPE protects team members from the potential hazard that they are working with or working around. Establishing this as a safety rule decreases the hazard risk of associated lab-related tasks. A comprehensive list of potential lab hazards can be found in Section 6.4.1.	See Safety Quiz in the Appendix	The Appendix Section 6.4.1	Safety Team	In Progress	Safe construction practices are maintained daily
LVS.3	When interacting with the NC State HPRC lab drill press, no gloves, rings, or bracelets SHALL be worn.	Wearing gloves increases the risk of entanglement in the machine and the risk of injury. More information can be found in Section 6.4.1.	See Safety Quiz in the Appendix	The Appendix Section 6.4.1	Safety Team	In Progress	Safe construction practices are maintained daily
LVS.4	When interacting with the NC State HPRC lab drill press, all hair and loose clothing SHALL be tied back.	Loose hair and clothing can get entangled with the machinery and result in personal harm or the incorrect drilling of a limited stock launch vehicle item. Reducing the risk of harm and distractions, reduces the risk of drilling mistakes. More information on the safety hazard can be found in Section 6.4.1.	See Safety Quiz in the Appendix	The Appendix Section 6.4.1	Safety Team	In Progress	Safe construction practices are maintained daily

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
LVS.5	When interacting with the NC State HPRC lab drill press, the drilling area and the area surrounding the drill press SHALL be clear of all potential hazards. Such hazards include, but are not limited to, hanging objects, active machinery that can interfere with the operation of the drill press, or articles of clothing from surrounding team members.	See Requirement LVS.3 and Requirement LVS.4 for team derived launch vehicle requirements.	See Safety Quiz in the Appendix	The Appendix LVS.4 LVS.5	Safety Team	In Progress	Safe construction practices are maintained daily
LVS.6	When interacting with the NC State HPRC lab drill press, safety glasses SHALL be worn at all times.	When drilling through materials on a drill press, the drilled material creates flying debri. These chips or particles can impact a team member's vision, leading to personal harm or mistakes in launch vehicle material. Safety glasses, as detailed in Section 6.4.1, decreases the risk of these issues.	See Safety Quiz in the Appendix	The Appendix Section 6.4.1	Safety Team	In Progress	Safe construction practices are maintained daily
LVS.7	During any use of epoxy while in the NC State HPRC lab, team members SHALL wear gloves to limit epoxy exposure to the skin. If epoxy is contacted to the skin, the team member SHALL immediately follow safety protocols and inform the elected Safety Officer or a member of the Safety Team.	Following safety protocol immediately decreases the time-related cost caused by the incident on the project timeline found in Section 7.4.2. Ensuring that team-members have a reduced risk to a common construction hazard ensures the safety of the personnel and the efficiency of the project.	See Safety Quiz in the Appendix	The Appendix Section 7.4.2	Safety Team	In Progress	Safe construction practices are maintained daily

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
LVS.8	During the drilling, sanding, or cutting of fiberglass components, all team members in the vicinity of the operating tool SHALL wear a particle mask and other appropriate PPE for the tool in use. These actions SHALL occur outdoors or in a well ventilated area. Additionally, one team member SHALL be responsible for holding the lab vacuum during fiberglass cutting or manipulation.	As defined in Requirement LVD.4, fiberglass will be the main component of the full-scale rocket. Thus, an established safety procedure is needed during any manipulation of the material. Fiberglass inhalation can irritate the respiratory system and the tiny fibers can become lodged in the lung tissue. This can impact personnel availability, Section 6.4, and reduce the number of educated individuals working on the project.	See Safety Quiz in the Appendix	Requirement LVD.4 The Appendix Section 6.4	Safety Team	In Progress	Safe construction practices are maintained daily
LVS.9	During any use of Colloidal Silica Epoxy Filler while in the NC State HPRC lab, team members SHALL wear gloves, a particle mask, and safety glasses. Additionally, all team members in the vicinity of the Colloidal Silica Filler SHALL wear a particle mask.	The construction process of the launch vehicle requires precision and attention to detail; any accidental exposure or injury can disrupt workflow and delay project timelines found in Section 7.4.2. Thus, maintaining a safe environment encourages productivity and allows the team to work efficiently.	See Safety Quiz in the Appendix	Appendix Section 7.4.2	Safety Team	In Progress	Safe construction practices are maintained daily
LVS.10	During any use of spray paint, HPRC members SHALL wear gloves and a mask. There SHALL not be any use of spray paint in non-ventilated areas.	Ensuring proper respiratory and ventilation protocols are followed, minimizes the risk of health-related incidents that could halt progress. Delays due to accidents or illnesses can lead to missed deadlines and increased costs, impacting the overall project timeline found in Section 7.4.2. Proper ventilation and PPE ensures that the painting process can proceed without interruptions.	See Safety Quiz in the Appendix	The Appendix Section 7.4.2	Safety Team	In Progress	Safe construction practices are maintained daily

Table 7.6: 2024-2025 Launch Vehicle Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
Environmental Requirements							
LVE.1	Left over epoxy SHALL be poured into a communal epoxy waste container and allowed to cure for 24 hours prior to disposal.	Pouring epoxy down the drain can damage a facilities piping and can harm aquatic ecosystems if it makes its way into the water system. Additionally, uncured epoxy can contaminate soil and produce compounds that irritate the respiratory system. Allowing for the epoxy to cure before disposal reduces the hazards that are associated with uncured epoxy in the environment. More environmental concerns for improper epoxy management can be found in Section 6.5.6.	See Wake County Waste Disposal Guidelines and the signed safety contract in the Appendix	Wake County Waste Disposal Guidelines Safety Contract Section 6.5.6	Safety Team, Structures	In Progress	Environmen-tally safe construction practices are maintained daily
LVE.2	All fiberglass shards and dust SHALL be vacuumed by the laboratories shop-vac.	Using a shop-vac captures fine particles and prevents airborne fiberglass from being inhaled. This practice minimizes the chance of contamination in the workspace and promotes responsible handling of materials, ensuring compliance with safety protocols found in the Appendix. Regular vacuuming also helps maintain equipment functionality and prolongs the lifespan of the lab's tools and workspace.	See Wake County Waste Disposal Guidelines and the signed safety contract in the Appendix	The Appendix	Safety Team	In Progress	Environmen-tally safe construction practices are maintained daily

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
Functional Requirements							
RF.1	Prior to AV bay assembly all wire connection points SHALL be visually inspected for frayed, bent, or loose wires.	Damaged wires pose the risk that the avionics and recovery systems won't function and record data properly. This could result in the black powder charges not being ignited and the total failure of a flight objective. Thus, wires must be visually inspected prior to assembling and integrating the AV bay into the launch vehicle.	TBD	N/A	Recovery	Not Verified	Subscale AV bay sled construction to begin soon
RF.2	Prior to AV bay assembly all wire connection points SHALL be tactilely inspected by "tugging". This involves applying a tensile force to the wired connection.	Similarly to Requirement RF.1, tugging on wires verifies the proper AV bay electronic connections. It also ensures that wire connections will not come loose due to in-flight forces. These connections are responsible for the altimeter, ejection charges, and GPS connections. Failure with a wire coming loose may result in total mission failure.	TBD	RF.1	Recovery	Not Verified	Subscale AV bay sled construction to begin soon
RF.3	Each cell of the LiPo SHALL be charged to above 4.1 V per cell.	The standard maximum charge for a LiPo cell is 4.2V. Charging the cells to 4.1V ensures that we are not exceeding the maximum value, but still ensuring maximum capacity of operation. This practice could help improve efficiency in applications requiring a high power output and successfully completing NASA Requirement 2.6.	TBD	NASA Requirement 2.6	Recovery	Not Verified	AV bay electronics selected
RF.4	Each cell of the LiPo SHALL not be charged to more than 0.03V above the recommended 4.1V per cell	LiPo cells can be overcharged and lead to malfunctions and failure of the equipment. It poses a safety hazard as an overcharged LiPos cell can potentially explode and cause a fire.	TBD	N/A	Recovery	Not Verified	AV bay electronics selected

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
RF.5	All utilized LiPo's will be tested at least once before each individual launch.	Verifying equipment performance and structure prior to every launch reduces the associated risks of the component during flight. Testing the LiPos prior to each launch event ensures that the LiPos are working properly and are producing an adequate voltage amount needed by its connected avionics. Failure could result in changes in the timeline, Table 7.18, or data collection failure.	TBD	Table 7.18	Recovery	Not Verified	AV bay electronics selected
RF.6	The voltage output of all utilized batteries SHALL be at or above 9.00 V.	Fully charged batteries are responsible for multiple electronics in the AV bay as clarified in Section 3.5. These batteries must be fully charged because the chosen altimeters will not work on a battery charge lower than 8.4 volts. Additionally, verifying that all batteries are fully charged helps the team meet NASA Requirement 2.6 and Requirement RD.3.	TBD	Section 3.5 NASA Requirement 2.6 RD.3	Recovery	Not Verified	AV bay electronics selected
RF.7	All batteries in the launch vehicle SHALL be removed during cleaning of the launch vehicle, occurring directly after the completion of field recovery.	Prompt removal of batteries from the launch vehicle minimizes the risk of battery-related incidents, such as overheating and leakage. Additionally, it allows for the safe handling and recharging of the batteries. This would allow the team to have the ability to relaunch the rocket and all of its components again in the same day as required by NASA Requirement 2.3.	TBD	NASA Requirement 2.3	Recovery	Not Verified	No current/ prior launches; Information added to be added to post-launch checklist

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
RF.8	Before every launch, all black powder used SHALL be measured and weighed prior to heading to the launch field.	Measuring black powder prior to heading to the launch field reduces measurement error introduced by launch field conditions. A windy day could blow away black powder particles during the measurement process if done at the launch site which could cause harm to personnel and the environment.	TBD	Section 3.4.9	Recovery	Not Verified	Black powder calculations found in Section 3.4.9
RF.9	The secondary black powder charge SHALL be at least 0.5 grams larger than the primary black powder charge.	Secondary black powder charges represent redundancy in the ejection charges. It's purpose is to separate the launch vehicle if the primary charge does not separate the launch vehicle. The secondary charges must be a measurable amount larger than the primary charge. If the sections do not separate, the recovery system does not function properly and can result in the total failure of the mission. This delays the project timelines in Section 3.4.9.	TBD	Section 3.4.9	Recovery	Not Verified	Black powder calculations found in Section 3.4.9
RF.10	The primary ejection charge SHALL be calculated imperially and verified by ejection tests.	The primary charge must be calculated empirically and not estimated based on size of the bay. This is done to ensure there is no major damage to recovery components or the launch vehicle. Ejection charge sizing is tested according to Requirement RF.24.	Calculations: See Table 3.10 Implementation: TBD	Requirement RF.24 Table 3.10	Recovery	In Progress	Black powder calculations found in Section 3.4.9
RF.11	All black powder calculations SHALL be done using the Ideal Gas Law.	Black powder calculations are performed in Section 3.4.9. This equation is from a reputable source and derived from Ideal Gas Law. Verifying the location and method of the equation reduces calculation and handlement error.	Calculations: See Table 3.10 Implementation: TBD	Table 3.10 Section 3.4.9	Recovery	In Progress	Black powder calculations found in Section 3.4.9

