NC STATE UNIVERSITY

Tacho Lycos

2025 NASA Student Launch

Critical Design Review

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

January 8, 2025

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	= Verification, Validation, and Testing

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1 Summary of Report

1.1 Team Summary

1.1.1 Team Name and Mailing Address

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

Mailing Address: 1840 Entrepreneur Drive, Raleigh, NC 27606

Primary Contact: 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 plans to complete the competition launch in Huntsville, Alabama, during launch week.

1.1.4 Time Spent on CDR Milestone

Approximately 1021 hours were spent on the CDR milestone between all members responsible for the project.

1.2 Launch Vehicle Summary

1.2.1 Official Target Altitude

The official target altitude of the Launch Vehicle is 4600 ft.

1.2.2 Motor Selection

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

1.2.3 Vehicle Size and Mass

The Launch Vehicle has an overall length of 95.75 in. with a maximum body diameter of 6.17 in. The dry mass of the Launch Vehicle is 30.41 lbs and the fully integrated wet mass is 38.39 lbs. No ballast is required to meet minimum stability or CG requirements. The estimated burnout and landing mass is 34.37 lbs. The external lengths and wet masses of individual sections are listed below.

Section	Length	Mass
Nose Cone/Payload Bay	27 in.	8.81 lbs.
Main Parachute Bay	30.5 in.	5.47 lbs.
Avionics and Air Brakes Bay	3 in.	6.60 lbs.
Drogue Parachute Bay/Fin Can	35.25 in.	17.51 lbs.

1.2.4 Recovery System

The final recovery design uses 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.

1.2.5 Rail Size

The Launch Vehicle will utilize a 1515 launch rail that is 12 ft. in length.

1.3 Payload Summary

The final payload design is a STEMCRaFT in the Nose Cone of the Launch Vehicle. The STEMCRaFT houses four STEMnauts and electronics to record and transmit data over the 2M band in the APRS packet format. The payload will collect and transmit data for all possible data points. The Launch Vehicle also features and Air Brakes system as an experimental payload used to control apogee.

2 Changes Made Since PDR

2.1 Changes Made to Vehicle Criteria

Table 2.1: Changes made to vehicle criteria since PDR submission.

Change Description	Justification	Affected Subsystem(s)
Use of two batteries on separate circuits for the secondary altimeter and the GPS tracker instead of one battery on the same circuit.	Increased battery life for each of the components.	Recovery
Main Parachute Bay section length extended 6.5 in., Drogue Parachute Bay/Fin Can section length reduced 2.5 in.	Better mass distribution, reduction of ballast, improved burnout CG position.	Structures, Aerodynamics
AVAB switchband position shifted 2.5 in. forward relative to coupler tube.	Better mass distribution, reduction of ballast, improved burnout CG position.	Structures, Aerodynamics
Removable Modular Fin System centering rings material changed from 6061-T6 aluminum to Baltic birch plywood.	Mass reduction in the aft end of the vehicle.	Structures
Removable Modular Fin System runner connection changed from L-brackets to retainer slots in centering rings.	Design simplification and reduced part count.	Structures

2.2 Changes Made to Payload Criteria

Table 2.2: Changes made to payload criteria since PDR submission.

Change Description	Justification	Affected Subsystem(s)
Use of two LiPo batteries to power the STEMCRaFT components.	Minimize risk of brownout. Enable sufficient power for the SA858 transmitter.	Payload Electronics
Implemented ESP32 as interface between Raspberry Pi and sensors.	Arduino based micro-controller allows improved support for with selected sensors.	Payload Electronics
Installed a small ventilation fan.	Enhance airflow and thermal management within the payload.	Payload Structural & Thermal Management
Replaced Si4464 w/ GRF5020 amplifier with SA858 transmission module with built-in amplifier 4 watt amplifier.	Simplify the transmission system by using an integrated amplifier, improving signal strength.	Payload Communications

2.3 Changes Made to Project Plan

Table 2.3: Changes made to project plan since PDR submission.

Change Description	Justification	Affected Subsystem(s)
Subscale launch moved to November 16th.	To allow more time for design changes.	Structures Subsystem, Payload Subsystem, Project Management Subsystem, Project Management Subsystem
VDF scheduled for February 22, 2025.	Earliest viable launch date at home launch field after Full-scale construction.	Structures Subsystem, Recovery Subsystem, Aerodynamics Subsystem, Project Management Subsystem
PDF scheduled for February 22, 2025.	Earliest viable launch date that allows time for reflights of the payloads for data collection.	Payload Subsystem, Project Management Subsystem
Added verification testing Gantt chart.	Required by NASA SL Handbook.	All Subsystems

Table 2.3: Changes made to project plan since PDR submission.

Change Description	Justification	Affected Subsystem(s)
Removed peer review deadlines.	Done individually to allow more time for team member feedback.	All Subsystems
Added Full-scale dry run dates.	To verify that the Launch Vehicle can be properly integrated on launch day.	All Subsystems
Added ejection testing dates.	Required by NASA SL Handbook and Team Derived Requirements.	Recovery Subsystem, Project Management Subsystem
Seniors leave for Huntsville on May 1st.	To allow seniors to attend their graduation ceremony.	All Subsystems
Scheduled CDR presentation.	Required by NASA SL Handbook.	All Subsystems
Added verification testing to individual subsystem schedules.	To ensure completion of verification testing before PDF/VDF flight.	All Subsystems
Updated subsystem development timelines.	Due to updates in design and testing plans.	All Subsystems

3 Vehicle Criteria

3.1 Launch Vehicle Mission Statement and Success Criteria

3.1.1 Mission Statement

The primary mission of the Launch Vehicle is to deliver the payload to the declared apogee and return it safely to the ground. 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. The criteria used to determine the level of mission success are listed in Table 3.1 below.

3.1.2 Success Criteria

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 vehicle 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 Design and Verification of Launch Vehicle

3.2.1 Launch Vehicle Design Overview

The final Launch Vehicle design has a total overall length of 95.75 in., with a maximum body diameter of 6.17 in. These dimensions yield a 16:1 aspect ratio. The fully integrated Launch Vehicle mass is 38.39 lbs. with a burnout and landing mass of 34.37 lbs. The final Launch Vehicle design is a refinement of the leading Launch Vehicle configuration presented during the Preliminary Design Review milestone. The Launch Vehicle features four sections: a combination Nose Cone/Payload bay, a Main Parachute Bay, a combination Avionics and Air Brakes Bay (AVAB), and a combination Drogue Parachute Bay/Fin Can. The use of multipurpose sections enabled optimal use of interior section volume for subsystems within the Launch Vehicle, and reduced the total required number of vehicle sections. This creates fewer required section interfaces, and ultimately reduces excess structural mass.

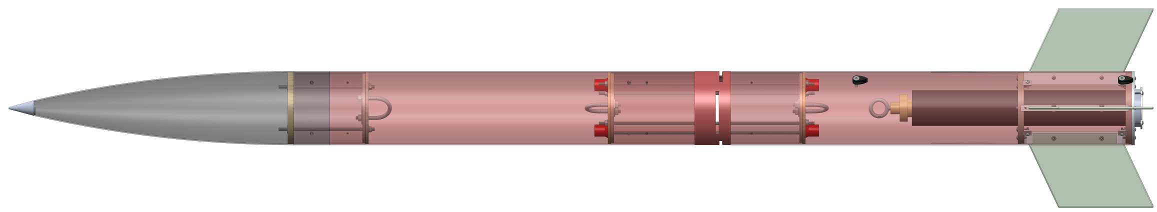


Figure 3.1: CAD model of the Launch Vehicle structure.

3.2.2 Separation Points and Location of Energetics

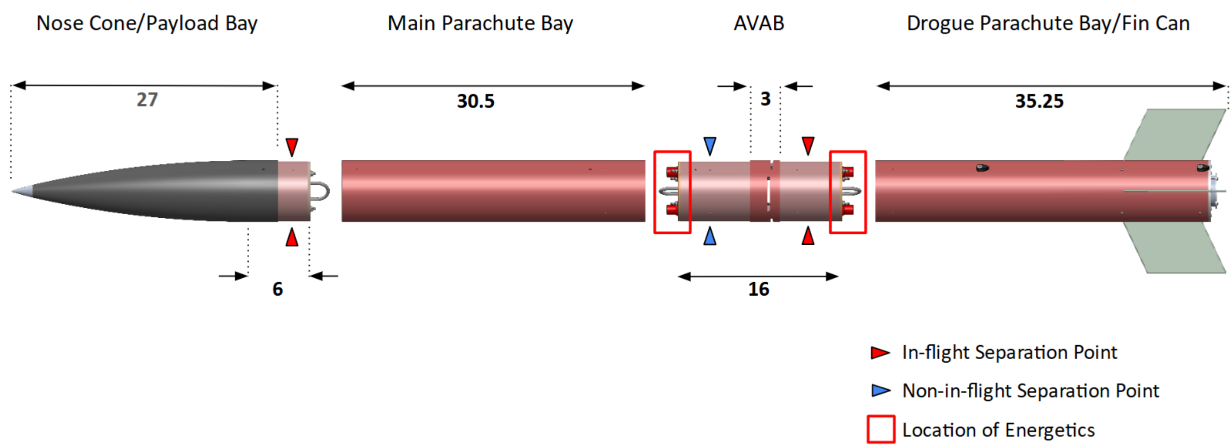


Figure 3.2: Launch vehicle section separation points and energetics location (in.)

The final Launch Vehicle design features two in-flight separation points and one non-in-flight separation point. The initial in-flight separation point is between the aft end of the AVAB and the Drogue Parachute Bay/Fin Can. Six in. of linear surface contact exists at this connection between the aft AVAB coupler section and the Drogue Parachute Bay/Fin Can airframe, which satisfies NASA Requirement 2.4.1. Separation at this location is initiated via a black powder charge located on the aft AVAB bulkhead. Prior to separation, this connection is secured using four 4-40 nylon shear pins.

The second in-flight separation point is located between the Nose Cone/Payload Bay and the Main Parachute Bay. Three in. of linear surface contact exists at this connection between the Nose Cone shoulder and the Main Parachute Bay airframe, which satisfies NASA Requirement 2.4.3. Separation at this location is initiated via a black powder charge located on the forward AVAB bulkhead. Prior to separation, this connection is secured using four 4-40 nylon shear pins.

The non-in-flight separation point is between the aft end of the Main Parachute Bay and the AVAB. Seven in. of linear surface contact exists at this location between the Main Parachute Bay airframe and the forward AVAB coupler section, which satisfies NASA Requirement 2.4.2. During flight, this connection is secured using four nylon push rivets.

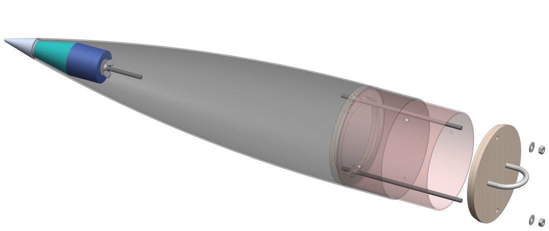
3.2.3 Nose Cone/ Payload Bay

The Nose Cone/Payload Bay forms the forward most section of the Launch Vehicle and houses the primary STEMCRaFT payload. This section will be manufactured from a commercially available G12 wound-fiberglass composite Nose Cone with an aluminum tip. This material was selected for its RF transparent properties. The overall shape of the Nose Cone is a 4:1 tangent ogive, which provides adequate balance of internal volume to accommodate the primary payload and aerodynamic performance. The Nose Cone shoulder consists of a 6 in. long coupler section bonded 3 in. into the Nose Cone body with epoxy resin. Just forward of the coupler section is a permanent ring bulkhead that is also bonded to the interior of the Nose Cone body and the coupler section. This ring bulkhead features two 1/4 in. threaded inserts that will retain two 8 in. lengths of 1/4-20 in. threaded rod. These threaded rods extend beyond the end of the Nose Cone shoulder and form the structural attachment point for the STEMCRaFT. A solid, removable bulkhead forms the aft closure of this section. This bulkhead mates to the aft end of the Nose Cone shoulder and is retained via the threaded rods. The Nose Cone/Payload bay also features pressure port holes for STEMCRaFT data collection during flight, and smaller shear pin holes for mating to the Main Parachute Bay.

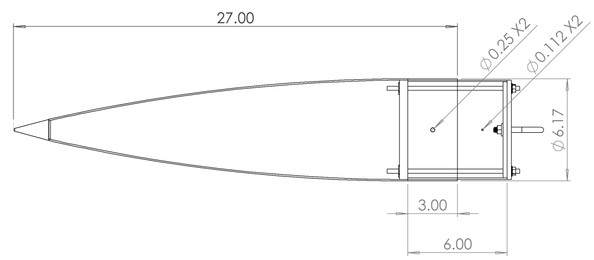
Forward Ballast System

An optional, adjustable ballast system will be located all the way forward in the Nose Cone and will attach to the aluminum tip via a 1/4 in. threaded rod. Slices of solid epoxy resin/sand mixture serve as the primary ballast mass and can be stacked along this rod and secured in place with a large fender washer and a thumb screw. The diameter and thickness of these slices can be varied to achieve the desired ballast mass.

CAD Drawings/ Cross Sectional Views



(a) CAD model of the Nose Cone/ Payload Bay with removed bulkhead and ballast system installed.



(b) Nose Cone/Payload Bay dimensional drawing (in.)

Figure 3.3: CAD model and dimensional drawing of the Nose Cone/ Payload Bay.

3.2.4 Nose Cone/ Payload Bay Bulkheads

The Nose Cone/Payload Bay permanent ring bulkhead and removable bulkhead will both be manufactured from 1/2 in. thick Baltic birch plywood. The permanent ring bulkhead will have a consistent outer diameter equal to the Nose Cone coupler to sit flush with the interior Nose Cone wall. The interior diameter is large enough for the STEMCRaFT payload to extend through, allowing access into the forward volume of the Nose Cone. Two wider sections of the ring bulkhead exist to mount tee nut threaded inserts for the threaded rods. The removable bulkhead features a 1/4 in. thick lip which will center it within the Nose Cone shoulder and ensure the aft closure is sealed from gasses generated during separation at Main Parachute deployment. This bulkhead is secured in place during flight with hex nut fasteners and washers on the threaded rods that run through the bulkhead. A U-bolt on the removable bulkhead serves as the forward anchor point for the Main Parachute gear.

CAD Drawings/ Cross Sectional Views

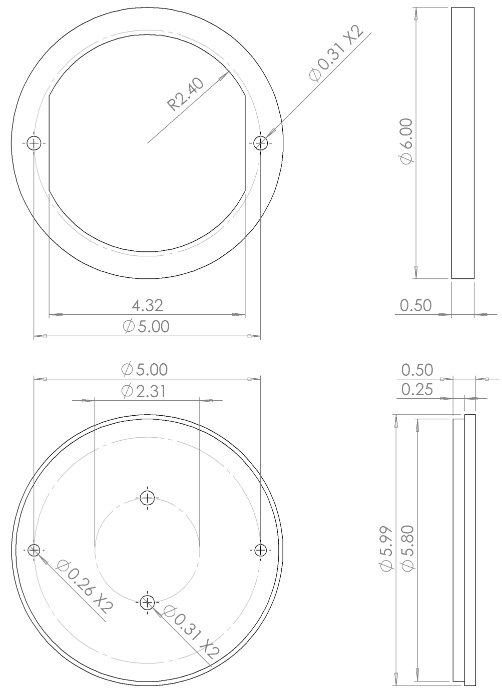


Figure 3.4: Nose Cone/Payload Bay bulkheads dimensional drawings (in.)

3.2.5 Main Parachute Bay

The Main Parachute Bay is a single 30.5 in. long G12 fiberglass airframe section that houses the main parachute, main parachute shock cord, and deployment bag. The forward end mates to the Nose Cone/Payload Bay shoulder at an in-flight separation point. The aft end mates to the forward AVAB coupler section at a non-in-flight separation point. Various holes are present for nylon shear pins, nylon rivets, and pressure ports for the recovery Avionics housed within the forward portion of the AVAB. The pressure ports are drilled through both the AVAB coupler and Main Parachute Bay airframe wall to position them as far upstream of the Air Brakes mechanism as possible.

CAD Drawings/ Cross Sectional Views

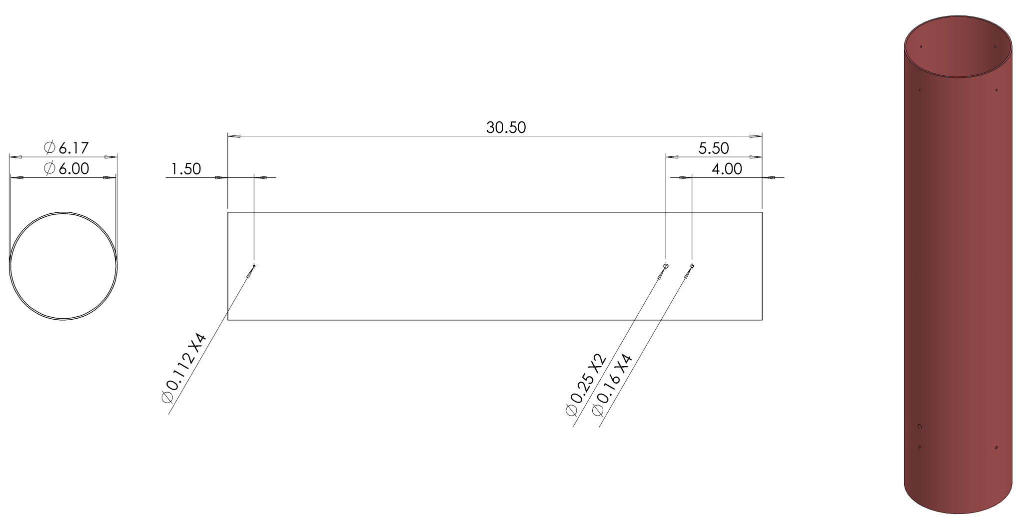
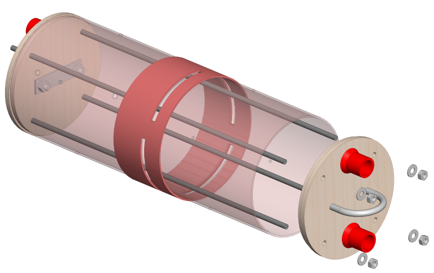


Figure 3.5: Main Parachute Bay dimensional drawing (in.)

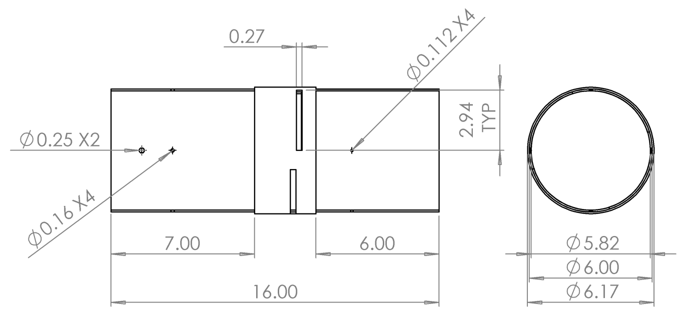
3.2.6 Avionics/ Air Brakes Bay (AVAB)

The AVAB consists of a 16 in. long G12 fiberglass coupler tube which houses both the Avionics and secondary Air Brakes payload. These subsystems are housed together to eliminate the need for an additional structural section within the Launch Vehicle. This section is partitioned into a forward and aft bays via internal horizontal sled bulkheads. The forward partition houses the recovery avionics and features two 1/4 in. holes for pressure readings as well as four holes for nylon push rivets. The forward end of the AVAB coupler mates to the aft end of the Main Parachute Bay with 7 in. of linear contact at the only non-in-flight separation point. The aft partition houses the Air Brakes payload system and mates to the forward end of the Drogue Parachute Bay/Fin Can with 6 in. of linear contact. The aft coupler section features four holes for 4-40 nylon shear pins which fasten this connection at an in-flight separation point. A 3 in. long switchband overlaps both interior sections and is bonded to the coupler tube with epoxy resin. A hole for the recovery avionics pull-pin arming switch will be drilled near the forward edge of the switchband. The aft portion of the switchband features two pairs of staggered, circumferential slots for the Air Brakes system mechanism. These slots allow the Air Brake drag fins to extend into the airflow during the coast phase. Four 18 in. long, 1/4 in. diameter threaded rods run the length of the bay and form the internal structure for mounting all of the Avionics and Air Brakes component sleds. Removable 1/2 in. thick Baltic birch plywood bulkheads form the forward and aft closures of this section. Both bulkheads contain primary and secondary ejection charges within charge wells on their exterior face for both recovery system deployment events.

CAD Drawings/ Cross Sectional Views



(a) CAD model of the AVAB structure with removed aft bulkhead.



(b) AVAB dimensional drawing (in.)

Figure 3.6: CAD model and dimensional drawing of the AVAB.

3.2.7 AVAB Bulkheads

The AVAB bulkheads will be made of 1/2 in. thick Baltic birch plywood. Similar to the Nose Cone/Payload Bay removable bulkhead, the AVAB bulkheads feature a 1/4 in. thick lip for centering and sealing purposes. They are retained to the AVAB coupler tube via hex nuts on the four threaded rods that extend through holes in the bulkheads. U-bolts on the forward and aft bulkheads are anchor points for the Main Parachute and Drogue Parachute gear, respectively. Each bulkhead also features two 3-D printed PLA charge wells that contain the separation energetics. Terminal blocks are also mounted on the bulkheads to provide an intermediate connection point for the e-matches which initiate the separation energetics.

CAD Drawings/ Cross Sectional Views

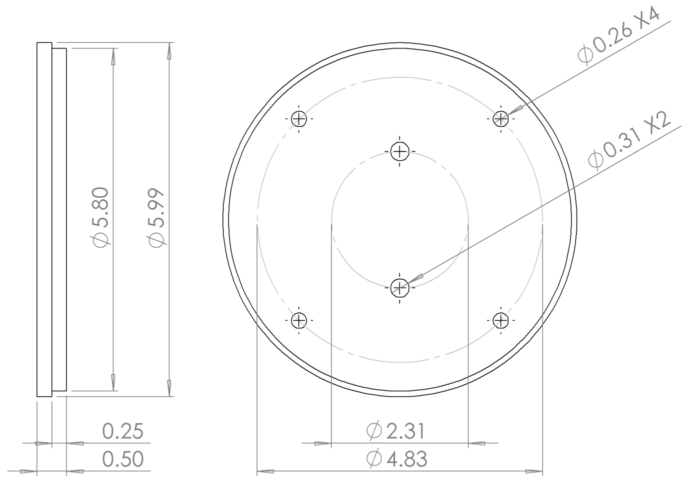


Figure 3.7: AVAB bulkheads dimensional drawing (in.)

3.2.8 Drogue Parachute Bay/ Fin Can

The Drogue Parachute Bay/Fin Can forms the aft end of the Launch Vehicle and houses the Drogue Parachute recovery gear, Removable Modular Fin System (RMFS), and the Aerotech RMS-75/3840 motor casing. The body is a 33.5 in. long section of G12 fiberglass airframe with four end-cut fin slots to accept the RMFS. Eight fastener holes are present between the fin slots for the #8-32 machine screws that secure the RMFS to the airframe body. Shear pin holes are also present near the forward end for mating to the AVAB.

Two commercially available 1515 airfoil rail buttons are attached to this section and are positioned 65 in. and 89 in. from the forward tip of the Launch Vehicle. The forward rail button screw fastens through the wall of the Fin Can and is secured with a washer and hex nut reinforced with Loctite thread locker. The aft rail guide screw replaces one of the RMFS mounting screws and is fastened through one of the L-brackets on the aft RMFS centering ring.

CAD Drawings/ Cross Sectional Views

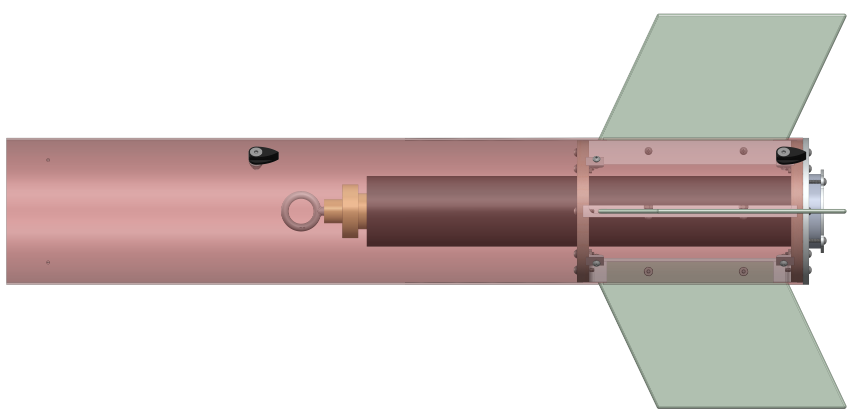


Figure 3.8: CAD model of the Drogue Parachute Bay/Fin Can with attached rail guides, RMFS, and motor casing.

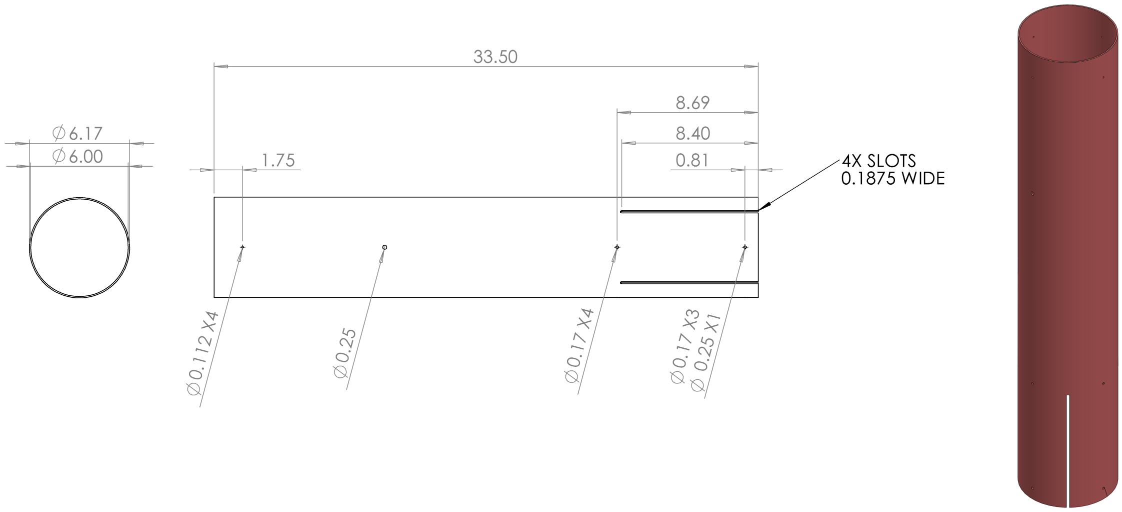


Figure 3.9: Drogue Parachute Bay/Fin Can airframe dimensional drawing (in.)

3.2.9 Removable Modular Fin System (RMFS)

The RMFS is a multipurpose structural assembly that mates into the aft end of the Drouge Parachute Bay/Fin Can. It serves as the attachment point for the fins and provides centering and retention of the Aerotech RMS-75/3840 motor casing. This design was chosen over a permanent epoxied fin/motor mount design to enhance the reusability of the launch vehicle in the event of damage to the Fin Can or fins.

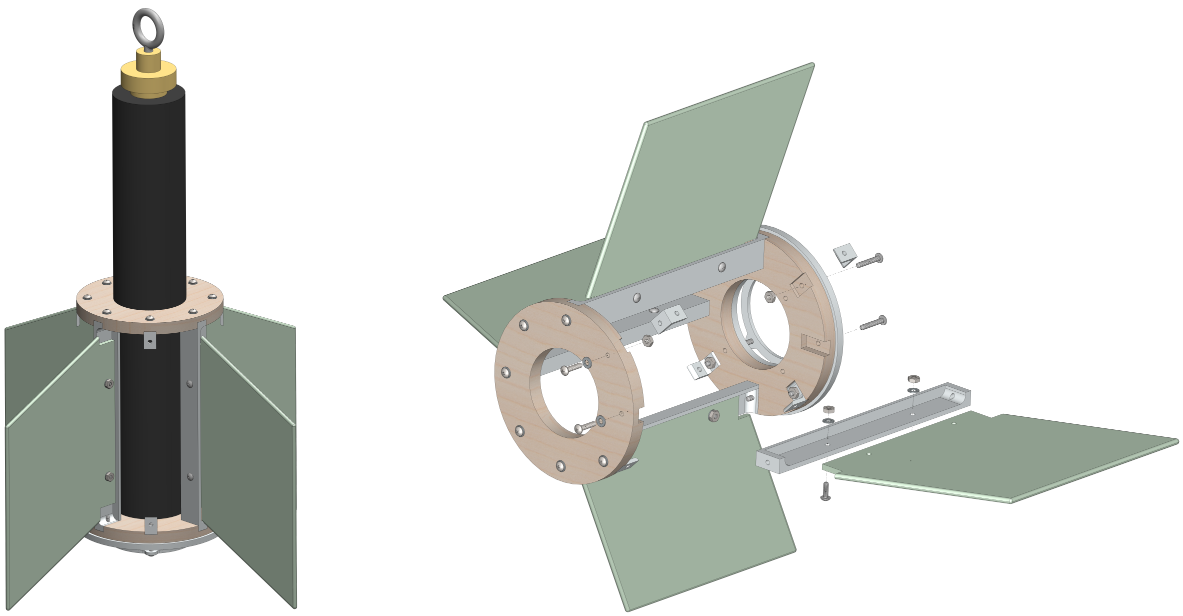
The RMFS consists of a forward centering ring, four fin runners, an aft centering ring, a thrust plate, and a motor retainer ring. The assembly is fully modular, with all components secured together with #8-32 machine screws. This enables parts to be quickly swapped in the unlikely event of damage, and contributes to rapid re-usability of the Launch Vehicle.

The forward and aft centering rings are constructed of 1/2 in. thick Baltic birch plywood. Four small L-brackets made from 1/8 in. thick 6061 aluminum angles sit into recessed slots 1/8 in. deep on the interior face of each centering ring. These L-brackets provide the attachment point for the machine screws and hex nuts that secure the RMFS to the airframe. Each centering ring also features four 1/4 in. recessed slots which seat the fin runners and prevent them from twisting. Through-holes on the centering rings align with threaded holes in each end of the fin runners, and four machine screws with washers fasten the fin runners and centering rings together as a unit. Spacing between the centering rings, airframe, and motor casing is such that a sufficient seal is created to contain the gasses generated during separation for drogue parachute deployment.

Four 9 in. long 6061 aluminum fin runners provide longitudinal strength and rigidity for the assembly. Each runner is a single aluminum part with an L-shaped cross section. This profile provides excellent resistance to bending, twisting, and buckling and results in a sturdy connection point for the fin. The forward and aft ends of each runner have an #8-32 threaded hole which retain the machine screws passing through the forward and aft centering rings. These connections secure the RMFS assembly together.

A 1/4 in. thick 6061 aluminum thrust plate sits flush with the aft end of the airframe and evenly distributes the motor thrust force to the aft circumference of the Launch Vehicle during the boost phase of flight. Four machine screws run through the thrust plate, aft centering ring, and into the threaded holes in the fin runners. These connections secure the aft portion of the RMFS assembly together. Finally, a motor retaining ring is attached via four additional machine screws that fasten into threaded holes in the thrust plate. This ring secures the motor casing to the RMFS assembly after motor burn out.

CAD Drawings/ Cross Sectional Views



(a) CAD model of the RMFS with attached fins and motor casing.

(b) Partially exploded CAD model of a fin runner assembly and L-bracket pair.

Figure 3.10: CAD model of RMFS.

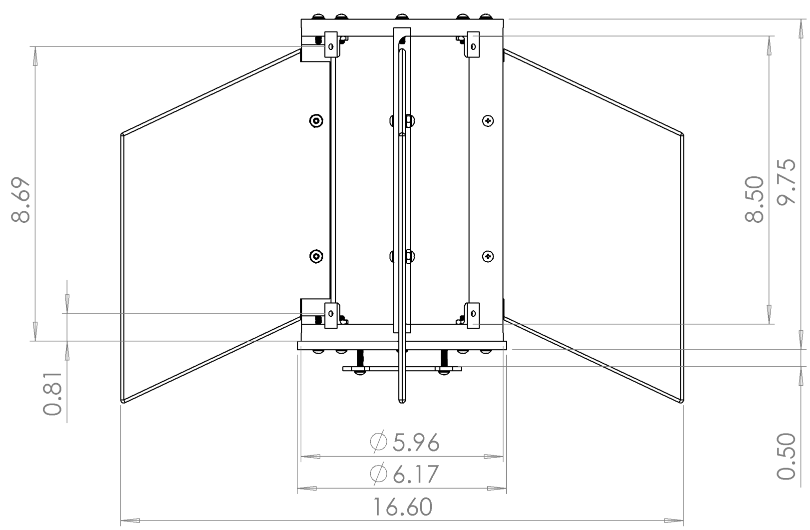
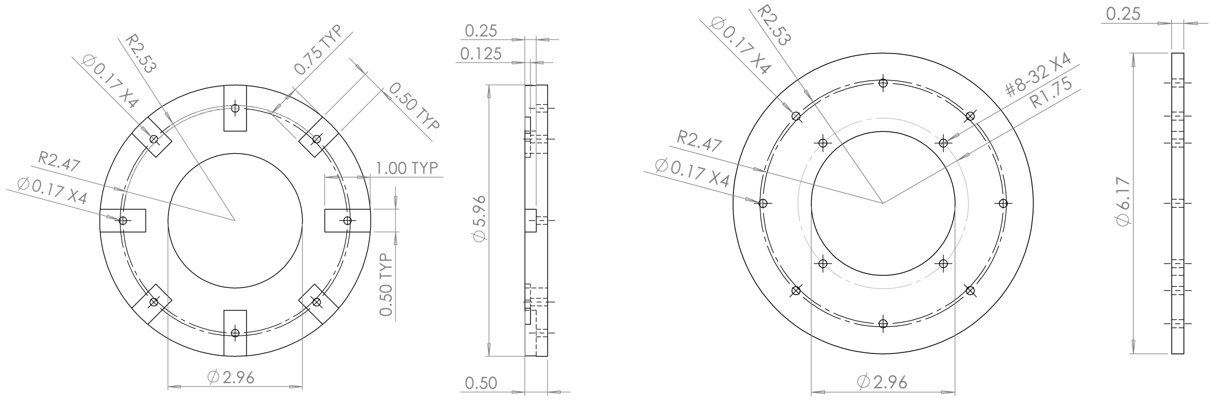


Figure 3.11: RMFS overall dimensions (in.)



(a) RMFS forward and aft centering ring dimensions (in.).

(b) RMFS thrust plate dimensions (in.).

Figure 3.12: RMFS centering ring and thrust plate dimensions.

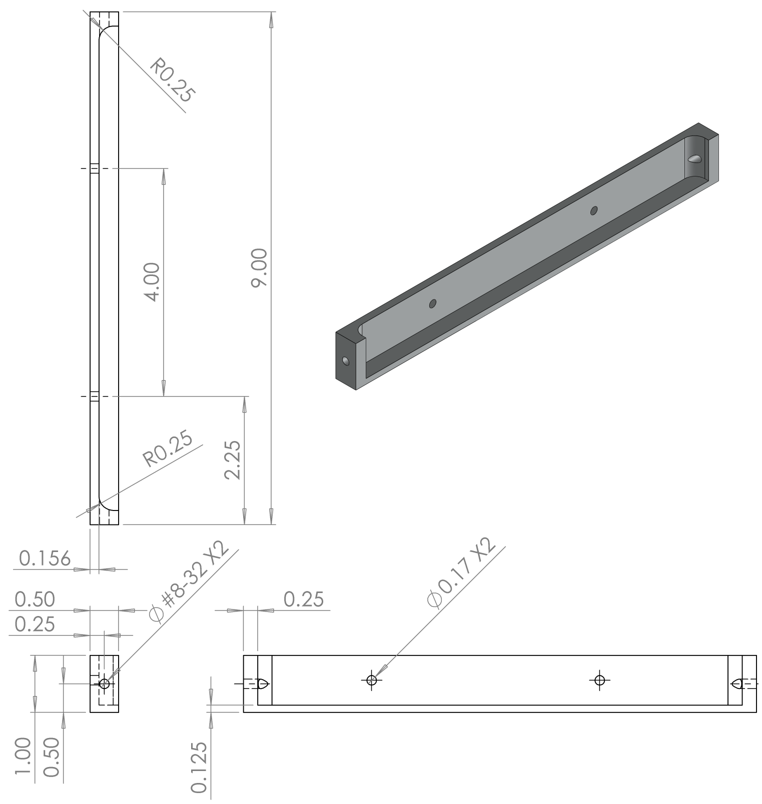


Figure 3.13: RMFS fin runner dimensions (in.)

3.2.10 Fins

The Launch Vehicle features four, swept, non-tapered fins arranged in a cruciform pattern. The fins are made of 3/16 in. G10 fiberglass laminate sheet and have rounded leading and trailing edges. The fins have a sweep angle of 25.3 degrees, a width of 5.3 in., and a uniform chord length of 8 in. The fins have rectangular tabs along the root chord that extend through slots in the airframe. The faces of these tabs sit flat against the RMFS fin runners and secure to the runners via two #8-32 machine screws with washers and hex nuts.

CAD Drawings/ Cross Sectional Views

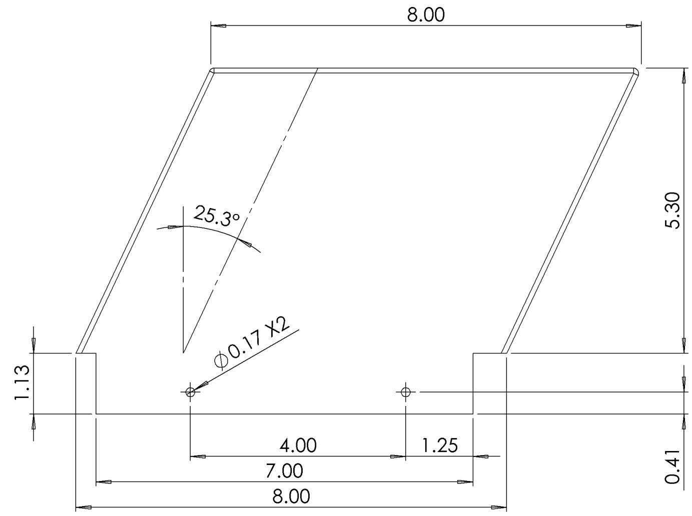


Figure 3.14: Fin dimensional drawing (in.)

Suitability of Design

A swept fin design has been selected for the Launch Vehicle. Swept fins provide reduced drag, velocity losses, and turbulence due to the pressure differences along the fin. The final fin design incorporates these factors while remaining durable and simple to manufacture. Figure 3.15, below, shows the velocity profile of the swept fin.

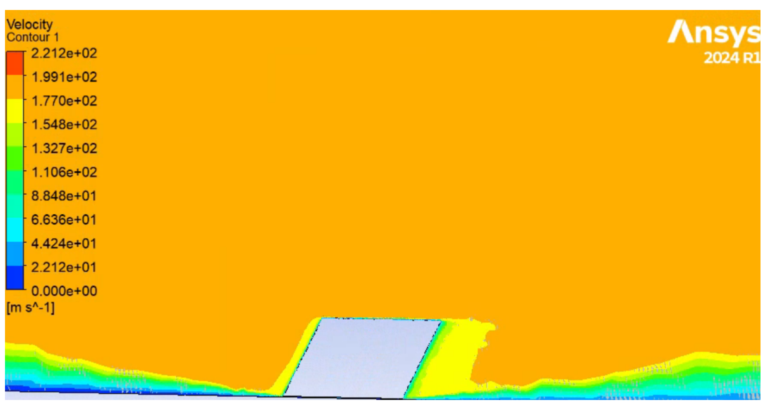


Figure 3.15: Final Fin Design Velocity Profile (600 fps)

Overall, the fins are designed to have balance between durability and aerodynamic performance. The fin material and thickness provide sufficient durability to accommodate the swept profile extending beyond the body tube. This fin design meets all required performance and re-usability criteria for the Launch Vehicle based on impact testing, aerodynamic simulations, and subscale test flight performance.

Flutter Susceptibility Analysis

Aerodynamic flutter is undamped oscillation caused by coupling of aerodynamic forces of a fluid flow with the inertial and elastic response of a body within that flow. In severe cases this results in violent oscillations which can cause structural damage or failure. This typically becomes a concern in the fins of high-power rockets when Launch Vehicles approach or exceed Mach 1.0. The Launch Vehicle is not predicted to approach supersonic velocity, however a preliminary study should still be conducted as part of the fin design for added safety. A simplified equation to predict the velocity threshold for fin flutter originally derived by Dennis J. Martin [42] and explained by John K. Bennet [21] is:

$$V_f = a\sqrt{\frac{G}{(\frac{DA^3}{(\frac{t}{c})^3(A+2)})(\frac{\lambda+1}{2})(\frac{p}{p_o})}} \tag{1}$$

Where V_f is the predicted velocity at which flutter will occur. This velocity is dependent on atmospheric properties, fin material properties, and fin geometry. The right hand side variables and their values are listed in Table 3.2 below:

Table 3.2: Flutter velocity equation variables.

Symbol	Variable	Value
a	Speed of sound at max velocity	1068 fps
G	Shear modulus of G10 fiberglass	600 ksi
D	Denominator constant	63.8 psi
A	Fin Aspect Ratio	0.66
t	Fin thickness	0.1875 in. (3/16 in.)
c	Fin root chord	8 in.
λ	Fin Taper Ratio	1
p	Atmospheric pressure at vehicle max velocity	14.2 psi
p_0	Atmospheric pressure at sea level	14.7 psi

The speed of sound and atmospheric pressure at the Launch Vehicle's maximum velocity were calculated using the standard atmospheric model. The maximum velocity is assessed to occur just prior to motor burnout, after which drag and gravitational forces will decelerate the Launch Vehicle. Therefore, the maximum velocity altitude used was the burnout altitude of 865.5 ft, as calculated in Section 3.6.1. Because this altitude is relatively close to sea level, the pressure difference has a small impact in the final calculation.

The denominator constant, D, has units of pressure and is further dependent on fin geometry and atmospheric conditions. It is calculated using:

$$D = \frac{24\epsilon\kappa p_0}{\pi} \tag{2}$$

In the equation above, ϵ is a ratio of the distance from the fin mass centroid from the quarter chord line, normalized against the root chord. For symmetrical fins this value is always 0.25, however the swept fin design used results in a value of 0.406. κ is the specific heat ratio of dry air (1.4), and p_0 is again the atmospheric pressure at sea level. With these values, the denominator constant is calculated as 63.8 psi.

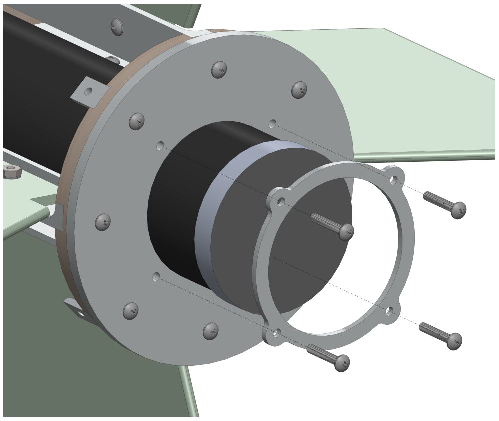
The fin aspect ratio is equal to the square of the fin height divided by the fin area. For the swept fin design, this value is calculated to be 0.66. Additionally, the fins are non-tapered and therefore, the taper ratio λ is equal to 1.

Finally, substituting these values into Equation 1 gives a predicted flutter velocity of V_f = 1150 fps. This velocity is 501.5 fps greater than the 648.5 fps calculated max velocity in Section 3.6.1. This results in an approximate 77% safety margin.

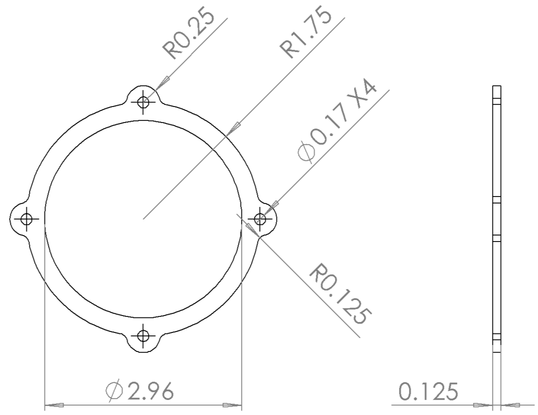
3.2.11 Motor Mounting and Retention

The primary and secondary motor choices utilize the AeroTech RMS-75/3840 motor casing. The motor casing is inserted into the RMFS and is centered via the forward and aft centering rings. The forward face of the casing's aft closure sits flush against the thrust plate. During the boost phase of flight, the motor thrust force is applied directly across this contact area. The motor casing is retained in place via a custom motor retainer ring made of 1/8 in. thick 6061-T6 aluminum. Four #8-32 machine screws run through the holes in the retainer plate into threaded holes cut into the thrust plate. These fasteners secure the motor casing aft closure between the motor retainer ring and the thrust plate and are unscrewed to remove or insert the motor casing between flights.

CAD Drawings/ Cross Sectional Views



(a) Exploded view of motor casing retention system.



(b) RMFS motor retainer dimensional drawing (in.)

Figure 3.16: Motor retention system.

3.2.12 Motor Selection

This Launch Vehicle utilizes a single motor propulsion system, satisfying NASA Requirement 2.11. Motor selection is based on altitude requirements, burn time, and thrust curve stability. The L1520T is the selected motor for this Launch Vehicle due to the predicted altitude when used, the low burn time, and the stability of its thrust curve. The secondary motor, the L1390G, has a similar altitude, a slightly longer burn time, and a less stable thrust curve. If needed, the L1390G could be used to replace the L1520T. Both motors will satisfy NASA Vehicle Requirement 2.1.

Table 3.3, below, displays the total impulse, thrust information, and burn times of the primary and secondary motors, respectively. These motors both remain within competition requirements, meeting requirement 2.12

Table 3.3: Primary and secondary motor Specifications

Motor	Total Impulse	Max Thrust	Average Thrust	Initial Thrust	Burn Time	Mass Before/ After Burn
L1520T	835.37 lbf-s	396.84 lbf	352.46 lbf	347.42 lbf	2.4 s	128.79/63.39 oz
L1390G	887.77 lbf-s	370.89 lbf	312.48 lbf	318.44 lbf	2.6 s	136.72/67.13 oz

The thrust-to-weight ratio provided by the L1520T is 9.05 and thrust-to-weight ratio provided by the L1390G is 8.19. Both motors satisfy Requirement NASA 2.15 regarding the minimum thrust-to-weight ratio. Table 3.4, below, shows the calculation of these values.

Table 3.4: Thrust to Weight Ratio Calculations

Motor	Initial Thrust	Initial Weight	Thrust to Weight Ratio
L1520T	347.42 lbf	38.4 lbf	9.05
L1390G	318.44 lbf	44.15 lbf	8.19

Rail exit velocity for both motors exceeds 52 fps, meeting NASA Requirement 2.17. The L1520T provides a rail exit velocity of 81.5 fps and the L1390G provides a rail exit velocity of 75.4 fps. The motors and their performances are compared below in Table 3.5, as well as in Figures 3.17 and 3.18.

Table 3.5: Motor Performance Comparison

Motor	Apogee	Time to Apogee	Velocity off Rail
L1520T	4809.76 ft	17.3 s	71.79 fps
L1390G	5068 ft	17.9 s	75.4 fps

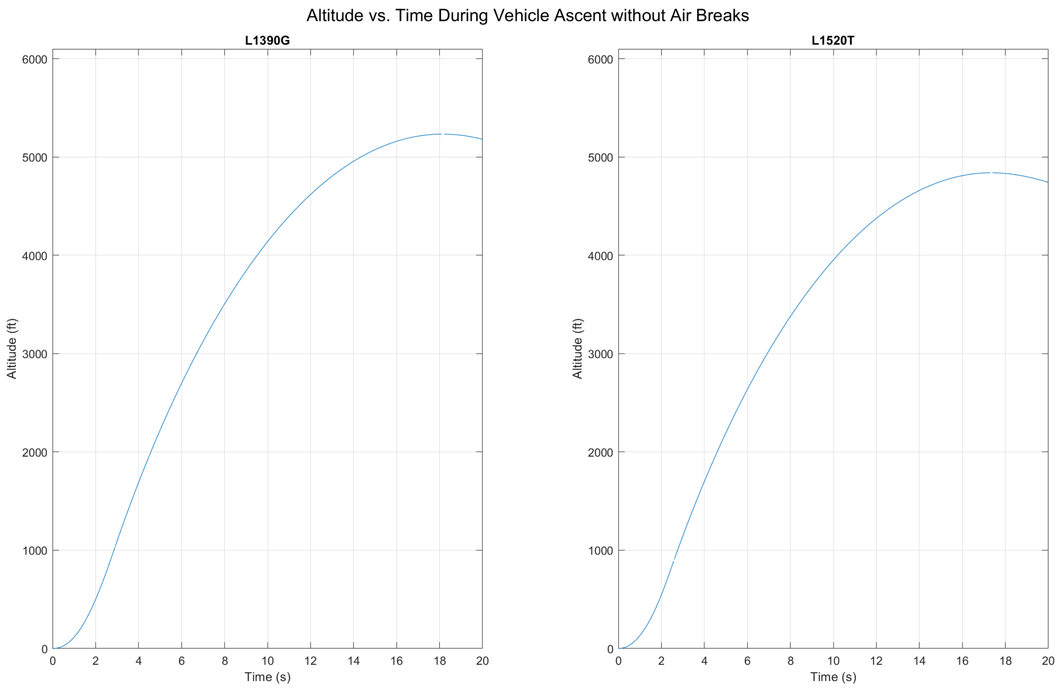


Figure 3.17: Altitude against Time for each Motor

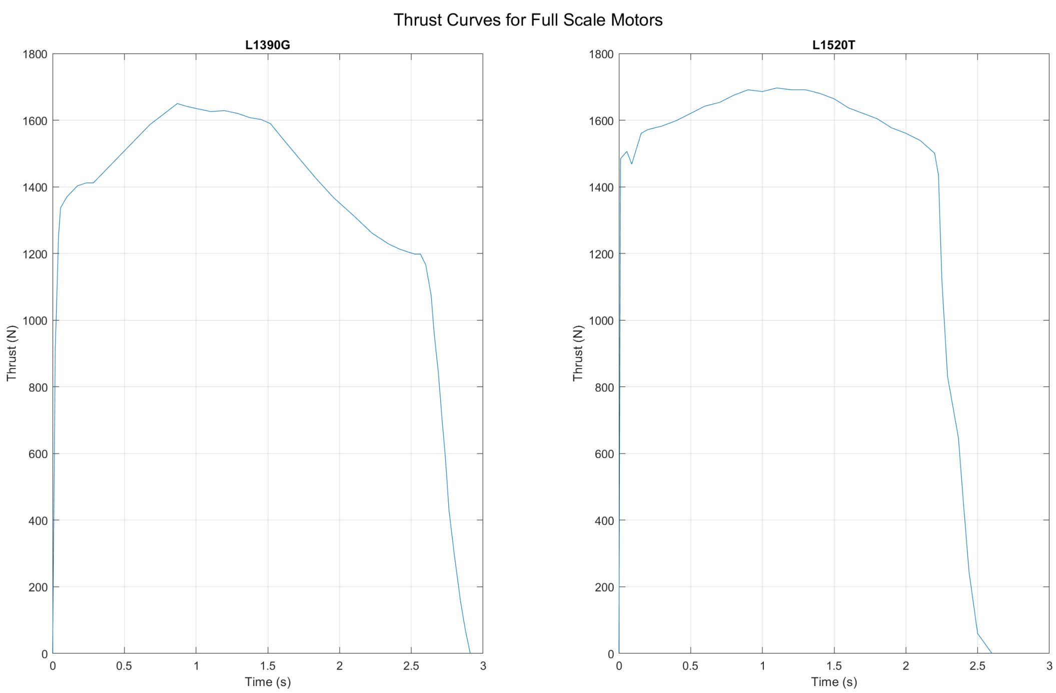


Figure 3.18: Thrust against Time for each Motor

3.2.13 Finite Element Analysis

Structural finite element method analysis (FEA) was conducted on Launch Vehicle components subject to high loading. Analysis focused on airframe compressive loading during powered flight, thrust plate loading at maximum thrust, bulkhead loading during parachute deployment, and ground impact of the Fin Can at landing. The purpose of this analysis was to validate design suitability prior to manufacture of the physical components. Real-world testing for verification of these designs is included in the Launch Vehicle Testing Suite under the Project Plan Section 7.1. Planned verification tests that align with the FEA studies include tensile testing for the Nose Cone and AVAB bulkheads, along with landing impact testing for the fins/RMFS. Table 3.6 lists the material assignments and associated properties used during the analysis.