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
RF.12	When assembling the AV bay, the black powder charges SHALL be securely contained within the "blast caps" with blue tape. To ensure that there is no leakage, the AV bay SHALL be turned upside down over white paper. If there is any black residue on the paper, the black powder SHALL be re-measured and the entire process repeated.	Using blue tape over black powder storage containers contains all black powder particles contained in a set location prior to ejection. This verifies that all black powder is ignited and that all of the black powder required, as calculated in Table 3.10, is utilized.	TBD	Table 3.10	Recovery	Not Verified	No current/ prior launches; Information added to pre-launch checklist
RF.13	Altimeters SHALL be tested prior to every launch by simulating flight. Flight will be simulated by placing the altimeter in a bucket that is connected to a vacuum and slowly decreasing the pressure in the bucket to simulate an increase in altitude and then slowly decreasing the pressure to simulate the descent of the vehicle..	Altimeters are selected in Section 3.4.1 to meet the NASA Requirement 2.18.2 that requires the team to verify the apogee of the rocket. Testing the altimeters reduces the risk of error that the altimeters don't work properly in flight. It also verifies that the altimeters are properly programmed.	TBD	NASA Requirement 2.18.2 Section 3.4.1	Recovery	Not Verified	No current/ prior launches
RF.14	On the launch pad, the altimeters SHALL be armed one at a time to ensure that the continuity beeps don't overlap.	Due to redundancy discussed in Section 3.4.1, two altimeters are used to verify the apogee of the rocket. Overlapping continuity beeps can create confusion and lead to incorrect determinations that all systems are functioning correctly. Apogee determines when the various black powder charges detonate and time the main and drogue parachute exits. If not followed, there is an increase risk of mission failure and total loss of the rocket.	TBD	Section 3.4.1	Recovery	Not Verified	No current/ prior launches

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
RF.15	Prior to launch day packing, all parachutes SHALL be inspected to visually verify that there are no holes or missing stitches.	Holes and missing stitches in the parachutes impact the parachute calculations made in Section 3.4.6. These deformities can decrease the effectiveness of the parachute and increase the kinetic energy values past what is allowed in NASA Requirement 3.3.	TBD	NASA Requirement 3.3 Section 3.4.6	Recovery	Not Verified	All HPRC owned parachutes have been inspected and cataloged
RF.16	Prior to launch day packing, shroud lines SHALL be inspected and de-tangled to verify that they are properly connected to the parachute fabric with no frayed edges of knots.	Similarly to Requirement RF.15, frayed and tangled shroud lines impact the integrity of the parachute performance and the calculations made in Section 3.4.8. Parachute failure would result in the total failure of mission objectives and delay timelines established in Section 7.4.2.	TBD	Requirement RF.15 Section 3.4.8 Section 7.4.2	Recovery	Not Verified	No current/ prior launches
RF.17	Packing parachutes for launch vehicle integration SHALL only be done with the supervision of someone knowledgeable of the recovery system and knows how to correctly fold parachutes as approved by the Recovery or Team Lead.	Parachute deployment is vital for the successful recovery of a rocket. Improperly packing and placing the parachute into the rocket could result in total mission failure or the failure of NASA Requirement 3.3.	TBD	NASA Requirement 3.3	Recovery	Not Verified	No current/ prior launches
RF.18	All parachutes SHALL be folded with the seams of the shroud line connections facing inward.	Having the seams of the shroud lines facing outwards increases the risk of shroud lines tearing and fraying. Following this procedure can potentially increase the lifespan of the parachute and ensure that Requirement RF.16 is met.	TBD	Requirement RF.16	Recovery	Not Verified	No current/ prior launches; will be added to pre-launch checklist
RF.19	Prior to launch the Nomex cloths SHALL be inspected for holes, tearing, and frayed edges. If any inconsistencies are found, another Nomex cloth SHALL be utilized.	Nomex cloths protect the parachute from the ejection charge explosion. The charges could burn holes in the parachute and reduce parachute effectiveness if not protected. Use of the Nomex cloth and more information can be found in Section 3.4.7.	TBD	Section 3.4.7	Recovery	Not Verified	No current/ prior launches; will be added to pre-launch checklist

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
RF.20	Parachutes SHALL be placed into the launch vehicle such that the Nomex cloth or deployment bag is not next to the black powder charges.	To further protect the parachute, there needs to be as much room as possible between the Nomex and the black powder charges as possible. The black powder charges could burn holes into the parachute and reduce the drag profiles needed to meet NASA Requirement 3.3.	TBD	NASA Requirement 3.3	Recovery	Not Verified	No current/ prior launches; will be added to pre-launch checklist
RF.21	All shock cord used inside the vehicle SHALL be accordion folded.	An accordion fold of the shock cord reduces the risk of entanglement during ejection.	TBD	N/A	Recovery	Not Verified	No current/ prior launches; will be added to pre-launch checklist
RF.22	All knots used in the shock cord SHALL be self-tightening knots.	The shock cord is under tensile stress during the recovery events. Self-tightening knots prevent knot slippage that could cause portions of the shock cord to separate from itself or the launch vehicle.	TBD	N/A	Recovery	Not Verified	No current/ prior launches; will be added to pre-launch checklist
RF.23	Prior to every launch of a NASA SL competition vehicle, the team SHALL perform an ejection test to verify ejection charges in the week leading to the launch day.	Ejection charges calculated in Table 3.10 and Section 3.4.9 need to be verified with real-life tests. This reduces risk of improper or insufficient black powder measurements and increases the change of successful ejection on launch day. An ejection test must be performed before every launch because of possible changes in the packing of recovery components that affect how the launch vehicle separates.	TBD	Table 3.10 Section 3.4.9	Recovery	Not Verified	Subscale construction still underway

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
RF.24	During the preparation of the launch vehicle for launch day or ejection testing, biodegradable insulation SHALL be packed into the rocket between the ejection charges and recovery equipment.	Packing the rocket with insulation reduces the area in compartments where black powder charges are located. Decreases the total volume of the compartment reduces the pressure required to separate the rocket and improves the performance of the black powder charges calculated in Section 3.4.9. This also prevents ejection charges from damaging the recovery equipment.	N/A	Section 3.4.9	Recovery	Not Verified	No current/ prior launches; will be added to pre-launch checklist
RF.25	During field recovery of any NASA SL competition rocket, before touching the launch vehicle, an image SHALL be taken to identify landing configuration and landing state of the rocket. Following the image, the rocket SHALL be secured and the altimeters disarmed.	Verifying and providing documented evidence of launch vehicle landing proves the quality and effectiveness of the recovery system. Additionally, it helps certify the payload capsule orientation data for the NASA challenge. This meets NASA Requirement numbers 2.18.4.2 and 2.19.1.8.2.	TBD	NASA Requirements 2.18.4.2 and 2.19.1.8.2	Recovery	Not Verified	No current/ prior launches; will be added to post-launch checklist
RF.26	Prior to moving a NASA SL competition rocket during field recovery, GPS coordinates of the landing site SHALL be recorded.	Recording GPS requirements helps verify that we are meeting NASA Requirement 3.11 .	TBD	NASA Requirement 3.11	Recovery	Not Verified	No current/ prior launches; will be added to post-launch checklist
RF.27	All threaded quick-links SHALL be additionally secured using tape during launch day assembly.	Adding tape is an extra verification that the threaded quick-link won't accidentally disconnected during flight.	TBD	N/A	Recovery	Not Verified	No current/ prior launches; will be added to pre-launch checklist
			Design Requirements				
RD.1	Terminal block connections SHALL only be made with commercially available electrical connectors or soldered connections.	Commercially available connectors or soldered connections ensure reliable and secure electrical connections. Secure connections are needed to maintain proper power and current configuration.	Design: See Section 3.3.3 Construction: TBD	Section 3.3.3	Recovery	In Progress	Preliminary design in Section 3.3.3

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
RD.2	All LiPos SHALL be chosen such that they have a battery life that exceeds 4 hours with idle current draw.	As defined in NASA Requirement 2.6, the launch vehicle must be able to remain in launch ready condition on the pad for 3 consecutive hours. To ensure that our LiPos meet this requirement, all LiPos need to sustain an idle current draw of 4 hours. The LiPos are connected to a series of avionic electronics, as detailed in Section 3.4.4. Failure of these electronics can result in the failure of mission objectives.	Design: See Section 3.4.4 Construction: TBD	NASA Requirement 2.6 Section 3.4.4	Recovery	In Progress	Preliminary material selection
RD.3	Shock cord length SHALL be long enough to allow all independent sections to be at least 10 ft. apart from each other during descent under parachute.	The main risk during descent is the various components of the rocket colliding with each other and the tangling of shock cord. This can result in launch vehicle damage and damage to the recovery system. Having a minimum shock chord length decreases the collision and tangling risk. More information can be found in Section 3.4.8.	Design: See Section 3.4.8 Construction: TBD	Section 3.4.8	Recovery	In Progress	Recovery system defined
RD.4	Shock cord connections to bulkheads SHALL be maintained using only "U-bolts".	U-bolts evenly spreads the tension load from the shock cord onto the bulkhead. Dispersing the initial shock to multiple points increases bulkhead stability and generates a strong anchor point for the recovery system.	Design: See Section 3.4.8 Construction: TBD	Section 3.4.8	Recovery	In Progress	Recovery connections defined
RD.5	Any GPS installed in the launch vehicle SHALL have a range of 1.5 miles and can maintain a battery life at average current draw for 4 hours.	Per NASA Requirement 3.11, the team is required to verify that the drift distance of the rocket does not exceed a certain value. To verify that the rocket lands within the established bounds, the GPS must have the appropriate range. GPS selection can be found in Section 3.4.2.	Design: See Section 3.4.2 Construction: TBD	NASA Requirement 3.11 Section 3.4.2	Recovery	In Progress	Preliminary electronics selected