Table 3.6: Material assignment properties used in FEA simulations.

Material	Yield Strength [psi]	Young's Modulus [ksi]	Poisson's Ratio	Data Source	Launch Vehicle Components
Birch Plywood	8125	2200	0.37	ANSYS Granta	bulkheads, centering rings
316 Stainless Steel	36564	28000	0.31	ANSYS Granta, MATWeb	U-Bolts, fasteners, threaded rods
6061-T6 Aluminum	37594	10000	0.33	ANSYS Granta, MATWeb	fin runners, thrust plate, L-brackets
G10 Fiberglass	38000	1890	0.12	MATWeb	fins
G12 Fiberglass	17260	287	0.21	Journal Article [23]	airframe and coupler tubing

Air Frame

An inertial relief method was applied to analyze the equivalent airframe stress contour of the Launch Vehicle airframe at peak thrust and drag force. Stress concentrations present around the Air Brake slots in the AVAB switchband and fastener holes in the Fin Can were well within acceptable values, with a minimum factor of safety of 20.

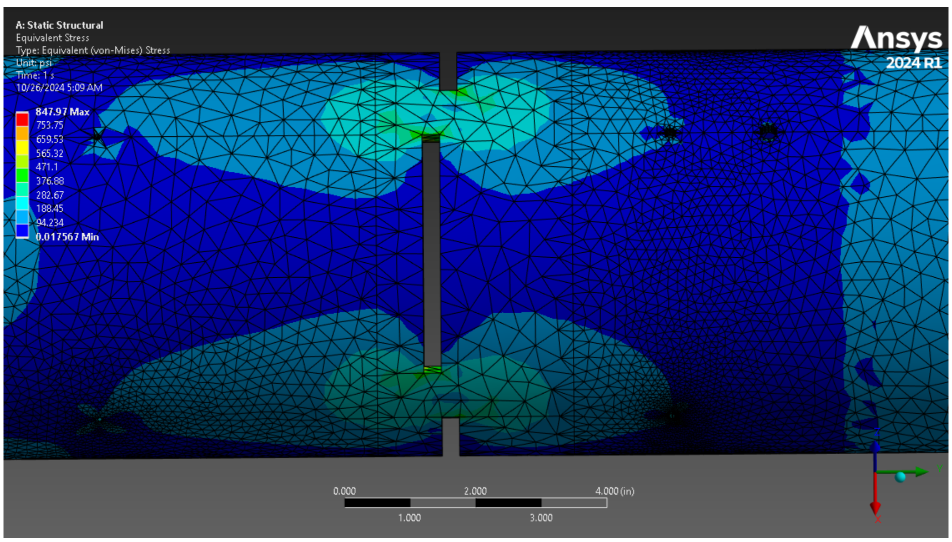


Figure 3.19: Stress contour around AVAB switchband slots at peak thrust/aerodynamic loading.

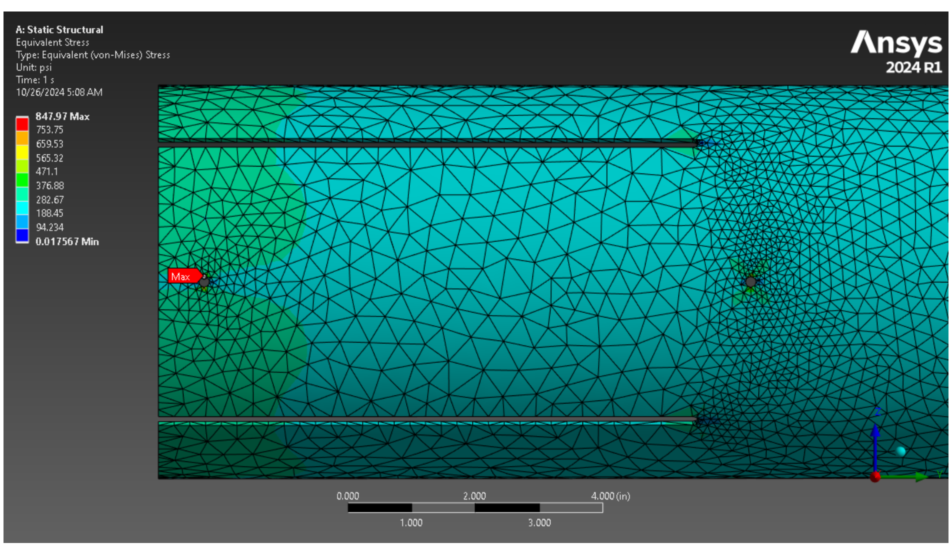


Figure 3.20: Stress contour around Fin Can RMFS fastener holes at peak thrust/aerodynamic loading.

Nose Cone/ Payload Bay Bulkheads

The permanent and removable Nose Cone/ Payload Bay bulkheads were analyzed against the expected maximum potential tensile force of 320.75 lbf. at main parachute deployment. In the recovery system design, the main parachute attaches to the removable bulkhead without a shock cord leader. Therefore, the actual maximum shock force experienced will likely be closest to the estimated maximum out of all of the tethered sections. Figure 3.21 depicts the safety factor contour of the removable bulkhead. A minimum safety factor of 2.73 is noted near the threaded rod hole on the wooden bulkhead, which exceeds team derived requirements. Safety factor analysis of the permanent ring bulkhead is depicted in Figure 3.22. A minimum safety factor of 2.48 is present at the interface of the tee-nut insert which retains the threaded rod. Again, this value exceeds team derived requirements for a minimum safety factor of 1.5.

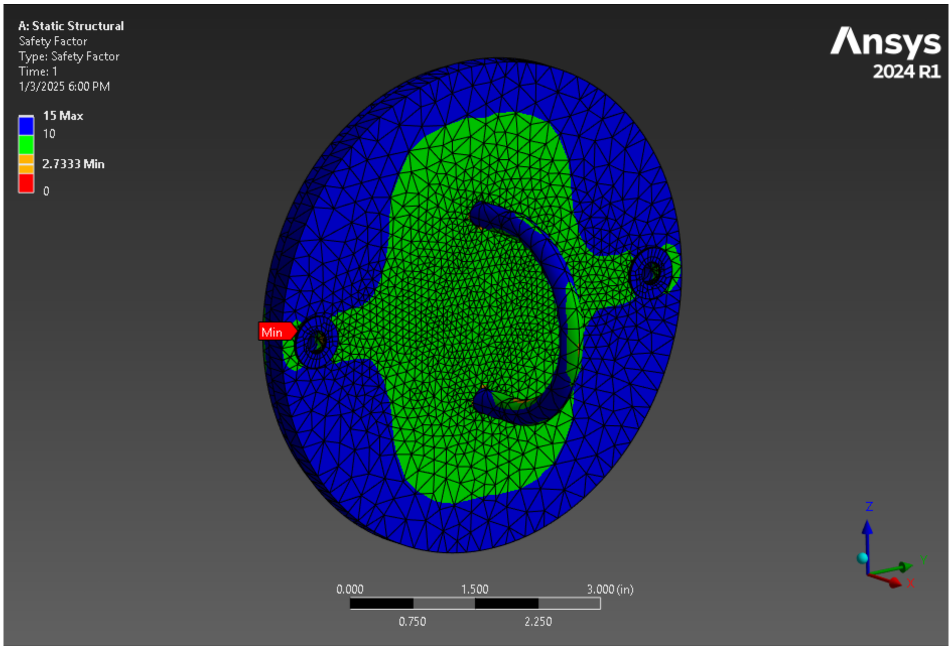


Figure 3.21: Nose Cone removable bulkhead safety factor contour at maximum tensile load from main parachute deployment.

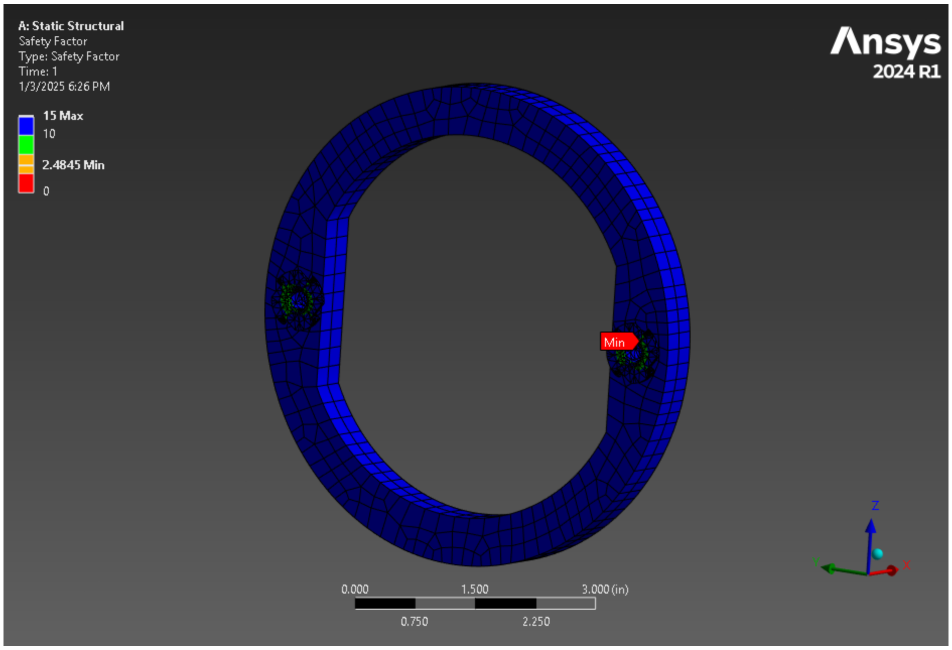


Figure 3.22: Nose Cone permanent ring bulkhead safety factor contour at maximum tensile load from main parachute deployment.

AVAB Bulkheads

Tensile loading was also simulated on the AVAB bulkhead assembly using the maximum shock force value of 320.75 lbf on the U-bolt. The resulting safety factor contour is depicted in Figure 3.23. The minimum safety factor in this simulation was present on the U-bolt arm with a value of 3.84. Stress concentrations on the bulkhead body were present at the U-bolt interface, however, were less exaggerated than on the Nose Cone/ Payload Bay removable bulkhead.

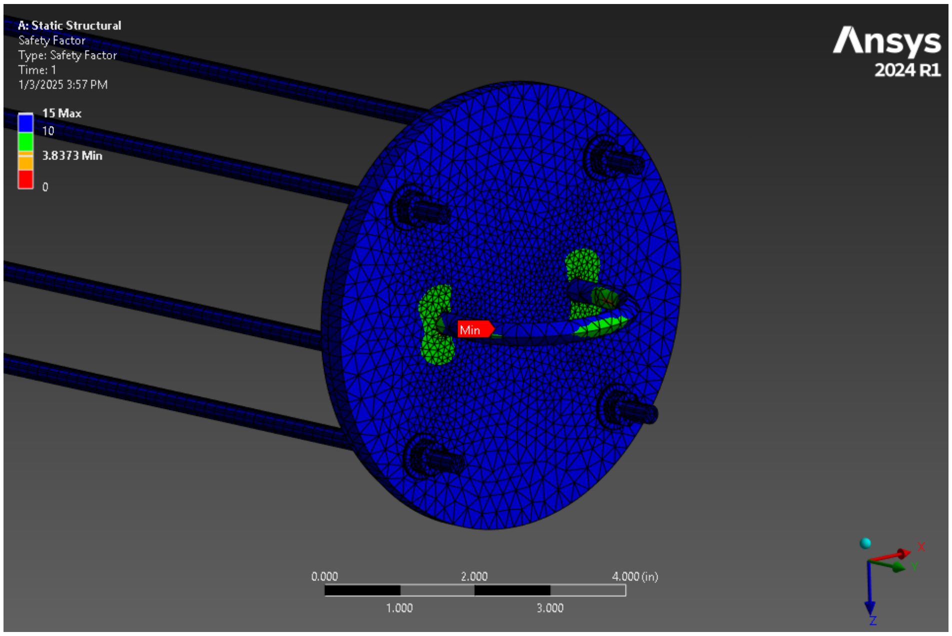


Figure 3.23: AVAB structural assembly safety factor contour at maximum tensile load from main parachute deployment.

RMFS/Thrust Plate

Thrust force distribution through the RMFS to the airframe was modeled by simulating the L1520T motor at peak thrust. A 490 lbf. load was applied to the area where the motor casing presses against the thrust plate. The model was constrained at the Fin Can airframe-thrust plate interface as well as the L-bracket fastener holes which secure the RMFS inside the Fin Can. The resulting equivalent stress contour is depicted in Figure 3.24. The thrust plate is subjected to the highest stresses, which meets the design intent. The point of minimum safety factor derived from this analysis was located on the aft centering ring with a value of 11.39, far exceeding team derived requirements.

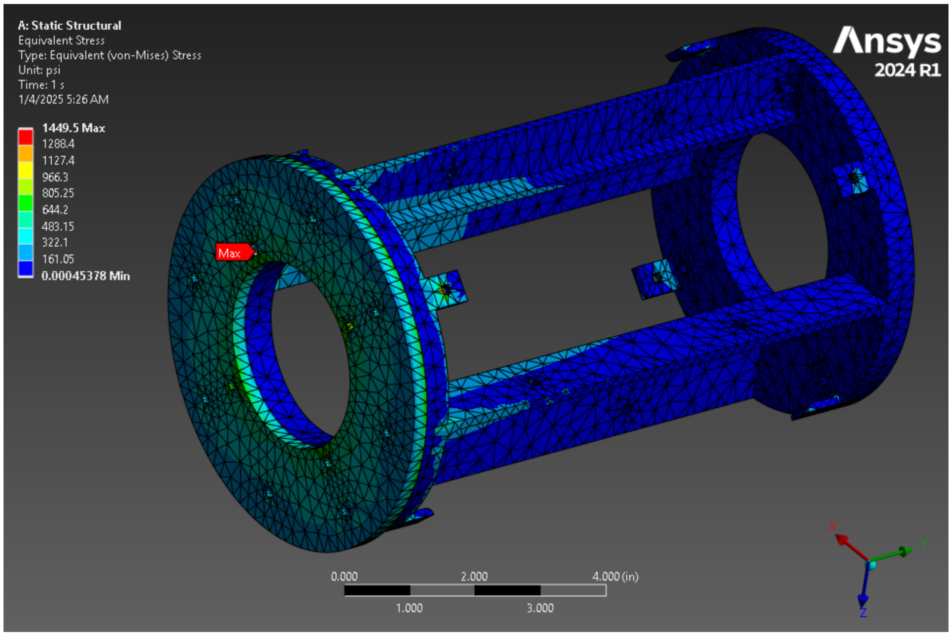


Figure 3.24: RMFS structural assembly equivalent stress contour under maximum motor thrust.

Fins

FEA was also utilized to roughly predict the stress response of the fins and RMFS components during landing impact scenarios. The momentum of the Fin Can descending under main parachute was obtained using the burnout mass and the predicted descent velocity from Section 3.6.9. Next, those values are used in the following basic equation derived from Newton's 2nd Law:

$$F = \frac{mv}{t} \tag{3}$$

Where F is the average impact force, m is the mass (in slugs), v is the impact velocity, and t is the impact time interval. Using an estimated Fin Can burnout mass of 13.5 lbs. (0.42 slugs), a main parachute descent velocity of 16.4 fpsec, and assuming an impact time of 0.1 sec, an average impact force value of approximately 70 lbf. is obtained.

This loading was applied to simulate worst-case landing scenarios where all impact force is transferred to a single fin at orientations generating the maximum torsional moments. Real-world drop testing previously conducted by the team has demonstrated the impact strength of G10 fiberglass fin material. However, the interaction between the Full-scale fin and final RMFS assembly had not been tested.

To simulate the response of the fin runner, centering rings, and L-brackets under axial torsion, a 70 lbf. load was applied along the tip chord normal to the fin area. The model was constrained at the L-bracket/airframe connection points. The resulting safety factor contour is depicted in Figure 3.25. A minimum safety factor of 1.87 occurred at the interface between the fin runner and aft centering ring which exceeds team derived requirements.

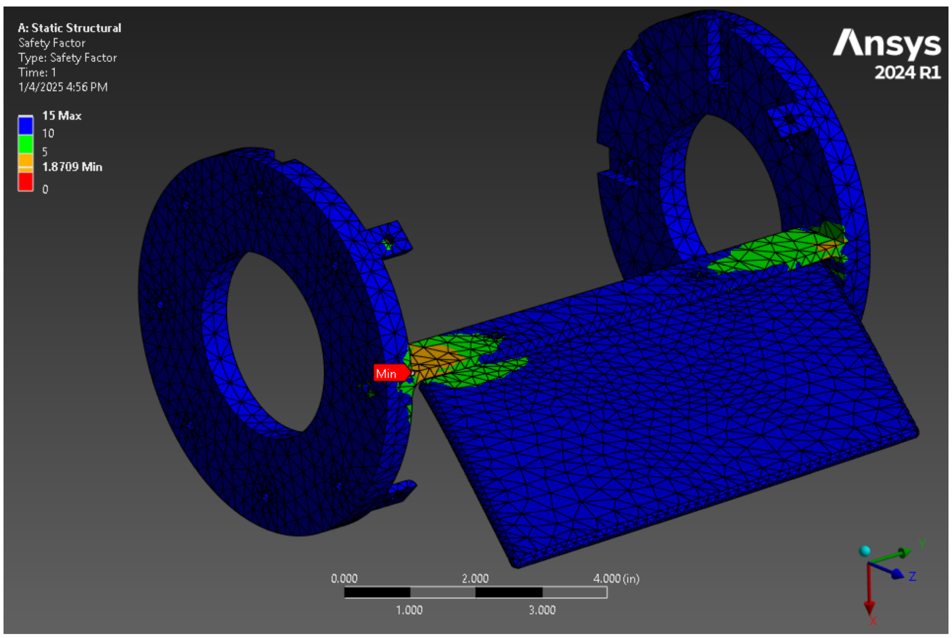


Figure 3.25: RMFS fin runner safety factor contour with 70 lbf. applied load normal to the planform area.

Another area of investigation was the stresses concentrations in the fin material at the fastener connections. Two #8-40 machine screws run through the fins to attach them to the aluminum runners. During a vertical Fin Can impact, the fins would make first contact with the ground and induce shear forces between the fin and fasteners. To simulate this behavior, a 70 lbf. force was applied along the trailing edge of a single fin which was constrained at the fastener holes. The resulting equivalent stress contour is depicted in Figure 3.26 below. As expected, stress concentrations were present at the fastener holes with a maximum noted stress value of 1576 psi. This value results in an approximate safety factor of 24 for the G10 fiberglass material, far exceeding team derived requirements.

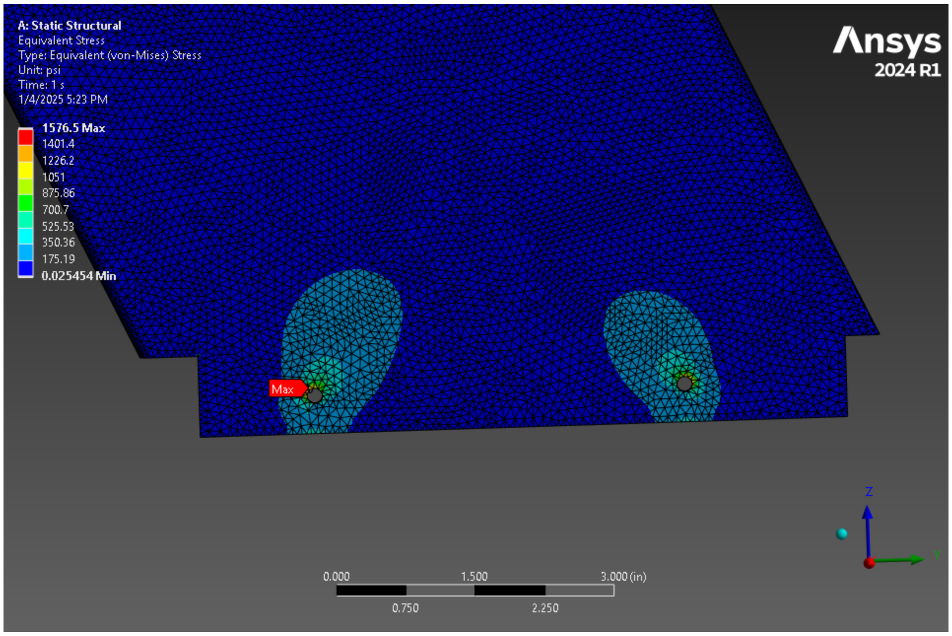


Figure 3.26: Fin equivalent stress contour with 70 lbf. applied load along trailing edge parallel to the chord.

3.2.14 Material Selection

Air Frame Material Selection

The airframe and airframe couplers will be fabricated from G12 fiberglass resin composite tubing. This composite material consists of 12 layers of wound fiberglass filament in an epoxy resin matrix. This material was selected for its strength, durability, water resistance, RF transparency, and relatively low weight. Additionally it is a more cost-effective choice than more high-performance composites. The G12 fiberglass Nose Cone, airframe tubing, and coupler tubing are commercially available construction materials intended for high-power rocketry. These materials have been used extensively by the current and previous Senior Design Teams with great success.

Bulkhead Material Selection

The Nose Cone/Payload Bay and AVAB bulkheads will be fabricated from 1/2 in. thick (9-ply) Baltic Birch plywood sheets. Baltic birch was selected as it is an affordable, strong, lightweight hardwood that is easily milled to the desired bulkhead dimensions. Baltic birch plywood is free of voids and softwood core plies, which adds to the consistency of the material strength. By utilizing 1/2 in. thick sheets, the bulkheads can be CNC milled from a solid piece of wood. This avoids the added time and material cost of conducting layups of thinner plies of wood.

RMFS Material Selection

The RMFS centering rings will be fabricated from 1/2 in. thick Baltic Birch plywood sheets. This material was selected for the same criteria as the Launch Vehicle bulkheads described above.

The RMFS thrust plate will be fabricated from 1/4 in. thick 6061-T6 aluminum extruded sheet. The thrust plate must be strong, rigid, lightweight, and thermally resilient to withstand and distribute the thrust force from the motor to the airframe. 6061-T6 aluminum alloy is a lightweight metal commonly used in aerospace applications. It is easily machined, provides greater strength and durability than wood material, and can be threaded to directly accept removable fasteners. The T6 temper designation indicates a heat treating process that hardens the metal to provide the highest yield strength (35 ksi) out of the 6061 series of aluminum alloys.

The RMFS motor retainer ring will be fabricated from 1/8 in. thick extruded 6061-T6 aluminum sheet. 6061-T6 was chosen for this for previously discussed material properties, as well as the motor retainer ring proximity to the exhaust jet.

The RMFS fin runners will be fabricated from 6061-T6 bar stock. This material was selected for its strength, rigidity, relative light weight, and ease of machining. The material strength and part geometry ensures the fin runners will be highly resistant to twisting, bending, or buckling. This also eliminates the need for additional longitudinal structural reinforcement within the RMFS. Furthermore, by using this material, each runner can be a monolithic piece of aluminum that directly accepts the fasteners on each end that secure the assembly together, enabling a simpler design with fewer fasteners.

Fin Material Selection

The fins will be fabricated from 3/16 in. thick G10 fiberglass resin composite sheets. This composite material is made from laminated layers of woven fiberglass cloth and epoxy resin. This material has superior stiffness, durability, and strength over plywood fins, while being less costly than carbon fiber composite fins. It is also relatively simple to fabricate fins out of this material and it results in a desirable smooth surface finish.

3.2.15 Launch Vehicle Mass Breakdown

Table 3.7: Summary of section weight estimates.

Section	Weight [lbs.]
Nose Cone/Payload Bay	8.81
Main Parachute Bay	5.47
AVAB	6.60
Drogue Parachute Bay/Fin Can	17.51
Launch Vehicle Total	**38.39**

Table 3.8: Individual section weight estimates.

Nose Cone/Payload Bay	
Component	Weight [lbs.]
Nose Cone	4.91
Coupler	0.66
Permanent Ring Bulkhead	0.12
Threaded Rods	0.17
Removable Bulkhead	0.31
U-bolt + Hardware	0.22
Quick Link	0.17
STEMCRaFT	2.25
Section Subtotal	**8.81**

Main Parachute Bay	
Component	Weight [lbs.]
Airframe	3.67
Main Parachute	0.84
Main Shock Cord	0.56
Deployment Bag	0.40
Section Subtotal	**5.47**

AVAB	
Component	Weight [lbs.]
Switchband	0.33
Coupler Tube	1.77
Bulkheads	0.62
U-bolts + Hardware	0.44
Air Brakes System	1.60
Threaded Rods	0.74
AV Sled	0.66
Quick Links	0.34
Charge Wells	0.10
Section Subtotal	**6.60**

Drogue Parachute Bay/Fin Can	
Component	Weight [lbs.]
Airframe	4.03
Drogue Parachute	0.11
Drogue Shock Cord	0.63
Nomex	0.30
Quick Link	0.17
Forward Centering Ring Assembly	0.26
Fin Runners + Hardware	0.76
Aft Centering Ring Assembly	0.26
Thrust Plate	0.56
Fins	2.27
1515 Airfoiled Rail Buttons	0.03
Motor Retainer	0.04
Forged Eye Bolt	0.11
L1520T Motor & Casing	7.98
Section Subtotal	**17.51**

3.3 Subscale Flight Results

3.3.1 Subscale Design

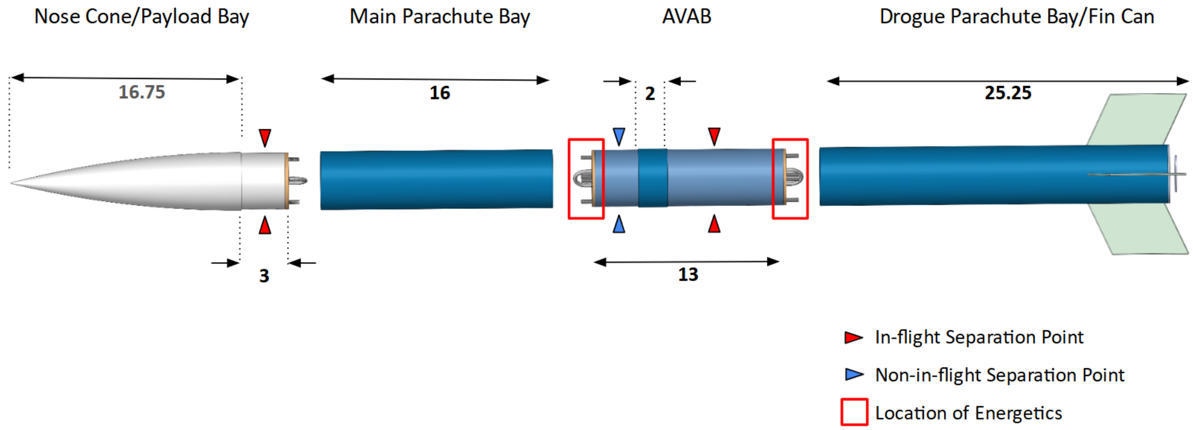


Figure 3.27: Subscale section dimensions, separation points, and energetics locations (in.)

Scaling Factor

The Subscale Launch Vehicle was developed to be an approximate 2/3 (66.6%) geometric scale of the final Launch Vehicle design. The scaling factors for the as-built Subscale vehicle compared to the final Full-scale design are recorded in Table 3.9. This scaling factor was mostly adhered to for the overall vehicle dimensions, however adjustments were made to section lengths of the final vehicle design based on results of the Subscale vehicle. These changes are documented in Section 2.1. Overall, the geometric scaling factors for the Subscale to the final Full-scale range from 62.7% to 66.6% which satisfies NASA requirement 2.18.5 for maximum Subscale vehicle dimensions.

The Subscale payload was an electronics sled used to test the data collection elements of the final STEMCRaFT payload. The mass scaling factors for both the primary payload and the total Launch Vehicle were approximately 38%, which ensured consistent payload mass fractions between the Subscale and Full-scale design. This mass scaling factor is lower than the dimensional scaling factors primarily due to the difference in airframe materials used in the Subscale and Full-scale Launch Vehicles. Due to funding considerations, the Subscale airframe was constructed using Blue Tube with a plastic Nose Cone. Both of these materials have lower density than the G12 fiberglass material used in the Full-scale design. The airframe was the only instance where this was necessary. All other Subscale components were manufactured of the same materials as their Full-scale counterparts.

Table 3.9: Scaling factors for the Subscale Launch Vehicle.

Parameter	Subscale	Full-Scale	Scaling Factor
Total Length	60.0 in.	95.75 in	62.7 %
Body Diameter	4.02 in.	6.17 in.	65.2 %
Fin Chord	5.33 in	8.0 in	66.6 %
Fin Span	11.08 in	16.77 in	66.1 %
CG	33.25 in.	58.9 in	56.5 %
CP	45.1 in.	71.8 in.	62.7 %
Static Stability	2.95	2.10	N/A
Payload Mass	0.86 lbs.	2.25 lbs.	38.2 %
Total Mass	14.6 lbs.	38.39 lbs	38.0 %

Burnout CG Verification

Prior to flight, the CG position following motor burnout was verified to ensure continued flight stability during Air Brakes deployment. NASA requirement 2.16 specifies that the Air Brakes fins must be aft of the burnout CG. To ensure this requirement was satisfied and to validate software predictions, the mass distribution of the Subscale vehicle after motor burnout was recreated. This was accomplished by first measuring the mass of the non-propellant components of the RMS motor, including the phenolic liner, nozzle, and o-rings. This mass value was 0.1 lbs. for the J500G motor used for the Subscale flight. This mass was then placed inside the RMS motor casing and inserted into the Subscale vehicle. The rest of the vehicle was fully integrated, then subjected to a balance test (Figure 3.28).

This process will be repeated and documented prior to launch of the Full-scale vehicle using the L1520T RMS motor components and the fully integrated Launch Vehicle.

Figure 3.28: Balance point test to verify burnout CG position for the Subscale Launch Vehicle.

3.3.2 Flight Predictions

Subscale Motor Selection

The selected motor for the Subscale flight was an AeroTech J500G motor. Motor properties can be found in the table below.

Table 3.10: AeroTech J500G Motor Properties.

Diameter	Length	Total Weight	Propellant Weight	Avg. Thrust	Initial Thrust	Total Impulse	Burn Time
38.0 mm	345.0 mm	654.0 g	363.0 g	500.0 N	634.5 N	723.0 Ns	1.4 sec.

Launch Day Flight Simulations

Below is a flight profile generated at launch day conditions. These conditions were a wind speed of 9.8 mph on the ground, a temperature of approximately 60 degrees Fahrenheit, and a pressure of 101,500 Pa.

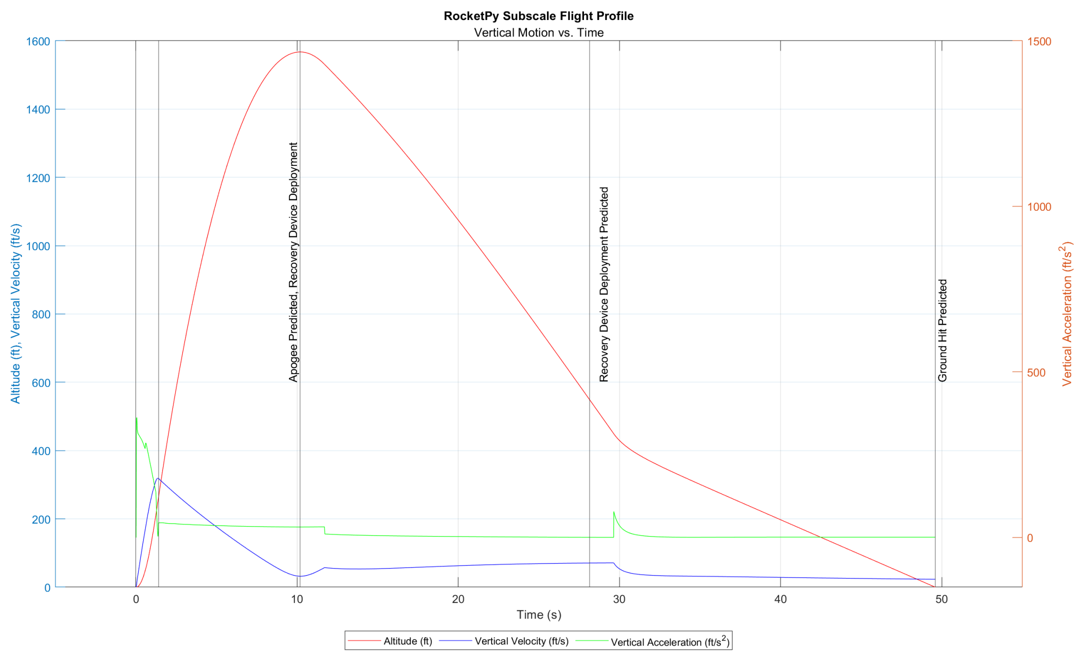


Figure 3.29: Launch Day Flight Simulation, RocketPy

This flight profile shows a predicted apogee of 1567.3 ft. This is likely the most accurate flight profile due to environmental input abilities. Weather data from the forecast on launch day is implemented into this flight profile, and the weather data is shown in Figure 3.30, below.

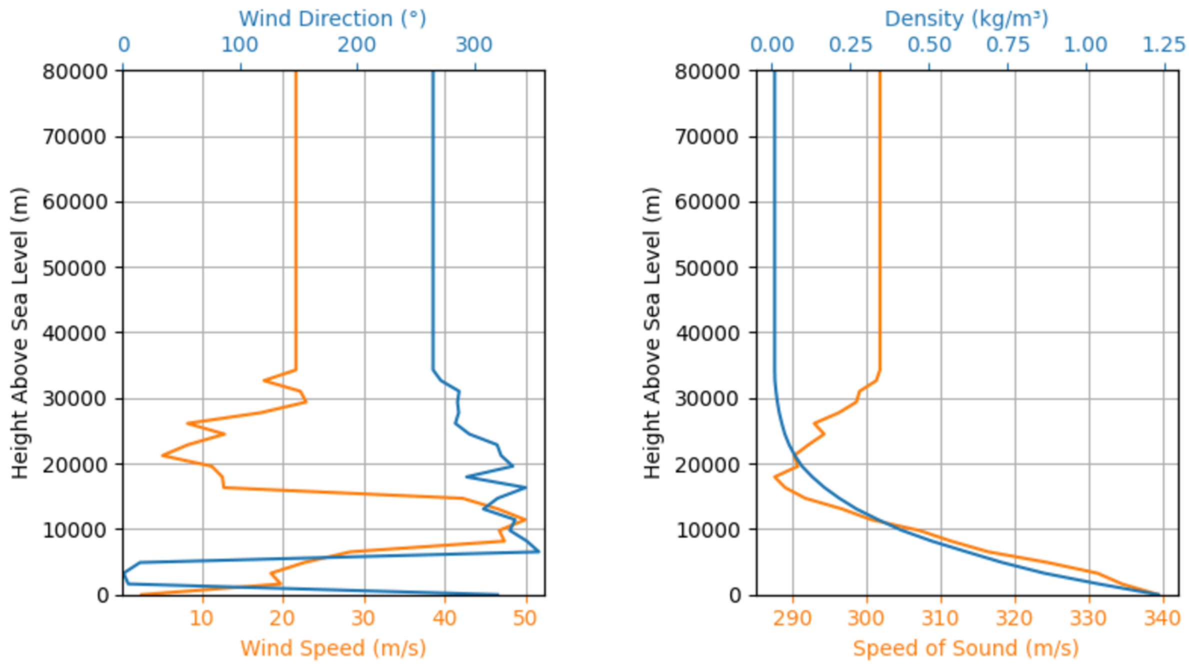


Figure 3.30: Launch Day Weather Conditions

Calculated Center of Gravity

Below is a simulated version of the Launch Vehicle geometry that was used in the estimation of flight profile and apogee. This estimates a center of gravity located at 34.65 in. with a static stability of 2.5.

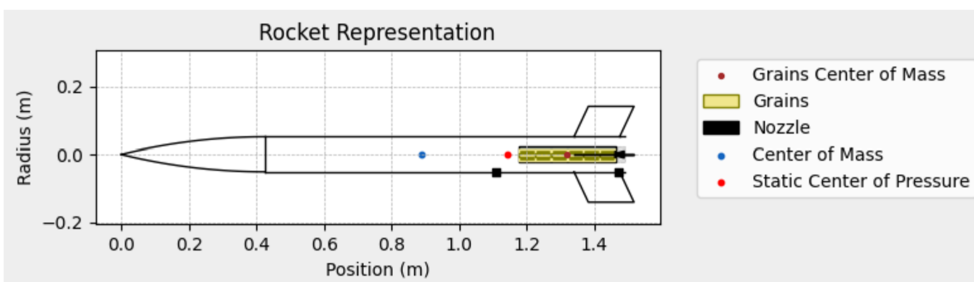


Figure 3.31: Launch Vehicle, RocketPy Illustration

Measured center of gravity on launch day was 33.25 in. This shows a percent error of 4 percent. This discrepancy may have be due to slight differences in loaded mass.

3.3.3 Flight Results

Launch Pad Information

The Subscale Launch Vehicle was launched from a 6ft. 1010 launch rail. An Aerotech FirstFire high-power igniter was utilized for motor ignition and initiated via a wired electronic launch control system with a 12V power supply.

Apogee

On launch day, the Launch Vehicle achieved an apogee of 1512 ft. This is a 3.6 percent difference from the predicted 1567.3 ft., indicating a high level of accuracy in the team's simulation predictions. However, this is still imperfect, and improvements may be found in more precision mass setup simulations.

Altimeter Flight Profile Graphs

The altimeter altitude plot for the primary StratologgerCF altimeter can be seen in Figure 3.32 below.

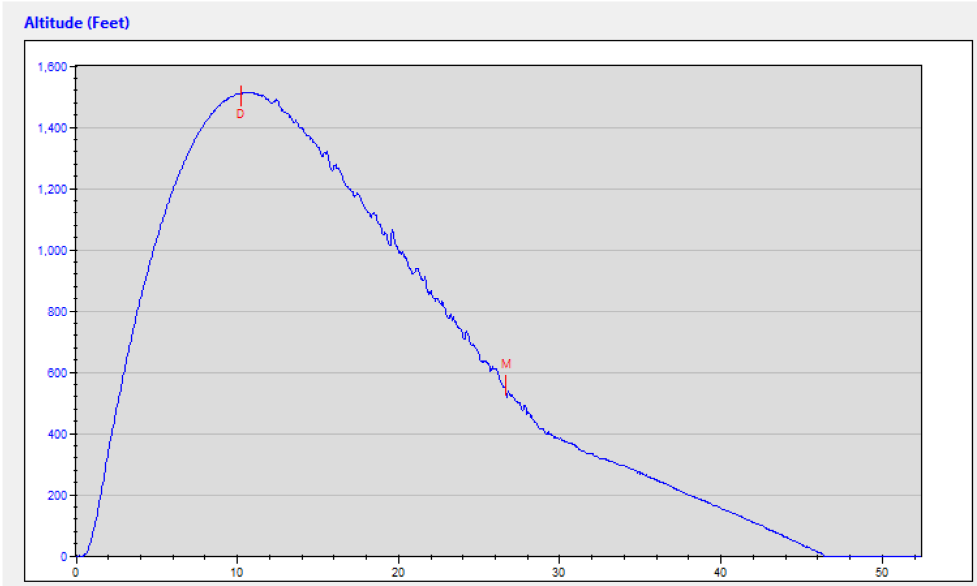


Figure 3.32: Primary Stratologger Altimeter Plot

The altimeter altitude velocity plot for the secondary EasyMini altimeter can be seen in Figure 3.33 below. This shows that the Launch Vehicle reached an apogee of 1503 ft.

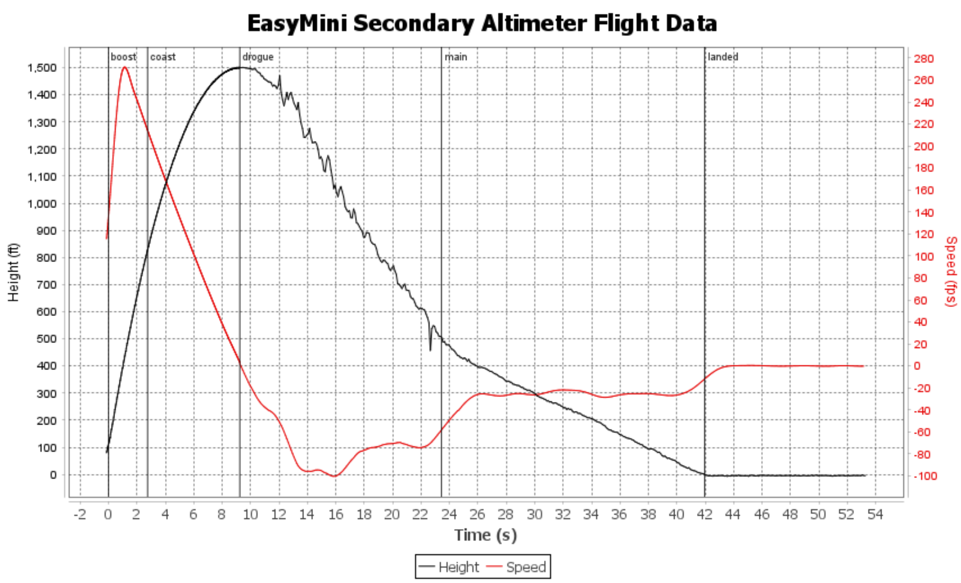


Figure 3.33: Secondary EasyMini Altimeter Plot

Recovery Results

As shown in Figures 3.32 and 3.33 above, the recovery system worked as intended. At apogee, the drogue parachute was deployed successfully. One second later, the secondary altimeter triggered the backup charge, which was not needed. At 550 ft., the main parachute was successfully deployed and the Launch Vehicle descended safely. At 500 ft., the secondary main parachute deployment charge was triggered, which was also not needed.

Landing Results

Figure 3.34 shows the Launch Vehicle during its descent under the main parachute. During its descent, the vehicle behaved as expected, mirroring the predicted model seen in Figure 3.41.

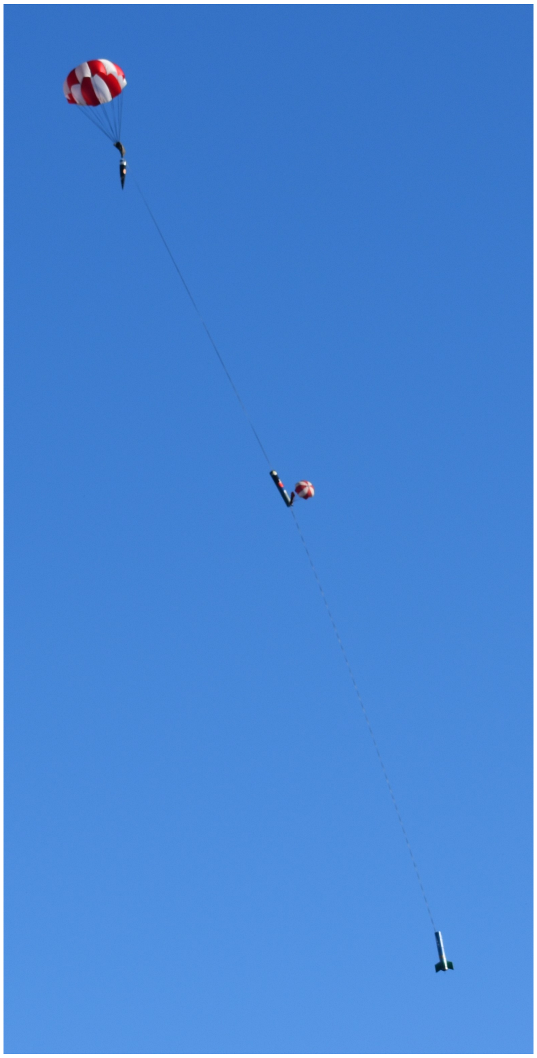


Figure 3.34: Subscale Descending Under Main Parachute

Figures 3.35 and 3.36 show the configuration of the Launch Vehicle upon landing.

Figure 3.35: Subscale Full Landing Configuration

Figure 3.36: Subscale Nose Cone (left) and AVAB/ Main Parachute Bay (right) Landing Configuration

As shown in Figures 3.35 and 3.36, the Launch Vehicle landed as expected with the drogue parachute attached to the Nose Cone, the main parachute attached to the aft end of the AVAB, and all sections of the Launch Vehicle tethered together by the shock cord. There was no damage to the Launch Vehicle upon landing and none of the shock cords or parachutes were tangled during deployment, descent, or landing. From the data pulled from the altimeters, the Launch Vehicle had a descent rate at landing of 22.55 fps and a total descent time of 35.75 sec. During this 35.75 second descent, the Launch Vehicle drifted approximately 304 ft. from the launch pad. Figure 3.37 below shows how similarly the Launch Vehicle's parachutes and descent phase compared to the team's predictions. With all of this in mind, the team considers the recovery system a success for the Subscale launch.

3.3.4 Flight Analysis

Predicted vs. Actual Flight Data

Figure 3.37, below, displays the flight profiles of both flights and the predicted flight profile on the day of launch. Flight 1, the official Subscale flight, is displayed in red. Flight 2 is displayed in green. The simulated flight profile is displayed in blue. It is clear that the flight profiles are very similar and that the prediction was very accurate. Flight 2 was a closer representation of this data, however. Key differences and error of prediction will be discussed in the Error Analysis Section, below.

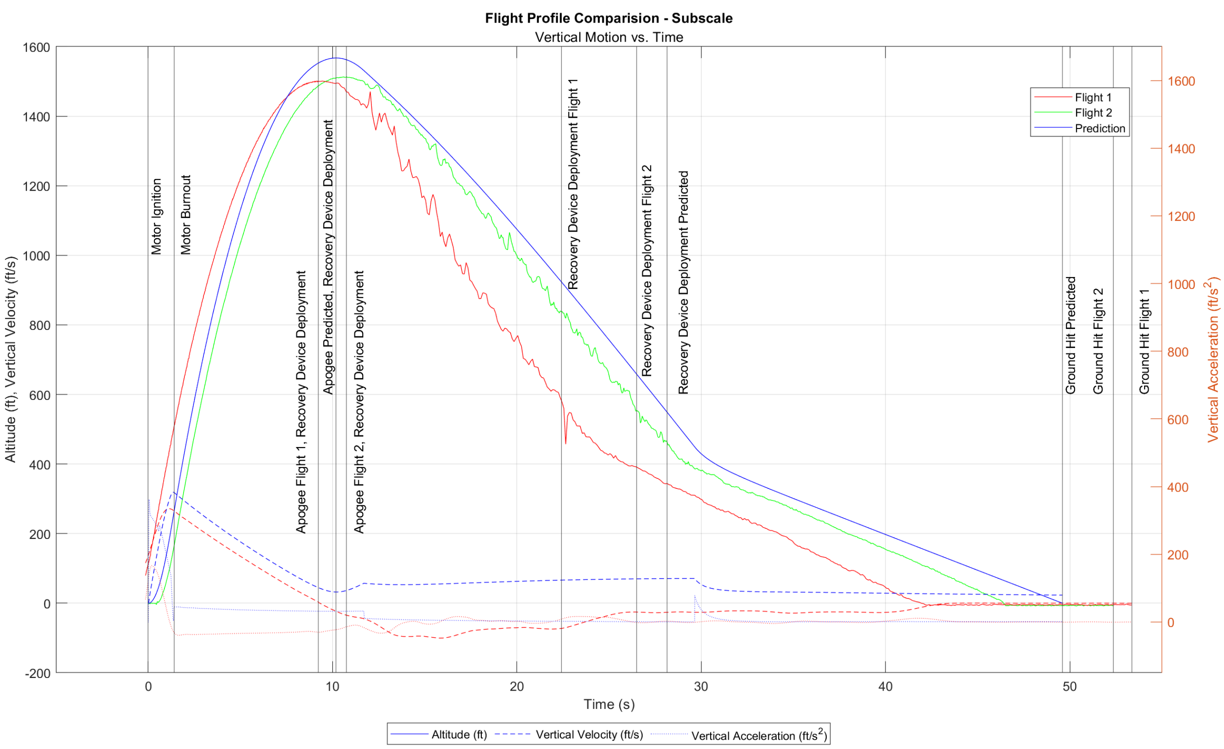


Figure 3.37: Flight Data Compared to Predicted Flight Data

Error Analysis

Table 3.11 includes percent error calculations between the official Subscale flight and the predictive simulations. Apogee predictions were found to be accurate within 10%. The time to ground was also found to be accurate within that margin. The percent errors and flight profile comparison in Figure 3.37 show a high level of fidelity in the simulations used. This system will be repeated for Full-scale to yield similar results.

Table 3.11: Subscale Predictive Error Analysis

	Flight 1	Flight 2	Prediction	Percent Error (Flight 1 vs Prediction)
Apogee (ft)	1500	1513	1567	4.37%
Time to Apogee (s)	9.23	10.75	10.193	9.92%
Main Parachute Deployment (s)	22.43	26.5	28.14	22.58%
Time to Ground (s)	53.35	52.35	49.589	7.31%

Estimated Drag Coefficient

With data collected from the sub-scale launch, the Coefficient of Drag can be estimated for the Launch Vehicle and compared to results from ANSYS Fluent. This derivation only works within the coast phase as the major forces acting on the vehicle are weight and drag force. Equation 4, below, shows the relationship between weight, acceleration, and drag force. Burnout mass is represented by m, acceleration is given from flight data and is represented by a, gravitational acceleration is represented by g, and drag force is represented by F_d.

$$F_d = -mg - ma \tag{4}$$

Once drag force is isolated, Equation 5 can be used to compute the coefficient of drag of the vehicle in the coast phase.

$$C_d = \frac{2F_d}{(\rho)v^2 A} \tag{5}$$

This calculation yielded the values below in Table 3.12. The values are similar, yielding additional confidence in the simulations run. Figure 3.38 shows the correlation of the data for the coefficient of drag along Mach number.

Table 3.12: Estimated Drag Coefficients- Coast Phase

Coefficient of Drag, Estimated	Coefficient of Drag, Predicted	Percent Error
0.46	0.53	14%

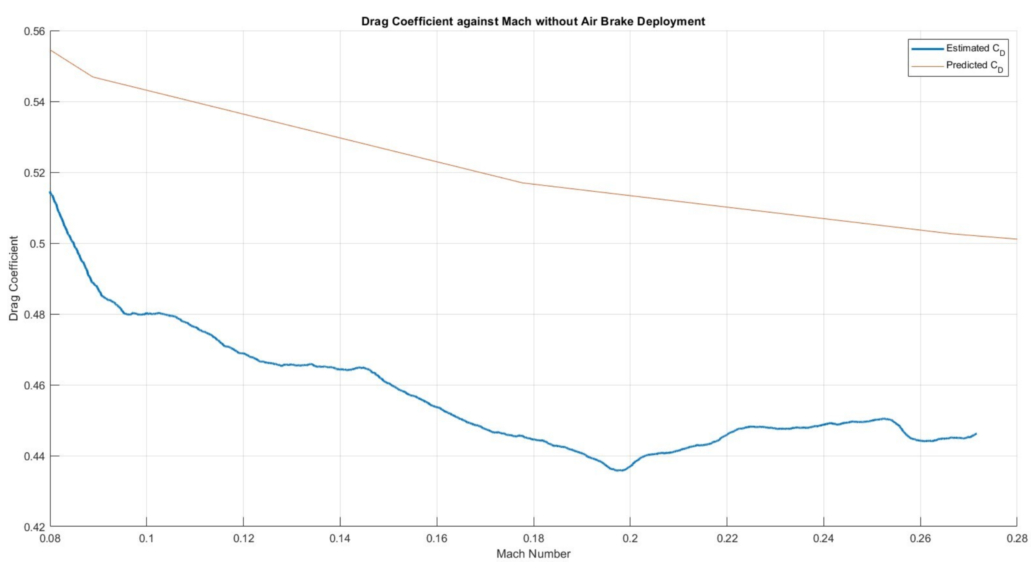


Figure 3.38: Coefficient of Drag in Coast Phase Comparison

3.3.5 Subscale Impact on Full-scale Launch Vehicle Design

The Subscale vehicle flight proved the overall viability of the vehicle and payload designs. The partial STEMCRaFT payload succeeded in data acquisition and logging, and the Air Brakes payload succeeded in data acquisition. The Air Brakes mechanism did not deploy as expected, which is assessed due to insufficient part clearance and slight shifting of the mechanism during flight. Improved retention of the mechanism and wider Air Brake deployment slots have been implemented for the final Launch Vehicle design. The Subscale vehicle also required more ballast than anticipated to satisfy burnout CG positioning requirements. Based on this, the Fin Can and Main Bay section lengths, and AVAB switchband location were adjusted slightly to position the AVAB slightly further aft on the Full-scale vehicle. The result was better overall mass distribution and burnout CG positioning. This eliminated the dependence on ballast to meet minimum stability requirements, though the option to incorporate ballast will still be available if needed on launch day.

3.4 Vehicle Manufacturing

3.4.1 Airframe and Coupler Cutting/Drilling

All airframe and coupler sections will be cut using appropriate PPE, including safety glasses and a respirator. Additionally, these tasks will only be performed in a well-ventilated area and a shop vacuum will be utilized near the cutting tool to control airborne debris. Larger sections of airframe will be cut in the NC State MAE Senior Design lab using a carbide-bladed miter saw, or using a lathe. For smaller cuts or shaping, a Dremel tool with a carbide or diamond cutting wheel will be used. When drilling, two layers of masking tape will be firmly applied to the back face of the material to minimize any delamination as the bit or tool cuts through the final layers of material. Any cut edges will be filed, sanded, then wiped to remove fiberglass shards and dust. Nitrile gloves must be worn during these final steps, and hands and arms must be thoroughly washed afterwards.

3.4.2 Airframe and Coupler Bonding

Airframe and coupler epoxy bonding will occur at two locations on the Launch Vehicle. The Nose Cone shoulder coupler into the Nose Cone body and the AVAB switchband to the AVAB coupler tube. First, all team members will ensure proper PPE is in place, including nitrile gloves and safety glasses. The contact areas of both parts to be bonded will be lightly sanded to promote a good mechanical bond and increase overall epoxy contact area. Next, the debris from sanding will be blown off with compressed air then the areas will be wiped down with isopropyl alcohol and allowed to dry. Next, proper placement will be measured and marked, and the parts will be test fit prior to the application of epoxy. These steps will be verified by the Structures Lead and an additional Senior Design team member. Next, the epoxy and hardener will be mixed and lightly applied to the contact areas and the parts pressed together. Any stray epoxy will be wiped up as soon as possible, and the bonded parts will be left to cure for at least 24 hours. After curing, and errant epoxy will be cleaned away using acetone.

3.4.3 Bulkhead Manufacturing

The AVAB removable bulkheads and both Nose Cone bulkheads share common materials and thickness. These bulkheads will be primarily fabricated using a ShopBot CNC router. Smaller holes will be drilled using a drill press.

These bulkheads will first be designed in CAD software and exported as a drawing or shape file. These files will be imported into VCarve Pro software which allows for generation of toolpaths for the CNC router. The raw Baltic birch plywood sheets will be screwed down to the ShopBot work surface to avoid slippage during the milling process. After milling, the holes for threaded rods, U-bolts and other hardware will be marked using 3D-printed alignment guides. The holes will be drilled using the drill press within the Rocketry Lab fabrication space. Required PPE while milling or drilling is safety glasses. The bulkheads will be sanded as required to remove any rough edges or improve final fit.

3.4.4 AVAB Sled Manufacturing

All Avionics and Air Brakes sleds housed in the AVAB will be designed in CAD by the respective Recovery Lead or Payload Leads. These models will be exported as STL files and imported into Prusa Slicer, a software for generating 3D printing machine code. After selecting the desired print settings and inspecting the sliced model for irregularities, the 3D printer code file will be exported and loaded into the team's Prusa Mk4S 3D printer and printed out of PETG filament. This process was successfully proven during Subscale construction.

3.4.5 RMFS Manufacturing

The RMFS Baltic birch centering rings will be manufactured in the same general process as the bulkheads as described above, and will also be fabricated out 9-ply, 1/2 in. thick Baltic birch plywood sheets. The recessed slots for the L-brackets and fin runners will be precisely milled to the correct depth and dimension using the ShopBot CNC router.

The RMFS fin runners will manufactured from 1 in. x 1/2 in. 6061-T6 aluminum bar stock. These components will be milled on the NC State MAE Senior Design shop mill by the Structures Lead. The runners will be cut to the rough length using a metal band saw then precisely milled to the correct final dimensions. The fin cutout will be created via side milling using a 1/2 in. double-fluted high speed steel end mill tool. The #8-32 threaded fastener holes in either end will also be created using the mill to first drill and chamfer the fastener hole, then a tapping fixture will be used to support a hand tap. The threads will then be cut using the hand tap and tapping fluid. Afterwards, debris and excess cutting/tapping fluid will be cleaned from the parts.

The RMFS thrust plate will be manufactured from a 1/4 in. thick extruded plate of 6061-T6 aluminum. A rough cut exceeding the final inner and outer diameter dimensions will first be made using the NC State Senior Design shop water jet using a drawing file generated by the Structures Lead. Next, the part will be turned to the final inner and outer diameters using a lathe. Finally, the through holes for the centering ring fasteners will be drilled using a drill press, and the motor retainer threaded holes will be drilled using a drill press and hand-tapped.

The RMFS motor retainer plate will also be fabricated using the water jet, but will be cut from a sheet of 1/8 in. thick 6061-T6 aluminum. The motor retainer dimensions do not require the same level of precision as the thrust plate, therefore no additional machining will be required. The through holes for screws to secure the motor retainer to the thrust plate will be drilled using a drill press.

3.4.6 Nose Cone Fabrication

The Nose Cone will be manufactured after the Nose Cone permanent ring bulkhead is complete and the Nose Cone coupler section is cut to correct size and prepared via sanding, cleaning, and marking. A 1/4 in. bolt or machine screw will be inserted into the threaded tee nut inserts of the ring bulkhead to ensure no epoxy gets into the threads of the inserts. The exposed threads of the fastener will be covered in masking tape. After final test fit checks, the outer circumference of the ring bulkhead will be coated in a thin layer of epoxy resin and inserted into the Nose Cone body. The Structures lead will verify the correct position and orientation, then the contact surface of the Nose Cone coupler will be coated in a thin layer of epoxy and inserted into the Nose Cone body. The Nose Cone coupler will seat against the aft face of the ring bulkhead when positioned. These parts will be left 24hrs to cure.

After curing, reinforcement fillets of epoxy with colloidal silica filler will be applied at the joints between the ring bulkhead, Nose Cone body, and Nose Cone coupler. Team members will ensure proper PPE is in place for utilizing epoxy resin with colloidal silica, including nitrile gloves, safety glasses, and a respirator. The epoxy and filler will be mixed to a peanut-butter like consistency and carefully applied with a gloved hand or wooden applicator, then left to cure for an additional 24 hours.

3.4.7 Main Parachute Bay Fabrication

The Main Parachute Bay will be cut to size and drilled as described in the airframe cutting section above (Section 3.4.1. All holes will be marked using a custom 3D printed marking guide and correct placement will be verified by the Structures Lead and an additional Senior Design team member. Additionally, pilot holes will be drilled before the final hole size and will utilize blue masking tape backing to minimize delamination.

3.4.8 AVAB Fabrication

The AVAB coupler sections and switchband will be cut and bonded as described in the relevant airframe manufacturing section above (Section 3.4.2. The Air Brake slot locations will be marked using a custom 3D printed marking guide and the slots will be cut using a handheld router or Dremel tool.

3.4.9 Drogue Parachute Bay/ Fin Can Fabrication

Drogue Parachute Bay/Fin Can manufacturing will initially be the same as the Main Parachute Bay. The fin slots for the RMFS will be marked using a 3D printed marking guide then cut using a jig and carbide tipped saw or using a Dremel tool with diamond cutting wheel. Additionally, pilot holes will be drilled prior to final holes and will utilize blue masking tape.

3.4.10 Fin Fabrication

Fins will be traced onto a 3/16 in. thick sheet of G10 fiberglass using a 3D printed marking guide. They will be fabricated using the same PPE and hazard controls as when cutting/drilling the fiberglass airframe. The fin shapes will be cut from the fiberglass sheet using a Dremel tool and then sanded to their final dimensions, where the edges will be rounded using a belt sander. The fastener holes will be drilled using a drill press. Finally, they will be washed with soapy water to remove any dust and debris and then dried.

3.5 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 altimeter will be a Perfect Flite StratologgerCF, the secondary altimeter will be an Altus Metrum EasyMini, the GPS tracker will be an Eggfinder Mini, the drogue parachute will be an 18 in. Fruity Chutes Classic Elliptical parachute, and the main parachute will be a 96 in. Fruity Chutes Iris Ultra Compact parachute.

3.5.1 Recovery System CONOPS

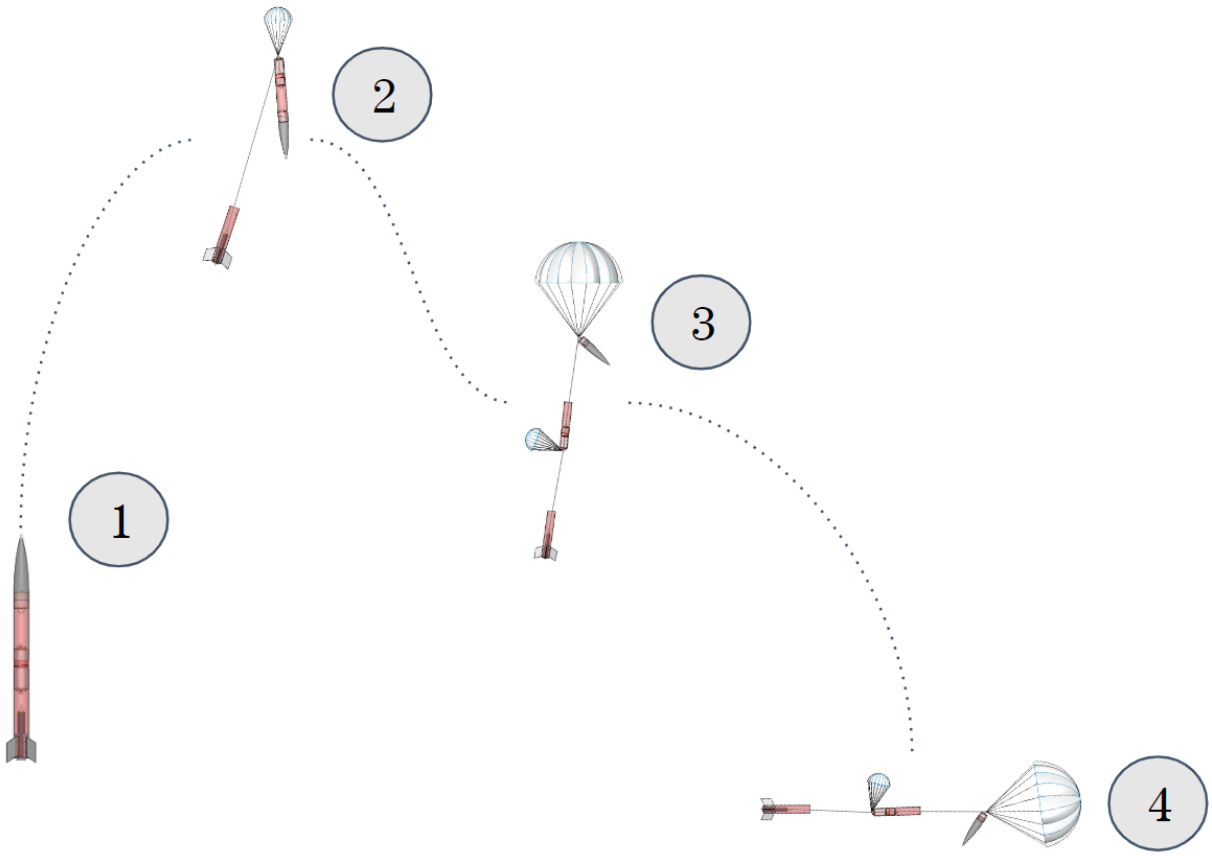


Figure 3.39: Recovery CONOPS

Figure 3.39 above shows the concept of operations for the recovery system during a nominal launch. Phase 1 is the launch phase, phase 2 is drogue parachute descent, phase 3 is the main parachute descent, and phase 4 is the landing.

Before takeoff, the main and secondary altimeters are armed on the launch pad by removing the pull pin switch. The team listens to the beeps to confirm that the main and secondary charges have continuity on both of the altimeters. The team also connects to the GPS using the receiver to confirm that it is transmitting on the pad. Only after all recovery avionics devices are confirmed to be working as expected, the team is go for launch.

During flight, once the Launch Vehicle reaches apogee, the primary altimeter ignites the primary drogue deployment charge and one second later the secondary altimeter ignites the secondary drogue deployment charge. This causes the Launch Vehicle to separate at the connection between the Fin Can and the AVAB, causing the drogue parachute to deploy and inflate. The Launch Vehicle then descends under the drogue parachute oriented such that the forward end of the vehicle is at 10 ft. above the Fin Can.

Once the Launch Vehicle has descended to 550 ft., the primary altimeter ignites the primary main deployment charge, and at 500 ft. the secondary altimeter ignites the secondary drogue deployment charge. This causes the main parachute to be ejected from the Launch Vehicle and inflate. The Launch Vehicle then descends under the main parachute such that all sections of the Launch Vehicle have at least 10 ft. of separation between them.

The vehicle then descends under the main parachute until it safely lands back on the ground. The Launch Vehicle should land undamaged such that it could be re-flown on the same day. It should also land such that the maximum kinetic energy is below 65 ft-lb, the total descent time is below 80 sec, and the total drift distance is under 2500 ft.

3.5.2 Parachutes

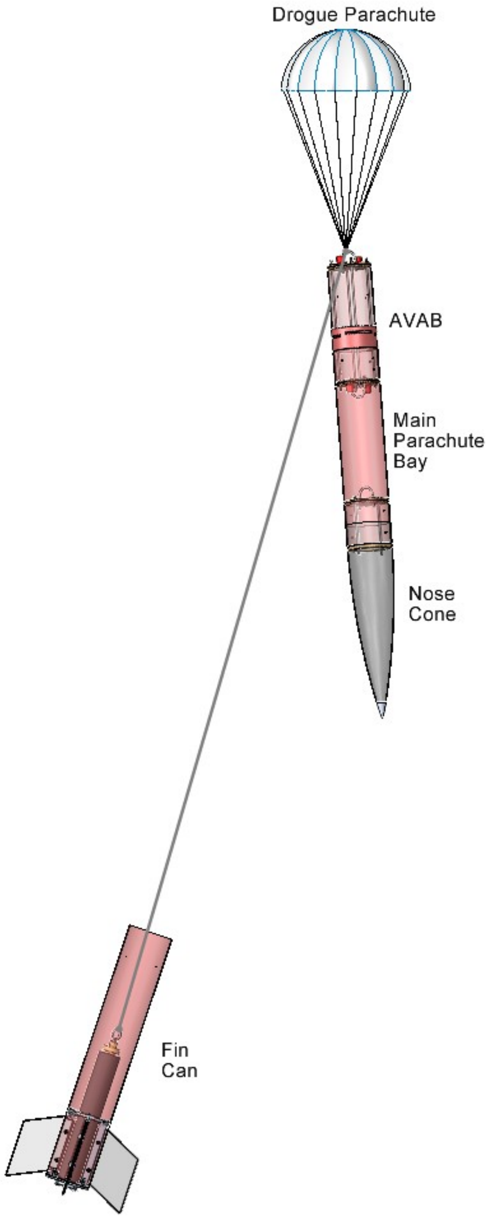


Figure 3.40: Drogue Deployment Configuration

For the drogue parachute, the team has selected the 18 in. Fruity Chutes Classic Elliptical parachute. This parachute will sit in the Fin Can/ Drogue parachute bay, just aft of the AVAB. A Nomex blanket will act as a layer of fire, heat, and abrasion protection from the drogue ejection charges.

This parachute was chosen because the team already owns it and it will allow the Launch Vehicle to descend fast enough to meet drift distance and descent time requirements, while remaining under our team derived maximum drogue descent speed of 110 fps. At a burnout mass of 34.366 lbs., this brings the total descent velocity under drogue to 106.582 fps.

For the main parachute, the team has selected the 96 in. Fruity Chutes Iris Ultra Compact parachute which will be protected by a parachute deployment bag. This parachute will sit in the Main Parachute Bay, forward of the AVAB. The parachute deployment bag will help to ensure a successful parachute deployment by organizing and holding the canopy and shroud lines until the point of ejection. The shroud lines will be z-folded and stowed within straps on the outside of the parachute deployment bag, allowing the lines to fully extend as the parachute is deployed, significantly reducing the chances of shroud line entanglement. Like the Nomex blanket, the parachute deployment bag will also protect the parachute from fire, heat, and abrasion from the main ejection charges.

This main parachute was chosen because the team already owns one and, when used in tandem with the 18" drogue parachute, the Launch Vehicle will remain under 65 ft-lbf of kinetic energy at landing while still reaching the ground in under 80 sec for bonus points on both requirements. This configuration also ensures the Launch Vehicle will not drift more than 2500 ft. from the launch pad during its descent. For more information on kinetic energy at landing, descent time, and drift distance, see sections 3.6.9, 3.6.10, and 3.6.11 respectively.

Parachute Opening Shock Calculations

The largest force that will act on the shock cord is caused by the main parachute deployment when the descent velocity decreases from 106.58 fps down to 16.42 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

$$t = \frac{8r}{v_d} \tag{6}$$

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 106.58 fps, the main parachute deployment time was calculated to be 0.3002 sec. With the main parachute deployment time, the total shock force experienced by the shock cord can be calculated with the equation

$$F = \frac{m\Delta v}{t} \tag{7}$$

Using 34.366 lbm for the vehicle descent mass mass, 90.16 fps for change in velocity, and 0.3002 sec for parachute deployment time, the maximum force the shock cords will experience is 320.75 lbf.

3.5.3 Shock Cord

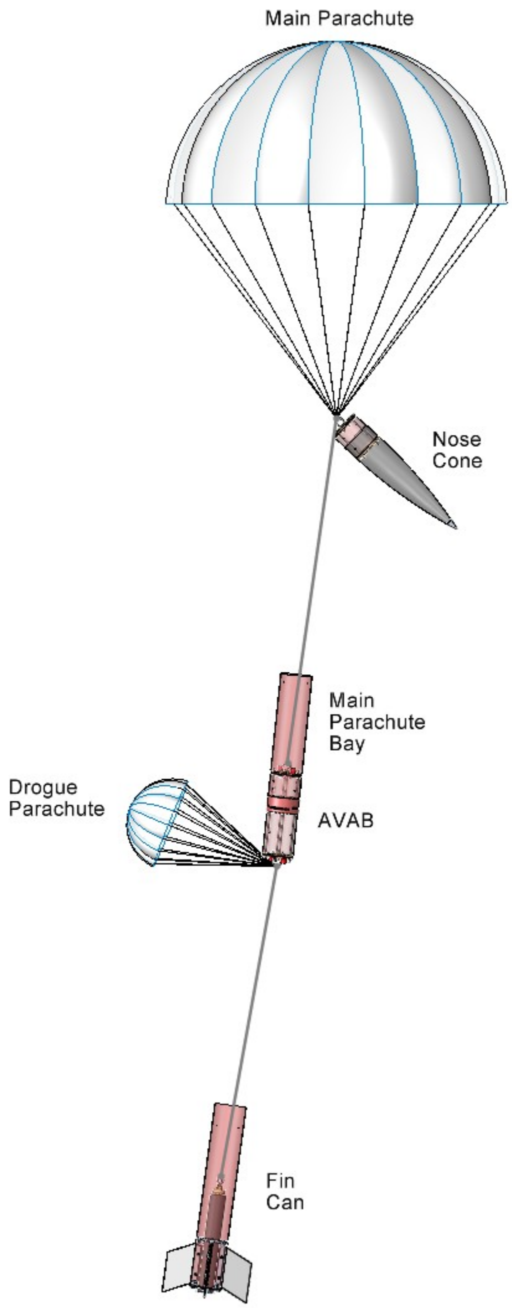


Figure 3.41: Main Deployment Configuration

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 20. While this is much higher than necessary considering the forces the shock cord will be under, the team already owns it, so it will not require any additional cost.

A diagram of the complete drogue parachute arrangement is shown in Figure 3.40 above. After the first recovery event at apogee, the Launch Vehicle will separate into two sections, with a separation point between the AVAB and the Drogue Parachute Bay. The shock cord will be tied onto a quick link attached to the AVAB U-Bolt using a bowline knot. The drogue parachute will also be attached directly to this quick link. Attaching the drogue parachute directly to the aft end of the AVAB will reduce the chance that the forward end of the Launch Vehicle gets tangled in the shock cord during descent, increasing the chances of a successful main parachute deployment. The other end of the shock cord will be tied to a different quick link using a bowline know that is connected to the eyebolt secured within the motor casing.

The overall length of the drogue shock cord will be 216 in. This arrangement will allow the Launch Vehicle to descend under the drogue parachute in two sections without them clashing together because there will be approximately ten ft. of vertical separation between the two sections on descent. Additionally, this configuration puts the Main Parachute Bay above the Fin Can to ensure that the main parachute does not get tangled in the Fin Can upon deployment.

After the second recovery event at 550 ft. above ground level, the forward section of the Launch Vehicle containing the AVAB, the Main Parachute Bay, and the Nose Cone will separate into two sections between the Main Parachute Bay and the Nose Cone. The Launch Vehicle will begin descending under main parachute as shown in Figure 3.41. Like the drogue parachute, the shock cord will be tied onto a quick link attached to the AVAB U-Bolt using a bowline knot and the other side of the shock cord will be tied onto a separate quick link which is attached to the Nose Cone bulk head. The main parachute is connected directly to the same AVAB quick link as the shock cord.

The overall length of the main shock cord will be 192 in. Like the drogue shock cord, this arrangement will allow the Launch Vehicle to descend under main parachute with all sections separated by at least 10 ft. to avoid clashing during descent.

During flight, the Launch Vehicle will be held together by four 4-40 nylon shear pins at each separation point. Each shear pin is rated for 2.5 psi of force, which will be experimentally verified by our team. These are strong enough to hold the Launch Vehicle together during flight, but weak enough to shear and separate the Launch Vehicle from the forces caused by the ejection charges.

3.5.4 Ejection Charges

The ejection charges necessary to separate the Launch Vehicle during recovery events have been selected for 777 grade FFF black powder. This grade of black powder was chosen because the fineness of the grain leads to a quicker combustion compared to that of larger grain sizes. In turn, this creates a more rapid pressurization of the bay and a cleaner separation event. Two primary and two redundant secondary charges will be housed in 3D printed blast caps on the outer surface of the AVAB bulkheads.

The required mass for the ejection charges is determined by the volume of the bay the charge is pressurizing, as well as the magnitude of the pressure required to separate the vehicle. The volume of the bay is determined by taking the empty space within the bay and subtracting the volume of the parachute and other recovery hardware. The shear pins used on the vehicle are rated for 2.5 psi. Thus, a pressure of at least 10 psi is required to separate the vehicle. Due to the presence of friction, as well as variation in the shear pins, a factor of safety of 1.5 is applied to the ejection charge pressure, making the required pressure to perform recovery events 15 psi.

To ensure that separation occurs, the mass of the secondary ejection charge will be increased by .5 grams from the primary charge. Detailed calculations of ejection charge sizing are performed in Section 3.6.12. The Main primary charge has been calculated to be 2.15 grams and the main secondary charge to be 2.65 grams. The drogue primary charge has been calculated to be 2.75 grams and the secondary charge to be 3.25 grams.

3.5.5 Avionics

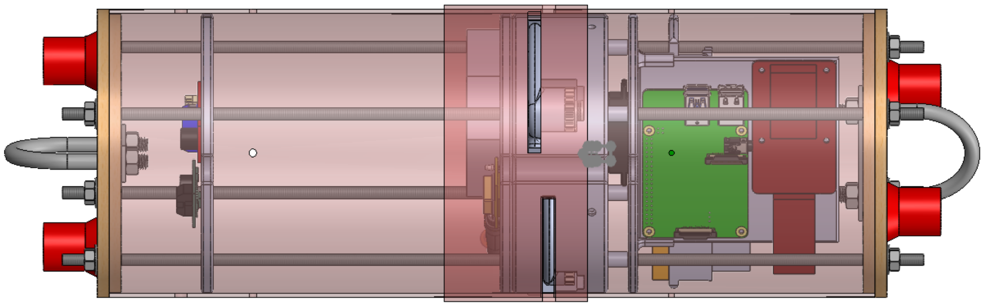


Figure 3.42: Full AVAB assembly.

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

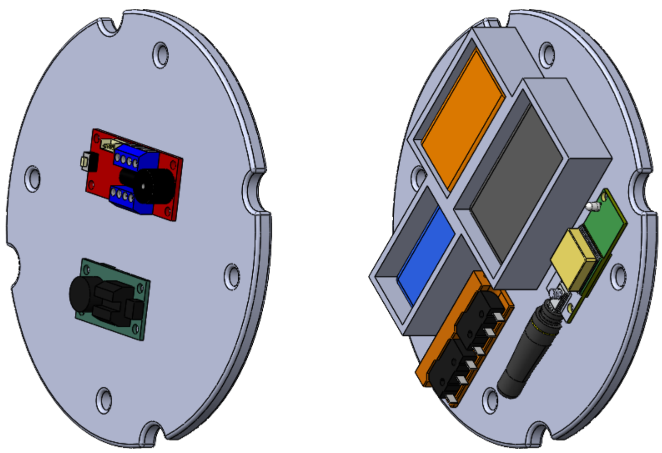


Figure 3.43: AV sleds.

Figure 3.43 above shows the AV Sled isolated from the rest of the AVAB. As shown in Figure 3.42, the AV Sled sits in the forward section of the AVAB, isolated from any other Air Brakes or Payload Electronics. The AV Sled was designed with two flat plates that will be 3D printed using PLA filament.

The top plate holds the Perfect Flite StratologgerCF altimeter and the Altus Metrum EasyMini altimeter. These will be secured to the plate using M2 standoffs and M2 screws. The open slits on the sides of the plate allow the wires to run down and connect to the batteries on the bottom plate.

The bottom plate holds the Eggfinder Mini, the Double Pull Pin Switch (which contains two micro switches), one 9V alkaline battery, one 7.4V 1000 mAH LiPo battery, and one 7.4V 400 mAh LiPo battery. Each of the altimeters are powered by separate batteries on independent circuits that are separated from all other payload and Air Brakes electronics.

The flat plate design allows for 5.5 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 7.18 in. of separation between the top of the Air Brakes servo and altimeters. The team will also cover the base of the top AV Bay plate with aluminum foil for further signal shielding.

Altimeters

The team has selected the 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, particularly for Subscale, these two altimeters offer outstanding performance relative to their size and fulfill all NASA and team derived requirements. The primary altimeter will be used for the purpose of reporting competition altitude.

Many members of the team have had great experiences with both of these altimeters in the past and they functioned exactly as expected during the team's Subscale launch.

The StratologgerCF will be powered by a single 9V alkaline battery as per manufacturer recommendations. With an average current draw of 1.5 mA, a single 9V battery should be able to power the StratologgerCF for more than 300 hours.

The Altus Metrum EasyMini will be powered by a 7.4V 400 mAh LiPo. With an average current draw of 8 mA, this battery should be able to power the EasyMini for around 50 hours.

Altimeter Arming Method

To arm and disarm the altimeters, the team will be using a Lab Rat Rocketry Double Pull pin switch that sits on the switchband. The double pull pin switch has two micro switches that are aligned so that one pull pin can be used to turn on both of the switches. On the launch pad, the team will begin by removing the pull pin only half way so that only one altimeter is armed. After the altimeter is verified to be working as expected, the pull pin will be fully removed to arm the second altimeter. This will make it easier to diagnose any altimeter problems on the launch pad.

This design was chosen 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.

Trackers

The tracker selected for this year's competition launch is the Eggfinder Mini GPS. This tracker was chosen primarily for its extremely small size while still having more than enough transmitting range to encompass the entire launch field.

The Eggfinder Mini will be paired with a handheld Eggfinder LCD Receiver that will be held by the recovery lead on the ground. There is no switch to turn the Eggfinder Mini on or off and will be turned on as soon as it is plugged in during assembly. This design was chosen because during preliminary testing the GPS often took between 5 to 15 minutes to connect to get a satellite fix and the team did not want those delays on the launch pad.

The location of the vehicle will be transmitted to the receiver continuously until the Launch Vehicle is recovered and the GPS is deactivated. The tracker will transmit at a frequency of 919 MHz. This frequency does not fall within amateur radio bands, therefore a HAM radio license is not required to operate it.

The Eggfinder Mini will be powered by a 7.4V 1000 mAh LiPo. With an average current draw of 70 mA, this battery should be able to power the EasyMini for more than 14 hours.

Electrical Schematics

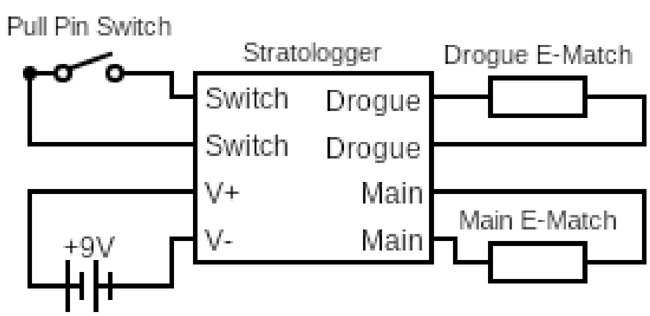


Figure 3.44: Primary Altimeter Wiring Diagram

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. Threaded wire is clamped down into these terminal blocks the make all the necessary 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.

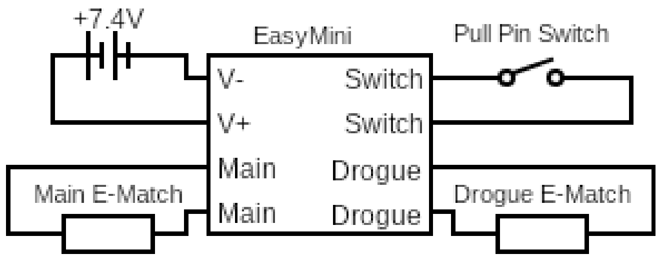


Figure 3.45: Secondary Altimeter Wiring Diagram

Figure 3.45 above shows the wiring diagram for the secondary altimeter. The circuit is independent from all other avionics electronics and is powered by a manufacturer recommended 7.4V 400 mAh LiPo battery. Like the Stratologger, the EasyMini 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.

The Eggfinder Mini is connected directly to a 7.4V 1000 mAh battery. The Eggfinder Mini is not connected to a switch and is powered on as soon as it is plugged in during AV Sled assembly. This is because it can take several minutes for the GPS to connect to a satellite and is not ideal to do on the launch pad while arming the altimeters.

3.6 Mission Performance Predictions

3.6.1 Launch Day Target Altitude

The target altitude of the Launch Vehicle is 4600 ft. above ground level. This target allows approximately 200 ft. of altitude for Air Brakes to impact apogee. This also provides room for adjustments based on wind speed, ballast addition, and payload impact. These qualities and their impact on mission performance will be further discussed in Section 3.6.3.

Predicted apogees from simulation suites are shown below in Table 3.13. These were all calculated at 10 mph with a 5 degree launch rail cant and a 144 in. launch rail.

Apogee predictions meet Requirement 2.1 and allow appropriate altitude ranges for Air Brake deployment. Air brake impact on mission performance will be discussed further in Section 3.6.7.

Table 3.13: Apogee Prediction Across Software Suites

Software	Predicted Apogee
OpenRocket	4840 ft.
RasAero II	5062 ft.
RocketPy	4809.76 ft.

Altitude Verification

Altitude predictions are verified using the following derivation. This utilizes the Fehskens-Malewicki equations.

First drag force, k, is calculated:

$$k = \frac{1}{2}\rho C_d A \tag{8}$$

Using thrust, drag, and gravity, q is calculated:

$$q = \sqrt{\frac{T - Mg}{k}} \tag{9}$$

The following equation solves for a ratio of drag force and q:

$$x = \frac{2kq}{M} \tag{10}$$

By combining Equations 9 and 10, maximum velocity can be calculated using the following formula:

$$v_{max} = q\frac{1 - e^{-xt}}{1 + e^{-xt}} \tag{11}$$

The following equation calculates the altitude of motor burnout:

$$Z_{burnout} = -\frac{M}{2k} \ln\left(\frac{T - Mg - kv_{max}^2}{T - Mg}\right) \tag{12}$$

The following equation calculates the coast distance:

$$Z_{coast} = \frac{m \ln\left(\frac{mg+kv^2}{mg}\right)}{2k} \tag{13}$$

Apogee is found by summing coast distance and burnout height:

$$Z_{apogee} = Z_{burnout} + Z_{coast} \tag{14}$$

Equations 8 through 14 are used to calculate the values found in Table 3.14 below.

Table 3.14: Apogee Calculation Constants and Results

Constant	Variable Name	Value	Units
M	Power On Average Mass	1.194	Slug
m	Power Off Average Mass	1.069	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	0.45	NA
Equation	Result		Units
k	0.00011103		slug/ft
q	1681.8		ft^2/s^2
x	0.3128		fps^2
v_{max}	648.496		fps
$Z_{burnout}$	865.534		ft
Z_{coast}	4128.72		ft
Z_{apogee}	4994.25		ft

This calculation yields a higher value than the simulation analyses due to approximations throughout the calculation. Differences can be attributed to the use of averages, thrust timing, and other aspects that simulations can account for, such as wind speed and launch rail cant. There is a 3.76 percent difference between the calculated value and the value from the RocketPy analysis, showing that the simulations are reliable.

3.6.2 Flight Profile Simulations

Figures 3.46 through 3.48, below, display the predicted flight profiles from the utilized simulation suites. These were all calculated at 10 mph with a 5 degree launch rail cant and a 144 inch launch rail. All are similar in apogee and flight profile.

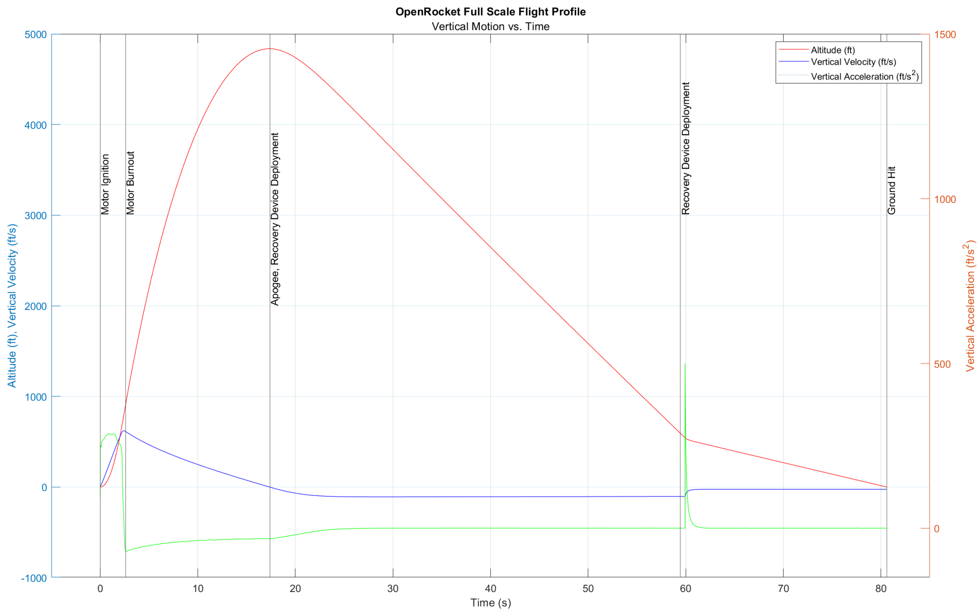


Figure 3.46: Flight Profile, Open Rocket

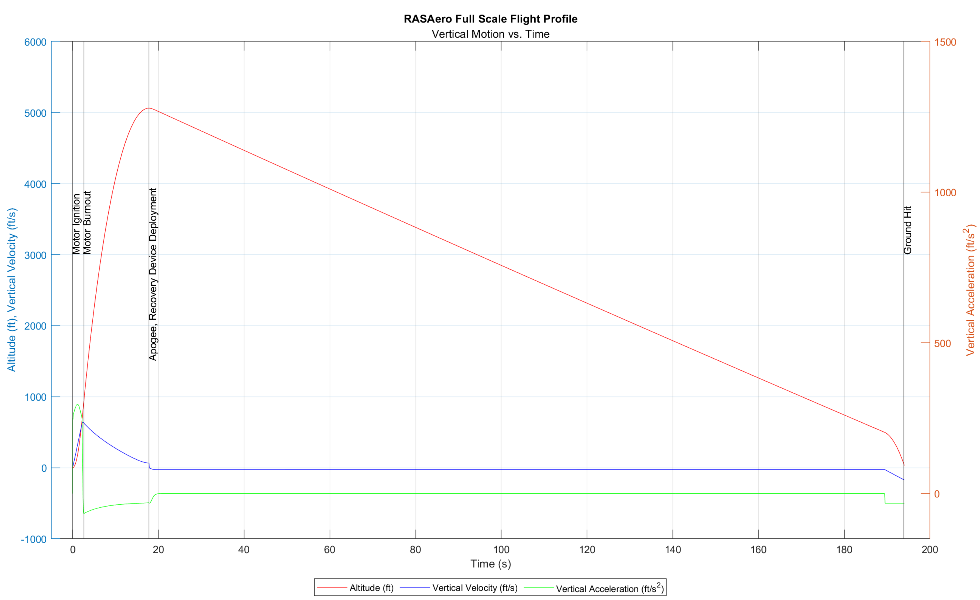


Figure 3.47: Flight Profile, RASAero II

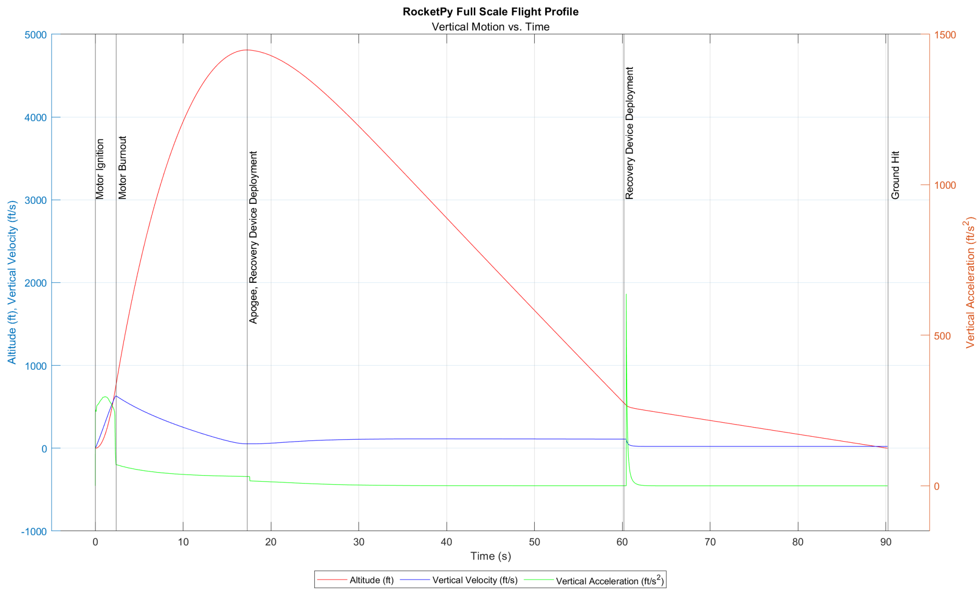


Figure 3.48: Flight Profile, RocketPy

Table 3.15, below, shows the maximum predicted velocity in flight and rail departure velocity for each simulation suite. These all remain below Mach 1, meeting Requirement 2.23.6. Each simulation suite yielded slightly different values due to variations in calculation methods. The high fidelity of RocketPy, achieved through input customization, dictates the final predictions regarding mission performance, with a maximum acceleration of 296.47 ft/s^2.

Table 3.15: Velocity in Flight

Software	Rail Exit Velocity	Maximum Velocity	Maximum Mach
OpenRocket	81.5 fps	621.2 fps	0.55
RasAero II	76.3 fps	638.14 fps	0.57
RocketPy	71.8 fps	632.8 fps	0.56

3.6.3 Other Impacts on Mission Performance

Sections 3.6.4 through 3.6.6 discuss other factors that may impact mission performance on launch day. This shows that the vehicle is designed to stay within requirements despite these conditions, and that target apogee is still attainable even if ballast weight increases, payload weight increases, or wind speed is not what was predicted.

3.6.4 Ballast Weight Impact

Due to the dry mass of the Launch Vehicle, ballast is limited to about 3 lbs. This ensures that Requirement 2.22.7 is met. The vehicle can utilize up to 3 lbs of ballast and remain within competition Requirement 2.1. However, in order to meet target apogee, ballast will need to remain at 1.5 lbs or lower. The current configuration requires 0 lbs of ballast, so this is not a concern. Figure 3.49, below, shows how apogee and stability are impacted by ballast adjustment. This figure also illustrates that the vehicle will remain within requirements if maximum ballast is added. It is important to note that as ballast increases, stability margin also increases. This is due to the weight distribution increasing in the forward section of the vehicle, shifting the center of gravity forward.

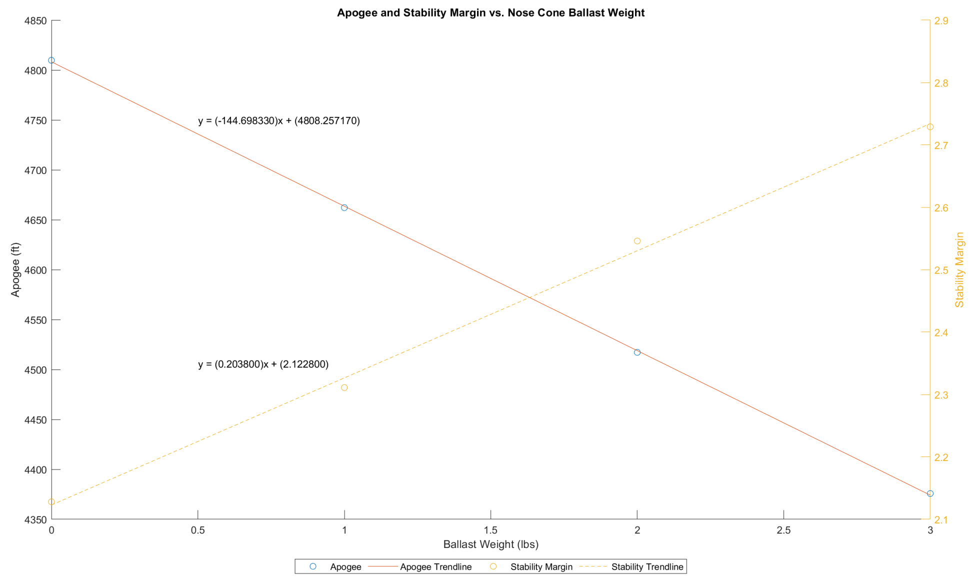


Figure 3.49: Ballast against Apogee and Stability Study

3.6.5 Payload Weight Impact

The Payload in this vehicle is estimated to weight approximately 2.25 lbs. This yields an apogee prediction of 4809.76 ft. and a stability margin of 2.13 calibers. As shown in Figure 3.50, below, target apogee can be achieved if payload remains below approximately 3.5 lbs. However, the vehicle can reach altitude requirements even if the payload reaches 10 lbs or higher. This displays the robust design on the vehicle. Static stability becomes a concern when payload is less than 2 lbs, but this could easily be corrected with the addition of ballast in the Nose Cone without significantly impacting altitude reached. Since the payload weight is also in the Nose Cone, the center of gravity is shifted forward regardless of whether the weight is ballast or payload.

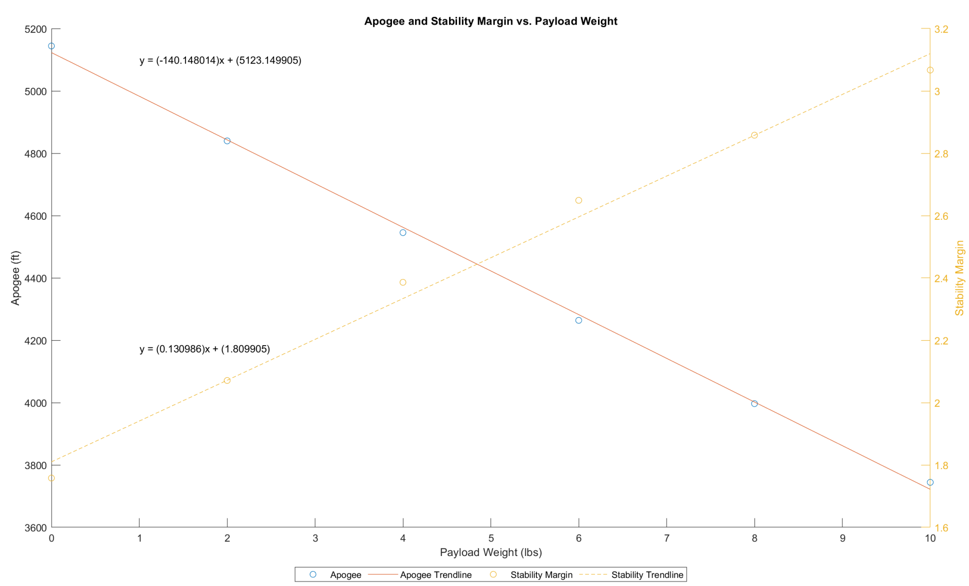


Figure 3.50: Payload Weight against Apogee and Stability Study

3.6.6 Wind Speed Impact

On launch day, wind speed is a concern. If wind speeds are above 20 mph, launch will be delayed. Since this is the bounding value, simulations were run from 0 mph to 20 mph winds to show that the vehicle will reach and overshoot target apogee across this range. This allows for Air Brake deployment and ensures that altitude requirements are met.