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
RD.6	All recovery harnesses and equipment SHALL be attached to launch vehicle attachment points with threaded quick-links.	Threaded quick-links have a high stress durability, are easy to install, and minimize the accidental disconnection during recovery events.	Design: See Section 3.4.8 Construction: TBD	Section 3.4.8	Recovery	In Progress	Recovery system defined
RD.7	The maximum descent velocity of any section of any 2025 NASA SL launch vehicle SHALL be less than 120 ft. per second.	High descent velocities under the drogue parachute could lead to high shock forces on the main parachute when it is deployed. This has the possibility to tear the shroud lines of the main parachute and could lead to the launch vehicle violating NASA Requirement 3.3.	Design: See Section 3.6.7 Construction: TBD	NASA Requirement 3.3 Section 3.6.7	Recovery	In Progress	Preliminary recovery calculations performed
Environmental Requirements							
RE.1	All packing insulation materials SHALL be biodegradable.	During rocket separation, packing material will fall out of the rocket and contaminate surrounding areas. Thus, biodegradable material that breaks down naturally overtime reduces the environmental impact and ecological footprint of the team's rocket.	TBD	N/A	Recovery & Safety	Not Verified	No current/ prior launches; will be added to pre-launch checklist
RE.2	When adhering rubber-bands to shock cord for recovery packing, the rubber-bands SHALL be connected to the shock cord such that they will not completely separate from the launch vehicle and remain tethered to the shock cord after it is released during flight.	Rubber bands are used to keep the shock cord untangled during vehicle assembly. Keeping shock cord untangled reduces risk of rocket sections colliding during recovery events. Rubber bands are not biodegradable and to prevent littering, they must be attached to the shock cord. Thus, the rubber bands need to be collected and properly disposed of after field recovery.	TBD	N/A	Recovery	Not Verified	No current/ prior launches; will be added to pre-launch checklist

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
RE.3	All recovery equipment SHALL be tethered to the launch vehicle in the fully separated descent state.	To prevent potential littering of the launch field, all non-biodegradable items are affixed to some section of the recovery system. This also enables the team to relaunch on the same day with minimal repairs as required by NASA Requirement 2.3.	Design: See Section 3.4.8 for recovery system design Construction: TBD	NASA Requirement 2.3	Recovery	In Progress	Recovery system defined
Safety Requirements							
RS.1	All black powder SHALL be transported to the launch field in a tightly sealed container which are placed in anti-static bags. During the transport, the sealed containers SHALL be stored in a flame-proof explosive containment box.	Black powder has the potential to combust and explode under certain circumstances such as friction and electric current. To prevent early ejection or explosion of black powder, the powder must be stored in a sealed container located in an explosive containment box.	TBD	N/A	Safety	Not Verified	No current/ prior launches
RS.2	During the event of a CATO of the launch vehicle, the designated Safety Officer and/or the Recovery Lead SHALL ensure that the black powder charges have blown prior to any other interaction with the launch vehicle by other team members.	During a motor CATO there is the potential that the black powder charges did not explode. A live black powder charge poses serious risk to any surviving part of the launch vehicle or internal equipment, as well as local personnel.	TBD	N/A	Recovery & Safety	Not Verified	No current/ prior launches
RS.3	The safety officer and/or recovery lead SHALL be the first to approach the rocket and to "touch" the rocket during field recovery.	Similarly to Requirement RS.2, at the recovery of a rocket there is the potential risk of live black powder. To prevent a detonation, a specific procedure, PPE, and training is required.	TBD	Requirement RS.2	Recovery & Safety	Not Verified	No current/ prior launches
RS.4	All altimeters SHALL be disarmed if they are still functioning during field recovery.	As stated in Requirement RS.2, there may be unexploded black powder still in the launch vehicle after a CATO or flight. To reduce the risk off the black powder exploding, altimeters must be disarmed after flight.	TBD	RS.2	Recovery	Not Verified	No current/ prior launches

Table 7.7: 2024-2025 Recovery Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
RS.5	All appropriate procedures to avoid the pre-emptive ejection of black powder during CATO recovery SHALL be followed. This includes, but is not limited to, wearing safety glasses and fireproof gloves.	In the event of a CATO, ejection charges are not necessarily blown because the launch vehicle did not reach in altitude at which parachutes were programmed to be deployed. Mitigation to Hazard TF.6 must then be followed to ensure pre-emptive ejection of black powder does not injure personnel.	TBD	Hazard TF.6	Safety	Not Verified	No current/ prior launches
RS.6	During field recovery, all personnel SHALL wear long pants, closed-toed shoes, safety glasses, and gloves. If they are a part of the initial handling of the rocket, the personnel SHALL wear fire-proof gloves.	Our launch field, prior to Huntsville, is an active farm and can contain many skin irritants. More information on hazards at the launch site can be seen in Section 6.4.1. Long pants prevent skin irritation and allergic reactions. This would allow for the field recovery timeline to continue smoothly with little to no breaks or pauses. Personnel are required to wear gloves in accordance with mitigation to Hazard TF.6.	TBD	Section 6.4.1 Hazard TF.6	Safety	Not Verified	No current/ prior launches
RS.7	When approaching the rocket during field recovery, the parachute SHALL be approached and secured from the back to avoid entanglement in the shroud lines.	During landing, parachute shroud lines can become entangled with the surrounding launch field. On windy days, these parachutes can drag rocket components across the field and interact with local team members. Shroud lines during windy days increase the risk of strangulation during field recovery if approached from the front. In the event where personnel is entangled in shroud lines, the shroud lines would have to be cut and the parachute becomes unusable.	TBD	N/A	Safety	Not Verified	No current/ prior launches

Table 7.8: 2024-2025 Payload Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
Functional Requirements							
PF.1	Prior to any launch of a NASA SL competition rocket with the addition of a version of the competition payload, all payload-related sensors SHALL be tested via a coded script/function within the week leading up to the launch day.	The entire payload challenge is judged based off the successful transmission of various data points as described in Section 4.1. To guarantee that the data is collecting and transmitting properly, the verification of sensors is needed. Without, there is the potential of failing the payload challenge and decreasing our team's score.	TBD	Section 4.1	Payload Team	Not Verified	Test code has yet to be developed
PF.2	During launch day assembly of a NASA SL competition rocket with the addition of a version of the competition payload, a Payload Lead SHALL be present for the entirety of payload assembly and payload-related checklist items.	The Payload Leads are primarily responsible for the design, software, and construction of the competition payload. They have the most information regarding the details of the system and would provide accurate information in the event that an issue arises during assembly.	TBD	N/A	Payload Team	Not Verified	Payload has yet to be launched
PF.3	During the construction of any version of the competition payload, a Payload Lead SHALL be present.	Similarly to Requirement PF.2, the Payload Leads have the most information and guidance for the payload project. They are responsible for leading the entire development of the payload.	TBD	Requirement PF.2	Payload Team	Not Verified	Construction has yet to be started
PF.4	During the testing of any version of the competition payload, a Payload Lead SHALL be present.	See Requirement PF.3.	TBD	Requirement PF.3	Payload Team	Not Verified	Testing has yet to be started
PF.5	Any soldering of electronics, wires, and sensors SHALL be done only under the supervision of a Payload Lead.	See Requirement PF.3.	TBD	Requirement PF.3	Payload Team	Not Verified	No soldering has yet to happen

Table 7.8: 2024-2025 Payload Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
PF.6	Any call-sign used during a flight SHALL be the call-sign of a consenting and present member of the NC State High-Powered Rocketry Club.	Per FTC requirements and services, a unique call sign is assigned to each amateur station during the processing of their license application. These call signs represent and are meant for one individual. To use a callsign without consent presents legal and moral issues.	TBD	N/A	Payload Team	Not Verified	Call-signs have yet to be used
PF.7	All 3D-printed material SHALL undergo structural testing and have a minimum infill of 25%.	3D printing material strength depends on the orientation of the object being printed, direction of the filament, and the infill percentage. Thus, different configurations have different strength allowables and need to be tested with some common variable (min infill).	TBD	N/A	Payload Structural Integration Lead	Not Verified	Official 3D printed designs have yet to be printed
PF.8	For all electronics and wires included in any version of the competition payload, all connections SHALL be secured via two methods. These methods may include, but are not limited to: solder, electrical tape, and hot glue.	Redundancy in wire and electronic connects offer a fail safe in case one connection method fails.	TBD	N/A	Payload Electronics Lead	Not Verified	Construction has yet to be started
PF.9	Payload battery SHALL be able to be active for over 4 hours at average payload power draw.	As defined in NASA Requirement 2.6, the launch vehicle must be able to remain in launch ready condition on the pad for 3 hours. Similar to Requirements RD.3 and RD.6, to ensure that payload batteries meet this requirement, they must be able to sustain average payload power draw for 4 hours. Failure of the payload batteries would result in complete payload failure, as the challenge is entirely electronics based.	Design: See Section 4.3.10 for battery specifications Demonstration: TBD	NASA Requirement 2.6 Requirement RD.3 & RD.6 Section 4.3.10	Payload Electronics Lead	In Progress	Payload battery has yet to be tested

Table 7.8: 2024-2025 Payload Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
Design Requirements							
PD.1	The payload housing SHALL be water resistant.	Our team's home launch field is surrounded by irrigation ditches. During launch vehicle landing, the rocket can end up in a water-filled ditch. Water can potential seep through the outer airframe, damaging the payload. Due to the strict budget outlined in Section 7.2, replacing sensors due to water damage is not feasible.	Design: For payload housing and electronic sled see Section 4.5 and Fig.4.19 Construction & Validation: TBD	Section 4.5 Section 7.2 Fig. 4.19	Payload Structural Integration Lead	In Progress	Design: Verified VV&T: TBD
PD.2	The broadcast call-sign SHALL not be hardcoded for transmission.	Different call-signs may have to be used based on personnel availability, and using a callsign without permission is forbidden in Requirement PD.3. Therefore, call-signs cannot be hardcoded into the payload code.	Initial Software Structure: See Section 4.3.4 for overall software schematic Software Code: TBD	Requirement PD.3 Section 4.3.4	Payload Software Lead	In Progress	Software Code Design: Verified Software code currently in construction
PD.3	The payload electronics sled and STEMnaut housing SHALL be primarily constructed using 3D printed material and techniques.	3D printing allows for improved flexibility and accuracy when it comes to tight design constraints and complex geometry.	Design: For payload housing and electronic sled see Section 4.5 and Fig.4.19 Construction & Validation: TBD	Section 4.5 Fig. 4.19	Payload Structural Integration Lead	In Progress	Sled and housing fully rendered
PD.4	The payload SHALL fit into the Nose Cone for both subscale and full-scale designs.	The Payload Team has selected a large antenna, detailed in Section 4.5.1. To compensate for the long length requirement, the payload has been located to the Nose Cone. This prevents other systems in the rocket, recovery and Air Brakes, from interfering or damaging the transmission device.	Measurements: See Section 3.3.5 for payload size and location in launch vehicle Design: See Section 4.5.4 and Fig. 4.27 for payload design Construction & Validation: TBD	Section 3.3.5 Section 4.5.1 Section 4.5.4 Fig. 4.27	Payload Structural Integration Lead	In Progress	Full-scale and subscale payload designs fit in CAD model of launch vehicle

Table 7.8: 2024-2025 Payload Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
PD.5	The combination of sensors in the payload SHALL be able to collect all data types offered in the challenge with some redundancy.	The team has decided to attempt all data types for transmission. Having sensors that can record multiple data types decreases the payload space in the Nose Cone and creates more room for the transmission antenna. More information can be found in Section 4.3 .	TBD	Section 4.3	Payload Electronics Lead	In Progress	List of potential sensors and designs have been developed (Section 4.3)
PD.6	All sensors for data point collection SHALL have a second redundant sensor collecting the same type of data.	In case one data point collection fails on one sensor, there is a second data sensor collecting the same data point plus others to provide a fail safe. Additionally, two sensors increases the accuracy and reliability of the data.	TBD	Section 4.3	Payload Electronics Lead	In Progress	List of potential sensors and designs have been developed (Section 4.3
PD.7	The electronics SHALL be shielded from the transmission signal.	Electronics could produce noise that, if not shielded, could impact and disrupt transmission lines. This follows NASA Requirement 3.14.2 for recovery electronics.	Electronic Sled Design: See Section 4.5 and Fig. 4.18 for details Construction & Validation: TBD	NASA Requirement 3.14.2 Section 4.5 Fig. 4.18	Payload Team	In Progress	Design: Verified VV&T: TBD
PD.8	The input power to all payload electronics SHALL not exceed 5V.	The selected electronics, detailed in Section 4.5.1, have fixed operating ranges. 5V is an acceptable power rating for all included electronics.	TBD	Section 4.5.1	Payload Electronics Lead	Not Verified	Preliminary electronic properties are confirmed (Section 4.5.1)
PD.9	All sensors SHALL be capable of handling altitudes up to 10,000 ft. above sea level.	Sensors must have reliable operation in various environments. Performance at high altitudes, while not 10,000 ft., is critical for the data points described in Section 4.3.7.	TBD	Section 4.3.7	Payload Electronics Lead	In Progress	Preliminary electronic properties are confirmed (Section 4.5.1)
PD.10	Onboard pressure sensors SHALL record data with accuracies between +/-200Pa.	The team needs reliable pressure monitoring to receive accurate data for data points detailed in Section 4.3.7.	TBD	Section 4.3.7 Table 4.3	Payload Electronics Lead	In Progress	Preliminary electronic properties are confirmed (Table 4.3)

Table 7.8: 2024-2025 Payload Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
PD.11	Onboard temperature sensors SHALL record data with accuracies between +/-2C.	The team needs reliable temperature monitoring to receive accurate data for data points detailed in Section 4.3.7.	TBD	Section 4.3.7 Table 4.3	Payload Electronics Lead	In Progress	Preliminary electronic properties are confirmed (Table 4.3)
PD.12	IMU SHALL be configured to operate at +/-16g.	The maximum G loading of the launch vehicle during motor burn is estimated at 10 g's. Since an IMU is necessary for this year's experimental payload, it must be able to operate within the flight conditions of the launch vehicle during ascent. Additionally, the IMU must be able to survive all flight conditions including descent, where a maximum of 15 g's is achieved.	TBD	Section 4.3.8 Table 4.4	Payload Electronics Lead	In Progress	Preliminary electronic properties are confirmed (Table 4.4)
PD.13	Payload transmission SHALL be able to transmit to the handheld radio with a standard antenna up to 500m away given no obstructions and open terrain.	The launch day transmission antenna will be located on a mill silo. This is high enough that there are no trees or obstacles blocking the transmission path. 500m is equivalent to approximately 1640 ft. and is within the max drift distance defined in NASA Requirement 3.11.	TBD	NASA Requirement 3.11	Payload Electronics Lead, Payload Software Lead	Not Verified	Initial transmission tests have to been conducted
PD.14	The payload SHALL have a maximum weight of 5.5 lbs.	The payload is currently located in the Nose Cone of the rocket. Due to adding Air Brakes and additional recovery devices in the aft portion of the rocket, a heavier payload is needed to maintain the stability required in Requirement LVD.10 and reduce the total amount of used ballast.	TBD	Requirement LVD.10	Payload Structural Integration Lead	Not Verified	Components have yet to be ordered and massed

Table 7.9: 2024-2025 Air Brakes Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
Design Requirements							
ABD.1	The location of the Air Brakes module on any version of the NASA SL competition rocket SHALL be located aft of the center of gravity after motor burnout.	As required by NASA Requirement 2.16, all protrusions have to be aft of the center of gravity. Therefore, Air Brakes must be located aft of the center of gravity.	See Fig.3.64 and Section 3.6.5 for the rocket simulation results of burnout CG and Air Brakes location.	NASA Requirement 2.16 Fig.3.64 Section 3.6.5	Aerodynam-ics	In Progress	Design: Verified Yet to enter construction phase.
ABD.2	The design of the Air Brakes mechanism SHALL use a gear ratio of 1:1 between the servo and the Air Brakes fins.	A 1:1 gear ratio reduces the friction forces experienced during deployment. It increases the speed at which the fins deploy and improves the efficiency of the Air Brakes code. This is explained further in Section 5.4.	Design: See Fig.5.8 and Section 5.4 . Construction: TBD	Fig.5.8 Section 5.4	Payload	In Progress	Design: Verified Yet to enter construction phase.
ABD.3	The Air Brakes SHALL consist of four identical fins, equally and radially spaced around the body of the rocket.	Four fins increases the aerodynamic drag of the entire rocket and improves the performance of the Air Brakes system.	Design: See Fig.5.7 and Section 5.4 Construction: TBD	Fig. 5.7 Section 5.4	Payload	In Progress	Design: Verified Yet to enter construction phase.
ABD.4	The Air Brakes system SHALL be located in the Avionics Bay.	Without combining the Air Brakes and Avionics bay there would be three different electronic bays. Due to length requirements of payload, the challenge payload could not be combined with the Avionics bay or Air Brakes. Combining the Air Brakes and Avionics Bay (AVAB) is the most efficient option. More information about the AVAB can be found in Section 3.5.	Design: See Section 3.5 Construction: TBD	Section 3.5	Payload, Recovery	In Progress	Design: Verified Yet to enter construction phase.
ABD.5	The Air Brakes system SHALL have two separate circuits for power.	To prevent the Raspberry Pi from browning out in the event that the servo is overamping or stalling, two separate power systems are needed. More details can be found in Section 5.3.3.	Design: See Section 5.3.3 & Fig. 5.1 Construction: TBD	Section 5.3.3 Fig. 5.1	Payload	In Progress	Design: Verified Yet to enter construction phase.

Table 7.9: 2024-2025 Air Brakes Team-Derived Requirements

Req. ID	Requirement Statement	Justification	Verification	Source	Subsystem Allocation	Status	Comments
ABD.6	Two pull-pin switches SHALL be used to arm the Air Brakes system.	To prevent idle power consumption prior to flight, the Air Brakes power systems should not be armed until the rocket is on the launch pad. The two pull-pin switches each individually arm the two power circuits as mentioned in Requirement ABD.5.	Design: See Section 5.3.3 Construction: TBD	Requirement ABD.5 Section 5.3.3	Payload	In Progress	Design: Verified Yet to enter construction phase.
ABD.7	The Air Brakes control system software SHALL be state-based.	A state-based software model separates the coding functions based on various stages of flight and reduces Air Brake failure and accidental deployment. This is further explained in Section 5.3.4.	Software Design: See Section 5.3.4 Implementation Success: TBD	Section 5.3.4	Payload	In Progress	Design: Verified Yet to enter construction phase.

7.2 Budget

Table 7.10 details the year long budget plan for the 2024 - 2025 academic school year. The table is organized in columns of Item, Vendor, Quantity, Price Per Unit, and Total Item Price. Highlighted in light gray at the end of each section is the summed total of all the prices. At the end of the budget section and highlighted in dark gray is the total expenses of the club throughout the year. All prices are based on both previous years recorded expense reports and the predicted expenses for this year. However, items may change slightly as the design for our rocket is finalized. This would lead to changes in items needed, vendors used, and the total amount spent throughout the year.

Table 7.10: 2024-2025 NASA Student Launch Competition Budget

	Item	Vendor	Quantity	Price Per Unit	Item Total
Subscale Structure	4” Nosecone	ARR	1	$ 27.75	$ 27.75
	4 in. Airframe	ARR	2	$ 39.95	$ 79.90
	Airframe-Nosecone Transition	ARR	1	$ 27.75	$ 27.75
	Subscale Motor	AeroTech	2	$ 95.99	$ 191.98
	38mm Motor Retainer	AeroTech	1	$ 39.17	$ 39.17
	Motor Casing	AeroTech	1	$ 98.86	$ 98.86
	Rail Button	Rail-Buttons	2	$ 4.25	$ 8.50
	Fiberglass Fins	Apogee Rockets	4	$ 16.50	$ 66.00
	U-Bolts	Prime Line	4	$ 1.50	$ 6.00
	Nuts, Screws, Eyebolts	McMaster-Carr	1	$ 12.71	$ 7.08
				Subtotal:	**$ 552.99**
Full Scale Structure	6 in. Nosecone 4:1	ARR	1	$ 199.99	$ 199.99
	6 in. G12 Fiberglass Tube (60 in.)	ARR	1	$ 259.00	$ 259.00
	6 in. G12 Fiberglass Tube (48 in.)	ARR	1	$ 207.20	$ 207.20
	6 in. G12 Fiberglass Coupler	ARR	1	$ 94.60	$ 94.60
	Full-scale Motor	AeroTech	2	$ 272.68	$ 545.36
	Motor Retainer	AeroTech	1	$ 59.50	$ 59.50
	Motor Casing	AeroTech	1	$ 526.45	$ 526.45
	Large Rail Button -1515	Apogee Rockets	2	$ 4.25	$ 8.50
	U-Bolts	Prime Line	8	$ 1.00	$ 8.00
	32mm Bore	goBILDA	2	$ 12.99	$ 25.98
	Double Pull Pin Switch	Apogee Rockets	1	$ 20.35	$ 20.35
				Subtotal:	**$ 1,954.93**
Payload	Barometric Pressure Sensor	Adafruit	2	$ 12.95	$ 25.90
	Temp & Humidity Sensor	Adafruit	1	$ 119.99	$ 119.99
	Inertial Measurement Unit	Adafruit	2	$ 39.95	$ 79.90
	Raspberry Pi 4B	Adafruit	1	$ 67.95	$ 67.95
	Buck Converter	HiLetGo	2	$ 4.95	$ 9.90
	Antenna	Pizarra	1	$ 69.99	$ 69.99
	Breakout Boards	ICBreakout	2	$ 5.95	$ 11.90
	Handheld Radio	BAOFENG	1	$ 39.99	$ 39.99
	AIOC Cable	Zenith	1	$44.99	$ 44.99
	APRS-K1 Cable	BTECH	1	$ 25.49	$ 25.49
	SI4464	Silicon Labs	2	$ 9.43	$ 18.86
	LiPo Battery	Adafruit	1	$ 33.85	$ 33.85
	PLA Filament	AMOLEN	4	$ 14.99	$ 59.96
	PETG Filament	AMOLEN	4	$ 16.99	$ 67.96
	Nuts, Screws, Eyebolts	McMaster-Carr	1	$ 12.71	$ 7.08
	Soldering Station	Pine Store	1	$ 165.00	$ 165.00
	Structural/Housing Materials	McMaster-Carr	1	$ 300.00	$ 300.00
				Subtotal:	**$ 878.71**