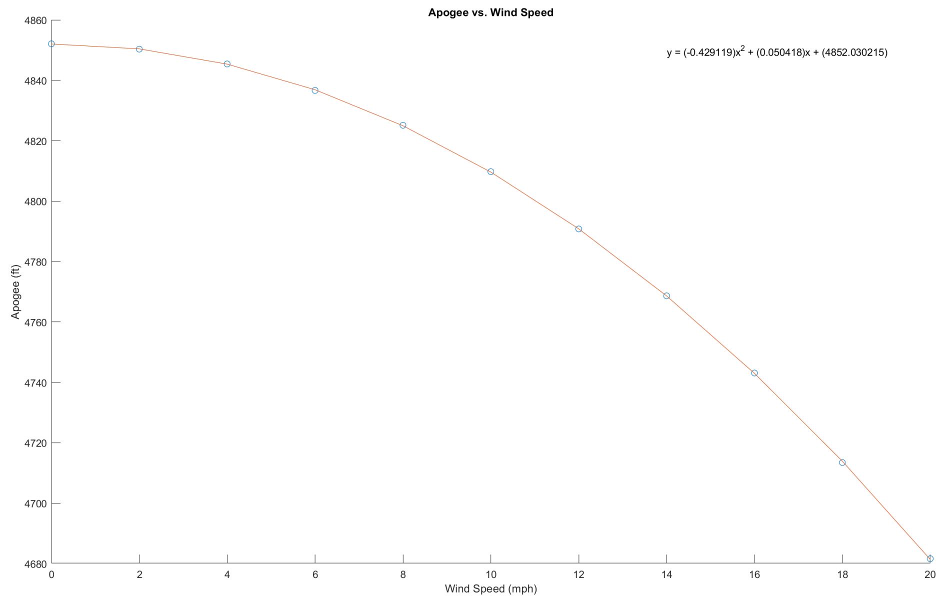


Figure 3.51: Ballast against Apogee and Stability Study

3.6.7 Air Brake Impact on Mission Performance

Estimated Air Brakes impact capability is shown in Figure 3.52. Based on this curve, Air Brakes should be deployed at 3184 ft. to reach an apogee of 4600 ft.

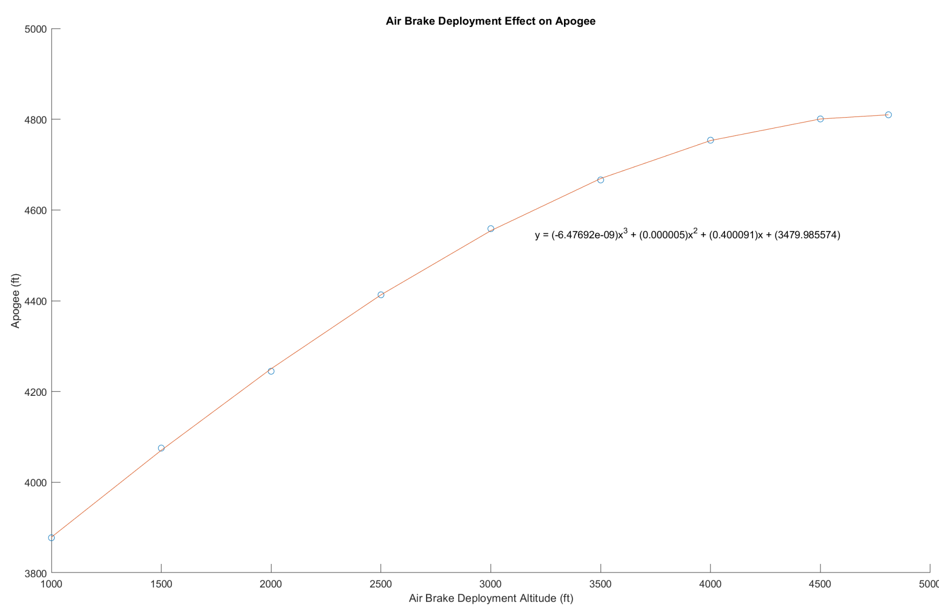


Figure 3.52: Air Brake Impact on Apogee

Figure 3.53, below, displays a predictive flight profile with Air Brake deployment at 3184 ft. in order to reduce apogee to the target, 4600 ft. This simulation was also calculated at 10 mph with a 5 degree launch rail cant and a 144 in. launch rail.

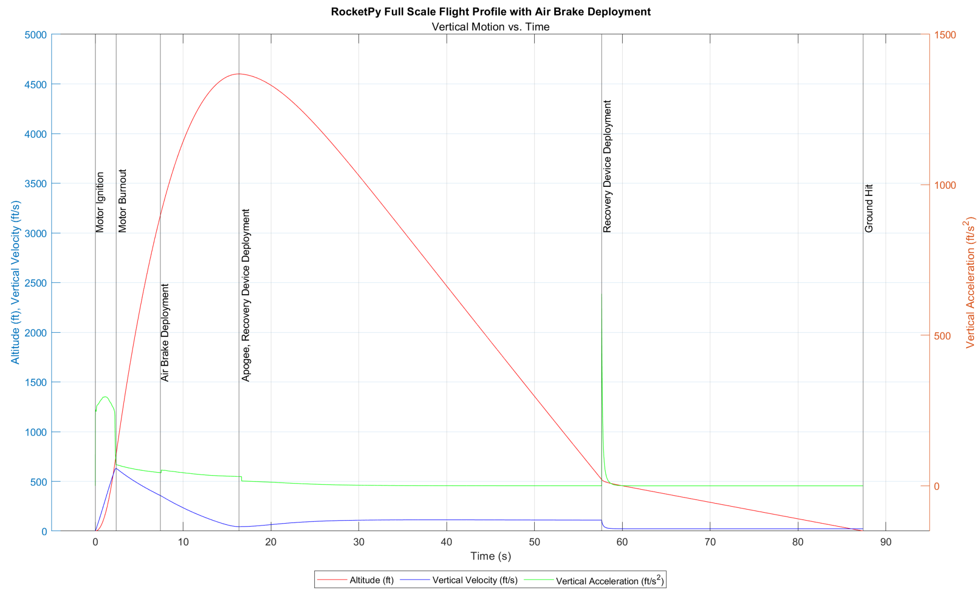


Figure 3.53: Flight Profile, RocketPy

Another concern is that the center of gravity must maintain in front of the Air Brakes protuberances during flight. The location of these protuberances is at 59 in. from the forward tip of the vehicle. Static center of gravity is located at 58.78 in. from the tip of the vehicle, which is forward of the Air Brakes protuberances. After motor burnout in flight, this center of gravity shifts further forward to 55.49 in. from the tip of the vehicle. This provides an ample distance between the protuberances and the center of gravity in flight of 3.51 in. This meets Requirement 2.15. Figure 3.54, below, provides a visual of the center of gravity over time in comparison to the Air Brake protuberance location.

Table 3.16: Center of Gravity Location in Comparison to Air Brake Protuberances

CG	Location
Static	58.78 in.
After Burnout	55.49 in.
Air Brake Protuberance	59 in.

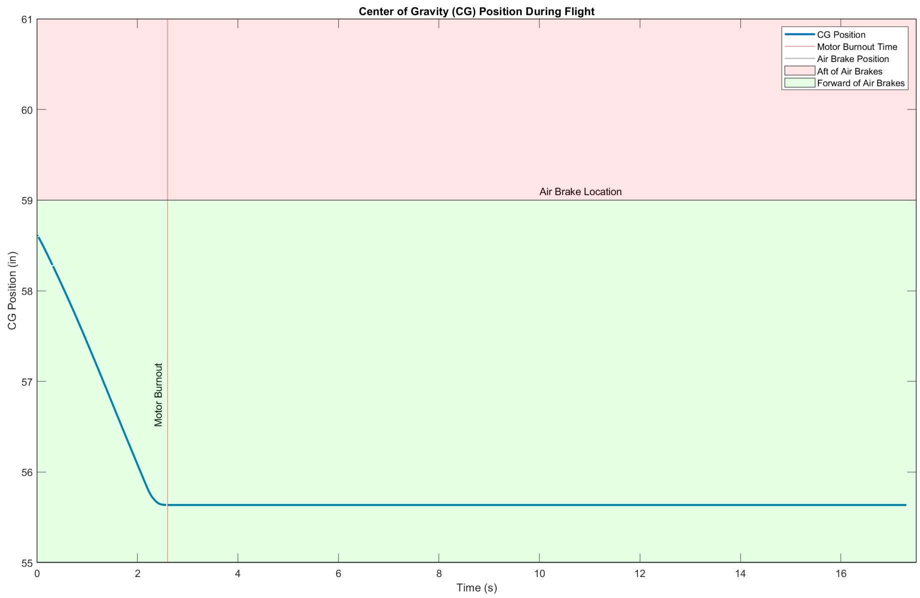


Figure 3.54: Center of Gravity During Flight

For further visualization, below are diagrams of the vehicle where approximate Air Brake location is highlighted in green, center of gravity is denoted by the blue and white circle, and center of pressure is denoted by the red dot. The first image, Figure 3.55, shows static configuration. The second, Figure 3.56, shows burnout configuration.

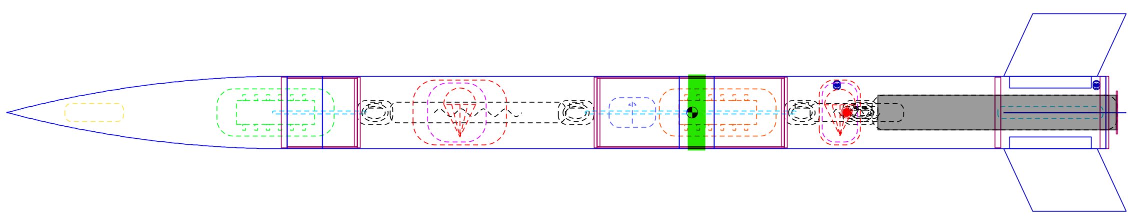


Figure 3.55: Static CG in Comparison to Air Brake Location

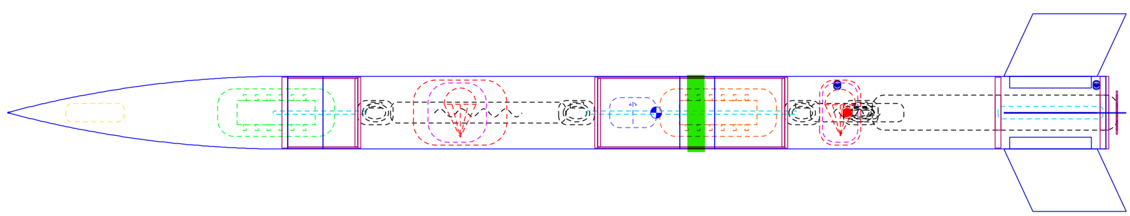


Figure 3.56: Burnout CG in Comparison to Air Brake Location

3.6.8 Stability Margin

Stability margin is approximated using the difference between the center of pressure and center of gravity locations divided by the diameter of the Launch Vehicle. Table 3.17, below, displays the relevant information produced by simulation suites. Using RocketPy, which dictates final predictions, the static stability margin at rail exit is calculated to be 2.18.

Table 3.17: Stability Margin Determination Across Software Suites

Software	Center of Pressure	Center of Gravity	Stability Margin
OpenRocket	71.82 in.	58.62 in.	2.14 Calibers
RasAero II	71.71 in.	58.62 in.	2.12 Calibers
RocketPy	71.89 in.	58.78 in.	2.13 Calibers

Figures 3.57 through 3.59, below, are physical diagrams of the center of pressure and center of gravity locations of each simulation suite.

The red dot represents center of pressure and the blue and white circle represents center of gravity.

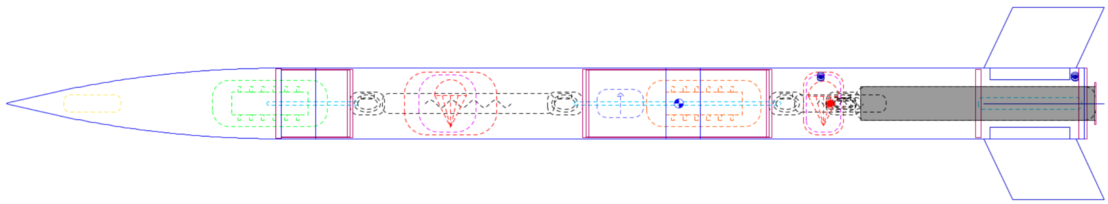


Figure 3.57: Launch Vehicle, Open Rocket

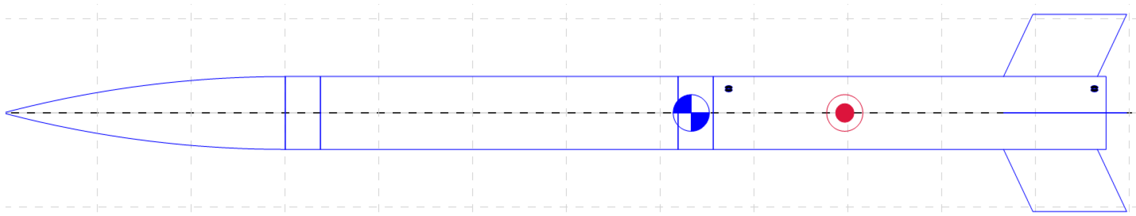


Figure 3.58: Launch Vehicle, RASAero II

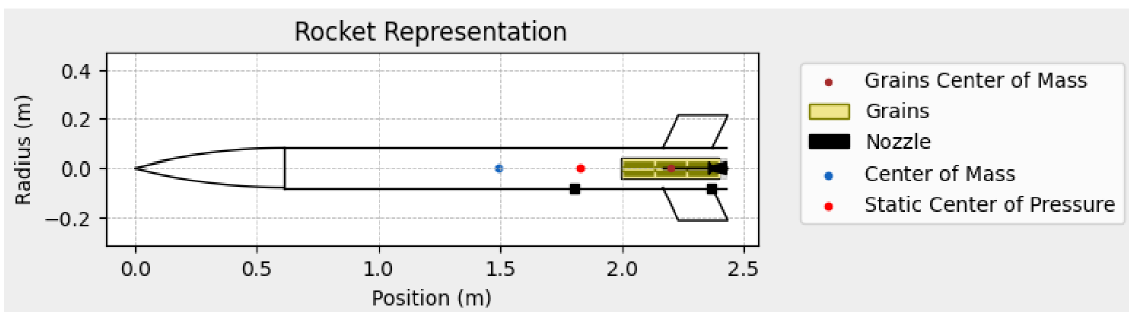


Figure 3.59: Launch Vehicle, RocketPy

Verification of Center of Pressure, Center of Gravity, and Stability

To verify simulation accuracy, the Barrowman equations are used to compute center of pressure and stability. The derivation process is shown below.

$$(C_{N_f}) = \left[1 + \frac{R}{S+R})\right]\left[\frac{4N(\frac{S}{d})^2}{1+\sqrt{1+(\frac{2L_F}{C_R+C_T})^2}}\right] \quad (15)$$

$$X_f = X_B + \frac{X_R(C_R+2C_T)}{3(C_R+C_T)} + \frac{1}{6}\left[(C_R+C_T-\frac{C_RC_T}{C_R+C_T}\right] \quad (16)$$

$$X_{CP} = \frac{C_N X_N + C_F X_F}{C_N + C_F} \quad (17)$$

$$SM = \frac{X_{CP} - X_{CG}}{2R} \quad (18)$$

Table 3.18: 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

Table 3.18: Stability Margin Constants and Results

Constant	Variable Name	Value	Units
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	85.25	in.
X_R	Tail to Root Chord LE length	2.5	in.
X_{CG}	Center of Gravity (RocketPy)	58.78	in.
Equation	Result		Units
$(C_N)_f$	7.2134		NA
X_f	88.5		in.
X_{CP}	71.72		in.
SM	2.097		Calibers

From this verification, center of pressure is estimated at 71.72 in. from the tip of the vehicle. In combination with estimated center of gravity at 58.78 in. from the Nose Cone, this yields a stability of 2.097 calibers. This center of pressure gives a percent difference of 0.24% from the RocketPy calculation. The stability margin calculated gives a percent difference of 1.56% when compared to the RocketPy estimation. This shows a high level of accuracy in the simulated values. This reinforces that stability margin will remain above 2.0, satisfying NASA Requirement 2.14.

In order to verify center of gravity is as calculated, a test is performed after assembly, before or on launch day. By balancing the vehicle on a rope, the center of gravity can be found. Generally, this value is very close to the simulated values, as this is based on weight distribution, a relatively predictable factor.

Once center of pressure is estimated or simulated and center of gravity is found experimentally, the stability margin is verified. Equation 21, below, is used to calculate stability margin. In this equation, SM is stability margin,

$$X_{CP} \tag{19}$$

is center of pressure location,

$$X_{CG} \tag{20}$$

is center of gravity location, and d is the diameter of the vehicle. These distances are measured from the tip of the vehicle. If needed, stability margin can be increased on launch day with addition of Nose Cone ballast. For more information on Nose Cone ballast and its impact on stability margin and altitude reached, please reference Section 3.6.4.

$$SM = \frac{X_{CP} - X_{CG}}{d} \tag{21}$$

3.6.9 Kinetic Energy at Landing

The descent velocity of the Launch Vehicle was calculated using the equation

$$v_D = \sqrt{\frac{2mg}{\rho A C_d}} \tag{22}$$

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 106.582 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 16.424 fps.

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

$$K = \frac{1}{2} m {v_D}^2 \tag{23}$$

where K is the maximum kinetic energy.

Using a drogue descent velocity of 106.582 fps and a main descent velocity of 16.424 fps, Table 3.19 shows the kinetic energy for each of the independent sections of the Launch Vehicle.

Table 3.19: Kinetic Energy Calculations

Section	Mass (lbm)	Drogue Descent Velocity (fps)	Drogue Kinetic Energy (ft-lbf)	Descent Velocity (fps)	Kinetic Energy (ft-lbf)
Nose Cone	8.81	106.582	3685.179	16.424	36.932
AVAB + Main Bay	12.065			16.424	50.577
Fin Can + Drogue Bay	13.491	106.582	2381.641	16.424	56.555

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 landing, 51.045 ft-lbf, satisfying the bonus points as per NASA Requirement 3.3.

RocketPy was used to cross verify these calculations by configuring the Launch Vehicle with the parachutes we are using. The velocity at impact was found to be 16.351 fps, bringing the kinetic energy at landing to 57.485 ft-lbf - a 4.58% difference from our hand-calculated kinetic energy at landing.

3.6.10 Descent Time

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

$$t_d = \frac{r_a - r_m}{v_d} + \frac{r_m}{v_m} \tag{24}$$

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 4600 ft, and a nominal main deployment at 550 ft, the total descent time was calculated to be 71.486 sec, satisfying the bonus points for NASA Requirement 3.12.

From the RocketPy simulation, the time of apogee was found to be 16.351 sec, with a landing time of 87.407 sec, bringing the total descent time to 71.056 sec - a 0.61% difference from our hand-calculated descent time.

3.6.11 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

$$r_{drift} = t_d v_w \tag{25}$$

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

Table 3.20 shows how the drift distance of the Launch Vehicle from the launch pads will vary with wind speeds up to a maximum of 20 mph.

Table 3.20: Wind Drift Distance

Wind Speed (mph)	Drift Distance (ft)
0	0
5	524.23
10	1048.47
15	1572.70
20	2096.93

These calculations assume that the Launch Vehicle will constantly drift with the wind and will reach apogee directly above the launch pad with no initial horizontal velocity. In actuality, the Launch Vehicle will start with an initial velocity into the wind from the flight. Since RocketPy calculates the actual flight path of Launch Vehicle before the descent starts, these drift distance calculations will be more accurate to what we would expect during a normal launch.

Figure 3.60 below shows the drift of the Launch Vehicle over time under 0 mph winds starting at takeoff (note that the units are in meters).

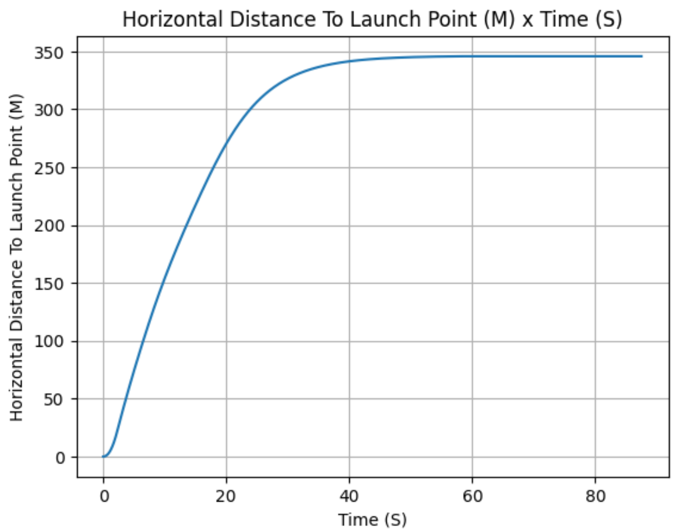


Figure 3.60: RocketPy Drift Distance from Launch Pad (0 mph Winds)

As shown, the Launch Vehicle drifts a little more than 1200 ft. during the flight and continues in that direction slowly during it's descent. This initial velocity, is the reason for the discrepancies in the drift distance between the team's hand calculations and RocketPy. All RocketPy calculated drift distances are shown in Table 3.21 below.

Table 3.21: RocketPy Wind Drift Distance

Wind Speed (mph)	Drift Distance (ft)
0	369.621
5	493.940
10	760.269
15	1078.738
20	1424.071

Looking at the more realistic RocketPy calculations and the hand calculations with no initial velocity, both of these methods verify that the Launch Vehicle will not drift more than 2500 ft. during its descent, satisfying NASA Requirement 3.11.

3.6.12 Ejection Charge Sizing

Ejection charges are used to 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 to separate the sections.

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

$$m = \frac{PV}{RT} \tag{26}$$

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-$^\circ$R and the combustion temperature is 3307°R. The empty volume of the Main Parachute Bay with the 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 3.22 below outlines the calculated primary and secondary charges for the main and drogue parachute deployment events.

Table 3.22: 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	290.38 in^3	3.1 g	3.6 g

These ejection charge values were verified using Chuck Pierce's Black Powder Ejection Charge Calculator. This method was used to calculate the black powder charges on the team's Subscale Launch Vehicle, where the calculated charges successfully separated the vehicle during ground ejection tests and during the flight as expected.

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.

4 Payload Criteria

4.1 Payload Mission Overview

4.1.1 Mission Statement

The primary objective of the STEMCRaFT payload is to safely house four STEMnauts while recording data throughout the launch. Upon landing, the STEMCRaFT will prepare and send a transmission that will relay the necessary data points to a NASA receiver. This transmission will take place on the 2 meter band using APRS and the transmission will stop after 5 minutes.

4.1.2 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.

4.1.3 Selected Payload Design

The design chosen from PDR is the Nose-Cone mounted STEMCRaFT. This design was picked for it's ease of integration into the Launch Vehicle and its compatibility with using the Air Brakes system. With a lander, the Launch Vehicle could not utilize Air Brakes. These changes are detailed further in Section 4.1.4. Many of the leading payload selections were determined through the analysis conducted for the Preliminary Design Review milestone, and their proven performance through the teams Subscale launch. In this section are the finalized payload design and the justifications for the selections made.

4.1.4 Payload Design Changes from PDR

ESP32

An ESP32 has been incorporated into the leading payload's design since implementation of the ESP32 as a MCU provides multiple benefits for the integration of sensors. Primarily, an ESP32 supports clock-stretching, a feature that many sensors, particularly Adafruit sensors, utilize to relay their data. While the Raspberry Pi can simulate clock-stretching, it is not as reliable as this feature is more supported in Arduino devices.

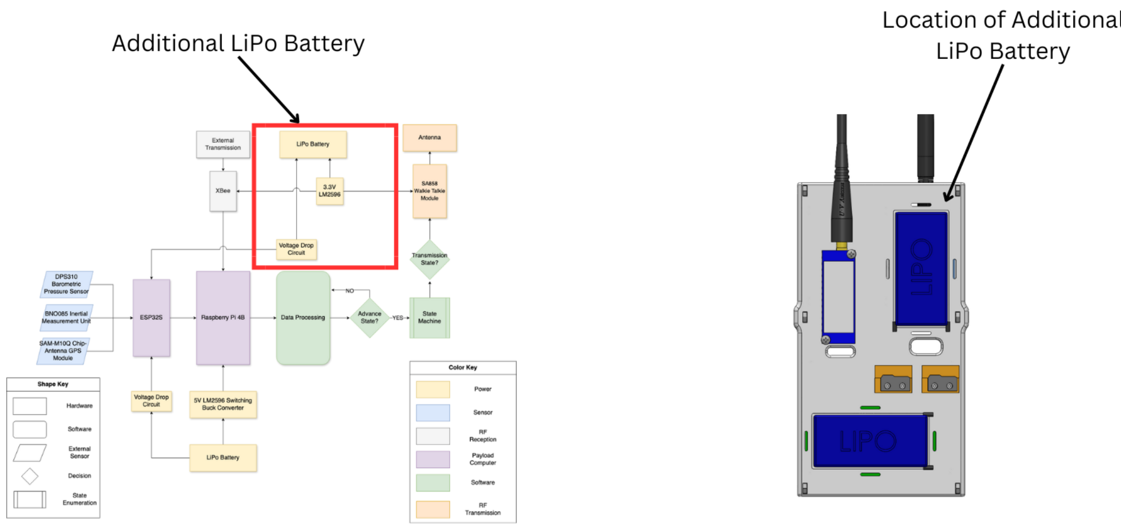
Additionally, using the ESP32 as a buffer between the sensors and the Raspberry Pi enables access to a significantly larger number of libraries. This is particularly advantageous for sensors that have relatively limited support in Python-based systems. With the ESP32, the data from the sensors can be processed through the Arduino's code and formatted in a way that is compatible with the system. The MCU will handle formatting the sensor data into a JSON format before transmitting the information to the Raspberry Pi over a USB serial connection.

Transmitter

Figure 4.1: Image of SA858 Transceiver Module.

The transmission system was changed to utilize the SA858 module instead of an Si4464 transceiver with a GRF5020 RF amplifier. This new transceiver module comes with the necessary components built in, such as a power filter, power amplifier, and additional signal filtering. This change simplifies the design while also improving the reliability by using a device made specifically to communicate data, such as that required for the STEMCRaFT. It may transmit on many HAM frequencies, including the 2 meter band, up to 4 watts meeting the mission requirements.

Transmission Power Supply



(a) Additional LiPo Battery in Block Diagram

(b) Location of Additional LiPo Battery

Figure 4.2: Transmission Power Supply Changes

In the finalized design, the transmission subsystem is powered by a separate LiPo battery instead of the Raspberry Pi. This change was made to accommodate the higher power demand of the SA858 module and to avoid any potential power capacity limitations. Additionally, the modification was necessary because the Raspberry Pi is unable to supply sufficient current to properly amplify the transmission while powering the sensors and the ESP32.

One of the primary benefits of using a separate battery is that it reduces the power demand on each battery and extends their individual lifespans. By separating the largest power-consuming components, such the the Raspberry Pi and the SA858 module, less current is drawn in each power circuit, reducing the risk of overheating and brown-out. This separation of power sources will improve battery lifespan, resulting in a more reliable payload and a lower risk of power issues during potential launch delays.

Capsule Design

The STEMCRaFT structure has changed from a sled with mounted electronic components to an enclosed capsule design. The updated configuration consists of a capsule shell that encases the sled, sealed with two bulkheads. This new design better aligns with the competition requirement for a sealed and detachable container. The finalized capsule design can be seen below in Section 4.2.2.

Ventilation

Another feature added to the final design was a fan to circulate the air within the housing. The electronics can easily heat the surrounding air by a few degrees, especially in a stagnant environment. In order to get an accurate measurement of the landing site, the air needs to be circulated so that the hot air is vented out and fresh air can enter.

This small fan will create airflow across the STEMCRaFT sensors by drawing in fresh nearby air and expelling, potentially heated, air. The fan will accomplish this by using the pressure ports and small slots built into the payload capsule. These small holes will allow air to move as necessary in order for the STEMCRaFT to properly obtain accurate air samples from its surrounds. The fan included into the STEMCRaFT design can be seen in Section 4.2.2 below.

4.2 STEMCRaFT Final Design Overview

4.2.1 Electronics

Block Diagrams

Shown below is the updated block diagram of the onboard Launch Vehicle payload system. This functional block diagram closely resembles the leading payload design presented in the Preliminary Design review, but incorporates the changes outlined in Section 4.1.4.

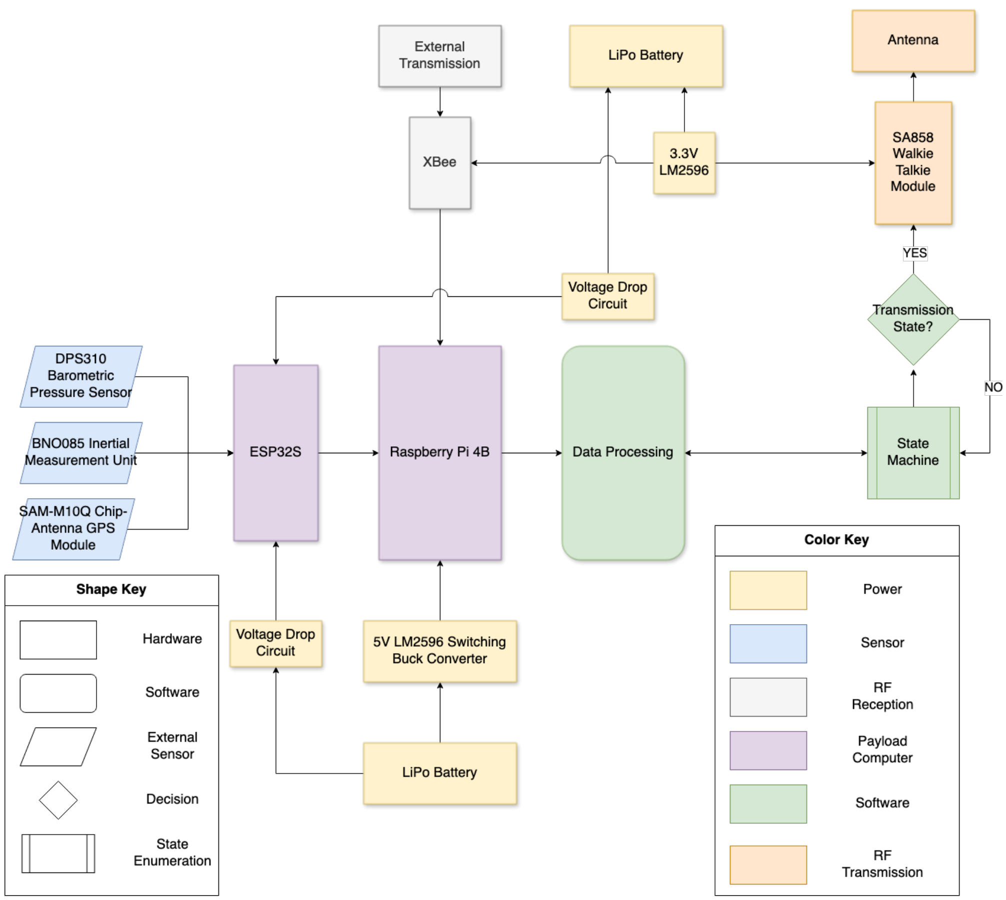


Figure 4.3: STEMCRaFT Functional Block Diagram.

At the center of the figure, shown in purple, are the payload computers. The primary payload computer is a Raspberry Pi 4 Model B, which is responsible for logging, processing, and relaying data to the transmitter. The Raspberry Pi also supplies power to the ESP32 and processes any commands received by the XBee from the ground station. These commands, detailed in the STEMCRaFT CONOPS, allow for the manual initiation and termination of transmissions.

The secondary payload computer is the ESP32, which handles reading raw data from the sensors and relaying it to the Raspberry Pi over a serial connection.

The sensors are shown in blue on the left-hand side and consist of the following:

- DPS310 Barometric Pressure Sensor
- BNO085 Inertial Measurement Unit
- SAM-M10Q Chip-Antenna GPS Module

These sensors were also utilized in the leading payload design, as described in the Preliminary Design Review, and were validated through the successful collection of flight data during the Subscale flight. Each sensor provided data throughout the Subscale flight. The accuracy of these sensors will be further verified in a second data collection flight performed on January 25th, 2025. At this flight, a VV&T test will be performed to verify sensor data using external sensor data, and altimeter data.

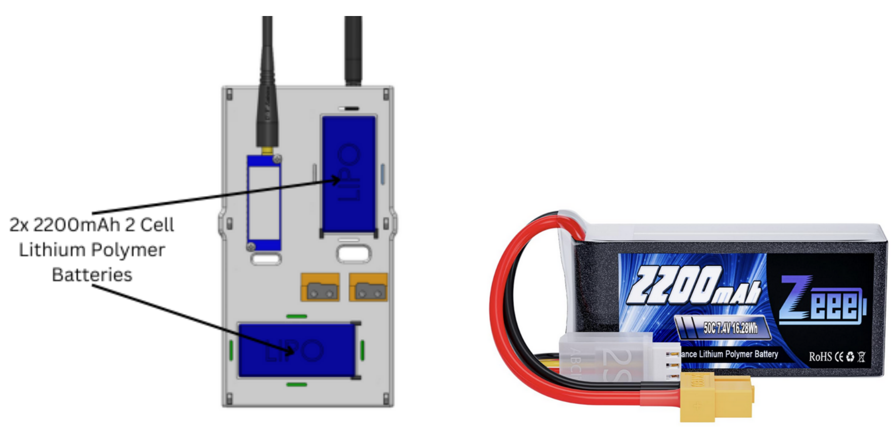
Shown in yellow are the two separate power systems. Both systems rely on 2-cell LiPo batteries and use switching buck converters to efficiently regulate their voltage to levels acceptable for the devices they power. Additionally, a voltage drop circuit is included to reduce the LiPo output voltage to a level readable by the ESP32. This enables the ESP32 to gauge the battery status of the system via analog pins. This process is discussed in further detail in 4.28.

Shown in the top section of the diagram is the RF reception system. The purpose of this section is to enable the payload to receive a signal from the ground station that can manually trigger or terminate the transmission. This ensures that no issues arise that could result in a disqualifying transmission or lack of a successful transmission.

The software processes are indicated in green, located to the right of the Raspberry Pi block. This block processes and stores the data after it is read from the Arduino. Using this processed data, the software will determine whether or not to advance the STEMCRaFTs finite state machine. This finite state machine will dictate the function of the STEMCRaFT throughout the flight. Once the state machine has reached the landed/transmission state, the Raspberry Pi will begin communicating with the SA858 Walkie Talkie module.

Once the software detects landing, it will relay data to the transmission section, shown in orange on the right-hand side of the diagram, and transmit APRS data using AFSK modulation. Due to APRS relying on an underlying AFSK method of encoding, the STEMCRaFT is utilizing a SA858 Walkie Talkie module that will broadcast the desired data on the 2M band. This signal will be amplified using an onboard SW-VHF200 Antenna, which is designed to perform well with signals on the 2M band.

STEMCRaFT Batteries



(a) Location of LiPo Batteries on STEMCRaFT (b) Commercial 2200mAh 2-Cell LiPo

Figure 4.4: 2200mAh LiPo Batteries on STEMCRaFT

The payload system will use two 2-cell 2200mAh LiPo batteries to power the various subsystems. The first LiPo battery will supply power to most of the electrical components on the STEMCRaFT. This battery will deliver power to the Raspberry Pi through a switching buck converter, which will then distribute power to the ESP32 and sensors. This power circuit will be isolated from the transmission power circuit to prevent brownouts that could result in mission failure.

The XBee Pro transceiver, SA858 Walkie Talkie module, and onboard fan are on the same power circuit. A split power system helps to keep the overall current draw low, avoiding damage to components, including the batteries. The separate batteries allow the electronics to remain operational for up to 10 hours in an idle state, with an estimated 3.85 hours under operating conditions. These batteries are mounted opposite of a majority of the electronics, sharing the same side with only the SA858 Module, and the pull pins.

Switches

The payload will utilize pull-pin switches to control the battery connection to the payload. This design allows the team to conserve battery power until the Launch Vehicle is positioned on the launch pad and ready for launch. Once the vehicle is ready, the team will pull the pin, which closes the circuit and provides power to the payload. The switches are rated to 5 amps each which means our system can handle 42 Watts on each independent circuit.

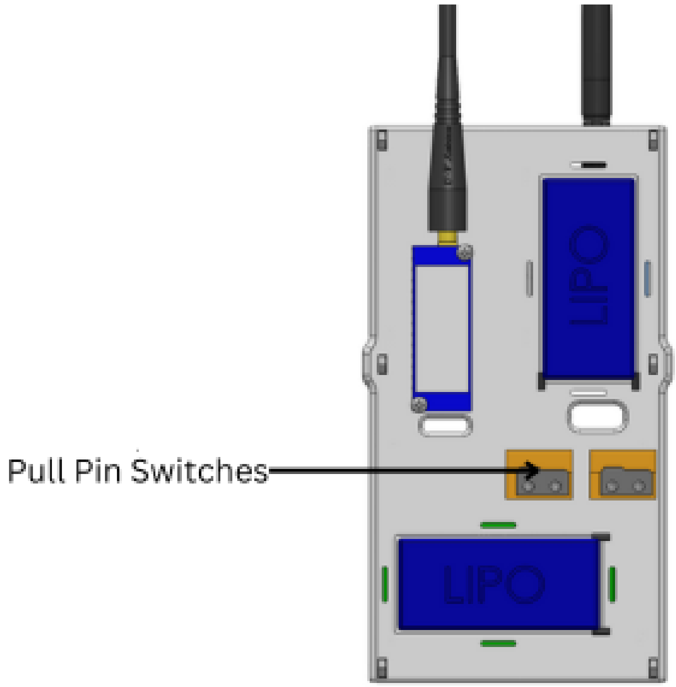
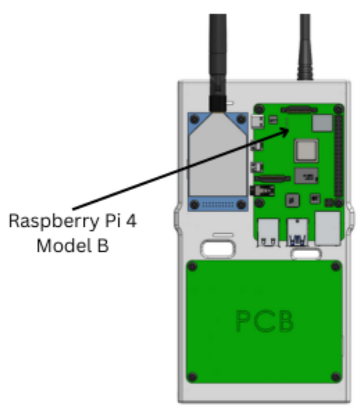


Figure 4.5: Enter Caption

Raspberry Pi 4 Model B



(a) Raspberry Pi located on STEMCRaFT

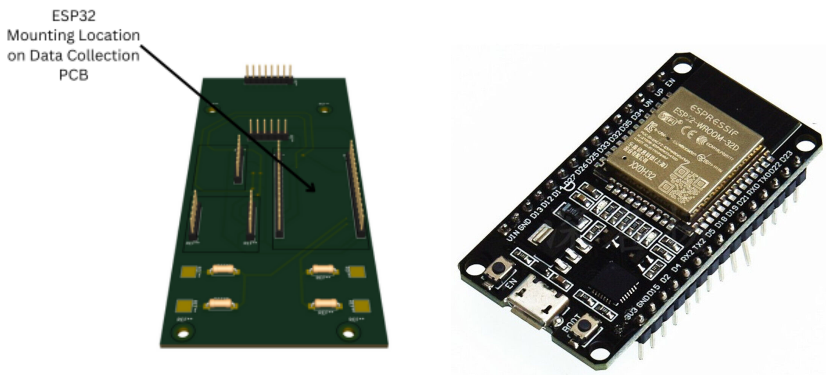
(b) Raspberry Pi 4 Model B

Figure 4.6: STEMCRaFT Primary Payload Computer

The primary payload computer is a Raspberry Pi 4 Model B. The Raspberry Pi serves as the primary computer responsible for handling computationally intensive calculations and processes. This includes storing sensor data sent through the ESP32, processing XBee external commands, and preparing and sending data to the transceiver. The estimated power draw for the Raspberry Pi is 540mA–1010mA, with the predicted draw expected to be closer to the lower end of this range due to an extended idle period prior to launch.

The Raspberry Pi was selected for its versatility and ease of user interaction, as discussed in the Preliminary Design Review. This enables the team to develop more robust software and avoid processing limitations that could interfere with team-derived requirements. Since the Raspberry Pi handles majority of the software and logic processes used in the STEMCRaFT, it is critical that the selected computer operates reliably and efficiently.

ESP32



(a) ESP32 located on Data Collection PCB

(b) ESP-WROOM-32

Figure 4.7: ESP32

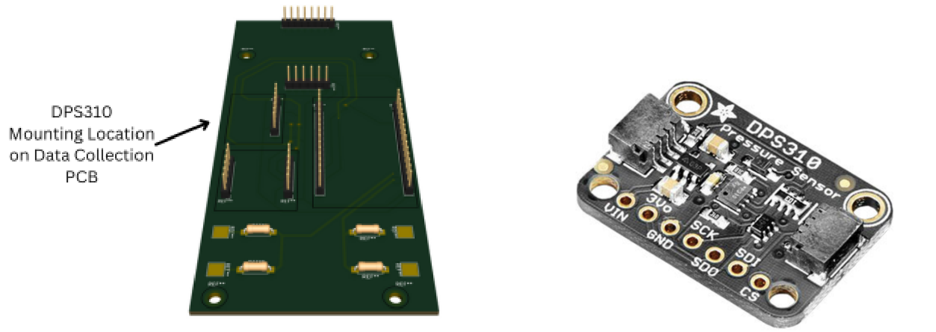
An ESP32 is included in the finalized STEMCRaFT design as a secondary processing unit. This addition represents one of the most significant changes between the Preliminary Design Review and the finalized STEMCRaFT design. The ESP32 was implemented for its ability to interface efficiently with the selected sensors and the Raspberry Pi.

The ES-32 enhances compatibility with a wide range of Adafruit sensors due to its clock-stretching capability, a feature lacking in the Raspberry Pi. Since most of our sensors are Adafruit products, the ESP32 ensures reliable data flow between the sensors and the processing units. While the ESP32 does not match the processing power of the Raspberry Pi, it functions as an intermediary, reading data from the sensors, performing minimal processing, and transmitting the information to the Raspberry Pi via a serial connection.

The ESP32 was selected as the secondary payload computer due to its superior performance compared to similar devices. Although Arduinos are commonly used for interfacing with sensors, they generally lack the same level of performance within a similar footprint. The ESP32's enhanced processing capability and compact size reduce the likelihood of processing bottlenecks.

The ESP32 consumes between 20mA and 68mA, depending on the selected performance mode. Similar to the Raspberry Pi, the ESP32 is expected to operate in a low-power mode prior to launch, resulting in an average power draw closer to the lower end of the range. Additionally, it is unlikely that the high-performance mode will be required for its processor, further reducing the expected average power consumption.

DPS310



(a) DPS310 located on Data Collection PCB

(b) Adafruit DPS310 Precision Barometric Pressure Sensor

Figure 4.8: Adafruit DPS310

The Adafruit DPS310 Precision Barometric Pressure Sensor serves as the STEMCRaFT's primary tool for determining the altitude and temperature at various points throughout the flight. The data from this device is read using the ESP32 and then sent to the Raspberry Pi for processing. The readings from this device are utilized in various ways to aid in the collection of the following data points:

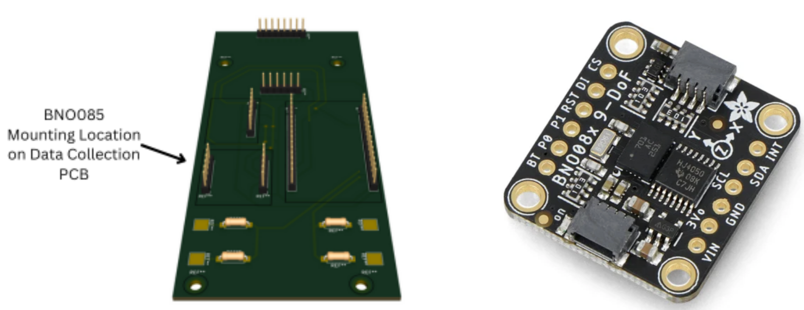
- Temperature of landing site
- Apogee reached
- Time of landing
- Maximum velocity
- Landing velocity, G-forces sustained
- Calculated STEMnaut survivability

The sensor is capable of providing relative pressure altitude and relative temperature readings within $\pm$6Pa(0.06m) and $\pm$0.5°C, respectively. This specified accuracy is well within the team-defined requirements for the STEMCRaFT. The accuracy and reliability of this sensor were verified through the team's Subscale flight, where it successfully recorded accurate data throughout the entire launch.

The DPS310 requires a power draw of up to 345μA when actively taking readings from its surroundings and operating in high-precision mode. Since this is the upper limit of its power draw, it provides a low-power solution for determining a number of data points required for transmission. Additionally, it occupies a small footprint of 1.00in × 0.70in × 0.18in.

Specification	Value
Power Draw (Active Mode)	345μA
Pressure Accuracy	$\pm$6Pa
Temperature Accuracy	$\pm$0.5°C
Dimensions	1.00in × 0.70in × 0.18in

BNO085



(a) BNO085 located on Data Collection PCB

(b) Adafruit BNO085 9-DOF IMU

Figure 4.9: Adafruit BNO085

The Adafruit BNO085 9-DOF IMU is the STEMCRaFT's means of measuring inertial properties, including the vehicle's velocity, acceleration, linear acceleration, rotation, and rotational acceleration. The data from this device is also read using the ESP32 and sent to the Raspberry Pi, similar to the DPS310. The data obtained from this device is utilized in determining the following data points:

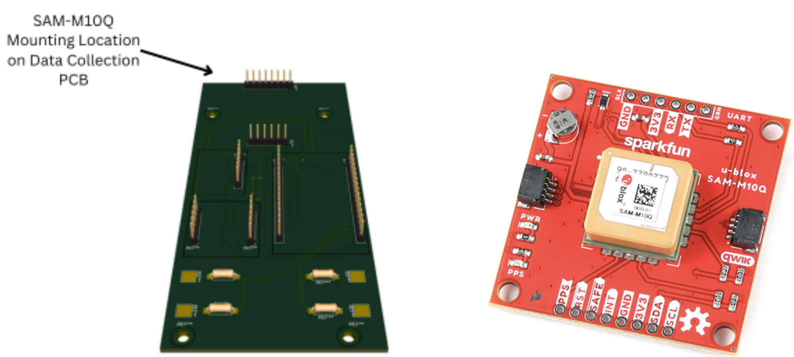
- Orientation of on-board STEMnauts
- Maximum velocity
- Landing velocity, G-forces sustained
- Calculated STEMnaut survivability

This sensor was utilized in the team's Subscale flight, where it was used to record acceleration, gyroscope, magnetometer, and quaternion data. The sensor is also capable of recording multiple other types of data that will aid in the process of obtaining accurate data for transmission. The BNO085 is capable of recording acceleration data and rotational data at up to ± 16g and ± 2000 deg $/s$, respectively. This fits well within the expected launch day parameters, was was suitable for the team's Subscale flight.

The BNO085 requires a power draw of between 0.4mA and 12.3mA, depending on the exact performance mode enabled. This measurement still indicates a low power draw, even if the sensor is performing at its highest operating levels. Similar to the Adafruit DPS310, this sensor also utilizes a relatively small footprint, taking up a 0.79in × 1.06in × 0.16in area, making it appropriately sized for use within the STEMCRaFT.

Specification	Value
Power Draw (Operating Range)	0.4mA–12.3mA
Acceleration Range	$\pm 16g$
Rotational Range	± 2000 deg $/s$
Dimensions	0.79in x 1.07in x 0.16in

SAM-M10Q



(a) SAM-M10Q located on Data Collection PCB (b) SAM-M10Q Chip Antenna Module

Figure 4.10: SAM-M10Q GPS Module

The SAM-M10Q Chip Antenna Module enables STEMCRaFT's ability to determine its location via GPS coordinates. This sensor is capable of determining the module's latitude, longitude, and altitude via satellite after a short startup period, depending on whether it is a cold or hot start. This sensor is relatively specialized, providing data relevant only to the following data point:

- Coordinates for approximate landing location

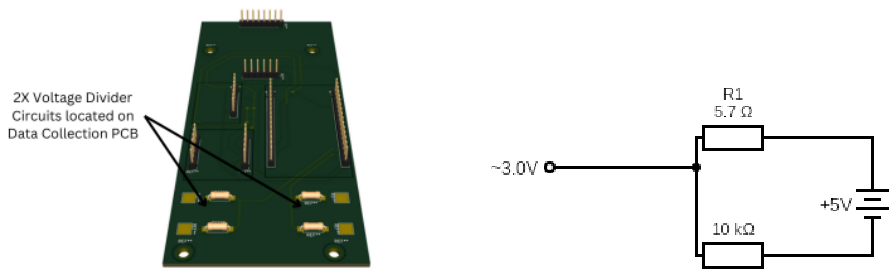
The SAM-M10Q is capable of obtaining a lock within 23 sec during a cold start and within 1 second during a hot start. Additionally, the SAM-M10Q may achieve a hot start if it has received power within the prior 4 hours, due to its onboard battery. This feature enables the STEMCRaFT to achieve a hot start on the pad, increasing the likelihood of obtaining a proper fix.

This GPS module can report the horizontal accuracy of the payload within approximately 1.5m and also provides the payload's altitude determined through GPS. For the purposes of the STEMCRaFT, the payload will only utilize the longitude and latitude data to determine the approximate landing coordinates.

The power draw of this module is up to 13mA while obtaining a fix and 10mA while continually tracking. Additionally, it is the largest of the onboard sensors, with a footprint of 1.6in × 1.6in x 0.2in.