Table 7.10: 2024-2025 NASA Student Launch Competition Budget

	Item	Vendor	Quantity	Price Per Unit	Item Total
Recovery and Avionics	120 in. Standard Parachute	Fruity Chutes	2	$ 313.37	$ 626.74
	18 in. Elliptical Parachute	Fruity Chutes	2	$ 80.95	$ 161.90
	Eggfinder Mini Transmitter	Eggtimer Inside	1	$ 105.00	$ 105.00
	Eggfinder LCD Receiver	Eggtimer Inside	1	$ 85.00	$ 85.00
	Altus Metrum Altimeter	Eggtimer Inside	2	$ 85.00	$ 170.00
	6 in. Deployment Bag	Fruity Chutes	1	$ 54.40	$ 54.40
	4 in. Deployment Bag	Fruity Chutes	1	$ 47.30	$ 47.30
	18 in. Cloth	Nomex	1	$ 26.40	$ 26.40
	13 in. Cloth	Nomex	1	$ 17.60	$ 17.60
	Kevlar Shock Cord	Huyett	40	$ 7.99	$ 319.60
	Quick Links	Huyett	18	$ 6.98	$ 125.64
	Electric Match	Firewire	16	$ 2.00	$ 32.00
	Ejection Charge	AeroTech	24	$ 1.25	$ 30.00
	Small Nylon Shear Pins	Essentra	40	$ 0.18	$ 7.20
				Subtotal:	**$ 1,808.78**
Miscellaneous	Paint	Krylon	6	$ 20.00	$ 120.00
	Birch Plywood 1/8 in.x2x2n	Rockler	6	$ 14.82	$ 88.92
	105 Epoxy Resin	West Systems	2	$ 109.99	$ 219.98
	206 Slow Hardener	West Systems	2	$ 62.99	$ 125.98
	Filament Spool	Atomic Filament	1	$ 26.00	$ 26.00
	Wire Strippers	Stanley	1	$ 34.97	$ 34.97
	Wire Cutters	Stanley	1	$ 12.99	$ 12.99
	Double Pull Pin Switch	IPL	4	$ 11.95	$ 47.80
	USB-C Cables	Belkin	2	$ 8.99	$ 17.98
	Quick Dry 2-Part Epoxy	Clearweld	1	$ 20.28	$ 20.28
	Wood Glue	Gorilla	1	$ 7.98	$ 7.98
	Misc. Bolts	Everbilt	1	$ 20.00	$ 20.00
	Misc. Nuts	Everbilt	1	$ 10.00	$ 10.00
	Misc. Washers	Everbilt	1	$ 8.00	$ 8.00
	Tinned Copper Wire Kit	DX Engineering	1	$ 12.00	$ 12.00
	Zip Ties Pack	HMRope	1	$ 6.59	$ 6.59
	9V Battery Pack	ACDelco	2	$ 12.00	$ 24.00
	Misc. Tape	Scotch	1	$ 20.00	$ 20.00
	Liquid Bandages	Equate	1	$ 5.00	$ 5.00
	Estimated Shipping				$ 1,000.00
	Incidentals (replacement tools, hardware, safety equipment, etc.)				$ 1,000.00
				Subtotal:	**$ 3,328.47**
Travel	Student Hotel Rooms – 4 nights	Hilton Hotels	8	$ 898.45	$ 7,187.60
	Mentor Hotel Rooms – 4 nights	Hilton Hotels	2	$ 556.03	$ 1,112.06
	NCSU Van Rental (# Vans)	NCSU	3	$ 798.00	$ 2,394.00
				Subtotal:	**$ 10,693.66**
Promotion	T-Shirts	Core365	50	$ 15.00	$ 750.00
	Polos	Core365	20	$ 25.00	$ 500.00
	Stickers	CustomInk	500	$ 0.43	$ 215.00
				Subtotal:	**$ 1,465.00**
				Total Expenses:	**$ 20,182.54**

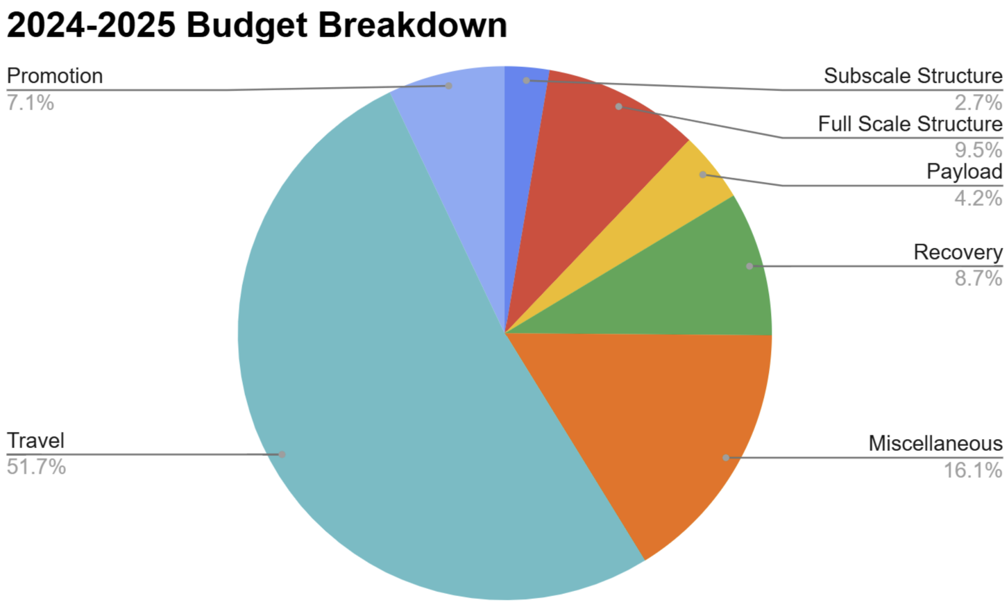


Figure 7.1: 2024-2025 Budget Breakdown.

7.3 Funding Plan

HPRC receives funding from a variety of NC State University's resources as well as from the North Carolina Space Grant (NCSG). Below is a detailed breakdown of each different funding source, followed by the specific allocations of the funds.

NC State's Student Government Association (SGA) provides appropriations to over 600 clubs and organizations on campus, including HPRC. At the beginning of each semester, clubs submit application proposals outlining their anticipated expenses. Following submission, the clubs meet with SGA representatives in a fifteen-minute interview to discuss their activities, clarify budget details, and describe the overall value they bring to the university. Subsequently, SGA allocates money to each organization on campus. For the 2023-2024 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, we requested $1,800 for the fall semester, with another $1,800 request for the spring semester. Although we are requesting this amount, it is predicted that the club will receive the same $796 per semester as in previous years. Student government funds in the fall are typically used almost entirely for the subscale rocket, with little revenue left for backup parts or full-scale materials. In the spring semester, Student Government funds will go to anything that is needed by the club, provided that all expenditures are tracked by receipts.

NC State's College of Engineering Enhancement Funds, provided by the "Engineer your Experience" (EYE) department supports engineering extracurricular activities typically related to travel. Student travel costs to Huntsville will be entirely covered by EYE. Based on last years expenses for Huntsville, it is estimated that HPRC will receive around $8,000 this year for travel costs.

The Educational and Technology Fee (ETF) is an NC State fund that allocates funding for academic enhancement through student organizations. In the 2023-2024 academic year, HPRC received $2,500 from ETF and the club anticipates to receive $2,500 for this academic year as well. This funding will be used exclusively to fund the team's faculty advisors' travel and hotel costs for the trip to Huntsville.

In addition to funding through multiple NC State University organizations, the North Carolina Space Grant (NCSG) is a significant source of HPRC's funds. The NCSG accepts funding proposals during the fall semester and teams can request up to $5,000 for participation in NASA competitions. They review the proposal submitted and inform the club of the amount rewarded. In previous academic years, we have received the maximum amount of $5,000, which will be available for use starting November, 2024. It is predicted that since we have received this amount in prior years we will be allocated the full $5,000 again this year.

Regarding sponsorships, HPRC has previously been sponsored by companies including Collins Aerospace, Jolly Logic, Fruity Chutes, and others. The club is currently seeking new sponsorships and is reaching out to past sponsors. We have found that companies are more likely to donate gifts in-kind rather than provide monetary sponsorship. The team estimates to receive $3,200 in gifts of this kind during this academic year. However, we can expect this amount to increase if we hear back from any other companies regarding gifts or sponsorships.

All of these totals are listed in Table 7.11 below, which outlines the projected costs and incoming revenue for the 2024-2025 academic year.

Table 7.11: Projected Funding Sources

Organization	Fall Semester	Spring Semester	Academic Year
NC State Student Government	$796	$796	$1,592
North Carolina Space Grant	$5,000	$0	$5,000
Engineer Your Experience	$0	$8,000	$8,000
Educational and Technology Fee	$0	$2,500	$2,500
Sponsorship	$1,600	$1,600	$3,200
Total Funding:			**$20,292.00**
Total Expenses:			**$20,182.54**
Difference:			**$109.46**

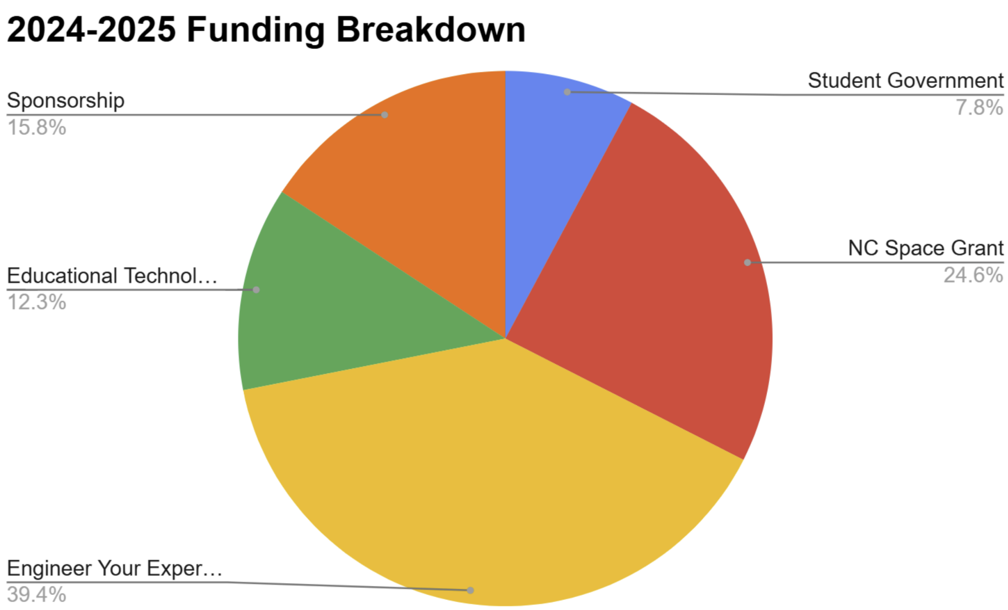


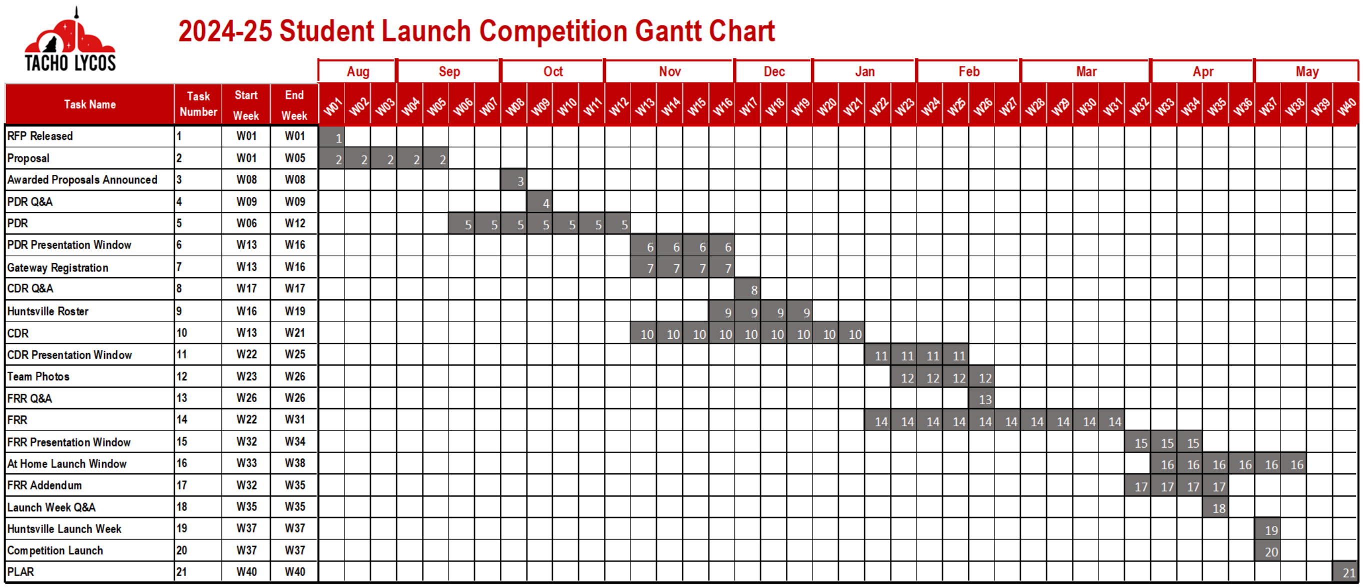
Figure 7.2: 2024-2025 Funding Breakdown.

7.4 Project Timelines

7.4.1 Competition Deliverables

Table 7.12: Competition Deadlines

Event/Task	Deadline/ Date
Request for Proposal Released	August 14, 2024
Proposal Submission Due	September 11, 2024
Awarded Proposals Announced	October 3, 2024
PDR Q&A	October 7, 2024
PDR Submission Due	October 28, 2024
PDR Video Teleconference	November 8, 2024
Gateway Registration Due	November 29, 2024
CDR Q&A	December 3, 2024
Huntsville Rosters Due	December 16, 2024
Subscale Flight Due	January 8, 2025
CDR Submission Due	January 8, 2025
CDR Video Teleconferences	January 15 - February 6, 2025
Team Photos Due	February 10, 2025
FRR Q&A	February 11, 2025
VDF Due	March 17, 2025
FRR Submission Due	March 17, 2025
FRR Video Teleconferences	March 24 - April 11, 2025
PDF Due	April 14, 2025
VDF Re-flight Due	April 14, 2025
FRR Addendum Due	April 14, 2025
Launch Week Q&A	April 17, 2025
Arrival in Huntsville	April 30, 2025
Launch Week Events	May 1-2, 2025
Launch Day	May 3, 2025
Backup Launch Day	May 4, 2025
PLAR Submission Due	May 19, 2025



Task Name	Task Number	Start Week	End Week
RFP Released	1	W01	W01
Proposal	2	W01	W05
Awarded Proposals Announced	3	W08	W08
PDR Q&A	4	W09	W09
PDR	5	W06	W12
PDR Presentation Window	6	W13	W16
Gateway Registration	7	W13	W16
CDR Q&A	8	W17	W17
Huntsville Roster	9	W16	W19
CDR	10	W13	W21
CDR Presentation Window	11	W22	W25
Team Photos	12	W23	W26
FRR Q&A	13	W26	W26
FRR	14	W22	W31
FRR Presentation Window	15	W32	W34
At Home Launch Window	16	W33	W38
FRR Addendum	17	W32	W35
Launch Week Q&A	18	W35	W35
Huntsville Launch Week	19	W37	W37
Competition Launch	20	W37	W37
PLAR	21	W40	W40

Figure 7.3: SL Competition Gantt chart.

7.4.2 Competition Development Timelines

Table 7.13 outlines the club's weekly meeting schedule. The Vehicle Meetings are joint meetings between the Structures, Aerodynamics, and Recovery Subsystems to work on developing the launch vehicle for the 2025 NASA SL Competition. The payload meetings are joint meetings between the Payload Structural Integration Lead, Payload Systems Lead, and Payload Electronics Lead to work on developing the payloads for the 2025 NASA SL Competition. WolfWorks Experimental Meetings are led by the Vice President of the club to develop experimental projects unrelated to Student Launch. Integration and Safety Meetings are joint meetings between the Integration Subsystem and Safety Officer that focus on Student Launch safety documentation, Student Launch requirement compliance, and safety education for new members. Officer Meetings are led by the President of the club and are used for club organization and management. General Body Meetings, led by the President, are used to provide updates from subsystems and share general club management information. Launch day packing occurs before launches on select weeks, as seen in Table 7.13.

Table 7.13: Weekly Club Schedule

Sunday	7:00 am - 7:00 pm: Launch Day Activities
Monday	4:30 - 5:30 pm: Wolfworks Experimental Meeting 6:00 - 6:30 pm: Integration and Safety Meeting 6:30 - 7:30 pm: Vehicle Meeting
Tuesday	6:00 - 7:30 pm: Payload Meeting
Wednesday	6:30 - 7:30 pm: Vehicle Meeting
Thursday	4:30 - 5:30 pm: Wolfworks Experimental Meeting 6:30 - 7:30 pm: Officer Meeting 7:30 - 8:30 pm: General Body Meeting
Friday	12:00 - 8:00 pm: Launch Day Packing
Saturday	7:00 am - 7:00 pm: Launch Day Activities

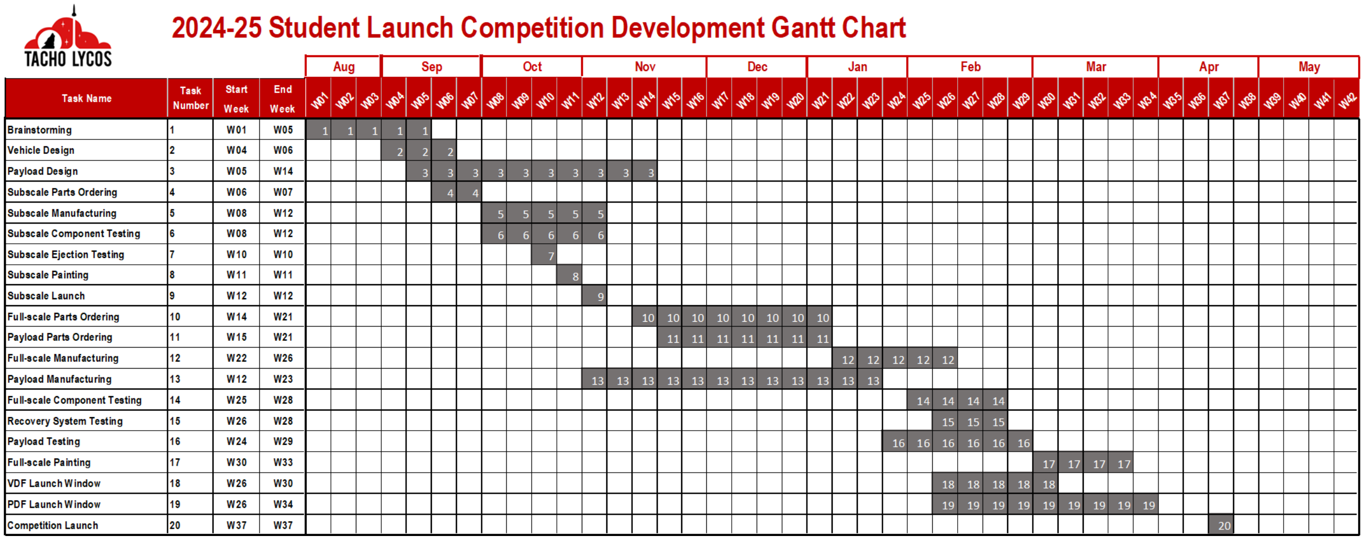


Figure 7.4: SL Development Gantt chart.

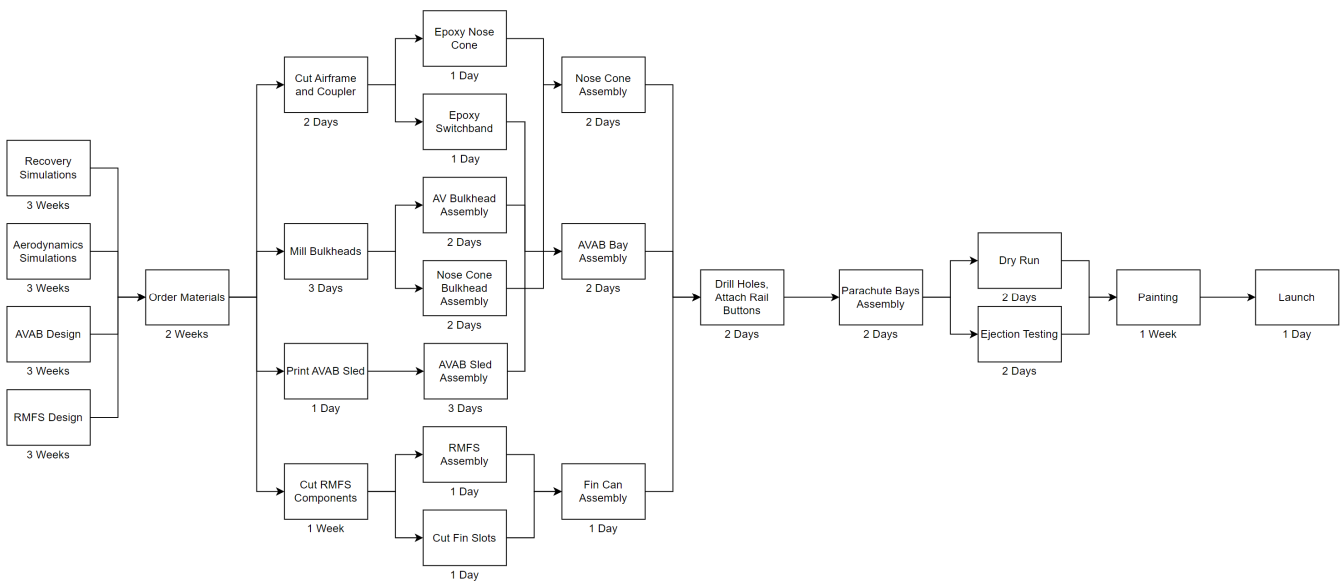


Figure 7.5: Subscale launch vehicle PERT chart.