Specification	Value
Cold Start Time	23 sec
Hot Start Time	1 second
Hot Start Retention Time	Up to 4 hours
Horizontal Accuracy	1.5m
Power Draw (Fix)	13mA
Power Draw (Tracking)	10mA
Dimensions	1.6in × 1.6in

Voltage Sensor



(a) Voltage Drop Circuits located on Data Collection PCB

(b) Voltage Drop Circuit Diagram

Figure 4.11: Voltage Sensor

The STEMCRaFT will utilize a simple built in voltage sensor circuit to monitor the power levels of the LiPo batteries. These sensors are constructed using simple voltage drop circuits that the ESP32 may read to determine the remaining charge in the LiPo. This is a specialized sensor that will yield data useful to determine the following data point:

- Battery Check/Power status

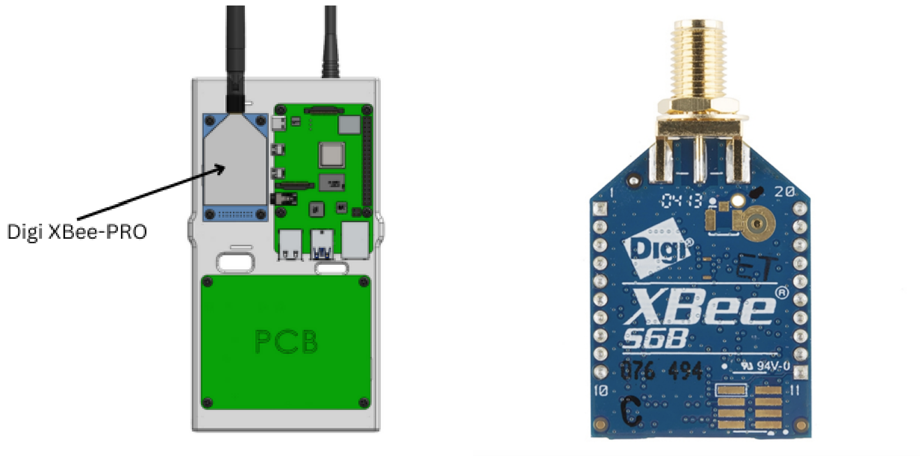
This sensor works by utilizing two resistors between the V_{in} and $Ground$ of a circuit, with an analog pin placed in the middle. This completes a voltage divider circuit that reduces the raw LiPo voltage down to a range which is acceptable by the ESP32, in this case 3.3V. Since the power sources are 2 cell LiPo batteries, the maximum and minimum charge voltages of 8.4V and 7.4V respectively are used to determine how much the voltage must be dropped.

$$V_{out} = \frac{Vin * R_1}{R_1 + R_2} \Rightarrow \frac{R_1}{R_1 + R_2} = R_{ratio} \tag{27}$$

Eqn. 27 yields the required ratio of resistors, which then allows for their resistances to be chosen. The size of the resistors allows the current to be controlled and which prevents overheating the circuit. The implementation of these circuits onto the sensor electronics PCB is detailed in 4.4.

These voltage sensor circuits produce negligible power draw on the system, since the only additional draw is the ESP32 reading additional data. The footprint is also negligible because it is primarily the footprint of resistors on the PCB, where they are capable of being placed under the other sensors due to their flat profile.

XBee Pro



(a) XBee Pro located on STEMCRaFT (b) Digi XBee Pro S3B

Figure 4.12: XBee Pro

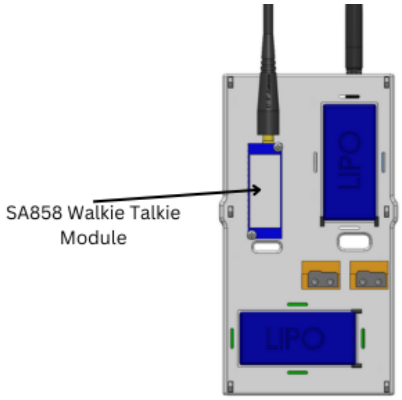
The STEMCRaFT will feature a Digi XBee Pro S3B transceiver in order to receive commands from the ground station over the UHF frequency band. This will allow the team to deliver commands to the STEMCRaFT remotely on launch day, ensuring that the transmission system functions as intended. The XBee operates in the 900MHz frequeny range, which means that the XBee will not share the same band as the primary transmission, avoiding any potential interference. The XBee has an operational RF range of up to 9 miles in flat outdoor conditions, such as those expected at launch fields.

The XBee will be powered by the same battery as the SA858 transmitter, separate from the rest of the payload electronics. This will aid in distributing the power load, and ensuring that the STEMCRaFT has sufficient power capacity for the mission timeline. The XBee has a power draw of up to 25mAh when receiving and up to 215mAh when transmitting. The STEMCRaFT will be utilizing the XBee as purely a receiver, since the SA585 will be serving as the primary transmitter. Since the XBee will only be acting as a receiver, we can expect the power draw to be roughly 25mAh throughout the mission.

The XBee will be mounted on the front side of the STEMCRaFT, opposite of the SA585 as indicated in Figure 4.2.1. This will assist in shielding the transceivers from each other, minimizing any potential interference that they may experience from each other. Additionally, the XBee will be utilizing a rubber ducky antenna, which provides a relatively compact antenna as opposed to more traditional antennas. The XBee occupies a 0.866” x 0.960” x 0.270” footprint, not including the rubber ducky antenna.

Specification	Value
Frequency Band	900MHz
Operational RF Range	Up to 9 miles (flat outdoor conditions)
RX Power Draw	25mAh
Antenna Type	Rubber ducky antenna
Dimensions (Without Antenna)	0.866” × 0.960” × 0.270”

SA858 Transmitter



(a) SA858 located on STEMCRaFT

(b) SA858 Walkie Talkie Module

Figure 4.13: SA858 Transmitter

The NiceRF SA858 module will serve as the STEMCRaFT's transmitter over the 2M band. The SA858 will be configured to transmit on the 2m frequency for APRS as assigned by NASA.

The SA858 is capable of transmitting between the 134MHz and 174MHz frequencies, meaning it covers the entire NASA USLI frequency range. The module features a built in PA circuit which can produce up to 4 watts of power, staying well within the competition requirements.

The SA858 will be mounted opposite the XBee and will have an antenna in order to help transmit the signal. It is mounted opposite the majority of the payload electronics, such as the Raspberry Pi, sensors, and XBee, in order to minimize any potential signal interference. The SA858 is 2.32″ × 0.82″ × 0.2″ not including the antenna. Since the SA858 is located on the opposite side of the STEMCRaFT, it leaves plenty of room for its larger footprint.

The SA858 may produce a power draw of up to 1500mAh while transmitting in high power mode, making it the highest power draw component on the STEMCRaFT. As such, the module is on a separate battery from most of the other components, only sharing a battery with the XBee. While the STEMCRaFT should only be transmitting for a short duration, it is crucial that the transmitter has sufficient power to produce a signal, even if the other components have drained a large amount of power by the time the transmission begins. As such, this component was given its own battery to help eliminate any power concerns related to transmission.

Specification	Value
Frequency Range	134MHz–174MHz
Transmission Power	Up to 4W
TX Power Draw (High Power Mode)	1500mAh
Dimensions (Without Antenna and Filter)	2.32″ × 0.82″ × 0.2″

SW-VHF200 Antenna

The SW-VHF200 is a straight rod antenna optimized for the 150 MHz frequency range, boasting a compact and efficient design with a height of 202±2 mm and weighing 23 grams. With a VSWR of less than or equal to 1.5, it ensures minimal signal reflection and maximized performance, which is critical for maintaining strong and reliable communications. The antenna provides a gain of 2.15 dBi and supports a maximum power input of 10 watts, making it suitable for various applications requiring moderate signal amplification.

This model is designed with vertical polarization and omni-directional radiation, offering consistent signal coverage in all directions, which is ideal for general VHF applications. The robust SMA-J interface facilitates easy installation ensuring long-term stability and performance. This antenna has been tested with a Network Analyzer in a simulated wireless environment to confirm its specifications and performance metrics.

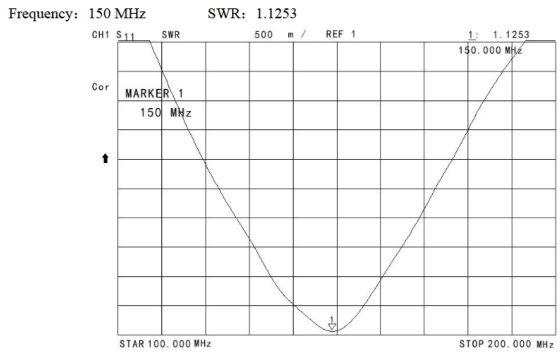


Figure 4.14: SWR chart of the SW-VHF200 antenna by NICERF.

Adafruit 5V Fan

Figure 4.15: Adafruit 5V Fan

In the finalized STEMCRaFT design, a small fan will be mounted inside the capsule to provide airflow throughout the STEMCRaFT. This will allow the sensors to have more consistent access to the outside air for landing site conditions such as pressure and temperature. The selected fan module is low-power draw and non-adjustable, meaning it will operate throughout the entire mission.

To enable the fan to draw in new air, the capsule and Nose Cone have small holes or slots included. These openings allow air from within the capsule to be blown out of the STEMCRaFT and new air to be drawn in. This airflow ensures that the DPS310 can obtain more accurate readings of temperature and pressure, subsequently providing more precise data for transmission. The fan component has a power draw of 200mA and occupies a footprint of 1.2” × 1.2” × 0.4”.

Specification	Value
Power Draw	200mA
Dimensions	1.2” × 1.2” × 0.4”
Justification	Improves accuracy of temperature and pressure data

LM2596 Switching Buck Converter

Figure 4.16: LM2596 Switching Buck Converter

The LM2596 Switching Buck Converter is the selected voltage regulator that will be used throughout the STEMCRaFT. Due to the selection of electronics utilized within the STEMCRaFT, there are two different voltage logic levels being used. As the required voltage differs between devices, the STEMCRaFT contains multiple LM2596 Switching Buck Converters that are used throughout the STEMCRaFT as necessary.

The LM2596 Switching Buck Converter is configurable and may provide a power output of between 3.3V and 37.0V, and taking an input of up to 40V. Since the STEMCRaFT electronics operate on either the 3.3V logic level or the 5V logic level, this converter can achieve voltage outputs compatible with every electronic device onboard the STEMCRaFT. Additionally, 40V far exceeds the output of the 2 cell LiPo batteries utilized as power sources.

As this is a switching buck converter, it provides a more efficient form of bucking in comparison to a linear converter. This results in minimizing any power losses that would normally be associated with power conversion. Each LM2596 is 45 mm x 20 mm x 14 mm and will be mounted inside the capsule, onboard the electronics sled.

Table 4.2: Key Specifications of the LM2596 Switching Buck Converter

Specification	Value
Input Voltage Range	Up to 40V
Output Voltage Range	3.3V–37.0V
STEMCRaFT Logic Levels Used	3.3V and 5V
Converter Type	Switching Buck Converter
Dimensions	45 mm × 20 mm × 14 mm

Power Draw

Included below are the power estimates for each battery and its connected components. These estimates are used to provide a theoretical calculation of battery life prior to VV&T verification. As discussed in the component overviews, the majority of the electrical components are connected to the same battery as the Raspberry Pi, with the remaining electronics (the SA858 and XBee) connected to the secondary battery. Both batteries are 2-cell 2200mAh LiPo batteries and are expected to have a battery life of approximately 4 hours.

Table 4.3: Power Draw for Battery 1

Component	Power Draw
Raspberry Pi 4 Model B	540mA–1010mA
ESP32	20mA–68mA
DPS310 Barometric Sensor	345μA
BNO085 IMU Sensor	0.4mA–12.3mA
SAM-M10Q GPS Module	10mA–13mA
Voltage Sensor	Negligible

Shown in Table 4.3 is the power draw for the devices powered by the first LiPo battery. Based on estimates, this results in a total power draw of 570.7mA at minimum and 1103.6mA at maximum, providing a theoretical lifespan of 3.85 hours at the minimum expected power draw and 2 hours at the maximum expected power draw. Since the STEMCRaFT is unlikely to reach maximum power draw frequently, it is likely that the actual battery lifespan will be closer to the upper band of 3.85 hours. These theoretical calculations indicate that the battery will be sufficient for the mission.

Table 4.4: Power Draw for Battery 2

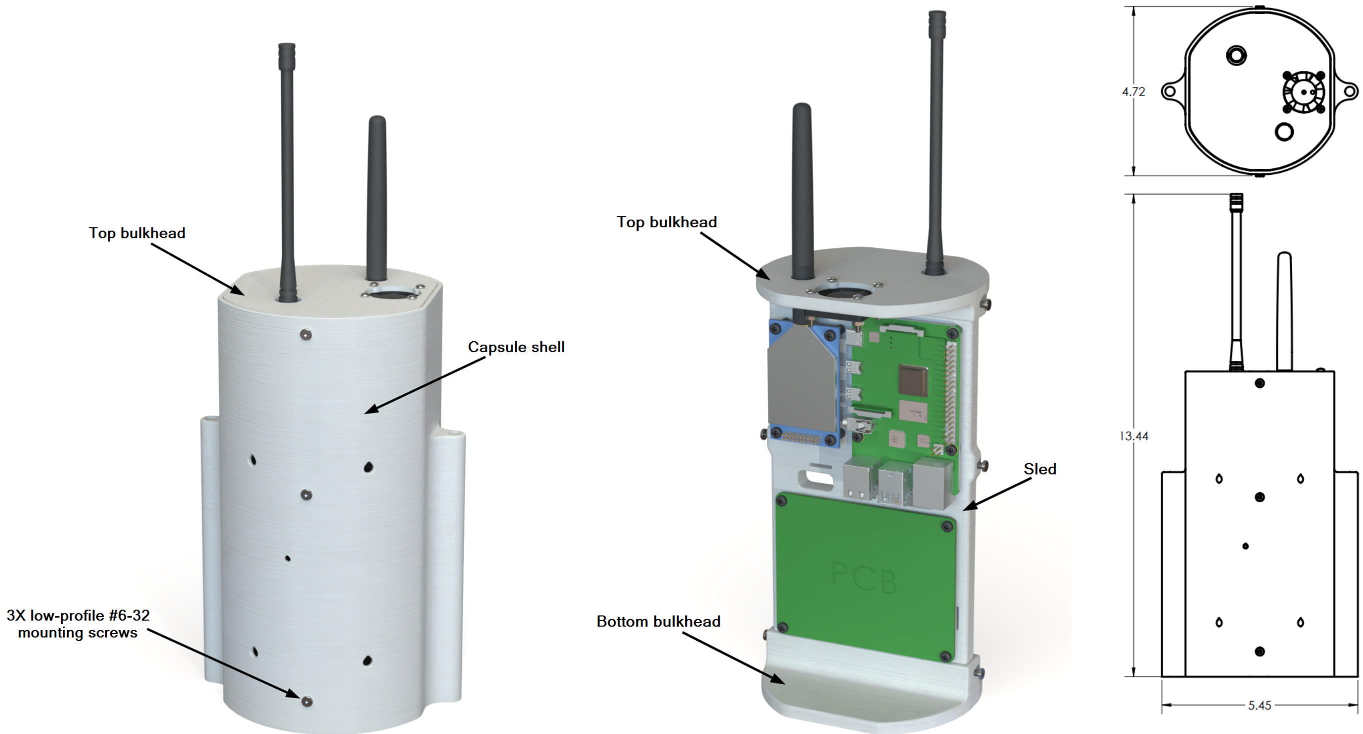
Component	Power Draw
SA858 Transmitter	Up to 1500mA
XBee Pro Transceiver	25mA
Fan Component	200mA

Shown in Table 4.4 is the expected power draw for the second battery, which powers the transceiver, receiver, and onboard fan. Similar to the analysis of the first battery, this battery is expected to experience a power draw between 225mA and 1725mA, depending on whether the STEMCRaFT is actively transmitting. These values correspond to a battery life of 1.28 hours at maximum draw and 9.78 hours at minimum draw. Since transmission will occur only briefly after landing, the battery should experience significant drain for only a few minutes, resulting in an average draw much closer to 225mA and a battery life closer to 9.78 hours.

These battery life estimations provide support for the battery having sufficient capacity for the STEMCRaFT's expected operational period. However, further validation will be performed through VV&T testing, as described later in Section 7.2.

4.2.2 Structures

Capsule Overview



(a) STEMCRaFT with capsule shell.

(b) STEMCRaFT without capsule shell.

(c) STEMCRaFT dimension drawing (in.)

Figure 4.17: STEMCRaFT design.

The STEMCRaFT is a self-contained system housed within the Nose Cone during flight. It is comprised of four primary structural components: the capsule shell, sled, bottom bulkhead, and top bulkhead. The electronic components are mounted on the sled, which is securely enclosed within the STEMCRaFT by bulkheads that sit flush with the edges of the capsule shell. The overall dimensions of the STEMCRaFT are illustrated in Figure 4.17c above.

Capsule Shell

The capsule shell houses all hardware and electrical components of the STEMCRaFT and interfaces with the Nose Cone to secure the system during flight. Its design maximizes usable space within the STEMCRaFT while ensuring compatibility with the Nose Cone's permanent ring bulkhead. Additional details about the bulkhead are provided in Section 3.2.4.

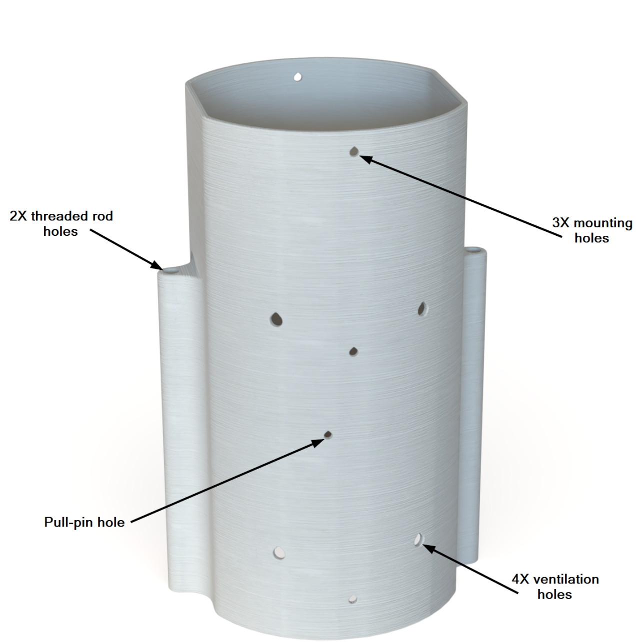
Two elongated holes on the capsule shell's sides allow it to be secured to the permanent threaded rods inside the Nose Cone. Three holes on the front and back facilitate mounting the sled and bulkheads to the capsule shell using six low-profile #6-32x1/2" screws. These screws interface with embedded nuts on the sled's sides. A low-profile screw was selected to maximize the capsule's internal space, as the top two screws must pass through the permanent ring bulkhead.

Two ventilation holes on each curved face of the capsule shell allow air circulation for accurate temperature measurement. The capsule shell's dimensions are illustrated in Figure 4.18b above.

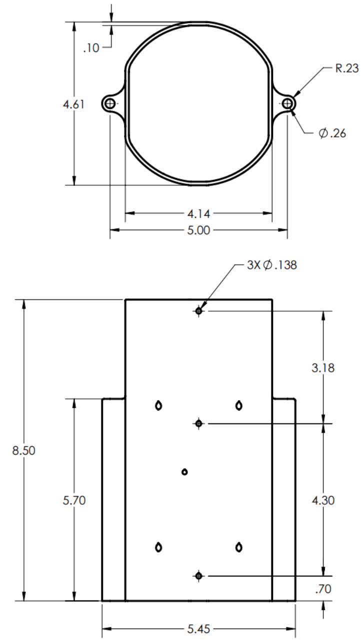
The sled serves as the mounting platform for all electronic components within the STEMCRaFT. One side of the sled houses the XBee, Raspberry Pi, and a custom PCB that integrates the data collection sensors. The opposite side accommodates the antenna, two batteries, and two pull-pin switches. The antenna is on the opposite side of the electronics to minimize potential interference.

Sled

On the antenna side, the sled features three slots on each side to hold #6-32 nuts, which secure the sled and bulkheads to the capsule shell. Additionally, two central slots allow wiring to pass between the two sides. The sled dimensions are illustrated in Figure 4.20 below.

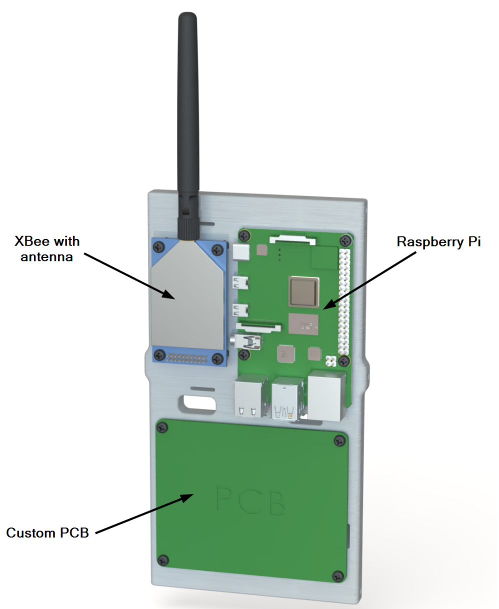


(a) Capsule shell.

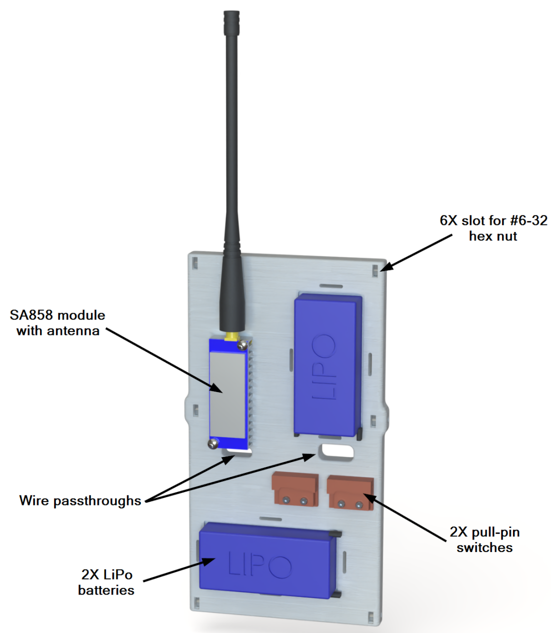


(b) Capsule shell dimension drawing (in.)

Figure 4.18: Capsule shell and dimensional drawing.



(a) Electronics side of the sled.



(b) Antenna side of the sled.

Figure 4.19: Payload sled.

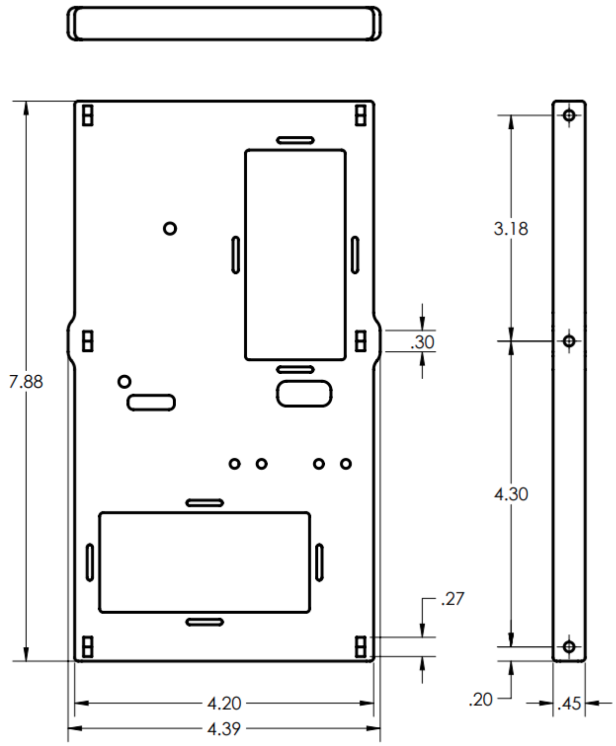


Figure 4.20: Sled dimension drawing (in.)

Bottom Bulkhead

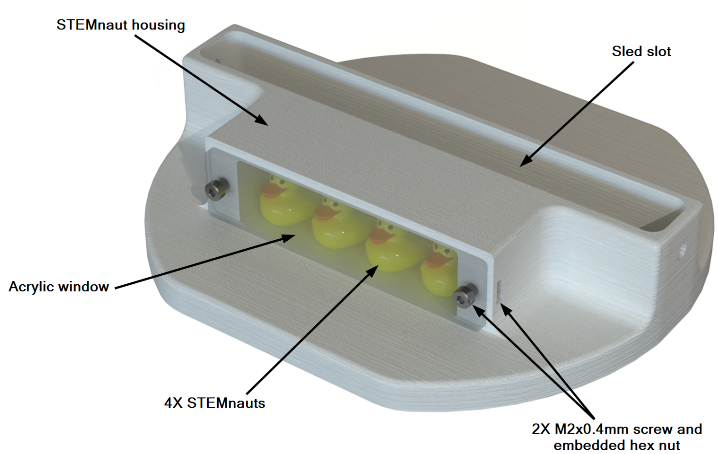


Figure 4.21: Bottom bulkhead.

The bottom bulkhead is located at the aft end of the STEMCRaFT and includes a slot to hold the sled. Together with the top bulkhead, it helps seal the capsule. The bottom bulkhead also houses the four STEMnauts, which are secured in place with Velcro at the base of the housing. Small resin ducks will be used for STEMnauts, as they previously flew on the team's SAIL in the 2023-2024 NASA Student Launch Competition. An acrylic window seals the housing, attached with two M2x0.4x6mm screws fastened to corresponding M2x0.4mm nuts embedded in the housing sides.

Additionally, the bottom bulkhead features a cutout at its aft end to accommodate the bracket and two nuts that attach to the U-bolt on the removable Nose Cone bulkhead. This design ensures the STEMCRaFT sits flush with the top of the removable bulkhead, allowing forces exerted on the base of the STEMCRaFT to be distributed over a larger area. The bottom bulkhead's dimensions are illustrated in Figure 4.22 below.

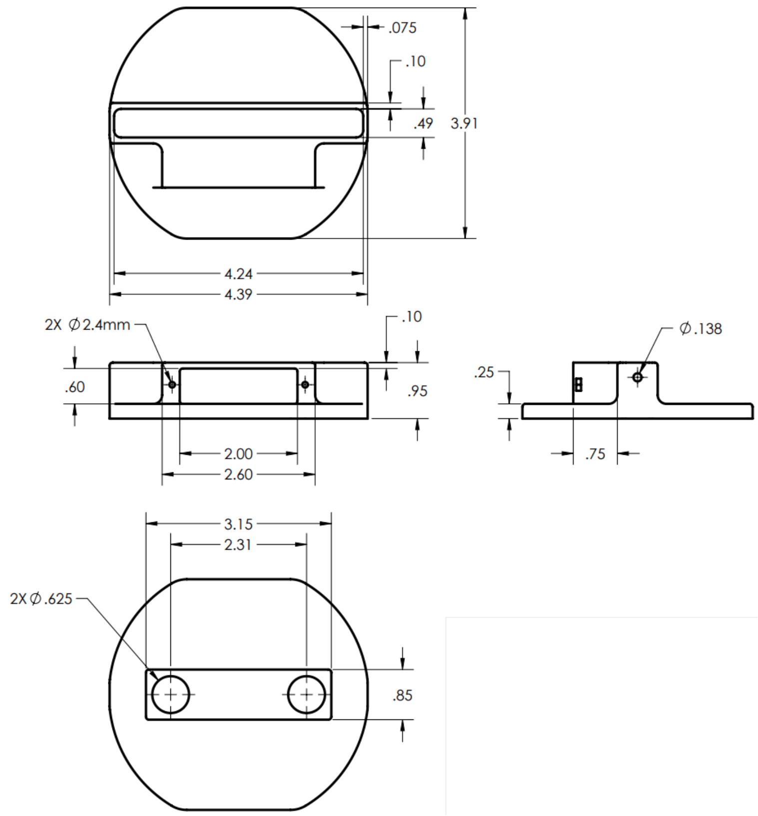
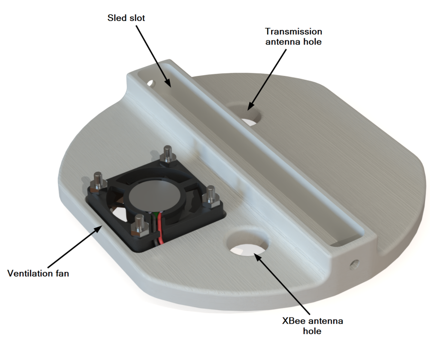
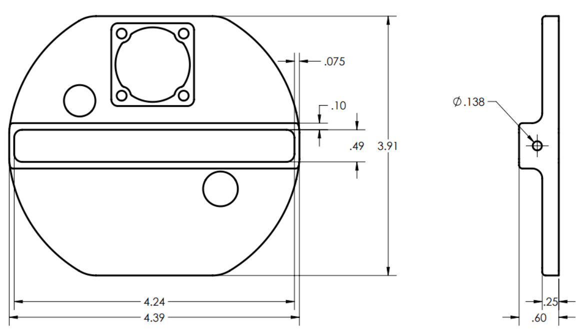


Figure 4.22: Bottom Bulkhead Dimension Drawing (in.)

Top Bulkhead



(a) Top bulkhead.



(b) Top bulkhead dimension drawing (in.)

Figure 4.23: Top bulkhead and dimensional drawing.

The top bulkhead seals the capsule at the top, using the same method as the bottom bulkhead. It includes two openings for the antennas to extend outside the STEMCRaFT. Additionally, a cutout is provided for a small cooling fan, which will be mounted using four M2.5x0.45mm screws and the corresponding hex nuts. The top bulkhead's dimensions are illustrated in the Figure 4.23b above.

Retention System

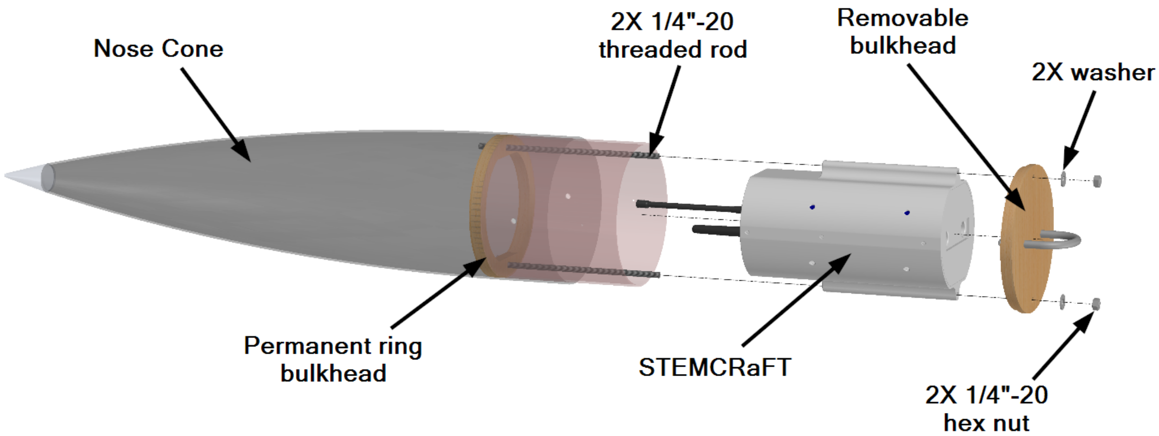
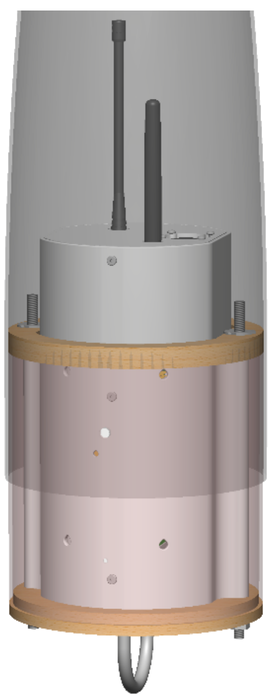


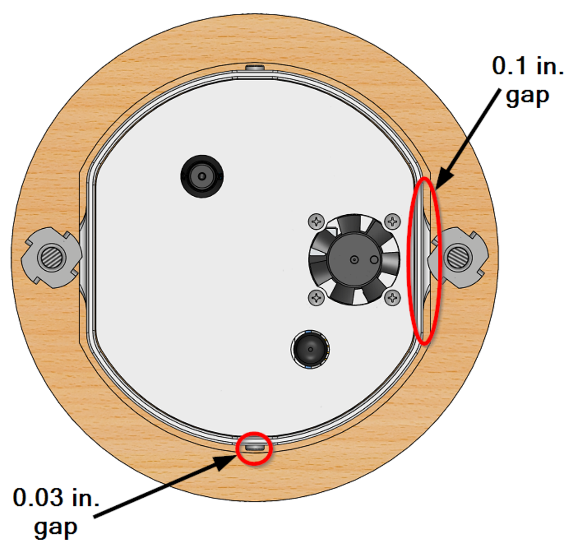
Figure 4.24: Exploded view of STEMCRaFT and Nose Cone.

The STEMCRaFT is secured inside the Nose Cone using two permanent threaded rods and the removable bulkhead. The threaded rods prevent the STEMCRaFT from rotating within the Nose Cone. Two side extrusions on the STEMCRaFT sit flush with the bottom of the Nose Cone's ring bulkhead, while the bottom of the STEMCRaFT rests flush against the top of the removable bulkhead, preventing axial movement. The removable bulkhead is fastened with two hex nuts and washers on the threaded rods.

Integration



(a) STEMCRaFT inside the Nose Cone.



(b) Top view of STEMCRaFT inside the Nose Cone.

Figure 4.25: STEMCRaFT integration into the Nose Cone.

The STEMCRaFT is fully contained within the Nose Cone, with ample clearance between the antennas and the Nose Cone body. A 0.1-inch gap exists between the STEMCRaFT body and the Nose Cone's permanent ring bulkhead, facilitating easy integration. The clearance between the low-profile mounting screw and the permanent ring bulkhead is 0.03 in.; however, only one set of screws will pass through this area. The clearance between the STEMCRaFT and Nose Cone is shown in Figure 4.25b above.

Pull-pin Locations

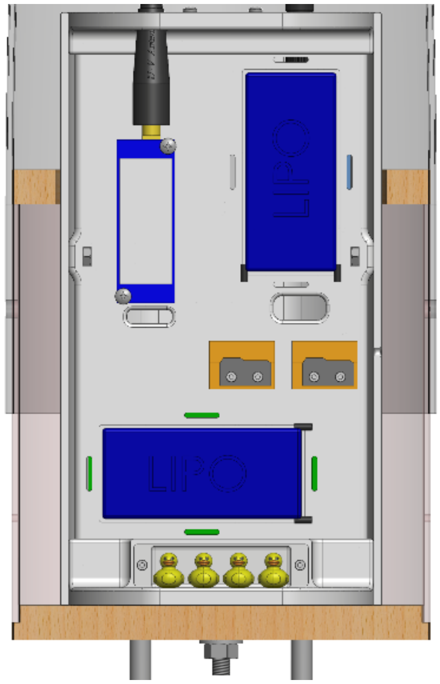


Figure 4.26: Section view of STEMCRaFT inside of the Nose Cone showing the location of pull-pin switches.

The two pull-pin switches are mounted on the Sled inside the STEMCRaFT. They are aligned to enable activation using a single pull-pin for both switches. The pull-pin will need to pass through the Nose Cone and capsule shell once the STEMCRaFT is fully integrated into the Launch Vehicle.

4.2.3 Software

State Machine

The STEMCRaFT's functionality will be driven by a finite state machine (FSM) that progresses through different states as the mission advances. The FSM will enable the STEMCRaFT to determine whether it should perform certain tasks, such as transmitting and recording data, depending on the current stage of the flight. This method was selected as the primary software design due to its ability to function dynamically and autonomously based on sensor data.

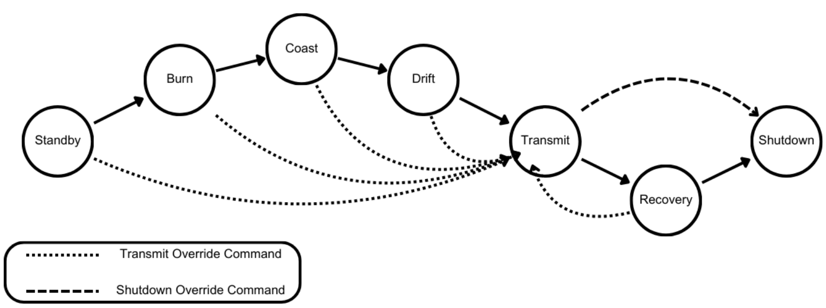


Figure 4.27: Finite State Machine Diagram.

Shown in Figure 4.27 is an overview of the various states utilized by the onboard computer. Additionally, the manual override jumps triggered by the XBee are shown. These jumps occur when the ground station sends a command for the STEMCRaFT to immediately transition to a specific state. Manual override jumps serve as a fail-safe in case the FSM fails to proceed nominally. The states used include:

- 1. Standby (Launchpad)
- 2. Burn
- 3. Coast
- 4. Drift
- 5. Landed/Transmission
- 6. Recovery
- 7. Shutdown

Additionally, by using a finite state machine, the team can more easily change transition parameters and the functionality of the STEMCRaFT throughout its flight. This added control allows the software to be fine-tuned and enables certain systems to be activated or deactivated at different points during the flight. The exact functionality of each state is defined further in 4.3.

Direwolf

Direwolf is a software-based terminal node controller that will serve as the STEMCRaFTs means of encoding the transmission data. This software serves as a ”software based” sound card that allows for the Raspberry Pi to generate an APRS signal that can be delivered to the SA858 for transmission. Using Direwolf, the process of encoding data is vastly simplified and more reliable.

NiceRF is a company well known for making a large variety of RF devices/modules and other wireless communication tools. One of the key factors that led to the selection of the SA858 as the STEMCRaFT's transmitter was the software available to configure their devices. Since the STEMCRaFT will utalize a NiceRF SA858 as the primary transceiver, the team will be able to use their provided software to configure the transmitter.

NiceRF software is designed to customize the functionality of NiceRF products, including the SA858 transceiver. This software provides an interface that allows various transmission settings to be configured prior to the transceiver's use on the STEMCRaFT. For the STEMCRaFT, the software will be used to configure the SA858 to operate on the desired frequency, set transmission power levels, and establish the APRS format for compatibility with the data being delivered to the SA858. Using the NiceRF software, the process of configuring the SA858 is greatly simplified.

4.3 Payload Functionality and CONOPS

4.3.1 Mission

Included in the following section are brief descriptions of the major functional systems involved in the operation of the STEMCRaFT. These functions involve the overall mission, the onboard electronics system, and the ground station. Each of these systems contribute to the overall success of the payload in its mission and contribute specific functionalities relevant to the STEMCRaFTs success.

The purpose and function of each subsystem and its related operation are described in further detail in the following sections.

Payload Flight CONOPS

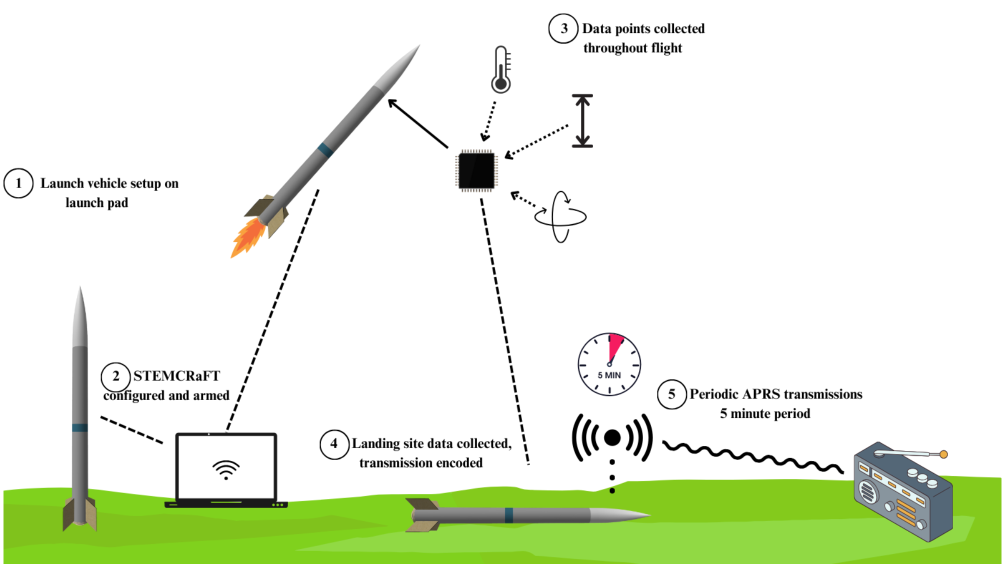
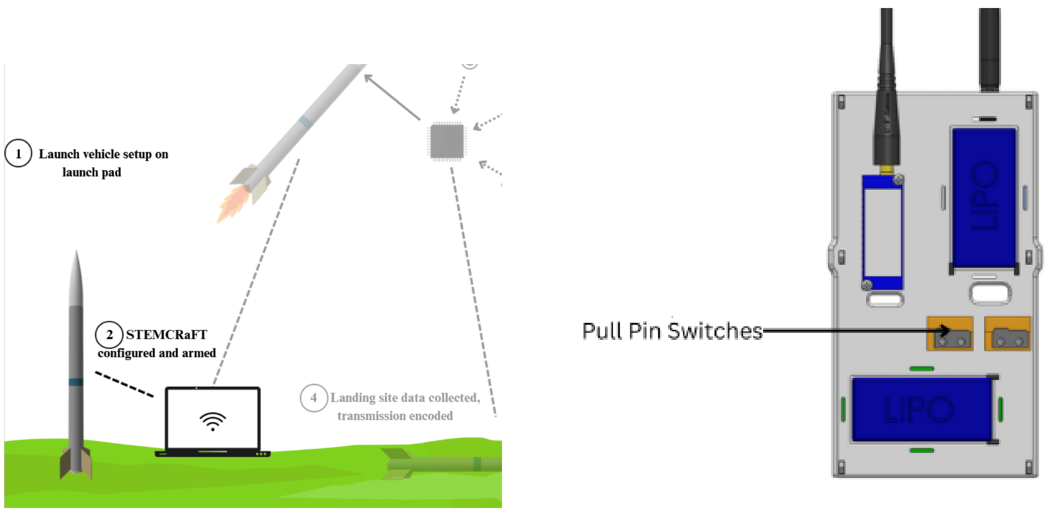


Figure 4.28: STEMCRaFT Mission CONOPS

Shown in Figure 4.28 is an overview of the STEMCRaFTs mission. This diagram contains the high-level overview of the STEMCRaFT's design, and how it will accomplish the NASA SL designated challenge. The detailed breakdown of the onboard electronics and the ground station are detailed further in the STEMCRaFT functionality and Ground Station functionality sections.

As indicated in the STEMCRaFT Mission CONOPS, the overall STEMCRaFT mission design necessitates the use of multiple stages that the mission must be designed for. These stages include the initialization and setup of the STEMCRaFT, performed on the launch pad; the operational flight period, where the payload is responsible for recording data; the transmission period, where the STEMCRaFT will transmit the data recorded; and lastly, the shutdown phase, where the STEMCRaFT will log any remaining data and shutdown while it awaits recovery.

The first stage, the launch pad and initialization phase, involves the process of arming and initializing the STEMCRaFT's software. Once the Launch Vehicle has been transported to the launch pad, the pull pins are removed, and the STEMCRaFT will be configured via software. This is required to ensure that the STEMCRaFT electronics are properly functioning, and that the transmission occurs as expected.



(a) Launch Pad and Initialization on CONOPS (b) Pull Pins location on STEMCRaFT

Figure 4.29: Launch Pad and Initialization

During the process of initialization, the team will run a short program that verifies the connection of all sensors onboard, and their connection to the Raspberry Pi. Additionally, one of the team members will enter their HAM radio call sign that will be utilized in the STEMCRaFT's transmission. After verifying the connection of components, and inputting a team members call sign, the launch software will be initialized and the STEMCRaFT will be armed for launch.

The next stage, the launch stage, will begin once the vehicle has detected a sufficient impulse. During this stage the onboard system will begin recording data obtained throughout the flight and recording a flight log. This stage is where the payload will experience the highest power draw, as it will be recording data points frequently and at a high level of precision. This will allow the STEMCRaFT to have high quality data that may be used in the transmission. This stage will persist until the STEMCRaFT has landed, at which point it will progress stages.

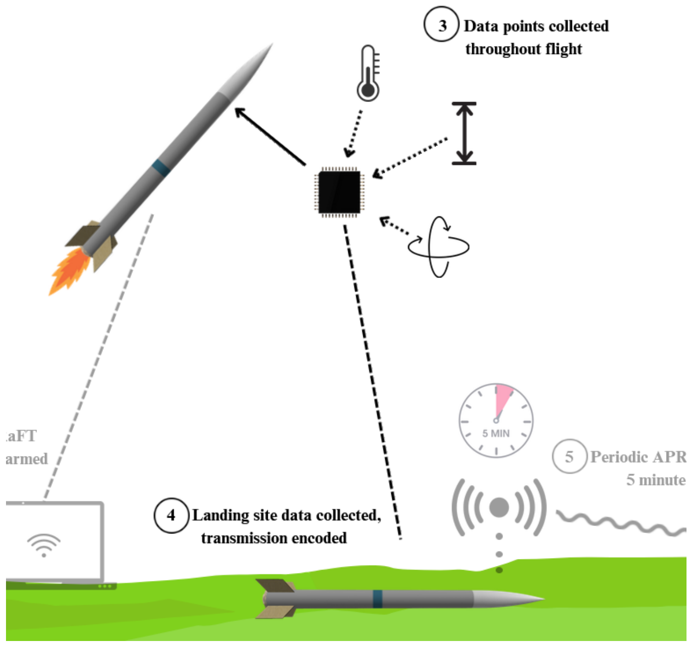


Figure 4.30: Flight and Landing Data Collection

Upon landing, the STEMCRaFT will begin recording data points related to the conditions of the landing site. These data points are required for the transmission data used by the STEMCRaFT. This stage will accomplish multiple goals of recording the final required data points prior to transmission, and providing a safety buffer for transmission. By ensuring this stage has a minimum duration, the team can safely test and prepare the payload software prior to launch, without concern of beginning a transmission prior to the competition landing.

Lastly, after the STEMCRaFT has obtained the necessary flight and landing site data, the system will progress to the transmission state. In this state, the STEMCRaFT will begin sending data to it's onboard transmitter where it will be transmitted on the 2M band in the APRS format. This will create a signal that will be receivable by the NASA FTM-300DR receiver at competition distances. This transmission will include the following data points:

- Temperature of landing site
- Apogee reached
- Battery check/power status
- Orientation of on-board STEMnauts
- Time of landing
- Maximum velocity
- Landing velocity, G-forces sustained
- Calculated STEMnaut crew survivability
- Approximate landing coordinates of STEMCRaFT

The transmission containing the above data points will occur multiple times across a 5 minute period. After the transmission period has elapsed, the STEMCRaFT will enter a shutdown state. Immediately before shutting down, the STEMCRaFT will log important flight metrics and stage timings for future reference. In the shutdown state, the STEMCRaFT will cease all functionality, with the exception of reading XBee received signals, and await field recovery by the team. Once the STEMCRaFT is recovered, the pull-pins will be inserted, and the STEMCRaFT will fully powered down.

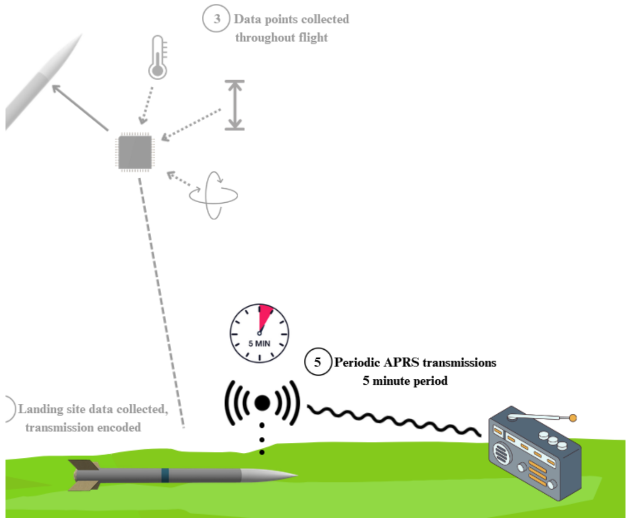


Figure 4.31: STEMCRaFT Transmission

4.3.2 STEMCRaFT

STEMCRaFT Onboard Systems CONOPS

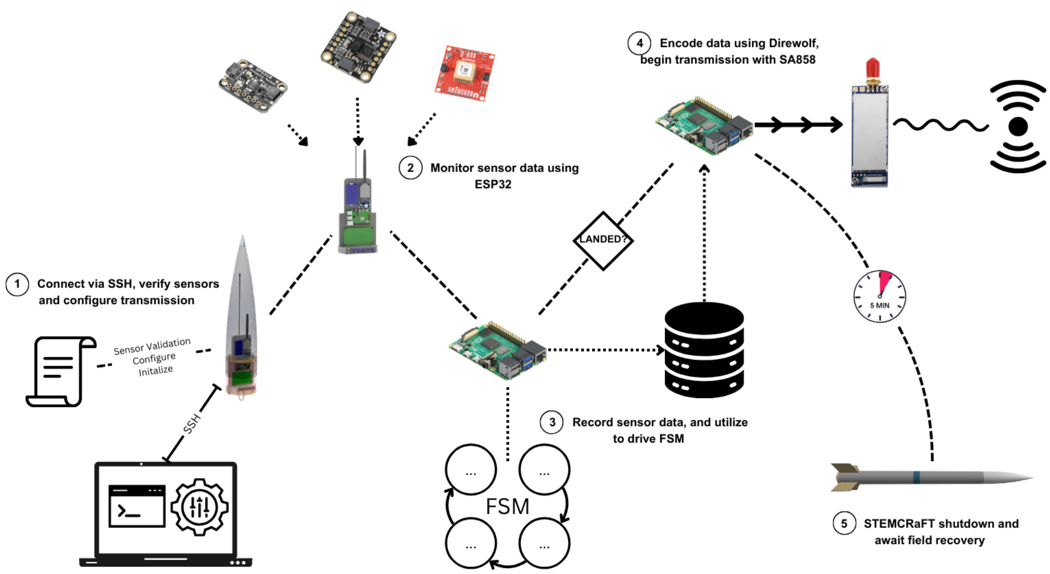


Figure 4.32: STEMCRaFT Onboard Systems CONOPS

As discussed previously in 4.2.3, the onboard payload system operates primarily off a finite state machine (FSM) that dictates the functionality of the payload. This finite state machine progresses through the following states:

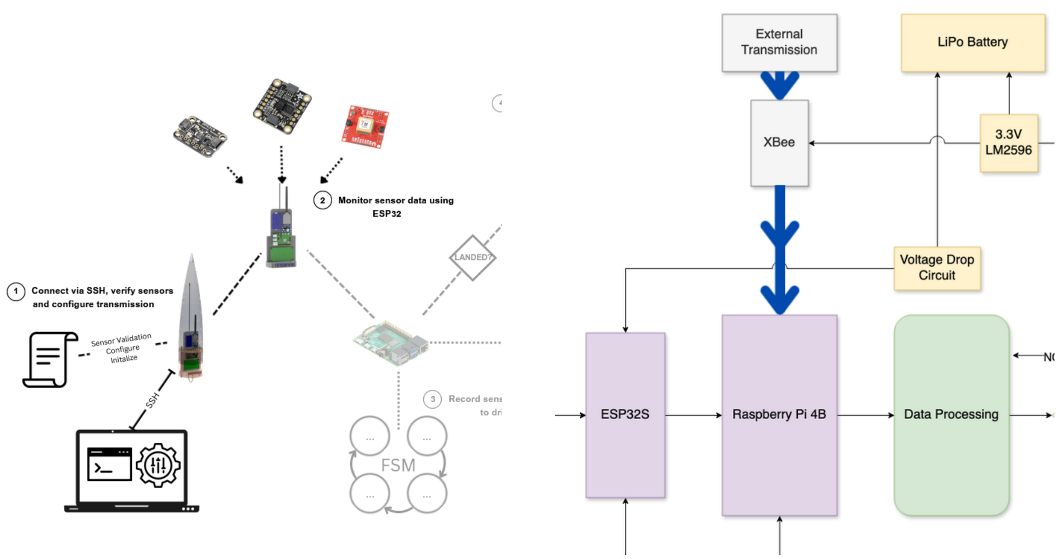
1. Standby (Launchpad)
2. Burn
3. Coast
4. Drift
5. Landed/Transmission
6. Recovery
7. Shutdown

The team will initialize the payload to its standby state, where it will function minimally to preserve power. During the initialization process, the team will configure multiple parameters related to the payload's performance. This will be performed through the team's interaction with the payload program via prompts. The payload will prompt for the following prior to entering the standby state:

- Transmission Enabled: [Y/N]
- Transmission Call Sign: [######]
- Call Sign Member Present: [Y/N]
- ESP32 Com Port: [######]
- XBee Com Port: [######]

Using the inputs displayed, the team will configure the transmission and the communication ports used by other hardware components. Additionally, these inputs allow the payload to function without certain components and functionalities. This provides flexibility for testing specific subsystems and features. The risk of accidental transmission is mitigated by requiring that a member enter their call sign and verify their presence each time the software is run. This prevents transmission from occurring without a valid call sign or without the member with the call sign present. Once the setup parameters are input, the payload initializes into its standby state.

While in any state from standby or later, the XBee will actively monitor for manual override signals. These signals will be transmitted over the UHF band, outside the competition range, to avoid potential interference or rule violations. This feature remains enabled throughout the entire software period, allowing the team to override functionality as needed at any state. The primary commands delivered to the STEMCRaFT are "transmit" and "shutdown." These commands will immediately transition the payload state machine to the corresponding states.



(a) Initialization and Data Collection on CONOPS

(b) XBee Begins Monitoring for Override Commands

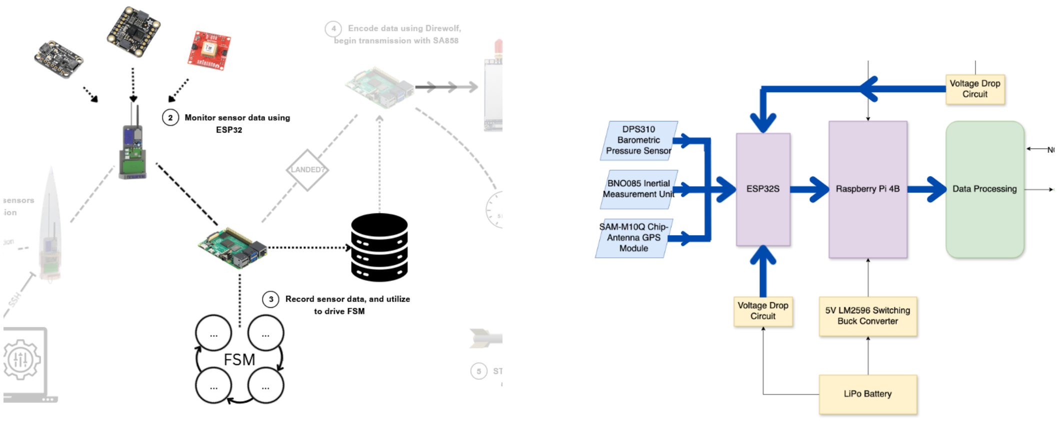
Figure 4.33: Initialization and Data Collection

In the first state, standby, the Raspberry Pi will read sensor information via the ESP32. This information will be communicated over a serial line, allowing the Raspberry Pi to decode the sensor data as required. During this phase, the Raspberry Pi will read and process sensor data to monitor for a large impulse indicating motor ignition. To accomplish this, the STEMCRaFT will actively read data from the following sensors:

- DPS310
- BNO085

The data obtained from these sensors will allow the software to monitor the altitude and acceleration experienced by the STEMCRaFT. These are the primary data points used to determine a takeoff, although other data points will be read and considered as needed. Upon detecting sufficient altitude and/or acceleration, the onboard system will transition to the burn phase and eventually to the coast and drift phases.

During the burn phase, the onboard system will continue to read data from the DPS310 and BNO085 through the ESP32. In this state, the STEMCRaFT will experience the highest g-forces of the entire flight. Since this is a relevant data point, it is crucial that the onboard computers read data points at a high frequency. This ensures the most accurate possible value for the maximum g-forces experienced by the STEMCRaFT. During this phase, the STEMCRaFT will not store data from the SAM-M10Q GPS, as it may provide inaccurate data due to the inability to maintain a fix during the sudden impulse.



(a) Data Collection and Data Processing on CONOPS (b) Data Collection System Flow

Figure 4.34: Data Collection and Data Processing

Throughout the coast and drift phases, the Raspberry Pi will continue to monitor the kinematic data of the Launch Vehicle. During these states, data will continue to be recorded in the flight data log, and the system will monitor for conditions that result in the state machine advancing. In these states, a drop in altitude that indicates apogee has been reached may progress the state machine from the burn state to the drift stage. Additionally, a sudden impulse will result in the STEMCRaFT progressing from the drift stage to the landed state.

Through the first few stages of the STEMCRaFT flight, from standby to coast, the STEMCRaFT should be able to determine and finalize the following data points:

- Apogee reached
- Maximum velocity

The apogee will be determined using the pressure readings from the DPS310 and converting these readings into altitude above sea level. To determine the maximum velocity and landing velocity, the payload computer will utilize data from both the DPS310 and BNO085 sensors. This will allow the payload computer to determine both the change in position and velocity with respect to time (using the DPS310), along with inertial changes (using the BNO085). The goal of utilizing data from both of these sensors is to provide the payload computer with sufficient data to produce the most accurate results possible.

After the STEMCRaFT detects a sufficient impulse or lack of velocity in the drift phase, the software will progress to the landed/transmission state. In this state, the software will begin utilizing the sensor data to determine the remaining data points required for transmission. These data points include the following:

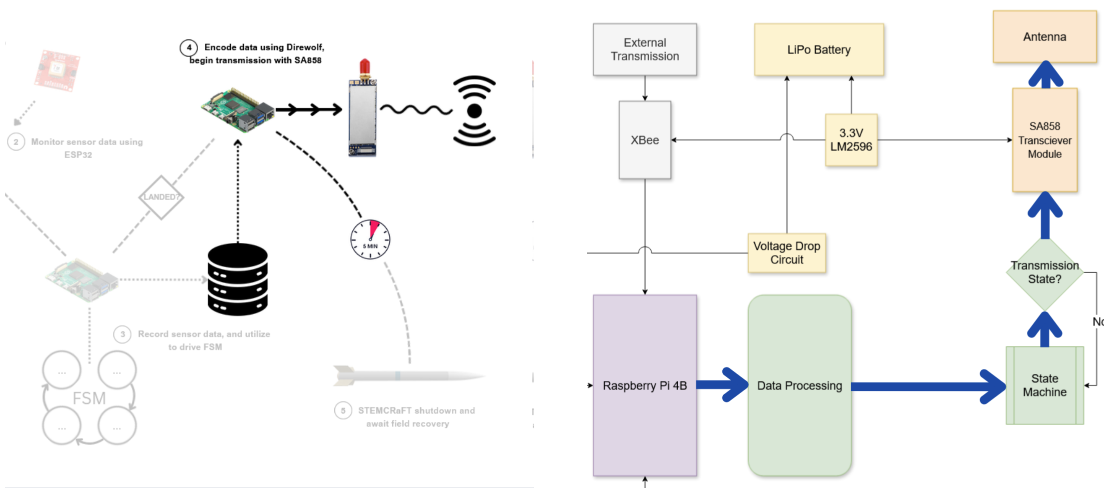
- Temperature of landing site
- Battery check/power status
- Orientation of on-board STEMnauts
- Calculated STEMnaut survivability
- Approximate landing coordinates
- Time of Landing
- Landing velocity/G-forces sustained

The STEMCRaFT will utilize the DPS310 and the onboard fan to determine the temperature of the landing site. The onboard fan will begin circulating air inside the STEMCRaFT at the landing site. This will be accomplished by pushing air out of the small pressure ports and slots on the capsule and Nose Cone. New air will be drawn in through pressure ports and slots on the opposite end of the capsule, providing air from the nearby surroundings of the landing site.

The battery check and power status will be determined using voltage divider circuits connected to both of the onboard batteries. This will allow the ESP32 to determine the remaining charge of both LiPo batteries as they decay from the full charge of 8.4V to an "empty" charge of 7.4V. The voltage divider circuit will reduce the voltage output to safe levels that can be read by the ESP32. The ESP32 will treat an unadjusted reading of 8.4V as a 100% battery level and an unadjusted reading of 7.4V as 0% charge, in accordance with lithium polymer battery standards.

The approximate landing coordinates will be provided by the SAM-M10Q. Since the GPS module can maintain a hot start for up to 4 hours after receiving power, it will be able to quickly obtain a fix should the GPS lose its fix due to the extreme acceleration in the burn phase. Once the STEMCRaFT has progressed to the landed/transmission state, the software will wait for the GPS readings to stabilize before preparing the coordinates for transmission.

Lastly, the orientation of onboard STEMnauts will be determined through the use of the BNO085 sensor data, particularly its built-in magnetometer, and the survivability of the STEMnauts will be determined using logged flight data. The STEMnaut survivability data will primarily be based on the landing site conditions, including temperature and pressure, and the maximum forces experienced throughout the launch, as well as the duration of these forces. The expected points of danger for STEMnaut survivability include the long, high-acceleration burn time, sudden acceleration from recovery deployment and landing, and landing site conditions such as temperature and pressure. Each of these parameters will be utilized to determine the calculated STEMnaut survivability at landing.



(a) Data Encoding and Transmission on CONOPS

(b) Active Transmission System Flow

Figure 4.35: Data Encoding and Transmission

After finalizing the desired data for transmission, the Raspberry Pi will use Direwolf, a software-based terminal node controller, to encode the data. Since APRS is based on Audio Frequency-Shift Keying as an encoding method, the transmission is simply a formatted audio signal being broadcast. As such, the audio transmission will be delivered to the SA858 Walkie Talkie module, where the signal will be broadcast on the 2M band. This transmission will occur multiple times, with set periods between transmissions, to provide the NASA transceiver multiple opportunities to receive the signal.

As mentioned previously, while at any stage up to and including the transmission stage, the STEMCRaFT will actively monitor the UHF band with the onboard XBee to receive any override signals. Particularly in the transmission stage, the STEMCRaFT will monitor for the shutdown signal. This will immediately interrupt the software's current function and result in all transmissions stopping. This ensures more security in preventing any competition rules from being violated during the transmission stage of the STEMCRaFT.

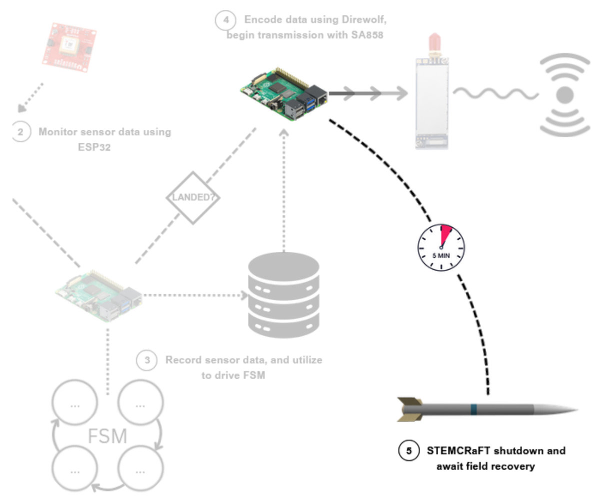


Figure 4.36: STEMCRaFT Recovery/Shutdown

After encoding and transmitting the relevant data points, the payload will enter a shutdown state. In this state, the payload will await field recovery while continuing to monitor for an XBee signal to begin transmitting again in case the transmission was not received on the first attempt. In this state, the STEMCRaFT will have no active functions and will simply await field recovery by the team. Once the team has reached the landed STEMCRaFT, a pull pin will be inserted to complete the STEMCRaFT's mission, and the Launch Vehicle will be recovered.

4.3.3 Ground Station

The ground station plays a critical role as a redundant system, ensuring monitoring and control over payload operations. Its primary function is to monitor the payload's status and provide the capability to remotely override system operations. This feature is crucial for terminating the primary transmission based on real-time assessments.

System Monitoring: The ground station actively monitors various operational parameters of the onboard system, including the system voltage and the overall state of the payload. This continuous surveillance allows for immediate response to any anomalies or unexpected changes in system performance.

Communication Setup: For effective communication, the ground station utilizes the XBee Pro module, which operates on the 900 MHz frequency. This choice of frequency ensures reliable long-distance communication with the payload. The XBee module is intricately set up to interface directly with the onboard Raspberry Pi. This setup not only allows the ground station to receive real-time data from the payload, but also enables it to send commands when necessary.

Operational Interface: The ground station will be able to interface with the Raspberry Pi and is designed for both data reception and command transmission. This dual capability ensures that the ground station can perform comprehensive monitoring, while also having the authority to intervene and control the payload operations if required by the mission.

4.4 Payload Manufacturing

4.4.1 Electronics Boards

The team will utilize custom PCBs to mount majority of the electrical components used onboard the STEMCRaFT. These PCBs will allow many of the connections to be much more secure and easily accessible. The finalized STEMCRaFT design utilizes two PCBs, the first of which is the data collection PCB. The data collection PCB will be used to mount the following sensors:

- ESP32
- DPS310
- BNO085
- SAM-M10Q GPS
- Voltage Sensors

This PCB will effectively contain the entire data collection subsystem and the required passive components. The primary benefit of using this custom PCB is that it provides a much more rigid and reliable connection compared to other methods of connecting electronics. Additionally, the use of a PCB vastly reduces the number of wires, overall footprint, and weight compared to other methods.

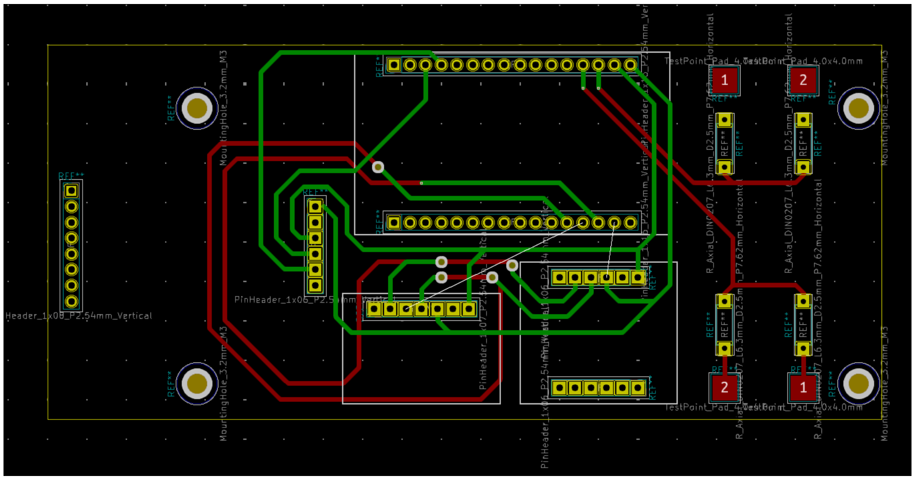
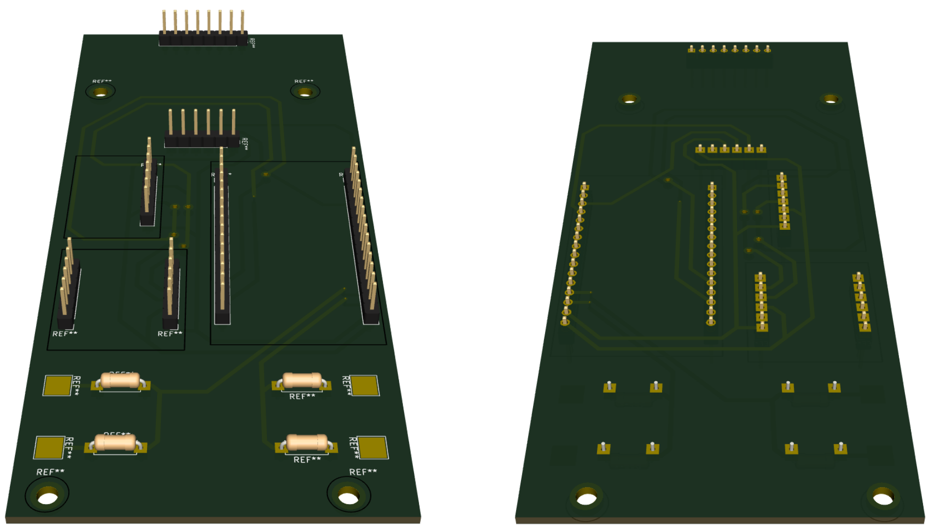


Figure 4.37: Data Collection PCB Schematic.

Shown above in Figure 4.37 is the design of the data collection PCB. The data collection PCB will primarily have an I2C communication line for the DPS310 and BNO085, a UART line for the SAM-M10Q, and passive components mounted directly on the board for the voltage sensors. In order to mount the sensors on the board, the team will have standard 0.1 in. pin headers mounted and connected to the board via solder. These pin header connectors are represented in yellow on the diagram.



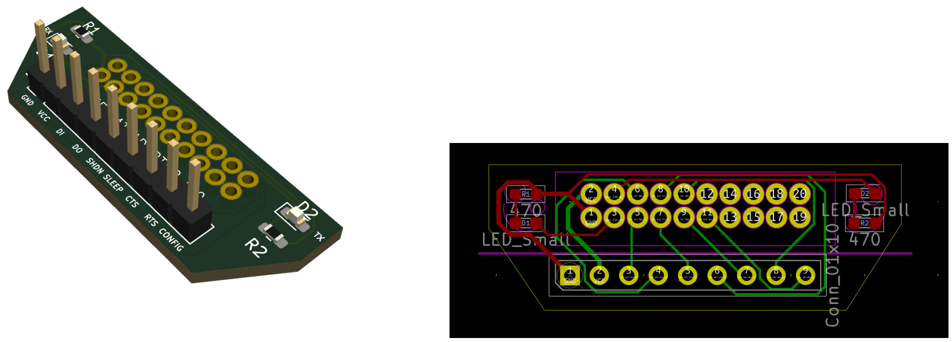
(a) Top Layer of Data Collection PCB

(b) Bottom Layer of Data Collection PCB

Figure 4.38: Data Collection PCB Renders

Shown in Figure 4.38 are the renderings of the top and bottom layers of the PCB for data collection. This PCB will be manufactured using an external manufacturer. The design provided to the external manufacturer will be the design presented above and will be entirely developed by members of the team. Using a third party to construct the finalized design, the team can ensure that the electronics board is of industry-standard quality and reliable for use in flight. Since the team does not have access to equipment to produce industry-standard quality PCBs, the use of a third party is necessary.

In the event of production delays from external manufacturers, the team may utilize milled PCB boards created using on-campus equipment. While these milled PCBs can be utilized in the case of complications in procuring proper PCBs, they contain a much larger potential for error, a reduced quality, and many limiting factors to the design.

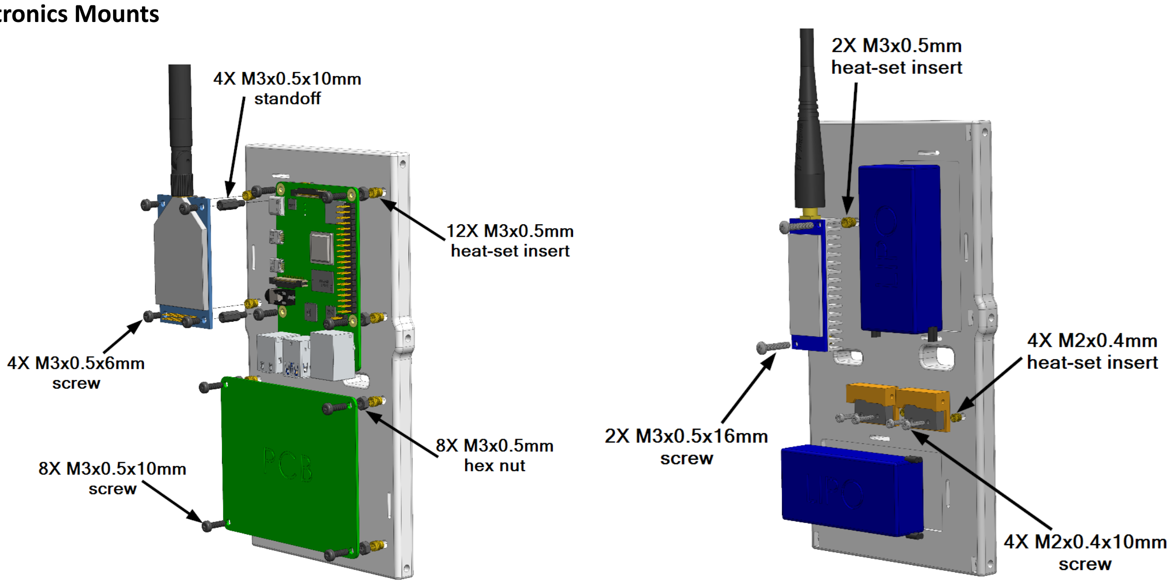


(a) XBee Breakout PCB (b) XBee Breakout PCB Design

Figure 4.39: XBee Breakout PCB

In addition to the data collection PCB, the team will also utilize a small PCB breakout for the XBee to simplify the wiring process. This PCB will be manufactured in a similar method, and the XBee will be mounted on the PCB via solder, which allows the pins to be broken out and more easily accessible.

4.4.2 Electronics Mounts



(a) Exploded view of electronics side of STEMCRaFT sled. (b) Exploded view of antenna side of STEMCRaFT sled.

Figure 4.40: Electronic mounts on the STEMCRaFT sled

The primary method for mounting electronic boards on the STEMCRaFT involves fastening screws into heat-set inserts with standoffs for spacing. The XBee, Raspberry Pi, PCB, and SA858 antenna module are secured using M3x0.5mm screws and heat-set inserts, while the pull-pin switches use M2x0.4mm screws and heat-set inserts.

On the electronics side of the sled containing the XBee, Raspberry Pi, and PCB, nylon screws and standoffs are used for their electrical insulation properties. The XBee is mounted with a 10mm standoff to ensure sufficient separation between the middle of the top bulkhead and the XBee antenna. The Raspberry Pi and PCB are mounted using single 3mm hex nuts as standoffs to prevent interference between the boards' underside components and the Sled.

On the antenna side of the Sled, the SA858 antenna module will be mounted using two M3x0.5x16mm metal screws, which are required to pass through the module and the heat sink. The two screws for each pull-pin switch will also be fastened directly into the heat-set inserts in the Sled. These heat-set inserts, made of brass, will be installed into pre-modeled holes in the sled, ensuring easy and precise installation of the components.

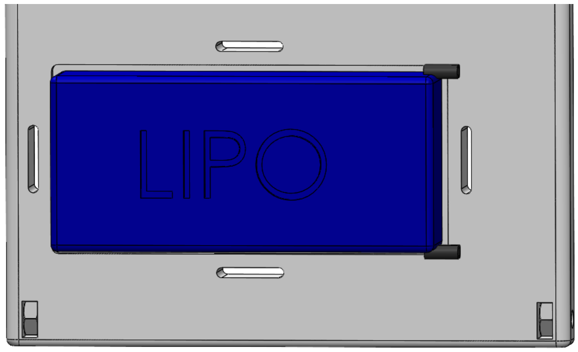


Figure 4.41: Closeup of battery mounting.

The two LiPo batteries will be secured to the sled using Velcro strips along their long and short sides. These strips will pass through two through-holes. Additionally, each battery will be seated in a 0.1 in. indentation to help prevent movement and ensure stability on the sled.

4.4.3 Payload Structures

The STEMCRaFT sled, bulkheads, and capsule shell will be 3D printed to achieve the complex geometries required. 3D printing enables features such as heat-set insert holes, wire pass-throughs, and mounting holes to be directly incorporated into the parts, ensuring alignment with the CAD model. These components will be printed with a minimum infill of 25%, as specified in Requirement PF.7, to ensure they can withstand in-flight forces. Additionally, the 3D printed parts will feature rounded edges to enhance strength and minimize stress concentrations. The components will be 3D printed with PETG filament due to its high strength and slight flexiblity.

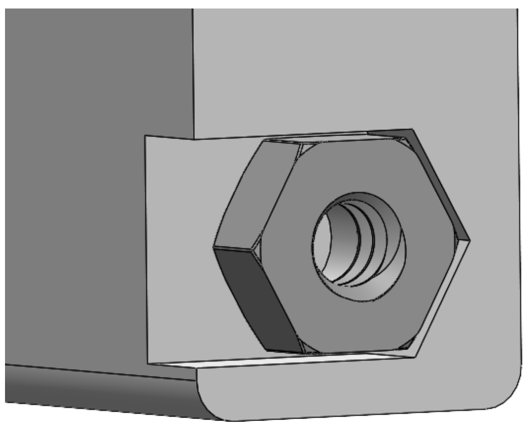


Figure 4.42: Section view of hex nut slot.

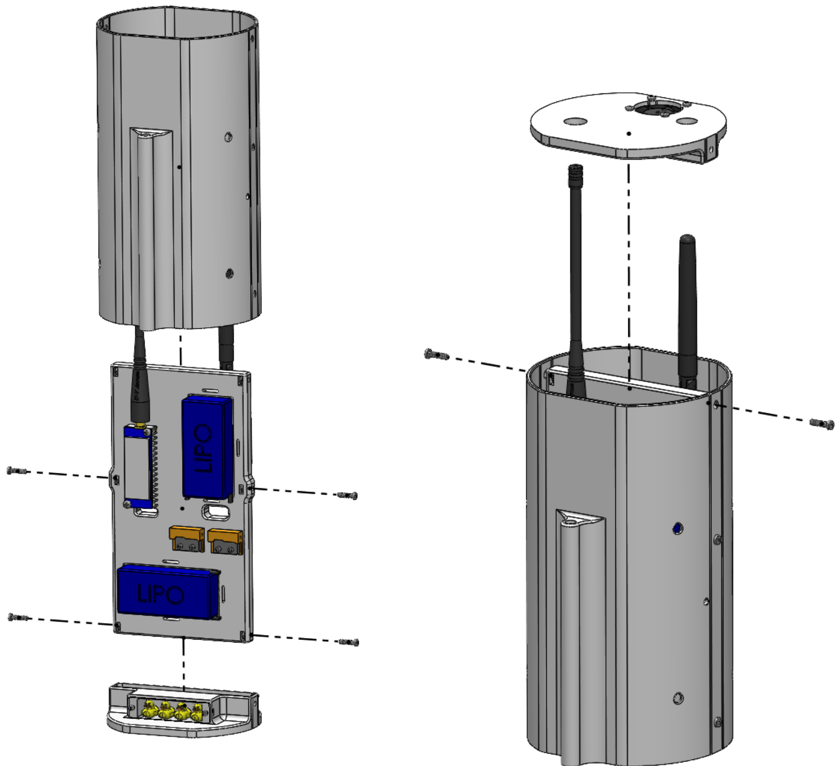
The side mounting holes on the sled and the STEMnaut window mounting holes on the bottom bulkhead feature slots designed to hold hex nuts, which serve as threads for securing screws. The slots are shaped to match the hex nut, preventing it from rotating when the screw is tightened. This method provides a simple and effective way to assemble components on 3D printed parts. Hot glue will be used to secure the hex nuts in the slots, preventing them from separating during the assembly process.

4.4.4 Assembly

The STEMCRaFT assembly process begins with mounting the electronics on the sled, which involves installing the heat-set inserts, securing the electronics with standoffs and screws, and sealing the side mounting hex nuts with hot glue. This procedure is a one-time process and does not need to be repeated during each assembly of the STEMCRaFT on the launch field. The only step that is repeated is attaching the batteries using Velcro.

Following the mounting of the electronics, the top and bottom bulkheads are prepared. The bottom bulkhead requires the seating of the four STEMnauts, which are then enclosed in their housing with the acrylic window secured by two screws. The top bulkhead requires installation of the fan, a one-time procedure that does not need to be repeated for each assembly.

Once the bulkheads are prepared, the STEMCRaFT is assembled. The bottom bulkhead is first placed on a flat surface, and the sled is slotted into it and held in place. The capsule shell is then slid onto the sled and bottom bulkhead until it is flush with the bulkhead. The



(a) Exploded view of STEMCRaFT assembly step 1.

(b) Exploded view of STEMCRaFT assembly step 2.

Figure 4.43: STEMCRaFT assembly.

bottom and middle side mount screws are then installed on the outside of the capsule shell.

Before the top bulkhead is installed, the fan must be plugged in to the Raspberry Pi. The top bulkhead is then inserted onto the sled, ensuring the antennas are fed through the corresponding holes. Once the top bulkhead is flush with the top of the capsule shell, the final two side mounting screws are fastened. The pull-pin switches are then engaged, which makes the STEMCRaFT ready for installation into the Nose Cone.

The full STEMCRaFT and Nose Cone assembly process is described in the Retention System section of Section 4.2.2. Once the STEMCRaFT is fully installed in the Nose Cone, the pull-pin is once again inserted to preserve battery life and complete the installation.

4.5 Payload Mass Breakdown

This section outlines the estimated masses of the STEMCRaFT, including the structural elements, electronics, and transmission hardware.

Component	Quantity	Unit Mass [lbs.]	Total Mass [lbs.]
Raspberry Pi	1	0.1013	0.1013
Xbee and duck antenna	1	0.0703	0.0703
Custom PCB	1	0.0219	0.0219
BNO085	1	0.0063	0.0063
DPS310	1	0.0088	0.0088
SAM-M10Q	1	0.0125	0.0125
ESP32	1	0.0220	0.0220
SA858	1	0.0313	0.0313
Voltage Regulator	2	0.0250	0.0500
Antenna	1	0.0507	0.0507
LiPo battery	2	0.2169	0.4338
Pull pin switch	2	0.0078	0.0156
STEMnaut duck	4	0.0031	0.0125
STEMnaut window	1	0.0047	0.0047
Wires	1	0.0625	0.0625
Sled	1	0.3291	0.3291
Bottom bulkhead	1	0.1284	0.1284
Top bulkhead	1	0.0898	0.0898
Capsule shell	1	0.5704	0.5704
Heat set insert (M3x0.5)	14	0.0113	0.1582
Heat set insert (M2x0.4)	4	0.0063	0.0250
Nylon standoff (M3x0.5x10mm)	4	0.0006	0.0025
Nylon nut (M3x0.5)	8	0.0004	0.0035
Nylon screw (M3x0.5x10mm)	8	0.0002	0.0013
Nylon screw (M3x0.5x6mm)	4	0.0002	0.0008
Metal screw (M3x0.5x16mm)	2	0.0025	0.0050
Metal nut (M2.5x0.45)	4	0.0005	0.0020
Metal screw (M2.5x0.45x16mm)	4	0.0013	0.0050
Metal nut (M2x0.4x2mm)	2	0.0003	0.0005
Metal screw (M2x0.4x10mm)	4	0.0006	0.0025
Metal screw (M2x0.4x6mm)	2	0.0005	0.0010
Metal nut (6-32x7/64”)	6	0.0009	0.0056
Metal screw (6-32x1/2”)	6	0.0020	0.0120
		Total Weight [lbs.]	2.2466

Table 4.5: STEMCRaFT estimated mass table.

5 Air Brakes

5.1 Air Brakes Mission Statement and Success Criteria

5.1.1 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 of the rocket throughout the flight. By strategically deploying and retracting the fins, the system can manage the rocket's ascent trajectory, slowing it down as needed to reach the desired target altitude.

5.1.2 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, the Air Brakes control system fails to deploy Air Brakes, the altitude reached is further than 50% of the target height.

5.2 Air Brakes Final Design Overview

5.2.1 Electronics

The Air Brakes system uses the following hardware:

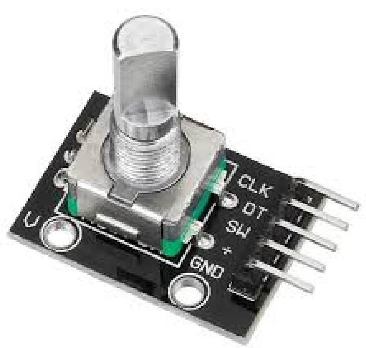


Figure 5.1: Encoder.

Figure 5.2: Voltage Regulator.

Figure 5.3: IMU.

Figure 5.4: Raspberry Pi.

1cm

Figure 5.5: Servo.

The electronics are powered by two separate batteries to isolate the harsh current draw of the servo which can cause the Pi to brown-out. A 2S 2200mAh LiPo battery powers the Raspberry Pi through an MPM3610 switching voltage regulator, which provides a stable supply of 5V. A 4S 2200mah LiPo is dedicated to powering the DS2685BLDP servo at 14v, which controls the deployment and retraction of the Air Brakes fins. Both batteries share a common ground, ensuring that the Pi can still send a signal to the servo while being on a separate power circuit. Both power circuits are armed via separate pull pin switches so that the system can stay disarmed until right before launch.

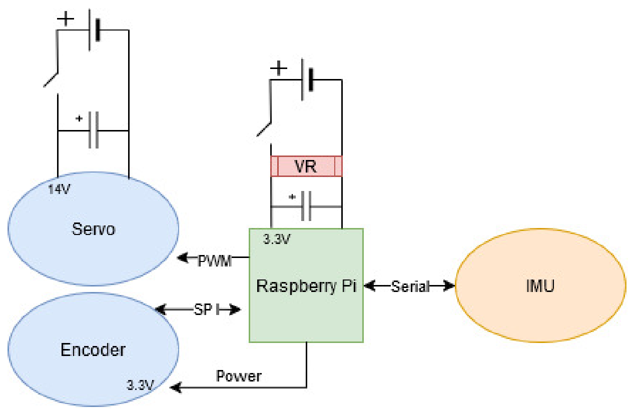


Figure 5.6: Diagram of power and signal circuits.

The Raspberry Pi acts as the single board computer (SBC), taking data from the IMU and encoder to process and log. The IMU provides accelerations, quaternions, altitude, and gyros at a rate of 500hz, and communicates to the Pi over USB serial. The encoder provides the exact angular position of the fins which is used to provide valuable information when doing post-flight analysis. The encoder uses SPI to connect with the Pi while also using power provided from the Pi.

5.2.2 Manufacturing & Assembly

The mechanical components such as the Housing, Fins, and Gears are designed in Solidworks and then 3D printed. This process allows for rapid prototyping and testing at next to no cost, resulting in a well refined product. Similarly, the electronics are mounted on a 3D printed sled.

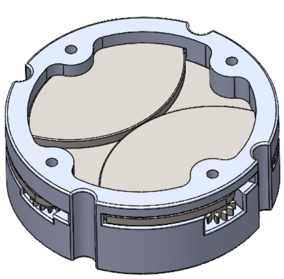


Figure 5.7: Air brakes closed.

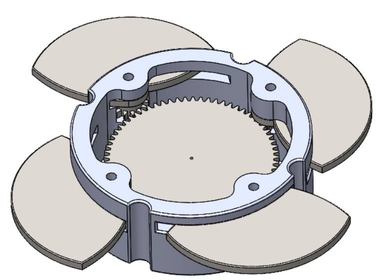


Figure 5.8: Air brakes open.

The Air Brakes fins are hinged around a threaded rod that passes through the housing. Bearings are placed on either side of the fins to reduce friction and ensure smooth operation during deployment and retraction. This design helps minimize wear, while also ensuring that the fins operate reliably throughout the mission. The fins are offset in height, where two opposing fins are placed at a higher elevation than the other pair. This configuration allows each fin to take up nearly half of the rocket's cross-sectional area, which increases the control authority of the Air Brakes.

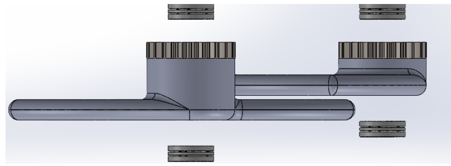


Figure 5.9: Air Brakes fins with bearings exploded view.

The servo is connected to a central gear via a servo horn, which serves as the primary actuator for the Air Brakes. A rotary encoder is coupled to the central gear to record the angular position of the servo and fins. This central gear aligns with four smaller fin gears, creating a synchronized actuation of all 4 fins. The gear ratio is 5:1, meaning that the small fin gears rotate five times for every one rotation of the central gear. While this allows for rapid deployment of the fins, the loss of torque in the gear ratio requires compensation from the servo. The servo horn is mounted to the central gear with Nylon screws, which serve as the fail point of the mechanism. In the unlikely event that the fins are jammed or bound in a way which causes the servo to stall, the nylon screws will shear before any gears strip or break. This allows the fins to always be in sync, mitigating any unnecessary moments on the Launch Vehicle.

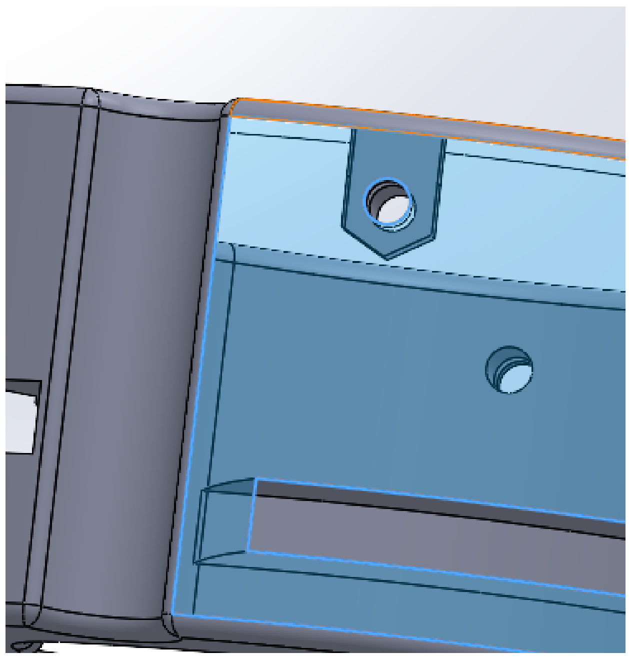


Figure 5.10: Housing with groove and nut slot.

The housing has 4 grooves which allow wires and cables to pass from one side of the Air Brakes assembly to the other. There are also four nut slots to insert nuts inside the housing. These allow the housing to directly mount to the switchband using four machine screws.

5.2.3 Software

The software for the Air Brakes system is built around a Finite State Machine (FSM) implemented in Python. The FSM is responsible for recording and managing the different stages of the rocket's flight, ensuring that the Air Brakes are deployed and retracted at the appropriate times. These states include Standby, Motor Burn, Coast, Free Fall, and Landing as seen by Figure 5.11. Each state transitions based on flight conditions, such as changes in acceleration and altitude, which are continuously monitored by the IMU and processed by the Raspberry Pi.

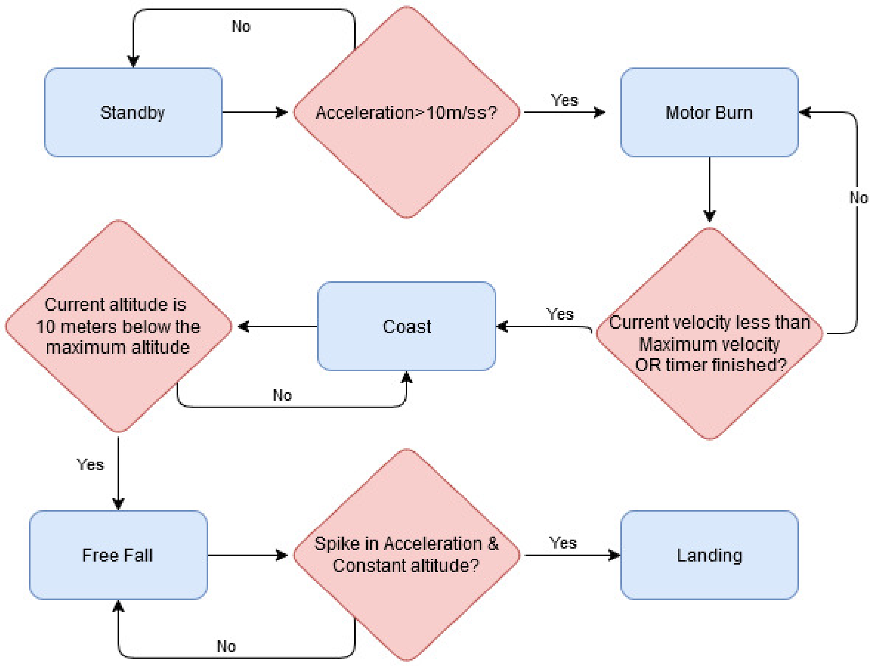


Figure 5.11: Diagram of the finite state machine.

The Standby state transitions into the Motor Burn state when a spike in acceleration is detected. The Motor Burn state transitions into the Coast state when the current velocity, which is determined from the acceleration, is less than the maximum velocity reached. The Coast state transitions to the Free Fall state when the current height is 10 meters less than the maximum height. The Free Fall state transitions to the Landing tate when a spike in acceleration is detected and the altitude stays within a meter.

To optimize performance of the Raspberry Pi, the software makes use of multiprocessing techniques. This allows the program to handle multiple tasks simultaneously, such as data processing/ logging flight data from the IMU, running the apogee prediction algorithm, and providing a control algorithm for Air Brakes deployment. The software can maintain responsiveness and accuracy of many sub-processes by leveraging multiprocessing. A key feature of the software is the apogee prediction algorithm. The algorithm uses real-time data from the IMU, including acceleration, velocity, and altitude, to generate a predicted flight curve.

Once the rocket transitions to the Coast state, the acceleration recorded by the IMU is used in conjunction with the orientation of the rocket to find the acceleration of the rocket in a global reference frame where the Z-axis extends perpendicular to Earth's surface.

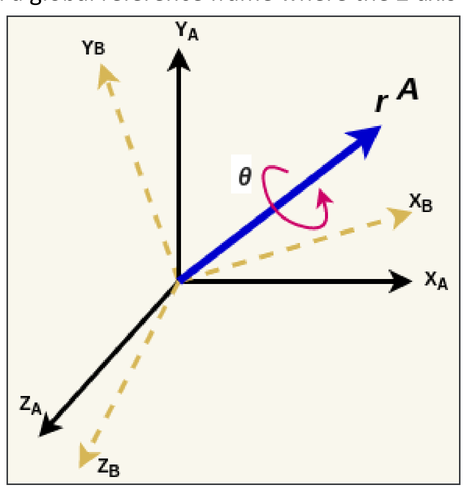


Figure 5.12: Example of 3D rotation with quaternion

Figure 5.12 gives an example how the 'B' coordinate system is rotated to the 'A' coordinate system using a quaternion rotation. The magnitude of gravity is removed from the Z-axis acceleration, which is then plotted vs. time, and a curve following the equation, $Y = A(1 - Bt)^4$ is fit to the data. Figures 5.13, 5.14, and 5.15 show how the curve, depicted by the red line is fit to the acceleration data, depicted by the blue points. This curve fit can be extrapolated to the where the z-axis acceleration is equal to zero. After 2 sec, the uncertainty of the 'A' and 'B' parameter converges within an acceptable range, meaning the curve fit does not have significant change to any incoming data. This allows the control system to take over and convert the curve fit to a unique flight profile.

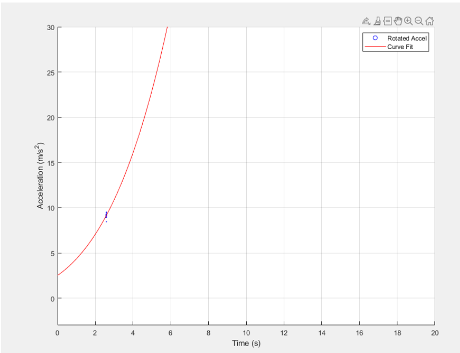


Figure 5.13: Curve fit at the start of Coast phase.

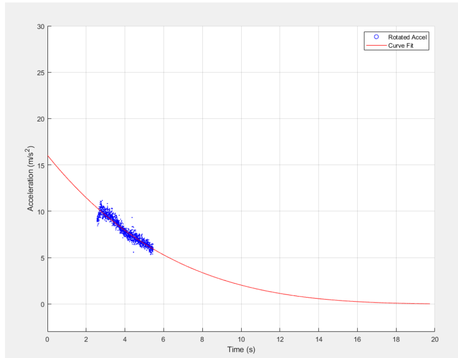


Figure 5.14: Curve Fit after 3 sec of data.

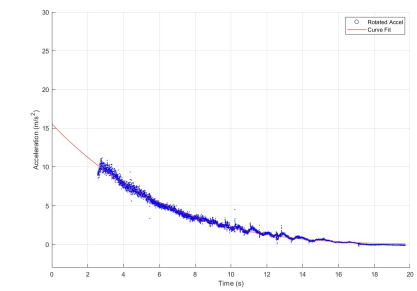


Figure 5.15: Curve fit of entire Coast phase.

Table 5.2: Apogee Prediction Backtest

Launch Name	Convergence Time (sec)	Predicted Apogee (m)	Actual Apogee (m)
Interest Launch	1.60	1896	1855
Genesis Launch 1	1.78	454	459.3
Genesis Launch 2	1.50	459	463

Shown in Table 5.2, the predicted flight profile is 98% accurate up to 1900m (6300ft) and is generated in under 2 sec of flight time. This accounts for half the acceptable error for complete mission success, with the other half coming from the control system.

A flight profile is generated from the acceleration curve fit which includes information of the entire flight such as velocity and height at a given time until apogee is reached. While this flight profile yields a predicted apogee, the relationship between velocity and height is more useful for the controller. Because the curve fit cannot be updated once the Air Brakes are deployed, the curve fit is used to estimate velocity and height for the remainder of the coast phase. The control system utilizes a Bang-Bang control scheme which allows for the simplest solution. This system will deploy Air Brakes once and retract them once to reach the target apogee.

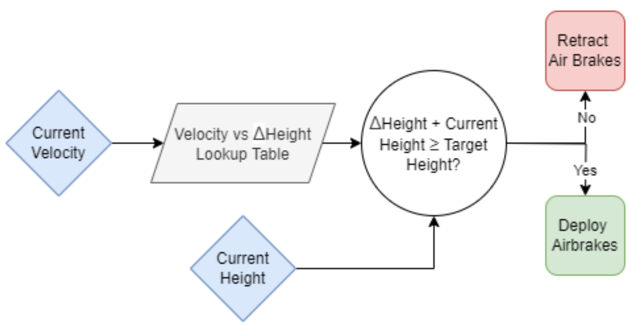


Figure 5.16: Diagram of the controller logic.

Shown in Figure 5.16 is the logic used by the controller. A lookuptable is generated from the predicted flight profile which stores the Velocity and ΔHeight, where ΔHeight is the distance remaining to the predicted apogee. This allows the controller to perform a simple check to see if the rocket has reached a velocity that will allow the rocket to coast the rest of the way to the target apogee. Once the rocket slows down enough, the Air Brakes retract and the rocket can continue on the predicted flight profile which now intercepts the target apogee.

5.3 Air Brakes Integration

5.3.1 AVAB

The Avionics and Air Brakes Bay (AVAB) holds the recovery electronics and the Air Brakes assembly. As seen in 5.17, 4 threaded rods serve multiple uses, acting as hinges for the Air Brakes and as structural components for mounting various sleds within the stack. They also secure the bulkheads on either side of the AVAB, adding the tensile strength needed during Recovery events. There are 4 slots cut into the Airframe of the AVAB section, allowing the Air Brakes fins to be deployed into the airstream. On either side of the Air Brakes housing is a sealing bulkhead that prevents the turbulent air flow from impacting the altimeters and pressure sensitive devices.

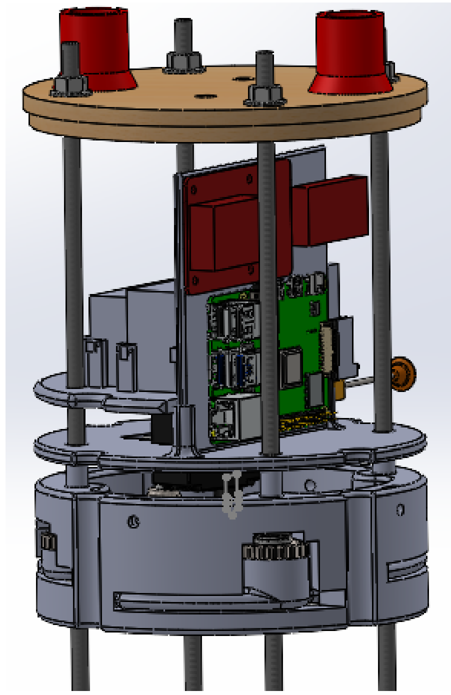


Figure 5.17: CAD of AVAB assembly.

5.4 Mass Breakdown

Component	Quantity	Unit Mass [lbs.]	Total Mass [lbs.]
Servo	1	0.08	0.08
Servo Horn	1	0.01	0.01
Center Gear (3D printed)	1	0.05	0.05
Housing (3D printed)	1	0.2	0.2
Fins (3D printed)	4	0.01	0.2
Bearings	8	0.01	0.08
Encoder	1	0.02	0.02
IMU	1	0.05	0.05
Raspberry Pi	1	0.1	0.1
LiPo batteries	2	0.35	0.7
Misc. wires	1	0.11	0.11
		Total Weight [lbs.]	1.6

Table 5.3: Air Brakes System Mass Breakdown.

6 Safety

6.1 Safety Officer

Megan Rink, the 2024-2025 Safety Officer, is responsible for verifying and maintaining safety documentation for use inside the team's lab space and in the competition. Megan ensures the team is informed about proper procedures and PPE for the lab tools and materials. This includes, but is not limited to, drill presses, hand tools, band saws, power tools, flammable items, and hazardous materials. Megan is required to attend all launches, team vehicle recoveries, and train members of the Safety Team. A member of the Safety Team must be present during the design, construction, assembly, and testing of the Launch Vehicle, payload, and associated components. Additionally, the Safety Officer or a member of the Safety Team must be present at all STEM engagement activities to verify safe material and construction interactions. Finally, Megan is responsible for maintaining the lab space and equipment to NASA, NCSU MAE Department, and local safety standards.