Structures Timeline

Table 7.14: 2024-2025 Structures Timeline

September						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7

Table 7.14: 2024-2025 Structures Timeline

8	9	10	11	12	13	14
			• Proposal due			
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					
	• Fabricate subscale motor retainer • Cut threaded rods					
October						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
			• Fabricate bulkheads • Epoxy Nose Cone permanent bulkhead	• Print fin brackets	• Print fin brackets	
6	7	8	9	10	11	12
	• Mill RMFS rings • Cut and caulk airframe tubes • Epoxy AVAB swtichband • Cut and shape fins	• Print AVAB components	• Drill and tap RMFS holes • Drill all airframe holes • Install forward rail button • Cut Air Brake slots	• Print AVAB components	• Subscale first assembly	
13	14	15	16	17	18	19
	• Fall break	• Fall break	• Ejection testing • Subscale assembly			
20	21	22	23	24	25	26
	• Painting	• Painting	• Painting	• Painting	• Dry run	
27	28	29	30	31		
	• PDR due					
November						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1	2
					• Packing	• Subscale launch
3	4	5	6	7	8	9
	• Begin compiling full-scale parts order					

Table 7.14: 2024-2025 Structures Timeline

10	11	12	13	14	15	16
	• Request full-scale parts				• Backup subscale packing	• Backup subscale launch
17	18	19	20	21	22	23
24	25	26	27	28	29	30
			• Thanksgiving break	• Thanksgiving break	• Thanksgiving break	
December						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
		• Last day of class		• Finals	• Finals	
8	9	10	11	12	13	14
	• Finals	• Finals	• Finals			
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				
January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1	2	3	4
5	6	7	8	9	10	11
	• First day of class • Mill bulkheads • Cut threaded rod • Cut and shape fins	• Print fin brackets • RMFS milling	• CDR due • Epoxy nose cone coupler • Epoxy permanent bulkhead • Epoxy AVAB switchband • Print fin brackets	• Print fin brackets • Drill and tap RMFS holes	• Print AVAB components	
12	13	14	15	16	17	18
	• Print AVAB components • Drill all airframe holes • Install forward rail button • Attach motor retainer to thrust plate		• Cut Air Brake slots • Full-scale first assembly			
19	20	21	22	23	24	25
	• MLK Day					

Table 7.14: 2024-2025 Structures Timeline

26	27	28	29	30	31	
	• Vehicle Workshops		• VV&T			
February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8
	• Vehicle Workshops • FRR Writing		• VV&T • Air Brakes Integration			
9	10	11	12	13	14	15
	• Vehicle Workshops • FRR Writing	• No class	• VV&T • Air Brakes Integration			
16	17	18	19	20	21	22
	• Vehicle Workshops		• VV&T • Air Brakes Integration			
23	24	25	26	27	28	
	• Vehicle Workshops		• Air Brakes Integration			
March						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8
	• Painting	• Painting	• Painting	• Painting	• Painting	
9	10	11	12	13	14	15
	• Spring break	• Spring break	• Spring break	• Spring break	• Spring break	
16	17	18	19	20	21	22
	• FRR due • Painting	• Painting	• Painting	• Painting	• Painting	
23	24	25	26	27	28	29
	• All systems test fit					
30	31					
April						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
6	7	8	9	10	11	12
	• All systems test fit		• Dry run			
13	14	15	16	17	18	19
			• Ejection testing			

Table 7.14: 2024-2025 Structures Timeline

20	21	22	23	24	25	26
		• Last day of class		• Finals	• Finals	
27	28	29	30			
	• Finals	• Finals	• Finals • Huntsville			
May						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1	2	3
				• Huntsville • Graduation	• Huntsville	• Launch day
4	5	6	7	8	9	10
• Huntsville						
11	12	13	14	15	16	17
	• PLAR writing		• PLAR review			• PLAR due
18	19	20	21	22	23	24
25	26	27	28	29	30	31

Recovery Timeline

Table 7.15: 2024-2025 Recovery Timeline

September						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
8	9	10	11	12	13	14
			• Proposal due			
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					
October						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
		• Subscale AVAB design		• Subscale AVAB design		

Table 7.15: 2024-2025 Recovery Timeline

6	7	8	9	10	11	12
	• Altimeter research • Ejection charge containment research	• PDR recovery team derived requirements • GPS research • Switches research • Batteries research • Sled material research	• Parachute research • Parachute deployment research • Shock cord research	• PDR writing • Subscale AVAB design		
13	14	15	16	17	18	19
	• Fall break	• Fall break • PDR writing	• Ejection testing • Full scale AVAB design	• Full scale AVAB design		
20	21	22	23	24	25	26
• PDR finishing touches	• PDR soft deadline	• Subscale AVAB design	• Subscale AVAB design • PDR review	• Subscale AVAB design	• Dry run	
27	28	29	30	31		
	• PDR due • Subscale AVAB manufacturing • Subscale Altimeter testing	• Subscale AVAB manufacturing	• Subscale AVAB manufacturing • Subscale GPS testing	• Recovery Lead launch day prep		
November						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1	2
					• Packing	• Subscale launch
3	4	5	6	7	8	9
	• Launch day altimeter flight review		• Full scale AV bay design			
10	11	12	13	14	15	16
	• Full scale AV bay design		• Full scale Air Brakes design			• Backup subscale launch
17	18	19	20	21	22	23
	• Full scale Air Brakes design		• Full scale Air Brakes design			
24	25	26	27	28	29	30
	• CDR writing		• Thanksgiving break	• Thanksgiving break	• Thanksgiving break	

Table 7.15: 2024-2025 Recovery Timeline

December						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
	• CDR writing • Purchase full-scale recovery parts	• Last day of class	• CDR writing	• Finals	• Finals	
8	9	10	11	12	13	14
	• Finals	• Finals	• Finals			
15	16	17	18	19	20	21
	• CDR writing	• CDR writing	• CDR writing	• CDR writing	• CDR writing	
22	23	24	25	26	27	28
29	30	31				
January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1	2	3	4
5	6	7	8	9	10	11
	• First day of class • CDR review		• CDR due			
12	13	14	15	16	17	18
	• CDR presentation prep		• CDR presentation prep			
19	20	21	22	23	24	25
	• MLK day		• CDR presentation prep			
26	27	28	29	30	31	
	• AVAB finalization • Air Brakes code		• AVAB finalization • Air Brakes code			
February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8
	• AVAB printing • Air Brakes code		• AVAB printing • Air Brakes code			
9	10	11	12	13	14	15
	• Altimeter testing • Air Brakes code	• No class	• Altimeter testing • Air Brakes code			

Table 7.15: 2024-2025 Recovery Timeline

16	17	18	19	20	21	22
	• FRR writing • Air Brakes code		• FRR writing • Air Brakes code			
23	24	25	26	27	28	
	• FRR writing • Air Brakes code		• FRR writing • Air Brakes code			
March						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8
	• FRR writing • Air Brakes code		• FRR writing • Air Brakes code		• FRR review	
9	10	11	12	13	14	15
	• Spring break	• Spring break	• Spring break	• Spring break	• Spring break	
16	17	18	19	20	21	22
	• FRR due		• Payload support • FRR presentation prep			
23	24	25	26	27	28	29
	• Payload support • FRR presentation prep		• Payload support • FRR presentation prep			
30	31					
	• Payload support • FRR presentation prep					
April						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
			• Payload support • FRR presentation prep			
6	7	8	9	10	11	12
	• Payload support • FRR presentation prep		• Payload support • FRR presentation prep			

Table 7.15: 2024-2025 Recovery Timeline

13	14	15	16	17	18	19
	• FRR addendum due • Air Brakes code		• Air Brakes code			
20	21	22	23	24	25	26
		• Last day of class		• Finals	• Finals	
27	28	29	30			
	• Finals	• Finals	• Finals • Huntsville • Graduation			
May						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1	2	3
				• Huntsville • Graduation	• Huntsville	• Launch day
4	5	6	7	8	9	10
• Huntsville	• PLAR writing • Recovery handover		• PLAR writing • Recovery handover			
11	12	13	14	15	16	17
	• PLAR writing • Recovery handover		• PLAR writing • Recovery handover			
18	19	20	21	22	23	24
	• PLAR deadline					
25	26	27	28	29	30	31

Aerodynamics Timeline

Table 7.16: 2024-2025 Aerodynamics Timeline

September						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
8	9	10	11	12	13	14
			• Proposal due			
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Table 7.16: 2024-2025 Aerodynamics Timeline

29	30					
October						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
6	7	8	9	10	11	12
					• PDR writing	• PDR writing • Open Rocket
13	14	15	16	17	18	19
• PDR writing • RASAero • RocketPy	• Fall break • PDR writing • RocketPy	• Fall break • PDR writing	• Finalize PDR • Ejection testing			
20	21	22	23	24	25	26
• PDR finishing touches	• PDR soft deadline	• Subscale Open Rocket • Subscale RASAero	• Subscale RASAero • PDR review		• Dry run	
27	28	29	30	31		
	• PDR due	• Subscale RocketPy	• Subscale RocketPy	• Subscale RocketPy		
November						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1	2
					• Dry run	• Subscale launch
3	4	5	6	7	8	9
	• Start working with Air Brakes					
10	11	12	13	14	15	16
			• Full-scale Air Brakes design			• Backup subscale launch
17	18	19	20	21	22	23
	• Full-scale Air Brakes design • CDR Writing		• Full-scale Air Brakes design • CDR Writing			
24	25	26	27	28	29	30
	• CDR Writing		• Thanksgiving break	• Thanksgiving break	• Thanksgiving break	
December						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
	• CDR Writing		• Finish CDR writing	• Finals	• Finals	
8	9	10	11	12	13	14
	• Finals	• Finals	• Finals			
15	16	17	18	19	20	21