6.2 Launch Procedures/ Checklist

An assembly checklist will be followed for each launch to ensure proper, timely, and safe assembly of the Launch Vehicle. Below is a draft of the Full-Scale Checklist used for the assembly, launch, and recovery of the Full-Scale Launch Vehicle for VDF, PDF, and the competition flight. Each step will be checked off upon completion by the Safety Officer, Team Lead, or necessary personnel, as designated by the checklist. This checklist is derived from the proposed design of the Full-scale Launch Vehicle and the completed design of the Subscale Launch Vehicle. At the beginning of each checklist, the necessary personnel, required materials, and required PPE are listed. Additionally, steps that require PPE or involve energetics are color-coded yellow and red.

Full-scale

Launch Day Checklist

This checklist completed by: ____________________________

On: __ / __ / __

Checklist Legend

PPE Required

Explosives/Energetics - DANGER!

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

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

1. E-MATCH INSTALLATION

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
E-Match Personnel 1		
E-Match Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Forward AVAB Bulkhead	1	Energetics Box	
Aft AVAB Bulkhead	1	Energetics Box	
Blue Tape	1	LD Toolbox Top Drawer	
Firewire Electric-Match (e-match)	4	Bulkhead	
Scissors	1	LD Toolbox Top Drawer	
Needle Nose Pliers	1	LD Toolbox Middle Drawer	
Wire Strippers	1	LD Toolbox Middle Drawer	
Terminal Bock Screwdriver	1	LD Toolbox Top Drawer	

Note: This checklist is to be executed on both AVAB bulkheads simultaneously

Number	Task	Completion
1.1	Unscrew all unoccupied terminal blocks on Aft AVAB bulkhead and Forward AVAB bulkhead.	
1.2	Take 4 e-matches and trim them to approximately 6 inches in length from the red cap using wire snippers.	
1.3	Remove the red plastic protective e-match cover for all 4 e-matches by sliding them down the wire.	
1.4	Feed one e-match through the MP Forward AVAB bulkhead wire hole, with the e-match head on the side of the bulkhead with the blast caps, and another through the MS wire hole.	
1.5	Feed one e-match through the DP Aft AVAB bulkhead wire hole, with the e-match head on the side of the bulkhead with the blast caps, and another through the DS wire hole.	
1.6	Flip over the forward and Aft AVAB bulkheads, and use wire snippers to separate the two e-match wires.	
1.7	Strip 3/4 inch of insulation from the end of all 4 e-match wires with wire strippers.	
1.8	Bend the exposed e-match wire into a loop with needle nose pliers.	
1.9	Place the MP e-match wires into the MP terminal block.	
1.10	Place the MS e-match wires into the MS terminal block.	
1.11	Place the DP e-match wires into the DP terminal block.	
1.12	Place the DS e-match wires into the DS terminal block.	
1.13	Tighten the screws on the MP, MS, DP, and DS terminal blocks.	
1.14	Verify e-match security by visual inspection and lightly tugging on the wires coming out of the MP, MS, DP, and DS terminal blocks.	**Safety Officer confirmation:**
1.15	Place the MP e-match head into the MP blast cap.	
1.16	Place the MS e-match head into the MS blast cap.	
1.17	Place the DP e-match head into the DP blast cap.	
1.18	Place the DS e-match head into the DS blast cap.	
1.19	Bend each e-match wire such that the head of the e-match lies flat against the bottom of each blast cap.	
1.20	Bend each e-match wire such that it is flush with the inner and outer wall of each blast cap.	
1.21	Using blue tape, tape each e-match wire to the outside of its respective blast cap.	
1.22	Confirm that all bulkhead and wiring labels are still visible.	**Safety Officer confirmation:**

2. MAIN BLACK POWDER

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Main Black Powder Personnel 1		
Main Black Powder Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Safety Glasses	4	Safety Box	
Nitrile Gloves	4	Safety Box	
Heavy Duty Gloves	4	Safety Box	
Resealable container	2	Flame Cabinet	
Main Primary Charge (1.4 grams)	1	Energetics Box	
Main Secondary Charge (1.8 grams)	1	Energetics Box	
Forward AVAB Bulkhead	1	Energetics Box	
Funnel	1	LD Toolbox Top Compartment	
Copy Paper	2	HPRC Lab	
Paper Towel	1	-	
Biodegradable insulation	1	-	
Blue Tape	1	LD Toolbox Top Drawer	
Plumbers Putty	1	LD Toolbox Top Compartment	
Scissors	1	LD Toolbox Top Drawer	
Anti Static Bag	2	Energetics Box	

Number	Task	Completion
2.1	Confirm all participating members are wearing safety glasses and nitrile gloves.	**Safety Officer confirmation:**
2.2	Place 1 small resealable container on the scale, on top of a piece of paper towel, such that the reading on the scale can still be read.	
2.3	Zero the scale.	
2.4	Using a spoon, carefully measure out 1.4 grams of black powder for the main primary charge.	
2.5	Reseal the container.	
2.6	Repeat steps 2.2-2.5 for 1.8 grams of black powder for the main secondary charge.	
2.7	Place the bottom of the funnel into the MP blast cap and carefully pour the main primary black powder charge into the MP blast cap over the e-match head.	
2.8	Slowly lift the funnel and tap it so the black powder falls into the blast cap.	
2.9	Slowly lift the e-match head so that it rests at the top of the black powder.	
2.10	Fill the remaining space in the blast cap with biodegradable insulation.	
2.11	Place 2 inch strips of blue tape over the top of the MP blast cap to cover the cap completely. If using multiple pieces of blue tape, do not have any overlaps greater than 5 mm.	
2.12	Wrap blue tape around the outside wall of the blast cap to ensure that the top layers of tape stay in place. Fold the excess tape to be flush with the top of the blast cap.	
2.13	Confirm all edges of the MP blast cap are covered with blue tape.	**Safety Officer confirmation:**
2.14	Place the bottom of the funnel into the MS blast cap and carefully pour the main primary black powder charge into the MS blast cap over the e-match head.	
2.15	Slowly lift the funnel and tap it so the black powder falls into the blast cap.	
2.16	Slowly lift the e-match head so that it rests at the top of the black powder.	
2.17	Fill the remaining space in the blast cap with biodegradable insulation.	
2.18	Place 2 inch strips of blue tape over the top of the MS blast cap to cover the cap completely. If using multiple pieces of blue tape, do not have any overlaps greater than 5 mm.	
2.19	Wrap blue tape around the outside wall of the blast cap to ensure that the top layers of tape stay in place. Fold the excess tape to be flush with the top of the blast cap.	
2.20	Confirm all edges of the MS blast cap are covered with blue tape.	**Safety Officer confirmation:**

2.21	Place a sheet of white copy paper on the assembly table and turn the bulkhead over on top of the paper.	
2.22	Confirm that no black powder has leaked onto the copy paper.	**Safety Officer confirmation:**
2.23	If black powder has leaked, pour the extra black powder grains back into the black powder container and repeat checklist items 2.7-2.13 or 2.14-2.20 depending on which blast cap leaked, then repeat checklist items 2.22-2.23.	
2.24	Use plumbers putty to seal any holes in the bulkhead.	
2.25	Tape over the ends of the e-match wires with electrical tape.	
2.26	Wrap the entire bulkhead in an anti-static bag and place it in the flame cabinet or flameproof explosive containment box.	

3. DROGUE BLACK POWDER

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Drogue Black Powder Personnel 1		
Drogue Black Powder Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Safety Glasses	4	Safety Box	
Nitrile Gloves	4	Safety Box	
Heavy Duty Gloves	4	Safety Box	
Resealable container	2	Flame Cabinet	
Drogue Primary Charge (1.0 grams)	1	Energetics Box	
Drogue Secondary Charge (1.4 grams)	1	Energetics Box	
Forward AVAB Bulkhead	1	Energetics Box	
Funnel	1	LD Toolbox	
Copy Paper	2	HPRC Lab	
Paper Towel	1	-	
Biodegradable insulation	1	-	
Blue Tape	1	LD Toolbox Top Drawer	
Plumbers Putty	1	LD Toolbox Top Compartment	
Scissors	1	LD Toolbox Top Drawer	
Anti Static Bag	2	Energetics Box	

Number	Task	Completion
3.1	Confirm all participating members are wearing safety glasses and nitrile gloves.	**Safety Officer confirmation:**

3.2	Place 1 small resealable container on the scale, on top of a piece of paper towel, such that the reading on the scale can still be read.	
3.3	Zero the scale.	
3.4	Using a spoon, carefully measure out 1.0 grams of black powder for the drogue primary charge.	
3.5	Reseal the container.	
3.6	Repeat steps 2.2-2.5 for 1.4 grams of black powder for the drogue secondary charge.	
3.7	Place the bottom of the funnel into the DP blast cap and carefully pour the main primary black powder charge into the DP blast cap over the e-match head.	
3.8	Slowly lift the funnel and tap it so the black powder falls into the blast cap.	
3.9	Slowly lift the e-match head so that it rests at the top of the black powder.	
3.10	Fill the remaining space in the blast cap with biodegradable insulation.	
3.11	Place 2 inch strips of blue tape over the top of the DP blast cap to cover the cap completely. If using multiple pieces of blue tape, do not have any overlaps greater than 5 mm.	
3.12	Wrap blue tape around the outside wall of the blast cap to ensure that the top layers of tape stay in place. Fold the excess tape to be flush with the top of the blast cap.	
3.13	Confirm all edges of the DP blast cap are covered with blue tape.	**Safety Officer confirmation:**
3.14	Place the bottom of the funnel into the DS blast cap and carefully pour the main primary black powder charge into the DS blast cap over the e-match head.	
3.15	Slowly lift the funnel and tap it so the black powder falls into the blast cap.	
3.16	Slowly lift the e-match head so that it rests at the top of the black powder.	
3.17	Fill the remaining space in the blast cap with the paper towel pieces.	
3.18	Place 2 inch strips of blue tape over the top of the DS blast cap to cover the cap completely. If using multiple pieces of blue tape, do not have any overlaps greater than 5 mm.	
3.19	Wrap blue tape around the outside wall of the blast cap to ensure that the top layers of tape stay in place. Fold the excess tape to be flush with the top of the blast cap.	

3.20	Confirm all edges of the DS blast cap are covered with blue tape.	**Safety Officer confirmation:**
3.21	Place a sheet of white copy paper on the assembly table and turn the bulkhead over on top of the paper.	
3.22	Confirm that no black powder has leaked onto the copy paper.	**Safety Officer confirmation:**
3.23	If black powder has leaked, pour the extra black powder grains back into the black powder container and repeat checklist items 3.7-3.13 or 3.14-20 depending on which blast cap leaked, then repeat checklist items 3.21-3.22.	
3.24	Use plumbers putty to seal any holes in the bulkhead.	
3.25	Tape over the ends of the e-match wires with electrical tape.	
3.26	Wrap the entire bulkhead in an anti-static bag.	

END OF NIGHT BEFORE CHECKLIST

1. AVAB BAY ASSEMBLY

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Recovery Lead	Trent Couse	
AVAB Bay Personnel 1		
AVAB Bay Personnel 2		

Required Materials			
Item	Quantity	Location	Completion
Safety Glasses	5	Safety Box	
AV Sled	1	AVAB Box	
Air Brakes Sled	1	AVAB Box	
1/16" Partition Bulkhead	1	AVAB	
Forward Bulkhead	1	AVAB	
Aft Bulkhead	1	AVAB	
AVAB Switch Band / Coupler Section	1	-	
2200 mAH Air Brakes Battery	1	Battery Bag	
1500 mAH Servo Battery	1	Battery Bag	
Main Altimeter Battery	1	Battery Bag	
Easy Mini Battery	1	Battery Bag	
Eggfinder Battery	1	Battery Bag	
Multimeter	1	LD Toolbox	
Pull Pins	3	Recovery Box	
AVAB Retention Screws	1	Vehicle Box	
¼" Hex Nuts	16	Vehicle Box	
¼" Washers	8	Vehicle Box	
Rubber Bands	4	LD Toolbox Bottom Drawer	
Servo Battery Rubber Band	1	LD Toolbox Bottom Drawer	
Electrical Tape	1	LD Toolbox Top Drawer	
Blue Tape	1	LD Toolbox Top Drawer	
Plumbers Putty	1	LD Toolbox Top Compartment	
Small Screwdriver	1	LD Toolbox Top Drawer	
Laptop	1	Student Backpack	
EggFinder Receiver	1	Student Backpack	

Number	Task	Completion
1.1	Confirm all members within the assembly tent are wearing safety glasses.	
1.2	Confirm the correct assembly of the AVAB sled. From forward to aft: Forward bulkhead, Avionics sled, 1/16 inch partition bulkhead, Air Brakes sled, spacers, servo battery sled, Aft bulkhead.	**Recovery Lead confirmation:** **Air Brakes Lead confirmation:**
1.3	Confirm the spacing of the sled is aligned with the Air Brakes slots in the AVAB switch band.	**Air Brakes Lead confirmation:**
1.4	Remove aft sled for assembly and to test batteries.	
1.5	Use a multimeter to test the voltage of the Air Brakes battery.	**Note voltage:**
1.6	If the battery measures below 8.0 volts, replace with a fresh battery and repeat checklist item 1.5.	
1.7	Insert the 2200mAh Air Brakes battery into the orange battery slot in the Air Brakes sled. Ensure the side labeled "out" is facing out.	
1.8	Connect the Air Brakes battery to the green battery connector.	
1.9	Secure the Air Brakes battery with the elastic retention system (ERS). Double over a medium sized rubber band and connect this to the "T" next to the battery compartment.	
1.10	Secure the 1500mAh Servo Battery to the white sled using ERS with the side labeled "up" facing up.	
1.11	Connect the Servo battery to the Red Battery Connector.	
1.12	Insert the IMU cable below the airbrakes battery sled and above the airbrakes mechanism.	

1.13	Slide the sled onto the threaded rods with the battery facing out and the "x" alignment marks aligned.	
1.14	Slide the yellow and green drogue JST connector up past the airbrake battery sled. Ensure the wires slide into the slot in the sled labeled "JST".	
1.15	Secure the air brakes battery sled into place with at least 2 nuts.	
1.16	Use rubber bands around the 4 threaded rods to hold all wires in place.	
	Avionics Sled	
1.17	Ensure Eggfinder mini is secure.	**Recovery Lead confirmation:**
1.18	Use a multimeter to test the voltage of the Main Altimeter 9V battery.	**Note voltage:**
1.19	If the battery measures below 9.0 volts, replace with a fresh battery and repeat checklist item 1.18.	
1.20	Connect the Main Altimeter battery to its battery clip.	
1.21	Friction fit the Main Altimeter battery in the Stratologger battery compartment such that the battery clip is toward the forward end of the launch vehicle.	
1.22	Use a multimeter to test the voltage of the Easy Mini lipo battery.	**Note voltage:**
1.23	If the battery measures below 8.0 volts, replace with a fresh battery and repeat checklist item 1.22.	
1.24	Place the Easy Mini battery in the central battery compartment (sled may need to be slid off of threaded rods to fit the battery).	
1.25	Connect the Easy Mini battery to its battery connector.	
1.26	Use a multimeter to test the voltage of the Eggfinder lipo battery.	**Note voltage:**
1.27	If the battery measures below 8.0 volts, replace with a fresh battery and repeat checklist item 26.	
1.28	Place the Eggfinder battery in the Eggfinder battery compartment.	
1.29	Connect the Eggfinder battery to its battery connector.	

1.30	Secure the recovery batteries by placing a piece of electrical tape over all three recovery battery compartments. Ensure the electrical tape does not interfere with the pull pin switch.	
1.31	Confirm the red wires connected to the pull pin switch are connected to the switch terminal on the green Easy Mini altimeter.	**Recovery Lead confirmation:**
1.32	Confirm the green wires connected to the pull pin switch are connected to the switch terminal on the red Stratologger altimeter.	**Recovery Lead confirmation**:
1.33	Lightly tug on all of the wires connected to both altimeters to verify security. Visually confirm that wires are connected.	**Safety Officer confirmation:**
1.34	Push the AV sled flush with the Air Brakes module and tuck wires away.	
1.35	Secure AV Sled with nuts.	
1.36	Remove all pull pin switches.	
1.37	Insert the AVAB assembly into the AVAB Bay aft end first, using the rail button hole for alignment. Ensure wires are not pinched during installation.	
1.38	Install the AVAB retention screw (0.5" long #8-32) into the AVAB bay.	
1.39	Insert the recovery pull pin through the hole in the AVAB switch band and tape it in place with blue tape.	
1.40	Insert both of the Air Brakes pull pins through the holes in the AVAB body tube and coupler. (2 pull pins installed)(the servo battery sled may need to be pulled down to install aft pull pin switch)	
1.41	Confirm all members within the assembly tent are wearing safety glasses.	**Safety Officer confirmation**:
1.42	Remove aft AVAB bulkhead from its anti-static bag.	
1.43	Lightly tug on the wires coming out of the DP and DS terminal blocks to verify security. Visually confirm that wires are connected.	**Safety Officer confirmation**:
1.44	While pointing the blast caps away from personnel, connect the aft JST connector on the aft bulkhead to the aft JST connector	

	from the altimeters, aligning yellow with yellow and green with green.	
1.45	Lightly tug on the wire connection between the aft bulkhead and the avionics to verify security. Visually confirm that wires are connected.	**Safety Officer confirmation**:
1.46	Slide aft AVAB bulkhead onto the threaded rods (using alignment marks) until the bulkhead is snug with the coupler. Ensure wires are not pinched.	
1.47	Secure aft AVAB bulkhead to the AVAB using four ¼ inch washers and four ¼ inch hex nuts, one for each threaded rod.	
1.48	Ensure plumbers putty seals both e-match holes on the bulkhead.	
1.49	Remove forward AVAB bulkhead from its anti-static bag.	
1.50	Lightly tug on the wires coming out of the MP and MS terminal blocks to verify security. Visually confirm that wires are connected.	**Safety Officer confirmation:**
1.51	While pointing the blast caps away from personnel, connect the forward JST connector on the forward bulkhead to the forward JST connector from the altimeters, aligning white with white and black with black.	
1.52	Lightly tug on the wire connection between the forward bulkhead and the avionics to verify security. Visually confirm that wires are connected.	**Safety Officer confirmation:**
1.53	Slide forward AVAB bulkhead onto the threaded rods until the bulkhead is snug with the coupler.	
1.54	Secure forward AVAB bulkhead to the AVAB using four ¼ inch washers and four ¼ inch hex nuts, one for each threaded rod.	
1.55	Ensure plumbers putty seals both e-match holes on the bulkhead.	
1.56	Use a small screwdriver to probe the pressure ports on the forward end of the AVAB to confirm they are clear.	**Safety Officer confirmation:**
1.57	Tighten all nuts and confirm the AVAB is properly aligned.	**Recovery Lead and Safety Officer confirmation:**

1.58	Connect to the gps and confirm it is correctly transmitting coordinates.	
	Only if an Air Brakes Lead is Available to do the following:	
1.59	Verify air brakes aren't rubbing/catching on anything, run: `python3 -m scripts.run_servo`	
1.60	Verify IMU works (should see it printing about 2 raw data packets for every estimated data packet, make sure values make sense), run: `python3 -m scripts.run imu`	
1.61	Insert both of the Air Brakes pull pins through the holes in the AVAB body tube and coupler. (2 pull pins installed)(the servo battery sled may need to be pulled down to install aft pull pin switch)	
	Recovery Procedure	
1.62	Confirm a club member with safety glasses and fireproof gloves holds the assembled AV bay in the shade at least 6 feet from other members until further use.	**Safety Officer confirmation:**

2. PAYLOAD ASSEMBLY

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Payload Lead		
Payload Personnel 1		
Payload Personnel 2		

Required Materials			
Item	Quantity	Location	Completion
Payload Sled	1	Payload Box	
Nose Cone	1	-	
¼" Hex Nuts	2	Vehicle Box	
¼" Washers	2	Vehicle Box	
LiPo Battery	1	Battery Bag	
Multimeter	1	LD Toolbox Top Compartment	
Pull Pin	1	Avionics Box	

Number	Task	Completion
2.1	Confirm correct assembly of payload sled.	**Payload Lead confirmation:**
2.2	Insert LiPo battery into the battery slot and secure using a rubber band and velcro strap.	
2.3	Fold LiPo battery cable beside the battery underneath the rubber band.	
2.4	Connect LiPo to Raspberry Pi.	
2.5	Verify sensors light up. Wait for the second light on the GPS module to begin flashing to ensure hot start during launch.	**Payload Lead confirmation:**
2.6	Verify all electronics and wires are secured by two methods.	
2.7	Slide the payload sled onto the two threaded rods in the nose cone making sure no wires get caught on the permanent ring bulkhead. Align alignment marks.	
2.8	Slide nose cone bulkhead onto the threaded rods until the bulkhead is snug with the coupler.	
2.9	Insert the pull pin through the hole in the nose cone.	
2.10	Secure nose cone bulkhead to the nose cone using two ¼ inch hex nuts, one for each threaded rod.	

3. FIN CAN ASSEMBLY

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Structures Lead	James Holley	
Fin Can Personnel 1		
Fin Can Personnel 2		

Required Materials			
Item	Quantity	Location	Completion
RFMS	1	Fin Can	
Forward Centering Ring	1	RMFS	
Fin Mounting Runners	4	RMFS	
Thrust Bulkhead	1	RMFS	
#8-32 ½" Screw	7	RMFS	
#8-32 ¾" Screw	3	RMFS	
Fins	4	RMFS	
Screwdriver	2	LD Toolbox Middle Drawer	

Number	Task	Completion
3.1	Check tightness of the forward rail button screw. Place electrical tape over the exposed part of the rail button screw on the inside of the fin can. (To prevent excessive friction).	**Structures Lead confirmation:**
3.2	Confirm the correct assembly of the RMFS including the forward volume reduction bulkhead, forward centering ring, fin mounting runners, and thrust bulkhead.	**Structures Lead confirmation:**
3.3	Verify all machine screws connecting the RMFS are secure.	
3.4	Slide the RMFS into the fin can, aligning the R and arrow etched on the bottom of the thrust plate with the rail button side (Bell X1).	
3.5	Confirm that the motor casing can be inserted without obstruction.	**Structures Lead confirmation:**
3.6	Insert the aft rail button into the bottom hole aligned with the forward rail button with a #8-32 ¾ inch screw. Place a #8 hex nut onto the exposed thread inside the fin can using your finger and hand tighten the machine screw/hex nut.	
3.7	Insert four #8-32 ½ inch screws through the forward RMFS airframe holes into the forward centering ring. Hand tighten.	
3.8	Repeat Step 3.5 with three #8-32 ¾ inch screws into the three remaining aft holes between the fins to secure the RMFS to the airframe.	
3.9	Confirm all screws are tight. Do not overtighten the screws.	**Structures Lead confirmation:**
3.10	Pull on each fin to confirm security.	**Structures Lead confirmation:**

4. MAIN RECOVERY ASSEMBLY

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Recovery Lead	Trent Couse	
Main Recovery Personnel 1		
Main Recovery Personnel 2		

Required Materials			
Item	Quantity	Location	Completion
Safety Glasses	5	Safety Box	
Nose Cone	1	-	
Main Parachute Bay	1	Recovery Box	
AVAB	1	-	
Main Parachute Nomex	1	Recovery Box	
Main Parachute	1	Recovery Box	
Plastic Rivets	4	Vehicle Box	
#4-40 ½" long nylon shear pins	2	Vehicle Box	
Shock Cord	1	Recovery Box	
Biodegradable Insulation	1	-	
Rubber Bands	2	LD Toolbox Bottom Drawer	
Quicklinks 4 and 5	2	Avionics Box	
Blue Tape	1	LD Toolbox Top Drawer	

Number	Task	Completion
4.1	Confirm that all members within the assembly tent are wearing safety glasses.	
4.2	Accordion fold the length of the shock cord between loops 4 and 5 in 8 inch lengths. Leave between 1 and 2 feet between the accordion folded shock cord and loop 5.	
4.3	Secure the length of shock cord between loops 4 and 5 with a single rubber band. Two fingers should fit snugly under the rubber band.	
4.4	Confirm the shock cord is folded accordion style.	**Recovery Lead confirmation:**
4.5	Attach quicklink 4 to shock cord loop 4. Do not tighten.	
4.6	Slide quicklink 4 through the forward end of the main parachute bay.	
4.7	Attach quicklink 4 to forward AVAB bulkhead U-bolt.	
4.8	Tighten quicklink 4 by hand until secure. Tape over the connection to ensure the shock cord will not unthread the closure.	
4.9	Confirm the shock cord is secured to the AVAB by visual inspection and pulling on the shock cord.	**Recovery Lead confirmation:**
4.10	Slide the main parachute bay onto the forward end of the AVAB coupler, aligning the alignment marks.	
4.11	Insert 4 plastic rivets into the rivet holes.	
4.12	Attach quicklink 5 to the stitched hole in the main parachute nomex.	
4.13	Attach quicklink 5 to the main parachute attachment mechanism.	
4.14	Attach quicklink 5 to shock cord loop 5. Tighten the quicklink by hand.	
4.15	Confirm the main parachute is folded properly.	**Recovery lead confirmation:**
4.16	Firmly grasp the main parachute and remove the rubber band securing the parachute.	
4.17	Confirm all rubber bands are removed from the main parachute and shroudlines.	**Recovery Lead confirmation:**
4.18	Wrap the nomex cloth around the main parachute like a burrito, continuing to firmly grasp the main parachute. Place the same rubber band from checklist item 5.16 around the folded up nomex with the main parachute inside to hold everything in place.	
4.19	Attach quicklink 5 to the nose cone bulkhead U-bolt.	
4.20	Tighten quicklink 5 by hand until secure. Tape over the connection to ensure the shock cord will not unthread the closure.	
4.21	Ensure the shock cord, main parachute, and nomex cloth is connected to quick link 5. Ensure quick link 5 is secured to the nose cone U bolt by visual inspection and pulling on the shock cord.	**Recovery Lead confirmation:**

4.22	Place 2 generous handfuls of biodegradable insulation into the main bay. Break up chunks in the insulation as it is inserted into the main bay.	
4.23	Carefully insert the main parachute shock cord into the main bay. Do it so that the loop 5 comes directly out of the forward end of the main parachute bay.	
4.24	Firmly grasp the nomex wrapped parachute. Remove the rubber band from the nomex wrapped main parachute (Team Lead: place rubber band on wrist).	
4.25	Confirm all rubber bands are removed from the nomex wrapped main parachute.	**Recovery Lead confirmation:**
4.26	Fold the main parachute in half vertically then carefully insert it into the main parachute bay.	
4.27	Slide the nose cone coupler into the forward end of the main parachute bay, aligning the alignment marks.	
4.28	Test the friction fit of the nose cone.	
4.29	Screw in 2 #4-40, ½ inch long nylon shear pins into the shear pin holes.	
4.30	Hold the Launch Vehicle vertically by the nose cone, letting the rest of the rocket hang free, and confirm that the launch vehicle holds its own weight. During the test, lightly shake the rocket.	**Recovery Lead confirmation:**

5. MOTOR ASSEMBLY

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Aerodynamics Lead	Aubri Sprouse	
Motor Personnel 1		
Motor Personnel 2		

Supervisor	Tripoli/NAR #	Confirmation

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Nitrile Gloves	5	Safety Box	
Motor Assembly Instructions	1	Energetics Box	
Motor Reload Kit	1	Energetics Box	
Motor Casing	1	Energetics Box	
Motor Liner	1	Energetics Box	
Super Lube	1	LD Toolbox Bottom Drawer	
Wire Strippers	1	LD Toolbox Middle Drawer	
Blue Tape	1	LD Toolbox Top Drawer	

Number	Task	Completion
5.1	Gather all materials and go to the L3 mentor at their table to receive permission to begin motor assembly.	
5.2	Confirm that all members constructing the motor are wearing nitrile gloves.	**Aerodynamics Lead confirmation:**
5.3	Inspect each motor grain for voids.	**Aerodynamics Lead confirmation:**

5.4	Use lube to lightly grease the O-Rings identified by motor manual.	
5.5	Use lube to lightly grease threads on the motor casing.	
5.6	Install smoke grain into an insulator tube with a spacer until snug.	
5.7	Use lube to lightly grease one end of the smoke grain.	
5.8	Install smoke grain into forward closure, greased side facing forward, until snug.	
5.9	Install forward seal disk O-Ring on forward seal disk.	
5.10	Install forward seal disk and O-Ring into one end of the motor liner until snug.	
5.11	Install three propellant grains into the motor liner.	
5.12	Install motor liner into motor casing, holding the liner centered within the casing.	
5.13	Install forward O-Ring into the forward end of the motor casing. The O-Ring MUST be seated against the forward end of the forward seal disk assembly.	
5.14	Install the forward closure with smoke grain assembly onto the forward end of the motor casing, on top of the forward O-Ring. Tighten until finger tight.	
5.15	Install aft nozzle on the aft end of the motor casing.	
5.16	Install aft O-ring onto aft nozzle.	
5.17	Install aft closure onto aft O-Ring.	
5.18	Install aft closure assembly into the aft end of the motor casing. Tighten until finger tight. NOTE: There will be exposed threads when the aft closure is snug.	
5.19	Install nozzle cap with a corner cut.	
5.20	Prepare the motor ignitor.	
5.21	Hold ignitor wire along the side of the motor casing.	
5.22	Designate appropriate length by parking ignitor wire with Tape.	
5.23	Separate ends of ignitor wire.	
5.24	Strip ends of ignitor wire with wire strippers.	
5.25	Coil ignitor wire back into original orientation.	
5.26	Tape ignitor to side of casing.	
5.27	Thank the mentor for assisting with motor assembly.	
5.28	Return to launch vehicle assembly tent with motor and prepared ignitor. Designate one person to hold the motor. Keep motor away from other personnel until checklist item 6.2	

6. DROGUE RECOVERY ASSEMBLY

Required Personnel		**Confirmation**
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Recovery Lead	Trent Couse	
Drogue Recovery Personnel 1		
Drogue Recovery Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Safety Glasses	5	Safety Box	
Motor Casing	1	Energetics Box	
Motor Eye-bolt	1	Vehicle Box	
Fin Can	1	-	
Motor Retainer	1	Vehicle Box	
Motor Retainer Screws (#8-32 ¾")	2	Vehicle Box	
AVAB	1	-	
Drogue Parachute	1	Recovery Box	
Drogue Parachute Nomex	1	Recovery Box	
Biodegradable Insulation	1	-	
Shock Cord	1	Recovery Box	
Quicklinks	3	Avionics Box	
#4-40 ½" Nylon Shear Pins	2	Vehicle Box	
Screwdriver	1	LD Toolbox Middle Drawer	
Rubber Bands	2	LD Toolbox Bottom Drawer	
Blue Tape	1	LD Toolbox Top Drawer	

Number	**Task**	**Completion**
6.1	Confirm that all members within the assembly tent are wearing safety glasses.	**Safety Officer confirmation:**
6.2	Slide motor casing into the fin can using the centering rings for alignment.	

6.3	Place the motor retainer on top of the motor casing. Align holes.	
6.4	Take off the red cap on the aft end of the motor.	
6.5	Secure the motor casing with the motor retainer. Insert 2 #8-32 ¾ inch screws into the two holes in the motor casing and tighten with a screwdriver. Note: tighten both screws simultaneously to ensure the motor retainer is attached to the RMFS straight.	
6.6	Thread the eye-bolt into the forward end of the motor casing.	
6.7	Accordion fold the length of the shock cord between loops 1 and 2 in 8 inch lengths. Leave between 1 and 2 feet between the accordion folded shock cord and loop 1 and 2.	
6.8	Secure the length of shock cord between loops 1 and 2 with a single rubber band. Two fingers should fit snugly under the rubber band. Ensure the rubber band is attached to the shock cord.	
6.9	Confirm the shock cord is folded accordion style.	**Recovery Lead confirmation:**
6.10	Attach quicklink 1 to shock cord loop 1. Do not tighten.	
6.11	Attach quicklink 1 to the eye bolt at the forward end of the motor casing.	
6.12	Tighten quicklink 1 by hand until secure. Tape over the connection to ensure the shock cord will not unthread the closure. Flip the quick link over so the threads face forward/up.	
6.13	Confirm the shock cord is secured to the motor casing by visual inspection and pulling on the shock cord.	**Recovery Lead confirmation:**
6.14	Attach quicklink 3 to the drogue parachute attachment mechanism. Do not tighten.	
6.15	Attach quicklink 3 to the hole in the drogue parachute nomex. Tighten.	
6.16	Confirm the drogue parachute is folded properly.	**Recovery Lead confirmation:**
6.17	Firmly grasp the drogue parachute and remove the rubber band securing the parachute.	
6.18	Confirm all rubber bands are removed from the drogue parachute and shroudlines.	**Recovery Lead confirmation:**
6.19	Wrap the nomex cloth around the drogue parachute like a burrito, continuing to firmly grasp the drogue parachute. Place the same	

	rubber band from checklist item 4.16 around the folded up nomex with the drogue parachute inside to hold everything in place.	
6.20	Ensure no open gap between nomex on the quicklink attachment side.	
6.21	Attach quicklink 3 to aft AVAB bulkhead U-bolt.	
6.22	Tighten quicklink 3 by hand until secure. Tape over the connection to ensure the shock cord will not unthread the closure.	
6.23	Attach quicklink 2 to shock cord loop 2. Do not tighten	
6.24	Attach quicklink 2 to aft AVAB bulkhead U-bolt.	
6.25	Tighten quicklink 2 by hand until secure. Tape over the connection to ensure the shock cord will not unthread the closure.	
6.26	Confirm the shock cord is secured to the AVAB by visual inspection and pulling on the shock cord.	**Recovery Lead confirmation:**
6.27	Confirm the parachute is secured to the aft AVAB U bolt by visual inspection.	**Recovery Lead confirmation:**
6.28	Place 2 handfuls of biodegradable insulation into the drogue bay. Break up the clumps in the insulation as it is inserted into the drogue bay.	
6.29	Carefully insert the length of shock cord between loops 1 and 2 into the drogue bay. Ensure the cord wraps around the outside of the motor casing.	
6.30	Firmly grasp the nomex wrapped parachute. Remove the rubber band from the nomex wrapped drogue parachute **(Team Lead: place rubber band on wrist).**	**Team Lead confirmation:**
6.31	Confirm all rubber bands are removed from the nomex wrapped drogue parachute.	
6.32	Remove the Air Brakes pull pin switch.	
6.33	Carefully insert the drogue parachute into the fin can such that blast caps will not touch the parachutes.	
6.34	Slide the AVAB coupler into the fin can, aligning the alignment marks.	
6.35	Screw 2 #4-40, ½ inch long nylon shear pins into the shear pin holes.	
6.36	Replace the Air Brakes pull pin switch.	
6.37	Hold the rocket vertically by the main parachute bay, letting the fin can hang free, and confirm that the launch vehicle holds its own weight.	**Recovery Lead confirmation:**

7. FINAL MEASUREMENTS

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Payload Lead		
Payload Personnel 1		
Payload Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Launch Vehicle (Assembled)	1	-	
Tape Measure	1	LD Toolbox Top Drawer	
Blue Tape	1	LD Toolbox Top Drawer	
Sharpie	1	LD Toolbox Top Compartment	
Rope	1	LD Toolbox Bottom Drawer	
Scale	1	-	
Field Recovery Box	2	-	

Number	Task	Completion
7.1	Measure the center of pressure of the launch vehicle. This point is 45.15 inches from the tip of the nose cone. Ensure that the tape measure is level to the rocket and does not follow the curvature of the nose cone.	
7.2	Use a circular sticker or blue tape to mark the location of the center of pressure of the rocket. Write CP on this marking.	
7.3	Using a rope, determine the location of the center of gravity of the rocket. Tie the rope around the rocket and move the rope to the appropriate location such that the rocket can balance at this single point.	
7.4	Use a circular sticker or blue tape to mark the location of the center of gravity of the rocket. Write CG or draw the CG symbol on this marking.	
7.5	Record the weight of the launch vehicle using the scale.	**Record weight here:**
7.6	Ensure that the center of gravity of the rocket is forward of the air brake fin slots.	**Integration Lead confirmation:**
7.7	Measure the center of gravity of the launch vehicle from the tip of the nose cone. Ensure that the tape measure is level to the rocket and does not follow the curvature of the nose cone.	
7.8	Calculate the stability margin of the rocket using the formula (CP-CG)/D. The stability margin must be at least 2.0.	**Record stability margin here: Integration Lead confirmation:**
7.9	Team Lead confirm that there are two rubber bands around wrist.	**Team Lead confirmation:**
7.10	Load the field recovery box with the items required by Checklist 8: Launch Pad	
7.11	Proceed to the RSO desk.	

8. LAUNCH PAD

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Recovery Lead	Trent Couse	
Payload Lead		
Launch Pad Personnel 1		
Launch Pad Personnel 2		

Required Materials			
Item	Quantity	Location	Completion
Launch Vehicle (assembled)	1	-	
Motor ignitor	1	Safety Box	
Vaseline	1	LD Toolbox Top Compartment	
Nitrile Gloves	1	Safety Box	
Heavy Duty Gloves	2	Safety Box	
Safety Glasses	1	Safety Box	
Shear Pin Screwdriver (Blue - good screwdriver)	1	LD Toolbox Middle Drawer	
Adjustable Wrench	1	LD Toolbox Middle Drawer	
Rubber Bands	6	LD Toolbox Bottom Drawer	
Phone	1	-	
Laptop	1	-	
Wire Snips	1	LD Toolbox Middle Drawer	
Wire Strippers	1	LD Toolbox Middle Drawer	
Blue Tape	1	LD Toolbox Top Drawer	
Fire extinguisher	1	Safety Box	
EggFinder Receiver	1	Student Backpack	

Number	Task	Completion
8.1	Confirm with RSO that field conditions are safe for launch	
8.2	Fill out flight card and submit to RSO for review	
8.3	Proceed to launch pad with RSO permission	
8.4	Record coordinates of launch pad	
8.5	Confirm blast deflector is mounted below the launch rail	
8.6	Carefully slide the launch vehicle onto the launch rail, aligning the rail buttons with the forward slots in the launch rail	
8.7	Confirm that the launch vehicle slides smoothly along the rail	**Safety Officer confirmation:**
8.8	If there is any resistance in sliding the launch vehicle along the rail, remove the launch vehicle, apply lube to the launch vehicle, and repeat checklist items 8.6-8.7	
8.9	Rotate the launch rail into the upright position and lock into place	
8.10	Orient launch rail such that it is pointed away from spectators at an angle of no less than 5 degrees from vertical	
8.11	Confirm the launch rail is locked	**Safety Officer confirmation:**
8.12	Invite the rest of the team to the launch pad for pictures	
8.13	Take team pictures	
8.14	All non-essential personnel leave the launch pad	
8.15	Confirm that all remaining individuals are wearing safety glasses	**Safety Officer confirmation:**
8.16	Complete steps 8.17-8.20 (airbrakes), 8.21, and 8.22–8.36 (recovery) simultaneously as necessary	
	Airbrakes	
8.17	Turn on air brakes (pull both pins).	
8.18	Create a mobile hotspot with name: HPRC, password: tacholycos, band: 2.4 GHz Wait for the pi to connect to the hotspot (note IP address), and then, run: `ssh pi@[Pi IP Address]` Connect via tmux, run: `tmux new -s airbrakes`	
8.19	Navigate to the AirbrakesV2 directory (if not already in it) run: `cd AirbrakesV2/` Now run: `python3 main.py -v` You should now see a display of what the air brakes code is doing	
8.20	Continue to monitor the display before launch, making sure it stays in **StandbyState.**	

	If the display reports an invalid field from the IMU, restart the pi by running: `` `sudo reboot` `` Then repeat steps 8.17-8.19. Once the rocket is about to launch, detach from the session by pressing **Ctrl + b**, then **d** *Note: even if you don't detach and it simply loses connection due to being out of range, everything will still run fine*	
	Payload	

8.21	Enable Hotspot:
	
	• Hotspot Name: HPRC
	• Password: tacholycos
	
	Remove the Pull Pin:
	
	• Ensure the pull pin is removed before proceeding.
	
	Verify Raspberry Pi Connection:
	
	• Confirm that the Raspberry Pi connects to the hotspot. Record the hotspot's IP address.
	
	Access the Raspberry Pi via SSH:
	
	• Establish an SSH connection to the Raspberry Pi.
	
	Initialize a TMUX Session:
	Create a new TMUX session using the following command:
	
	`tmux new -s launch`
	
	Activate the Python Virtual Environment:
	Navigate to the appropriate directory (if not already there), then activate the virtual environment:
	
	`source env/bin/activate`
	
	Run the Main Script:
	Execute the main program:
	bash
	Copy
	`python main.py`
	
	• Verify that all data streams are functioning correctly.	

	Detach the TMUX Session: • Detach from the session without stopping it: ○ Press `Ctrl + b`, then `d`.	
	Recovery	
8.22	Confirm gps continuity via phone	
8.23	Pull pull pin half way out of the pull pin switch to arm the easy mini	
8.24	Confirm the secondary altimeter is programmed correctly using 10. Appendix	
8.25	Pull the pull pin completely out of the pull pin switch to arm the stratologger	
8.26	Confirm the primary altimeter is programmed correctly using 10. Appendix	
8.27	Confirm both altimeters are powered on with full continuity.	**Safety Officer confirmation**:
8.28	Insert ignitor fully into the motor	
8.29	Secure the ignitor into place at the aft end of the launch vehicle via a motor cap or tape	
8.30	Confirm that launch pad power is turned off	
8.31	Connect ignitors wires to launch pad power wires	
8.32	Confirm launch pad continuity, measurements should read between 1.5 and 3.5.	
8.33	All personnel return to spectator location	
8.34	Ensure all pull pins are in the field recovery toolbox	
3.35	Pass the primary checklist and field recovery toolbox to the Safety Officer	
8.36	Inform the RSO that the launch vehicle is ready for launch	
8.37	Launch!	

9. FIELD RECOVERY

Required Personnel		Confirmation
Student Team Lead	Katelyn Yount	
Safety Officer	Megan Rink	
Recovery Lead	Trent Couse	
Field Recovery Personnel 1		
Field Recovery Personnel 2		

Required Materials			
Item	Quantity	Location	Completion
Launch Vehicle (Assembled)	1	-	
Safety Glasses	5	Safety Box	
Nitrile Gloves	5	Safety Box	
Heavy Duty Gloves	1	Safety Box	
Adjustable Wrench	1	Safety Box	
Rubber Bands	1	Safety Box	
Wire Cutters	1	Safety Box	
Wire Strippers	1	Safety Box	
Blue Tape	1	Safety Box	
Fire Extinguisher	1	Safety Box	
Pull Pins	5	Safety Box	

Number	Task	Completion
9.1	Confirm that all personnel are wearing safety glasses	
9.2	Confirm that all personnel handling the launch vehicle are wearing nitrile gloves	
9.3	Approach the launch vehicle on foot	
9.4	Take pictures of the launch vehicle in its landed orientation	
9.5	If a parachute is open and dragging the launch vehicle across the field, follow the procedure below. Otherwise, proceed to checklist item 9.6. a. Approach the parachute from the billowed side b. Use your hands and body to pull down the parachute from the back and by the canopy. Do not grab the shroud lines or shock cord c. Repeat for second parachute if necessary	
9.6	If the launch vehicle appears to be on fire or smoking, use the fire extinguisher to put out the fire	
9.7	Use a rubber band to secure the main parachute	
9.8	Use a rubber band to secure the drogue parachute	
9.9	Carefully pick up the forward end of the main parachute bay and inspect the forward AV bulkhead for un-blown black powder charges. The Recovery Lead or Safety Officer must be the first people to touch the launch vehicle	
9.10	Carefully pick up the aft end of the AVAB and inspect the aft AV bulkhead for un-blown black powder charges	
9.11	Listen to the altimeter beeps and record flight data using 10. Appendix	
9.12	Power off both altimeters by inserting the pull pin switch into the AVAB	
9.13	Record the coordinates of the final resting position of the launch vehicle	
9.14	Take pictures of any damage to the launch vehicle	
9.15	Inspect the launch field for non-biodegradable waste	
9.16	Collect the launch vehicle and return to the launch site. If there are un-blown charges, hold that section with fireproof gloves, and point the past caps away from personnel	

10. Appendix

Perfect Flite StratologgerCF Beep Chart

When the altimeter is turned on, it will report its current settings and other information before readying itself for flight. This is what you will hear:

- If the altimeter detected an abnormal condition on the previous flight, a short siren tone will sound, followed by one or more digits representing the error code(s), and a second siren tone. The error codes are listed below:
  - **1: Total power loss during last flight.** Downloading the data with the optional DT4U USB interface can help you to determine the exact time of the power loss, which will aid in diagnosing the underlying cause.
  - **2: Momentary power loss during last flight.** The battery voltage to the altimeter dropped briefly to less than 50% of its initial voltage at some point during the flight. The altimeter's brownout protection allowed the altimeter to continue normal operation, but a loose connection or other issue is likely. Inspecting the downloaded voltage data will aid in diagnosing the underlying cause.
  - **3: Drogue current exceeded 6 amps.** When the drogue output was activated, the e-match current was greater than 6 amps. The e-match may have been shorted, or an inappropriate e-match/battery combination is in use. Repeated operation with this condition can lead to damage of the altimeter.
  - **4: Main current exceeded 6 amps.** When the main output was activated, the e-match current was greater than 6 amps. The e-match may have been shorted, or an inappropriate e-match/battery combination is in use. Repeated operation with this condition can lead to damage of the altimeter.
  - **5: Problem detected with FLASH memory.** The selftest detected a read/write error with the flight data memory. Contact PerfectFlite for assistance.
  - **6: Problem detected with pressure sensor.** The selftest detected an error with the pressure sensor. The altimeter will not continue with the powerup sequence if this error is present. DO NOT FLY. Contact PerfectFlite for assistance. If you get an error code on powerup, please inspect your installation and make any corrections necessary to prevent future problems. The error will clear automatically after the next flight if new errors are not encountered.
- A one digit number (range of 1 to 9) corresponding to the currently-selected program preset. The preset stores the main chute deployment altitude setting (and the apogee delay setting, if used). The factory default is preset 3, which equates to main deployment at 700 feet and no apogee delay (see table on page 23).
- A two second pause, and then a three or four digit number (range of 100 feet to 9,999 feet) corresponding to the main deploy altitude setting from the currently-selected program preset. This is the altitude that your main chute will deploy at.
- (optional, only if you have added an apogee delay to the currently selected preset: A two second pause, and then a five second continuous tone to warn you that your apogee firing is set to be delayed. If you hear this tone, and don't expect an apogee delay, then: STOP, do not launch, and either modify the preset with a computer or select another preset that does not have an apogee delay.)
- A two second pause, and then a three to six digit number (range of 160 feet to 103,500 feet) representing the apogee altitude of the last flight.
- A two second pause, and then a two or three digit number representing the battery voltage in tenths of a volt (e.g. 9.2 volts would report as 92).
- A two second pause (or more if you have added an optional Powerup Delay using the setup software), and then continuity beeps repeated every 0.8 seconds: A single beep means drogue e-match continuity is OK, two beeps means main e-match continuity is OK, three beeps means both drogue & main have good continuity. If the altimeter remains silent at this point, it means that there is no continuity on either e-match terminal block. If the reported continuity does not match what you expect, inspect your e-match wiring and correct before launching!

While reporting continuity, the altimeter will begin tracking ground level pressure, and will continuously update its internal ground reading to follow fluctuations in ground level pressure until time of launch. The altimeter is ready to launch at this point.

After flight the altimeter will report in this sequence:

- An extra-long tone to indicate the start of the reporting sequence.
- A three to six digit number representing the peak altitude in feet.
- A long separator tone followed by a two to five digit number representing the maximum velocity during the flight in miles per hour.
- If the "siren delay" number is set to a number greater than zero (the default is 5 seconds, and it is changeable in the setup menu of the download software), the altimeter will wait for the specified siren delay time, and then emit a 10 second warbling siren tone. This will aid in locating the rocket if it is hidden from sight in a tree, tall grass, etc. If you do not want to use this feature, set the Siren Delay setting to "0" and it will be disabled.
- After a 10 second period of silence, the sequence repeats until power is disconnected. Flight data and peak altitude are preserved when power is turned off.

Altus Metrum EasyMini Beep Chart

Here's a short summary of all of the modes and the beeping that accompanies each mode. In the description of the beeping pattern, "dit" means a short beep while "dah" means a long beep (three times as long). "Brap" means a long dissonant tone.

Name	Beeps	Description
Neither	brap	No continuity detected on either apogee or main igniters.
Apogee	dit	Continuity detected only on apogee igniter.
Main	dit dit	Continuity detected only on the main igniter.
Both	dit dit dit	Continuity detected on both igniters.
Storage Full	warble	On-board data logging storage is full. This will not prevent the flight computer from safely controlling the flight or transmitting telemetry signals, but no record of the flight will be stored in on-board flash.

6.3 Safety Documentation Methods

Safety documentation is performed with the use of FMEA (Failure Modes and Effects Analysis) tables. This process identifies hazards to the project, subsystems, personnel, or environment, along with their causes, effects, likelihood and severity pre-mitigation, mitigation measures, the likelihood and severity post-mitigation, and the verification methods. Verification methods include the use of documentation, safety codes, checklists, tests, and requirements, both from NASA and derived by the team.

Figure 6.1 below shows the likelihood and severity (LS) matrix used to evaluate hazards before and after mitigation procedures. The level of severity is defined as low, medium, high, or severe risk (Figure 6.1). The likelihood is defined as very unlikely, unlikely, likely, or very likely (Figure 6.1). The combined likelihood and severity are color coded, where orange and red represent failure modes, which are eliminated after mitigation.

Additionally, Fault Tree Analysis is conducted on each major subsystem of the project, including structures, recovery, payload, and Air Brakes. This enables the team to identify potential causes of system failure by visualizing fault paths in a hierarchal diagram. By analyzing these failure modes, the team can assess the impact of specific risks and develop specific mitigation methods.

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 Analysis

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							
Hazards to Skin and Soft Tissues							
TL.1	Slips, trips, falls.	(1) Material spills. (2) Cluttered work environment.	Injury requiring first aid, skin abrasion.	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	Review: HPRC Safety Handbook (Appendix 8.4).
TL.2	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	Review: HPRC Safety Handbook (Appendix 8.4).
TL.3	Fingers or other appendages caught in bandsaw blade.	(1) Misuse of equipment. (2) Bandsaw contact with clothes, jewelry, or gloves.	Skin and soft tissue abrasion.	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 drill press.	4A	Review: HPRC Safety Handbook (Appendix 8.4).
TL.4	Exposure to uncured epoxy.	Working with epoxy.	Skin rash or irritation.	2D	Personnel are provided with and are required to use gloves and to limit skin contact with epoxy.	1B	Inspection: Lab Safety Cabinet. Inspection: Budget Section 7.4.
TL.5	Exposure to vaporous chemicals.	HazMat off-gassing.	Skin rash or irritation.	2D	Personnel are provided with and required to use gloves when working with vaporous materials.	2A	Review: HPRC Safety Handbook (Appendix 8.4). Inspection: Budget Section 7.4.
TL.6	Contact with hot components of soldering iron.	Misuse of equipment.	Mild to severe burns.	3D	Personnel must be trained on operation of the soldering iron and proper use of PPE.	2B	Review: HPRC Safety Handbook (Appendix 8.4).
TL.7	Contact with ejection charges.	Inadvertent contact with blown ejection charges during ejection testing.	Mild to potentially severe burns.	4B	Only trained personnel are authorized to conduct ejection testing, trained safety personnel are required to be present for all ejection tests.	3A	Review: Black Powder Safety Presentation (Appendix 8.4).
TL.8	Contact with airborne shrapnel.	Sanding, cutting, drilling brittle or granular materials.	Skin and soft tissue abrasion.	3C	Personnel must wear the required PPE when working with power tools.	1B	Review: HPRC Safety Handbook (Appendix 8.4). Inspection: Budget section 7.4.
TL.9	Skin exposure to APCP.	Motor assembly.	Skin rash or irritation.	2C	Personnel must wear gloves when assembling any motor.	2A	Inspection: Checklist Section 6.2 (Checklist Step 5.2).

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
TL.10	Improper lifting of heavy equipment.	(1) Poor posture during lifting procedures. (2) Repetitive lifting.	Muscle strain.	2C	(1) & (2) Personnel are taught how to properly lift heavy objects.	2A	Review: HPRC Safety Handbook (Appendix 8.4).
Hazards to Bones and Joints							
TL.11	Slips, trips, falls.	(1) Material spills. (2) Cluttered work environment.	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	Review: HPRC Safety Handbook (Appendix 8.4).
TL.12	Fingers or other appendages caught in bandsaw blade.	(1) Misuse of equipment. (2) Bandsaw contact with clothes, jewelry, or gloves.	Bone break/fracture.	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 drill press.	4A	Review: HPRC Safety Handbook (Appendix 8.4).
TL.13	Collision with dropped heavy equipment.	(1) Poor grip or handling of tools. (2) Overloading of personnel. (3) Heavy objects in high places.	Bone break/fracture.	4C	(1) Gloves are provided as needed for assistance with carrying objects. (2) Heavy equipment shall be handled by more than one person. (3) Heavy equipment must be bolted down to tables within the lab space.	4A	(1) Inspection: Budget Section 7.4. (2) Review: HPRC Safety Handbook (Appendix 8.4). (3) Mounting retention verified by NC State.
TL.14	Falls from elevated platforms.	Retrieving objects in high places.	Bone break/fracture, joint dislocation.	4B	Personnel shall not stand on movable objects to retrieve objects from high places.	3A	Review: HPRC Safety Handbook (Appendix 8.4).
Hazards to Respiratory System							
TL.15	Exposure to chemical fumes.	Handling paints and chemicals.	Respiratory irritation, difficulty breathing.	2D	Personnel are provided with and are required to use N95 masks or respirators when handing paint or other vaporous chemicals.	2A	Inspection: Budget Section 7.4. Review: HPRC Safety Handbook (Appendix 8.4).
TL.16	Exposure to carcinogenic particles.	Working with colloidal silica for epoxy fillets.	Respiratory irritation, difficulty breathing, cancer.	4C	Personnel are required to wear N95 particle masks.	3A	Inspection: Budget Section 7.4 Review: HPRC Safety Handbook (Appendix 8.4).
TL.17	Inhalation of spray paint fumes.	Working with spray paint for rocket aesthetics.	Respiratory irritation/ infection.	2D	Spray painting is required to occur outside or in a designated indoor paint booth equipped with ventilation. Personnel are required to wear masks when using spray paint.	2A	Inspection: Budget Section 7.4. Review: HPRC Safety Handbook (Appendix 8.4).
TL.18	Inhalation of fiberglass particles.	Sanding/ cutting fiberglass components.	Respiratory irritation, difficulty breathing.	3C	Personnel are required to wear particle masks when cutting or sanding fiberglass and use a vacuum.	3A	Inspection: Budget Section 7.4. Review: HPRC Safety Handbook (Appendix 8.4).

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
TL.19	Inhalation of aerosolized particles.	Sanding, cutting, or drilling.	Respiratory irritation, difficulty breathing.	2D	Personnel working with power tools that produce matriculate matter that could cause respiratory irritation are required to wear masks.	2A	Review: HPRC Safety Handbook (Appendix 8.4).
				Hazards to Head			
TL.20	Slips, trips, falls.	(1) Material spills. (2) Cluttered work environment.	Concussion, head wound, dizziness, headaches, drowsiness.	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	Review: HPRC Safety Handbook (Appendix 8.4).
TL.21	Collision with construction equipment.	(1) Cluttered lab floor. (2) Distracted personnel.	Concussion, head wound, dizziness, headaches, drowsiness.	2C	(1) Lab floors are cleaned and inspected after handling of construction materials. (2) Presence of a safety officer at construction meetings to monitor safety.	2A	(1) Review: HPRC Safety Handbook (Appendix 8.4). (2) Review: NASA Requirement 5.3.1.
TL.22	Rocket falls from ceiling mount.	(1) Loose ceiling tile. (2) Mounting retention failure.	Concussion, head wound, dizziness, headaches, drowsiness.	4A	(1) Yearly maintenance from University Building Management. (2) Use of sufficiently strong mounting hardware.	2A	(1) Team lab space registered with NC State University. (2) Mounting retention verified by NC State Building Management staff.
TL.23	Exposure to chemical fumes.	(1) Opening the flame cabinet. (2) Working with chemicals.	Headaches, dizziness, drowsiness.	2D	(1) The flame cabinet in the lab space must remained closed when not in use. Any chemicals emitting fumes must be kept in the flame cabinet. (2) Personnel must wear proper PPE when working with chemicals: respirators, particle masks, face masks.	2A	(1) Inspection: HPRC Lab. (2) Review: HPRC Safety Handbook (Appendix 8.4).
				Hazards to Eyes			
TL.24	Exposure to fumes.	Working with chemicals.	Eye irritation.	2D	Personnel working with chemicals are required to wear safety glasses.	1A	Review: HPRC Safety Handbook (Appendix 8.4).
TL.25	Exposure to aerosolized particles.	(1) Working with spray paint. (2) Sanding, cutting, or drilling.	Eye irritation, eye abrasion, temporary blindness, permanent blindness.	2D	(1) Personnel are required to wear safety glasses when working with spray paint. (2) Personnel are required to wear safety glasses when drilling or cutting and are provided with safety glasses as needed for sanding.	2A	Review: HPRC Safety Handbook (Appendix 8.4).
TL.26	Exposure to intense visible light.	Welding.	Retinal damage temporary/ permanent blindness.	4B	Personnel using welding techniques must be trained and tested prior to welding.	1A	Review: Welding training handbook (Appendix 8.4).

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Ears							
TL.27	Exposure to loud noises.	(1) Personnel work with/around power tools. (2) Premature black powder ignition.	Temporary or permanent hearing loss.	1D	(1) Ear plugs and other hearing protection is provided to personnel when working with power tools. (2) Energetics are not armed until the LV reaches the launch pad.	1B	(1) Inspection: Budget Section 7.4. (2) Inspection: Launch Day Checklist Section 6.2.
Hazards Encountered at Launch Sites							
Hazards to Skin and Soft Tissues							
TF.1	Slips, trips, falls.	Uneven launch field conditions.	Skin abrasion, bruising.	2C	Only required personnel are allowed to recover the Launch Vehicle, closed toe shoes are required.	2A	Inspection: Launch Day Checklist Section 6.2.
TF.2	Insect sting/bite.	Exposure to outdoors for prolonged periods of time during launch day activities.	Skin itchiness, rash, 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	Inspection: Launch Day First Aid Kit (Appendix 8.4).
TF.3	Allergic reaction.	(1) Personnel with outdoor allergies are exposed to wildlife for prolonged periods of time. (2) Accidental exposure to allergens. (3) Personnel are allergic to the crops grown at launch site.	Runny nose, sinus pressure, mild allergic symptoms, swelling, rash, hives, anaphylaxis.	3C	(1) Emergency antihistamine is kept in launch day safety box at all times and is readily available to personnel. (2) Safety Officer is made aware of any severe allergies before launch day activities. (3) If 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	(1) Inspection: Launch Day First Aid Kit (Appendix 8.4). (2) Review: Allergy Information Form. (3) Inspection: Launch Day Checklist Section 6.2.
TF.4	Contact with ejection charges.	Contact with unblown black powder after touchdown, battery short during avionics installation/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 completion of recovery procedures.	3A	Inspection: Launch Day Checklist Section 6.2.
TF.5	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	Inspection: Launch Day First Aid Kit (Appendix 8.4).

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
TF.6	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. (4) Sideways propulsion of LV due to instability.	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. (4) Stability margin must be above 2.0 per NASA Requirement 2.14.	2A	(1) Inspection: Launch Day Checklist Section 6.2. (2) Inspection: See Section 3.5.2 for parachute selection and Section 3.6.9 kinetic energy calculations. (3) Test: See Section 7.1 for parachute and shock cord folding, along with planned altimeter test. (4) Analysis: See Section 3.6.8 for stability margin analysis for final Full-scale design.
TF.7	Contact with LV.	(1) Launch vehicle tips over on launch rail. (2) Launch vehicle rolls off construction table. (3) Launch vehicle lands near spectators.	Skin abrasion, bruising, muscle tear.	3B	(1) Launch rails are locked into place when LV is vertical. (2) LV utilizes stands that do not roll. (3) Launch rail is angled 5 degrees away from spectators. Personnel are instructed to not try to catch the LV upon landing.	2A	(1) Inspection: Launch Day Checklist Section 6.2. (2) Inspection: Launch Day Packing List (Appendix 8.2.) (3) Review: HPRC Safety Handbook (Appendix 8.4).
TF.8	Excessive load placed on personnel muscles.	Personnel lift heavy LV components.	Muscle strain.	2C	At least two personnel are required to carry the LV while it is fully configured.	1A	Review: HPRC Safety Handbook (Appendix 8.4).
TF.9	Contact with airborne shrapnel.	CATO.	Skin abrasion/ laceration.	4A	Personnel are the required distance away from the LV according to Tripoli/NAR safety codes. AeroTech motors are chosen for their low likelihood of catastrophic failure.	2A	Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4).
Hazards to Bones and Joints							
TF.10	Slips, trips, falls.	Uneven launch field conditions.	Bone break, joint dislocation.	2C	Only required personnel are allowed to recover the Launch Vehicle, closed toe shoes are required.	2A	Inspection: Launch Day Checklist Section 6.2 Review: HPRC Safety Handbook (Appendix 8.4).
TF.11	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	Inspection: Launch Day Checklist Section 6.2.
TF.12	Contact with airborne shrapnel.	CATO.	Bone fracture, limb loss.	4A	Personnel are the required distance away from the LV according to Tripoli/NAR safety codes. AeroTech motors are chosen for their low likelihood of catastrophic failure.	2A	Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4).

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Respiratory System							
TF.13	Inhalation of combustion products.	Close proximity to motors and ejection charges.	Respiratory irritation, difficulty breathing.	2B	Personnel stand a minimum distance away from burning motors as determined by NAR/ Tripoli code.	1B	Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4).
TF.14	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	(1) Review: HPRC Safety Handbook (Appendix 8.4). (2) NASA Requirement 2.23.2 .
Hazards to Head							
TF.15	Contact with airborne shrapnel.	(1) High kinetic energy LV sections. (2) CATO.	Concussion, head trauma, dizziness, headaches, memory loss.	4A	(1) The LV has a dual deploy recovery system. (2) Personnel are the required distance away from the LV according to Tripoli/NAR safety codes. AeroTech motors are chosen for their low likelihood of catastrophic failure.	2A	(1) Inspection: See Section 3.5 for final recovery system design. (2) Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4).
TF.16	Contact with LV.	(1) LV lands near spectators. (2) LV tips over on launch rail.	Concussion, head trauma, dizziness, headaches, memory loss.	3B	(1) The launch rail is angled 5 degrees away from spectators. (2) Launch rails are locked into place when LV is vertical.	2A	(1) & (2) Inspection: Launch Day Checklist Section 6.2.
Hazards to Eyes							
TF.17	Eyes have prolonged exposure to the sun.	Maintaining vision of a descending LV on a bright/sunny day.	Permanent blindness, temporary blindness, cataracts, solar retinopathy, macular degeneration.	3C	Personnel are encouraged to wear sunglasses or shield their eyes from direct solar contact.	1C	Review: HPRC Safety Handbook (Appendix 8.4).
TF.18	Exposure to black powder.	Premature ignition of black powder charges into personnel's face.	Permanent or temporary blindness, eye irritation.	4C	Personnel are required to wear safety glasses when black powder is present during assembly.	3B	Inspection: Launch Day Checklist Section 6.2 .
TF.19	Exposure to APCP combustion products.	Premature ignition of black powder charger or the motor.	Permanent or temporary blindness, eye irritation.	4B	Personnel are required to wear safety glasses at the launch pad on launch day.	3A	Inspection: Launch Day Checklist Section 6.2.
Hazards to Ears							
TF.20	Exposure to loud noises.	Motor ignition/burn.	Ear drum damage, hearing loss.	2D	Personnel are the required distance away from the LV according to Tripoli/NAR safety codes and provided with ear plugs as needed.	2A	Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4).

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
General Hazards to Health							
TF.21	Dehydration.	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	Review: HPRC Safety Handbook (Appendix 8.4).
TS.22	Heat stroke.	Personnel overheats due to prolonged exposure to high temperatures.	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	Inspection: Launch Day Packing List (Appendix 8.2).
Hazards Encountered at STEM Engagement Event							
Hazards to Skin and Soft Tissues							
TS.1	Slips, trips, falls.	(1) Uneven ground & distracted personnel. (2) Cluttered work environment & material spills.	Skin abrasion, bruising.	2C	(1) Personnel are instructed to pay attention during Estes/bottle/straw rocket launches and not run during recovery procedures. (2) Instructors maintain a safe school environment.	2A	(1) Review: HPRC Safety Handbook (Appendix 8.4). (2) Individual school policy.
TS.2	Cut with X-acto knife/ scissors.	(1) Distracted personnel. (2) Untrained use of equipment.	Skin and soft tissue abrasion.	3D	(1) Club members are kept on task by the outreach officer. (2) X-acto knives and scissors are only provided to students who know how to use them.	2B	Review: HPRC Safety Handbook (Appendix 8.4).
TS.3	Allergic Reaction.	(1) Personnel with outdoor allergies are exposed to wildlife/environment for prolonged periods of time. (2) Accidental exposure to allergens.	Runny nose, sinus pressure, mild allergic symptoms, swelling, rash, hives, anaphylaxis.	3C	STEM engagement activity hosts keep record of students allergens.	1B	Individual school policy.
TS.4	Estes rocket hits personnel.	(1) Improper launch angle or launch setup. (2) Inadequate safety perimeter.	Skin abrasion, bruising.	3B	(1) Estes rocket launch stand is angled away from spectators by greater than 5 degrees. (2) Spectators are the required distance away from the rocket according to Tripoli/NAR safety codes.	2A	Review: HPRC Safety Handbook (Appendix 8.4). Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4).

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
TS.5	Water bottle rocket hits personnel.	(1) Improper launch angle or launch setup. (2) Inadequate safety perimeter. (3) Water bottle rocket lands on personnel.	Skin abrasion, bruising.	3B	(1) Water bottle rocket launch stands are anchored to the ground with a stake to ensure it does not become angled towards spectators during launch. (2) Spectators are required to be at least 25 ft. away from the launch stand. (3) Spectators are instructed to not try to catch the rockets.	2A	Review: HPRC Safety Handbook (Appendix 8.4).
TS.6	Super glue contact with skin.	(1) Mishandling of super glue. (2) Accidental skin contact.	Rash, skin abrasion, skin irritation.	2C	(1) Students are instructed on the proper use of super glue during the demonstration. (2) Students are provided with tools to avoid contact of super glue with their skin.	1B	Review: HPRC Safety Handbook (Appendix 8.4).
Hazards to Bones and Joints							
TS.7	Slips, trips, falls.	(1) Uneven ground & distracted personnel. (2) Cluttered work environment & material spills.	Bone break/fracture.	2C	(1) Personnel are instructed to pay attention during Estes/bottle/straw rocket launches and not run during recovery procedures. (2) Instructors maintain a safe school environment.	2A	(1) Review: HPRC Safety Handbook (Appendix 8.4). (2) Individual school policy .
TS.8	Model LV falls.	(1) Improper assembly of model LV. (2) Improper safety perimeter.	Bone break/fracture.	2B	(1) Model LV is assembled prior to student arrival and is secured with shear pins. (2) Volunteers prevent students from interacting with model LV without supervision.	1A	Review: HPRC Safety Handbook (Appendix 8.4).
Hazards to Head							
TS.9	Slips, trips, falls.	(1) Uneven ground & distracted personnel. (2) Cluttered work environment & material spills .	Concussion, head wound, dizziness, headaches, drowsiness.	2C	(1) Teachers and volunteers ensure clean floors and ample space prior to starting activity. (2) Team members ensure material spills are cleaned and that the area is organized before use.	2A	Inspection: STEM engagement activity location.
TS.10	Water bottle rocket hits personnel.	(1) Improper launch angle or launch setup. (2) Inadequate safety perimeter.	Concussion, head wound, dizziness, headaches, drowsiness.	3B	(1) Only team members trained by the Outreach Officer control launch setup and ensure proper launch angle. (2) Team members inspect safety perimeter and ensure it is clear of personnel before launch.	2A	Review: HPRC Safety Handbook (Appendix 8.4).

Table 6.4: Personnel Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
TS.11	Flying debris.	(1) Over pressurization of water bottle rocket. (2) Improper LV assembly.	Concussion, head wound, dizziness, headaches, drowsiness.	3A	(1) Only team members trained by the designated Outreach Officer control launch set up and pressurization. (2) Team members inspect student LV prior to launch.	2A	Review: HPRC Safety Handbook (Appendix 8.4).
TS.12	Model LV falls.	(1) Improper assembly of model LV. (2) Inadequate safety perimeter.	Concussion, head wound, dizziness, headaches, drowsiness.	2B	(1) Model LV is fastened together with rivets and shear pins, similar to how it would be constructed on launch day. (2) Spectators are not allowed to touch the model rockets without assistance from club members.	1A	Review: HPRC Safety Handbook (Appendix 8.4).
Hazards to Eyes							
TS.13	Eye trauma.	Straw rocket is aimed towards personnel and hits a spectator's eye.	Temporary loss of sight, blurred vision, bruising.	2B	Personnel are instructed to not launch straw rockets towards spectators.	1A	Review: HPRC Safety Handbook (Appendix 8.4). Inspection: Water bottle rocket stand design.
TS.14	Flying debris.	Over pressurization of water bottle rocket.	Water bottle rocket explodes on stand.	3A	(1) Water bottle rocket is not pressurized over 80 psi. (2) Water bottle rocket launch stand has an over pressurization valve that is not blocked.	2A	Review: HPRC Safety Handbook (Appendix 8.4). Inspection: Water bottle rocket stand design.
General Hazards to Health							
TS.15	Dehydration.	Lack of water at STEM engagement event.	Muscle cramps, kidney damage, drop in blood volume, headache, dizziness.	2B	Personnel are instructed to pack water, water is provided if necessary.	2A	Review: HPRC Safety Handbook (Appendix 8.4).
TS.16	Heat stroke.	Extreme exposure to warm temperatures.	Dehydration, organ damage, heart and kidney stress, nausea, headache, confusion.	2B	Personnel provided with water and a tent is used when allowable during outreach activities.	2A	Review: HPRC Safety Handbook (Appendix 8.4).
TS.17	Hypothermia.	(1) Extreme exposure to cold temperatures. (2) Personnel sprayed with water from water bottle rocket during assembly/ launch.	Numbness, fatigue, confusion, frostbite.	4A	(1) Personnel attending STEM engagement events are instructed to wear proper attire for the weather conditions. Time outside is minimized. (2) A string is used on the water bottle rocket stand to allow personnel to stand far away from the rocket during launch.	2A	Review: HPRC Safety Handbook (Appendix 8.4).

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 arrive one day late to Huntsville. (2) Current subsystem leads train future subsystem leads to replace them at Huntsville.	1A	(1) Huntsville Roster indication of some team members arriving late. (2) Back-up subsystem leads included on Huntsville Roster.
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 7.46). (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 (Appendix 8.6). (2) Develop comprehensive and detailed schedules.	2B	(1) General Body Meeting Slide in Appendix 8.6. (2) See Section 7.5.
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) Integration Lead has taken (and takes) notes at all meetings.
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 Section 7.5. (2) Integration Lead has taken (and takes) notes at all meetings.

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.	Project communication and coordination challenges.	4B	Integration 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.2	Integration Lead becomes unavailable.	Unforeseen circumstances.	Decreased subsystem communication.	4B	Team Lead takes over position.	2B	N/A.
PA.3	Structures Lead becomes unavailable.	Unforeseen circumstances.	Incomplete Launch Vehicle.	4B	Recovery Lead takes over position.	2B	N/A.
PA.4	Recovery Lead becomes unavailable.	Unforeseen circumstances.	Incomplete recovery system.	4B	Aerodynamics Lead takes over position.	2B	N/A.
PA.5	Aerodynam-ics Lead becomes unavailable.	Unforeseen circumstances.	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.	Incomplete payload design.	4B	Other Payload Leads take over position.	2B	N/A.
PA.7	Treasurer becomes unavailable.	Unforeseen circumstances.	Decrease in project funding.	2B	New Treasurer elected.	1B	Club constitution.
PA.8	Safety Officer becomes unavailable.	Unforeseen circumstances.	Decrease in project safety.	3B	New Safety Officer elected.	2B	Club constitution.
PA.9	Outreach Lead becomes unavailable.	Unforeseen circumstances.	Decrease in STEM engagement activities.	2B	New Outreach Lead elected.	1B	Club constitution.
PA.10	Necessary members absent for NASA design review pre-sentations.	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 Modes and Effects Analysis

In tangent with Table 6.1, the LS (likelihood and severity) matrix is updated to reflect the risk occurrence of each LS rating. Table 6.7 represents the percentage of occurrence of each rating prior to mitigation, while Table 6.8 represents the percentages after mitigation. As seen below, mitigations significantly reduce the number of medium, high, and severe risk hazards. Before mitigations, 48.02% of failure modes are in the red or orange zones. After mitigations, 0.00% of failure modes are in the red or orange zones. This complies with all team derived requirements, detailed in Section 7.3.2.

Table 6.7: Risk Assessment Before Mitigation

		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0.00%	1.13%	5.65%	5.08%
	B Unlikely	1.13%	12.99%	11.30%	19.21%
	C Likely	1.13%	12.43%	7.91%	9.04%
	D Very Likely	1.13%	8.47%	3.39%	0.00%

Table 6.8: Risk Assessment After Mitigation

		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	15.25%	38.42%	14.69%	10.17%
	B Unlikely	11.30%	5.08%	2.23%	0.00%
	C Likely	2.82%	0.00%	0.00%	0.00%
	D Very Likely	0.00%	0.00%	0.00%	0.00%

6.5.1 Launch Vehicle FMEA

Table 6.9: 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. Thermal analysis on motor tube	1B	(1) Inspection: See Section 3.2.10 for final fin design (2) Test: See Section 7.1.9 for planned Fin Can impact test (3) Inspection: See Section 3.2.10 for final fin design
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 (Section 7.1)	2A	Test: See Section 7.1.9 for planned Fin Can impact test
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	Inspection: Launch Day Checklist Section 6.2
VF.4	RMFS loses functionality	Motor CATO	RMFS deformation	4A	Inspect motor grains and motor casing prior to launch	2A	Inspection: Launch Day Checklist Section 6.2
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.24)	1A	(1) Inspection: See Section 3.2.11 for final motor retainer design (1) Inspection: Launch Day Checklist Section 6.2 (2) Review: Requirement RF.24 Verification
VM.2	Cracks or voids in propellant grain	Manufacturer error	CATO	4B	Inspection prior to launch will determine if a motor is viable to launch on	4A	Inspection: Launch Day Checklist Section 6.2
VM.3	Premature ignition of motor	(1) Excessive heat exposure during handling (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	(1) Review: HPRC Safety Handbook (Appendix 8.4). (1) & (2) Inspection: Launch Day Checklist Section 6.2
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	(1) Analysis: See Figure 3.24 for force analysis on thrust plate (2) Inspection: See Section 3.4.5 for final thrust plate material selection
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	(1) Calculate black powder ejection charge size empirically (Section 3.6.12) (2) Size parachutes for a landing kinetic energy of less than 75 ft-lbf (Section 3.6.9)	1B	(1) Inspection: See Section 3.6.12 for black powder charge calculations (2) Inspection: See Section 3.6.9 for landing kinetic energy of each section and final recovery design

Table 6.9: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
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 3.5.2)	1B	(1) Inspection: See Section 3.2.14 for final airframe material selection (1) Analysis: See Section 3.2.13 for force analysis on airframe (2) Inspection: See Section 3.5 for final recovery system design
VAF.3	Stripped fastener	Excessive forces when installing/during flight	Separation of fin from vehicle	3A	Follow checklist procedures to not over-tighten fasteners during assembly	2A	Inspection: Launch Day Checklist Section 6.2
VAF.4	Deformation of RMFS	Motor CATO	Fin loses functionality	4A	Minimization of stress concentrations	2A	Inspection: See Section 3.2.9 for final RMFS design
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	Inspection: See Section 3.5 for final recovery system design
VAF.6	Airframe exposed to flame/burning ejection charges	Excessive amount black powder used in ejection charge	Airframe disintegration/ rupture	2C	(1) Ejection charges are calculated and tested prior to launch (2) LV airframe constructed from flame-resistant fiberglass and Blue Tube	1A	(1) Review: Requirements RF.8 - RF.11 Verification (2) Inspection: See Section 3.2.14 for final airframe selection
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	(1) Construct motor under the supervision of personnel possessing a L2 Certification or higher (Requirement LVS.11) (2) Inspect motor grains and motor casing prior to launch
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	(1) Tensile testing of bulkheads (2) Bulkhead material chosen according to force analysis (3) Bulkhead retained with two points of contact	4A	(1) Test: See Section 7.1.5 for planned testing of bulkheads (2) Inspection: See Section 3.2.14 for final avionics bulkhead material selection (3) Inspection: See Section 3.2.7 for final avionics bulkhead design
VB.2	Nose Cone bulkhead detached	Excessive forces	Payload exposed to the elements	3C	Bulkhead is epoxied and retained by Nose Cone shoulder	3A	Inspection: See Section 3.2.4 for final Nose Cone bulkhead design
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	(1) Inspection: See Section 3.2.14 for final bulkhead material selection and design (2) Inspection: Launch Day Checklist Section 6.2

Table 6.9: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
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 3.6.12 (2) Test correct containment of black powder in blast caps after construction to ensure no leaks	1A	(1) Inspection: See Section 3.6.12 for ejection charge sizing calculations (1) Test: See Table 7.43 (Recovery Timeline) for planned ejection testing to confirm the correct amount of black powder (2) Inspection: Launch Day Checklist Section 6.2
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/inconsistencies during motor assembly	4A	(1) & (2) Inspection: Launch Day Checklist Section 6.2
VA.2	LV is over-stable	CG is too far forward	Weathercocking	1C	(1) Vehicle CG location is measured prior to launch as a part of checklist (2) Vehicle is designed to include removable ballast in Fin Can and Nose Cone	1B	(1) Inspection: Launch Day Checklist Section 6.2 (2) Inspection: See Section 3.2.3 for removable ballast system
VA.3	LV over/under expected weight	(1) Payload is over-weight/underweight (2) Material mass differs from aerodynamic simulations (3) Too much/little ballast	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 (2) Team measures all material components and records results on a shared document (3) Vehicle is designed to include removable ballast in Fin Can and Nose Cone	2A	(1) Inspection: See Table 7.41 for weekly meeting times (2) Inspection: See Sections 3.2.15 and 4.5 for all recorded LV and payload masses (3) Inspection: See Section 3.2.3 for removable ballast system
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	(1) & (2) Inspection: Launch Day Checklist Section 6.2 (2) Inspection: See Section 3.5 for final recovery system design
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	(1) & (2) Inspection: Launch Day Checklist Section 6.2

Table 6.9: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
VR.3	Main parachute deploys at apogee	(1) Drag separation of Main Parachute Bay (2) Altimeter failure (3) E-matches 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	(1) Inspection: See Section 3.5 for final recovery system design (2) Test: See Section 7.1.10 for planned altimeter testing (3) Inspection: See Launch Day Checklist Section 6.2 for essential personnel
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 packed incorrectly	Ballistic descent, kinetic energy requirement failure, complete mission failure	4C	(1) Black powder calculations are made according to Requirements RF.8 - RF.12. 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) See Requirement RE.2 (5) Parachutes are folded using the "Z-fold"	4A	(1) Test: See Table 7.43 for planned ejection test (1) Review: Requirement RF.24 Verification (2) Inspection: See Launch Day Checklist Section 6.2 (3) Inspection: See Section 3.5 for final recovery system design (3) Inspection: See Launch Day Checklist Section 6.2 (4) Review: Requirement RF.22 Verification (5) Inspection: See Launch Day Checklist Section 6.2
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 3.5.2 to accommodate expected drag forces.	1B	(1) Test: See Section 7.1.10 for planned altimeter testing (2) Inspection: See Section 3.5.2 for parachute sizing calculations
VR.6	LV sections collide	(1) Insufficient length of shock cord (2) Shock cord entanglement	Damage to LV by collision or landing velocity	2C	Allotted more than 5 ft separation between falling sections under parachute	1B	Inspection: See Section 3.5 for final recovery system design
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	Test: See Section 7.1.10 for planned altimeter testing
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	Inspection: Launch Day Checklist Section 6.2
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	Inspection: See Section 3.5 for final recovery system design

6.5.2 Payload FMEA

Table 6.10: 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	(1) & (2) Test: See Sections 7.2.4 and 7.2.2 for planned payload transmission test (3) Inspection: See Section 4.2 for final payload design (3) Test: See Sections 7.2.4 and 7.2.2 for planned transmission set-up test
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 will then be entered correctly (2) Test encoder prior to launch	1A	(1) Inspection: See Sections 7.2.4 and 7.2.2 for payload code (2) Test: See Sections 7.2.4 and 7.2.2 for planned payload encoder test
PT.3	Early transmission	Software detects landing at wrong time	Payload challenge fails, failure to meet NASA Requirement 4.2.6.1	4C	Robust state based model to detect landing	4A	Inspection: See Section 4.2.3 for state based model design
PT.4	Transmission 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 X-Bee	1B	(1) Inspection: See Section 4.2.3 for hard-coded stop time software (2) Test: See Section 7.2 for X-Bee signal reception test
PT.5	Electronics hardware disconnection	(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	(1) Inspection: See Section 3.3 for results of Subscale demonstration flight (2) Inspection: Launch Day Checklist Section 6.2 (2) Review: Requirement PF.8 Verification
PT.6	Data formatted improperly	Mistake in payload software	Failure to adhere to NASA specifications, payload failure	3A	(1) Verify expected data format (2) Perform test transmissions using the desired data format prior to launch day	1A	(1) & (2) Inspection: See Sections 7.2.4 and 7.2.2 for the planned payload transmission tests
Hazards to Receivers							
PR.1	Mismatched X-Bee transmission and receiving frequencies	Improper frequency/ channel setup	Payload unable to receive manual shut off signal	1B	(1) Verify correct frequency (2) Test receiver on specified channel prior to launch	1A	(1) & (2) Test: See Section 7.2.3 for planned failsafe activation test

Table 6.10: Payload Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
PR.2	Transmission goes over allotted time	Software issue/ improper X-Bee configuration	Failure to adhere to NASA requirements	1B	(1) Ensure automatic transmission shutoff software is tested (2) Ensure X-Bee manual shutoff is configured to recieve signal	1A	(1) Test: See Section 7.2 for transmission shutoff test (2) Test: See Section 7.2 for X-Bee signal reception test
PR.3	Noise/ feedback	Hardware interference	Inability of payload to transmit/receive information	1C	(1) Test receivers in payload bay prior to launch (2) Test transmission systems for interference prior to launch day	1A	(1) Test: See Section 7.2 for planned payload receiver test (1) & (2) Inspection: Launch Day Checklist Section 6.2 (2) Test: See Section 7.2 for planned payload transmission test
Hazards to Wiring Components							
PW.1	Lack of com-munication between components	(1) Wires improperly secured (2) Soldering disconnection	Wire disconnection	3C	(1) Include a checklist item to ensure wires are secured (2) Adhere to Team Derived Requirement PF.8	2A	(1) Inspection: Launch Day Checklist Section 6.2 (2) Review: Requirement PF.8 Verification
PW.2	Data not collected, received, and/or transmitted	Excessive forces in launch/ preparation	Pin headers disconnected from electronics	4B	(1) Ensure proper connections on launch day with checklist (2) Adhere to Team Derived Requirement PF.8	4A	(1) Inspection: Launch Day Checklist Section 6.2 (2) Review: Requirement PF.8 Verification
Hazards to 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	Inspection: See Section 3.3 for results of Subscale demonstration flight Test: See Section 7.2 for sensor data verification test
PE.2	Electronic lose power	(1) Loose connection (2) Impact forces	Voltage regulator failure	4B	(1) Ensure proper connections and solder joints connected to the Voltage regulator (2) Test connections after simulated impact	4A	(1) Review: Requirement PF.8 (2) Test: See Section 7.2 for planned payload impact test
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	(1) & (2) Inspection: Launch Day Checklist Section 6.2
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	(1) Inspection: Launch Day Checklist (Section 6.2) (2) Inspection: Launch Day packing list (Appendix 8.2

Table 6.10: Payload Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
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	(1) Inspection: See Section 5.2 for Air Brakes fin design (2) Test: See Section 7.2.7 for Air Brakes deployment test
PA.2	Failed Air Brakes deploymen-t/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, compliance with Team Derived Requirement ABF.5	2A	(1) Inspection: See Section 5 for Air Brakes fin friction reduction methods (2) Test: See Section 7.2.9 for planned Air Brakes flight test (3) Inspection: Launch Day Checklist Section 6.2
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	Test: See Section 7.2 for planned test on payload sled structural integrity
PS.2	Loss of flight data points	(1) In-flight/ landing forces (2) Improper adhesion/ connection	Damage to payload electronics,	2B	(1) Ensure proper connection of payload electronics to capsule (2) Test connections under similar conditions to in flight forces	2A	(1) Inspection: Launch Day Checklist Section 6.2 (1) Review: Requirement PF.8 Verification (2) Test: See Section 3.3 for results of Subscale demonstration flight

6.5.3 Integration FMEA

Table 6.11: Integration Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to System Integration							
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 due to sizing error	4B	Sizes are verified by Integration Lead before purchases are made	2A	Inspection: See Section 3.5 for final recovery connection hardware
IS.2	Threaded rods for sleds improperly sized	Measurement miscommunication, unit conversion error	Sleds do not fit on threaded rods	3B	Sizes are verified by Integration Lead before purchases are made or sleds are printed	2B	Inspection: See Section 3.4.4 for AVAB sled design and Section 4.4 for Payload sled design
IS.3	Payload doesn't fit in Nose Cone	Miscommunication between subsystems, lack of test fitting	Payload cannot be included in LV, payload failure	4C	Sizes verified by Integration Lead before construction	3A	Inspection: See Sections 4.4 and 4.2for payload size and integration into the Nose Cone

Table 6.11: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
IS.4	Payload too heavy	Miscommunication, improper calculations of weight	Stability margin outside of defined range of 2.0-2.7, apogee lower than predicted 4600 ft	3D	Measurements and calculations verified by Payload Leads and communicated to the Structures Lead	2A	(1) Review: Adhere to Requirement PD.14 for maximum payload size (2) Inspection: See Section 4.5 for payload design and mass
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.3).	3B	(1) Inspection: See Section 3.5 for final recovery system design (2) Test: See Section 7.1 for test fitting in project plan
IS.6	Main recovery system doesn't fit	(1) Miscommunication in dimensions between subsystems (2) Lack of testing	Failed recovery system	4B	Test fit recovery system and design system to have an additional breadth	3A	(1) Inspection: See Section 3.5 for final recovery system design (2) Test: See Section 7.1 for test fitting in project plan
IS.7	Inability to use Air Brakes to control launch apogee	(1) Incorrect tolerancing (2) Miscommunication in dimensions between subsystems	Air Brakes do not fit in LV	2D	Model Air Brakes and LV together in CAD to determine proper sizing	1B	(1) & (2) Inspection: See Section 5 for final Air Brakes design and integration
IS.8	LV components do not connect properly	Misaligned marking/ measurements for fastening hole placement	Misalignment of holes for fasteners	3D	3D print alignment and marking devices before drilling	1A	Review: Adhere to Requirement LVF.7 about confirmation before cutting/drilling
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	Inspection: See Section 6.2 for Launch Day Checklist
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	Inspection: Launch Day Checklist Section 6.2

6.5.4 Launch Support Equipment FMEA

Table 6.12: Launch Support Equipment Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Launch Support Equipment							
SL.1	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	(1) Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4) (2) Inspection: Launch Day Packing List (Appendix 8.2)
SL.2	LV prematurely detaches from launch rail	Improper connection of rail button to LV	Rail button stripped out of Launch Vehicle on launch pad	3B	Rail button security tested during construction	2A	Inspection: See Section 3.2.8 for rail button placement and design.
SL.3	Motor doesn't ignite	(1) Igniter is not in direct contact with motor grains (2) Bad igniter	Igniter fails to ignite motor	1D	(1) Igniters are installed under the guidance of NAR/TRA L3 personnel (2) Redundant igniters brought to launch	1A	(1) Inspection: Launch Day Checklist Section 6.2 (2) Inspection: Launch Day Packing List (Appendix 8.2) (2) Inspection: Launch Day Checklist Section 6.2 Required Materials
SL.4	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	(1) Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4) (2) Inspection: Launch Day Packing List (Appendix 8.2)
SL.5	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	Test: See Section 7.1.8 for planned shear pin testing
SL.6	Ignition system failure	Powering of ignition system insufficient/ wire shortage	Inability to launch	2A	Ignition system operated by NAR/TRA personnel	1A	N/A

6.5.5 Launch Operations FMEA

Table 6.13: 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	Inspection: FAA flight waiver
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 angled to avoid flights over spectators and vehicles	3A	Inspection: Launch Day Checklist Section 6.2

Table 6.13: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
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	Inspection: Launch Day Checklist Section 6.2
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	Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4)
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	(1) & (2) Inspection: Launch Day Checklist Section 6.2
OL.6	LV components accidentally left in lab	Components overlooked/missed during packing	Missing necessary components for launch	4C	Follow pre-written checklist/packing list	2A	Inspection: Launch Day Packing List (Appendix 8.2)
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	Inspection: Launch Day Packing List (Appendix 8.2)
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	N/A
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	Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4)
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	Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4)
OL.11	Lack of qualified person-nel/prefects to manage launch day operations	Unforeseen circumstances	Launch canceled/ delayed	4B	Team moves launch to another date/location, team uses backup launch	2A	Inspection: See planned back up launch dates in project plan (Table 7.46)
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	Inspection: Launch Day Checklist Section 6.2 Required Materials

6.5.6 Environmental Hazard Analysis

Table 6.14: Environmental Hazard Analysis

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards From Vehicle to Environment							
Hazards to Land/Vegetation at Launch Sites							
VE.1	Fire on launch field	(1) Motor ignition (2) Premature ejection charge detonation (3) CATO	Tree/shrubbery 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	(1) Inspection: See Section 3.3.3 for Subscale launch set up (2) & (3) Inspection: See Launch Day Checklist Section 6.2
VE.2	Compromised 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 with tent	2A	(1) Inspection: See Figure 5.17 for AVAB design (2) Inspection: Launch Day Packing List (Appendix 8.2)
VE.3	LV lands in tree	Parachute deploys at apogee	Tree damage/death	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) Review: NASA Requirement 1.12 (2) Review: VR.3 Mitigation
VE.4	Soil becomes contaminated from fiberglass, carbon fiber, or other contaminants	(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.8 (3) Trash Bags are brought to launch field	3A	(1) Review: VA.1 Mitigation (2) Review: Requirement RS.8 Verification (3) Inspection: Launch Day Packing List (Appendix 8.2)
VE.5	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) Review: Requirement RE.1 Verification (2) Review: NASA Requirement 2.22 Verification
VE.6	Littering of launch field	(1) Disconnection of parachutes/ Nomex (2) Disconnection of rubber bands from shock cord (3) Spillage of wadding	Environmental contamination	2C	(1) See VR.1 and VR.2 Mitigations (2) Adhere to Requirement RE.2 (3) Adhere to Requirement RE.1	1A	(1) Review: VR.1 and VR.2 Verifications (2) Review: Requirement RE.2 Verification (3) Review: Requirement RE.1 Verification
VE.7	High-energy impact of LV with ground	(1) Improper parachute sizing (2) No parachute deployment	Permanent ruts in launch field that lead to reduced crops	4B	(1) Adhere to Requirement RD.8 (2) Altimeter testing	3A	(1) Inspection: See Section 3.5.2 for parachute calculations (1) Review: Requirement RD.8 Verification (2) Test: See Section 7.1.10 for planned altimeter testing

Table 6.14: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
Hazards to Air/Water at Launch Sites							
VE.8	Microplastics 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	Inspection: See Section 3.2.1 for final LV design
VE.9	Chemical off-gassing	Motor ignition, CATO	Air pollution	3B	AeroTech motors are selected for their high safety factor	2A	Inspection: See Section 1.2.2 for motor selection
VE.10	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	(1) Inspection: See Section 1.2.2 for motor selection (2) & (3) Inspection: See Section 3.2.1 for final LV design (4) Review: Requirement EL.1 Verification
VE.11	Greenhouse gas emissions	(1) Transportation 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	(1) Inspection: HPRC Safety Handbook (Appendix 8.4) (2) Review: EA.3 Verification
VE.12	Creation of vaporized hydrochloric acid	APCP combustion byproduct comes into contact with water	Air pollution	3A	Level 2 Aerotech motors do produce enough by product to create hydrochloric acid	1A	Review: NASA Requirement 2.12
Hazards to Wildlife at Launch Sites							
VE.13	Fire on launch field	motor ignition, premature ejection charge detonation, battery explosion, CATO	Wildlife injury, habitat loss, crop damage, team member injury	4B	See EL.1 Mitigation	3A	Review: EL.1 Verification
VE.14	LV collides with birds in flight	Birds fly into clear airspace	Wildlife injury or death	4A	RSO confirms that range and sky are clear before of launch	3A	Review: HPRC Safety Handbook (Appendix 8.4)
VE.15	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	(1) Review: HPRC Safety Handbook (Appendix 8.4) (2) Inspection: Launch Day Packing List Section 8.2
VE.16	LV lands in tree	Premature parachute deployment, strong wind drift	Habitat loss, wildlife injury or death	2B	See EL.4 Mitigation	1A	Review: EL.4 Verification
VE.17	Permanent jettison of Nomex sheet	(1) Rips and tears in Nomex (2) Breakage at Nomex connection	Contamination of wildlife food/water supply	3B	See VR.1 Mitigation	2A	Review: VR.1 Verification

Table 6.14: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
VE.18	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	Review: VA.1 Verification
VE.19	Battery ejection	(1) Frayed wires on battery connection (2) Damaged battery connector (3) Poor battery retainment	Battery acid leakage onto launch field, high-energy impact of LV upon landing	3B	(1) Batteries inspected during assembly (2) Battery connection inspected during assembly (3) Battery securement tested during assembly	3A	Inspection: Launch Day Checklist Section 6.2
VE.20	Black powder in irrigation ditches	(1) Unblown black powder charges (2) Ballistic LV landing	Toxin consumption by wildlife	2B	(1) Check for unblown charges upon landing and dispose of them properly (2) Test altimeters/ parachutes	1B	(1) Inspection: Launch Day Checklist Section 6.2 (2) Test: Section 7.1.10 for planned altimeter testing
Hazards From Environment							
Hazards to Launch Vehicle							
EV.1	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	(2) Inspection: Tripoli/ NAR safety procedures (Located in HPRC Safety Handbook in Appendix 8.4) (3) Inspection: Launch Day Checklist Section 6.2
EV.2	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	Inspection: Tripoli/ NAR safety procedures (Located in the HPRC Safety Handbook in Appendix 8.4) Inspection: Launch Day Checklist Section 6.2
EV.3	Damage to Launch Vehicle upon ascent	LV collides with birds/ aircraft	Damage to airframe, broken fins, unsuccessful flight	2A	Range safety officer ensures clear sky and range prior to launch	1A	Inspection: Tripoli/ NAR safety procedures (Located in HPRC Safety Handbook in Appendix 8.4)
EV.4	Damage to Launch Vehicle upon descent	LV sections collide under parachute	Broken fins, cracked airframe	3C	Selection of shock cord lengths such that sections don't collide	2B	(1) Review: Requirement RD.4 verification (1) Inspection: Section 3.5.3 for shock cord length calculations
EV.5	Damage to Launch Vehicle upon landing	(1) LV lands out of landing area (2) LV lands in parking lot	LV hits building/ car	2B	(1) Selection of parachutes such that LV lands within 2500 ft. of launch pad under maximum wind (2) Angle launch rail 5 degrees away from spectators	2A	(1) Review: NASA Requirement 3.11 verification (1) Inspection: Section 3.6.11 for max drift distance (2) Inspection: Launch Day Checklist Section 6.2

Table 6.14: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Pre-Mitigation	Mitigation	LS Post-Mitigation	Verification
EV.6	Damage to Launch Vehicle after landing	LV dragged into irrigation ditch pipe	Cut in fin/ airframe	3C	(1) Retrieve LV in a timely manner (2) Collapse main parachute first during recovery procedures	3B	Inspection: Launch Day Checklist Section 6.2
EV.7	LV lands in tree	Parachute deploys at apogee	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) Review: NASA Requirement 1.12 (2) Review: VR.3 Mitigation
Hazards to Payload							
EV.8	LiPo explosion	Exposure to high temperature	Compromised payload electronics/ avionics	4C	Shade LV during assembly/ transfer to launch pad	4A	Inspection: Launch Day Checklist Section 6.2
EV.9	Thermal expansion/ contraction	Rapid heating/ cooling of components	3D printed payload structure	2B	(1) Shade LV during assembly (2) Use of heat resistant materials	2A	(1) Inspection: Launch Day Packing List (Appendix 8.2) (2) Inspection: Section 4.2.1 for final payload design
EV.10	Payload contact with water	Payload lands in/ is dragged into water on the launch field	Electronics waterlogged/ damaged	3A	(1) Recover payload in a timely manner to avoid contact with water (2) Shield payload electronics from the external environment	2A	(1) Inspection: Launch Day Checklist Section 6.2 (2) Inspection: Launch Day Checklist Section 6.2
EV.11	Transmission failure after landing	Landscape interferes with transmission	NASA doesn't receive collected data points	4B	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.)	4A	Test: Section 7.2 for planned payload transmission testing
Hazards to Mission Success							
EV.13	Damp propellant grains	(1) High humidity (2) Sudden rainfall	No motor ignition, motor failure	4B	Launches are not conducted in incliment weather and weather is monitored	4A	Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4)
EV.14	Damp black powder	(1) High humidity (2) Sudden rainfall	No black powder detonation, unblown black powder charges	4B	Launches are not conducted in inclement weather and weather is monitored	4A	Inspection: Tripoli/NAR Safety Codes (Located in HPRC Safety Handbook in Appendix 8.4)

6.6 Project Risks FMEA

Table 6.15: 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 documentation	Medium	High	Soft deadlines 1 week before due date. Check in points throughout project development.	A 1 week soft deadline allows the project management team to review the entire document after it's written.

Table 6.15: Project Risks

Label	Risk	Effect	Likelihood	Impact	Mitigation	Quantified Impact of Mitigation
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 the use of a backup Subscale launch date.
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	Mitigation reduces need for backup launch dates. If not followed, VDF will be pushed very closed to the deadline.
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.	VDF and PDF do not occur on the same date before FRR deadline.
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. This decreases 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	According to timelines in Section 7.5, failed testing results in 2 weeks buffer to rebuild the payload between the verification testing and vehicle flight testing.
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 7.5, failed testing results in 2 weeks buffer to rebuild the Launch Vehicle between the verification testing and vehicle flight testing.
TR.12	Failed Subscale launch	Failure to complete milestone	Low	High	Re-fly at next launch, allow time for backup launches	Creates a buffer of 2 weeks.
TR.13	Failed VDF	Failure to complete milestone	Low	High	Re-fly at next launch, allow time for backup launches	Re-fly on March 8th.
TR.14	Failed PDF	Failure to complete milestone	Low	High	Re-fly at next launch, allow time for backup launches	Re-fly on March 8th.
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. Full-scale motors have been purchased.
RR.2	No launches in April at home launch field	Missed PDF	High	Medium	Plan to do PDF in March, use identified backup launch field	Delaying PDF allows more time for testing.

Table 6.15: Project Risks

Label	Risk	Effect	Likelihood	Impact	Mitigation	Quantified Impact of Mitigation
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 3.2.9) results in a significant decrease in strength and requires extra hardware connections.
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.
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 7.39.
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.
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 7.39.
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 7.39.
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 their own travel	If 25% of funding is still lost this results in a loss of $625 per Table 7.39.
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.
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	Use other sources of funding, use club savings
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.

Table 6.15: Project Risks

Label	Risk	Effect	Likelihood	Impact	Mitigation	Quantified Impact of Mitigation
BR.10	Student steals/ takes money from club	Reduction in funding/ resources for club projects	Low	Medium	Remove student from the club, contact 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	High	Re-register club each year and fill out forms to submit to IRS	Adds approximately 30 minutes of paperwork.
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. Decreases the possibility of 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. Decreases the possibility of 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) Need to update Air Brakes 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 documentation in milestone documents	Requires time spent on Air Brakes documentation in all milestone documents. Reduction in resources allocated to competition payload.
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 outreach score.

6.7 Fault Tree Analysis

6.7.1 Vehicle Fault Tree Analysis