Table 7.16: 2024-2025 Aerodynamics Timeline

22	23	24	25	26	27	28
29	30	31				
January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1	2	3	4
			• CDR soft deadline			
5	6	7	8	9	10	11
	• CDR review		• CDR due			
12	13	14	15	16	17	18
	• CDR presentation prep		• CDR presentation prep			
19	20	21	22	23	24	25
	• MLK Day		• CDR presentation prep			
26	27	28	29	30	31	
	• Air Brakes code		• Air Brakes code			
February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8
	• Air Brakes code		• Air Brakes code			
9	10	11	12	13	14	15
	• Air Brakes code		• Air Brakes code			
16	17	18	19	20	21	22
	• FRR writing • Air Brakes code		• FRR writing • Air Brakes code			
23	24	25	26	27	28	
	• FRR writing • Air Brakes code		• FRR writing • Air Brakes code			
March						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8
	• FRR writing • Air Brakes code • Moment of inertia test		• FRR writing • Air Brakes code		• FRR review	

Table 7.16: 2024-2025 Aerodynamics Timeline

9	10	11	12	13	14	15
	• Spring break	• Spring break	• Spring break	• Spring break	• Spring break	
16	17	18	19	20	21	22
	• FRR due		• FRR presentation prep			
23	24	25	26	27	28	29
	• FRR presentation prep		• FRR presentation prep			
30	31					
	• FRR presentation prep					
April						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
			• FRR presentation prep			
6	7	8	9	10	11	12
	• FRR presentation prep		• FRR presentation prep			
13	14	15	16	17	18	19
	• FRR addendum deadline • Air Brakes code		• Air Brakes code			
20	21	22	23	24	25	26
				• Finals	• Finals	
27	28	29	30			
	• Finals	• Finals	• Finals • Huntsville			
May						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1	2	3
				• Huntsville • Graduation	• Huntsville	• Launch day
4	5	6	7	8	9	10
• Huntsville • PLAR writing	• PLAR writing					
11	12	13	14	15	16	17
18	19	20	21	22	23	24
	• PLAR due					
25	26	27	28	29	30	31

Payload Timeline

Table 7.17: 2024-2025 Payload Timeline

September						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
8	9	10	11	12	13	14
			• Proposal due			
15	16	17	18	19	20	21
22	23	24	25	26	27	28
		• Create list of parts • Research technology and software needed			• Finalize parts list • Order components • Start initial CAD model	
29	30					
October						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
		• Get components • Start soldering electronics • Get an initial idea of coding	• Get components	• Get components	• Get components • 3D print first draft of sled • Finalize electronics/ wiring	
6	7	8	9	10	11	12
		• Mount electronics on sled • Iterate sled design if needed			• Finalize sled mounting • Finalize logging/ transmission code	
13	14	15	16	17	18	19
	• Fall break • PDR writing	• Fall break • Iterate design for potentially damaged components • PDR writing	• PDR writing	• Full scale AVAB design • PDR writing	• PDR writing	• PDR writing
20	21	22	23	24	25	26
• PDR writing	• PDR writing finalization					
27	28	29	30	31		
	• PDR due	• Dry run				

Table 7.17: 2024-2025 Payload Timeline

November						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1	2
					• Packing	• Subscale launch
3	4	5	6	7	8	9
		• Coding • Air Brakes design • Review launch data				
10	11	12	13	14	15	16
		• Air Brakes design • Review launch data			• Finalize full-scale parts list • Order components	
17	18	19	20	21	22	23
24	25	26	27	28	29	30
			• Thanksgiving break	• Thanksgiving break	• Thanksgiving break	
December						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
	• CDR writing	• Last day of class • CDR writing		• Finals	• Finals	
8	9	10	11	12	13	14
	• Finals	• Finals	• Finals			
15	16	17	18	19	20	21
	• CDR writing	• CDR writing	• CDR writing	• CDR writing	• CDR writing	
22	23	24	25	26	27	28
29	30	31				
January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1	2	3	4
			• CDR writing		• CDR writing finalization	
5	6	7	8	9	10	11
		• Print payload sled	• CDR due	• Solder payload and Air Brakes electronics		

Table 7.17: 2024-2025 Payload Timeline

12	13		15	16	17	18
		• Finish soldering electronics		• Begin attaching electronics to the payload sled		
19	20	21	22	23	24	25
	• MLK Day	• Complete payload sled		• Test payload data collection		
26	27	28	29	30	31	
	• Air Brakes finalization • Air Brakes code	• Test payload transmission	• Air Brakes finalization • Air Brakes code			
February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8
		• Air Brakes testing				
9	10	11	12	13	14	15
		• VV&T • Air Brakes testing				
16	17	18	19	20	21	22
		• VV&T • Air Brakes testing				
23	24	25	26	27	28	
		• VV&T • Air Brakes testing				
March						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8
		• Air Brakes testing • FRR writing		• FRR writing	• FRR writing finalization	
9	10	11	12	13	14	15
	• Spring Break	• Spring Break	• Spring Break	• Spring Break	• Spring Break	
16	17	18	19	20	21	22
	• FRR due					
23	24	25	26	27	28	29
30	31					

Table 7.17: 2024-2025 Payload Timeline

April						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
	• FRR addendum due					
20	21	22	23	24	25	26
				• Finals	• Finals	
27	28	29	30			
	• Finals	• Finals	• Finals • Huntsville			
May						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1	2	3
				• Huntsville • Graduation	• Huntsville	• Launch day
4	5	6	7	8	9	10
• Huntsville						
11	12	13	14	15	16	17
	• PLAR writing		• PLAR review			• PLAR due
18	19	20	21	22	23	24
25	26	27	28	29	30	31

Project Management Timeline

Table 7.18: 2024-2025 Project Management Timeline

September						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
				• Proposal soft deadline		
8	9	10	11	12	13	14
			• Proposal due			
15	16	17	18	19	20	21
		• No class				
22	23	24	25	26	27	28
29	30					

Table 7.18: 2024-2025 Project Management Timeline

October						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
				• Awarded proposals announced		
6	7	8	9	10	11	12
	• PDR Q&A			• All participants create Gateway account	• Create Challenge Team Lead Application	
13	14	15	16	17	18	19
	• PDR peer review deadline • Fall break	• Fall break		• All participants submit registration application	• Challenge Team Lead Application deadline	
20	21	22	23	24	25	26
	• PDR soft deadline	• Write Checklist	• Write Checklist	• Confirm participants submit registration application	• Gateway registration application deadline	
27	28	29	30	31		
	• PDR due	• Write Checklist	• Write Checklist	• Write Checklist	• Write Checklist	• Write Checklist

November						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1	2
	• Write Checklist	• Finalize Checklist			• Packing	• Subscale launch
3	4	5	6	7	8	9
				• All participants accept Gateway offer		
10	11	12	13	14	15	16
					• Backup packing	• Backup subscale launch
17	18	19	20	21	22	23
				• Confirm all participants accept Gateway offer		

Table 7.18: 2024-2025 Project Management Timeline

24	25	26	27	28	29	30
			• Thanksgiving break	• Thanksgiving break	• Thanksgiving break • Gateway offer acceptance deadline	
December						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
• CDR peer review deadline		• Last day of class • Determine Huntsville travel roster • CDR Q&A		• Finals	• Finals	
8	9	10	11	12	13	14
	• Finals	• Finals	• Finals	• Finalize Huntsville travel roster		
15	16	17	18	19	20	21
	• Huntsville travel roster deadline					
22	23	24	25	26	27	28
29	30	31				
	• CDR soft deadline					
January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1	2	3	4
5	6	7	8	9	10	11
	• First day of class		• CDR due • Subsclae flight due			
12	13	14	15	16	17	18
19	20	21	22	23	24	25
	• MLK Day					
26	27	28	29	30	31	
				• Determine date of team photos		
February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8

Table 7.18: 2024-2025 Project Management Timeline

9	10	11	12	13	14	15
	• Team photos due	• No class • FRR Q&A				
16	17	18	19	20	21	22
23	24	25	26	27	28	
March						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8
	• FRR peer review deadline					
9	10	11	12	13	14	15
	• FRR soft deadline • Spring Break	• Spring Break	• Spring Break	• Spring Break	• Spring Break	
16	17	18	19	20	21	22
	• FRR due • VDF due					
23	24	25	26	27	28	29
30	31					
April						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
					• FRR addendum peer review deadline	
6	7	8	9	10	11	12
			• FRR addendum soft deadline			
13	14	15	16	17	18	19
	• FRR addendum due • PDF due • VDF reflight due			• Launch week Q&A		
20	21	22	23	24	25	26
		• Last day of class		• Finals	• Finals	
27	28	29	30			
	• Finals	• Finals	• Finals • Huntsville			

Table 7.18: 2024-2025 Project Management Timeline

May						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1	2	3
				• Huntsville • Graduation	• Huntsville activities	• Launch Day
4	5	6	7	8	9	10
• Backup Launch Day						
11	12	13	14	15	16	17
	• PLAR peer review deadline			• PLAR soft deadline		
18	19	20	21	22	23	24
	•PLAR due					
25	26	27	28	29	30	31

7.4.3 Funding Timeline

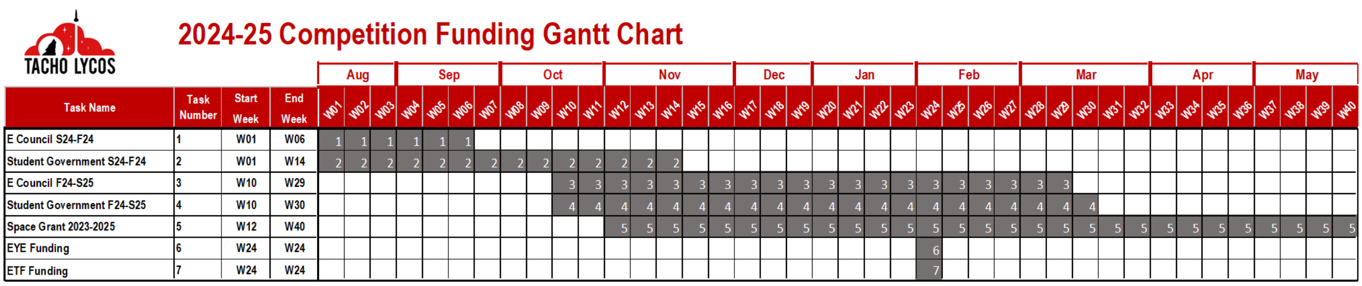


Figure 7.6: SL Budget Gantt chart.

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Appendix

NC State University High Powered Rocketry Club Constitution

NC State University High Powered Rocketry Club Lab Safety Quiz

Signed Safety Acknowledgment/Contract

Wake County Waste Disposal Guidelines and Resource Website

West Systems 105/206 Epoxy Resin Datasheet

Mental Health Resource Slide for HPRC General Body Meetings: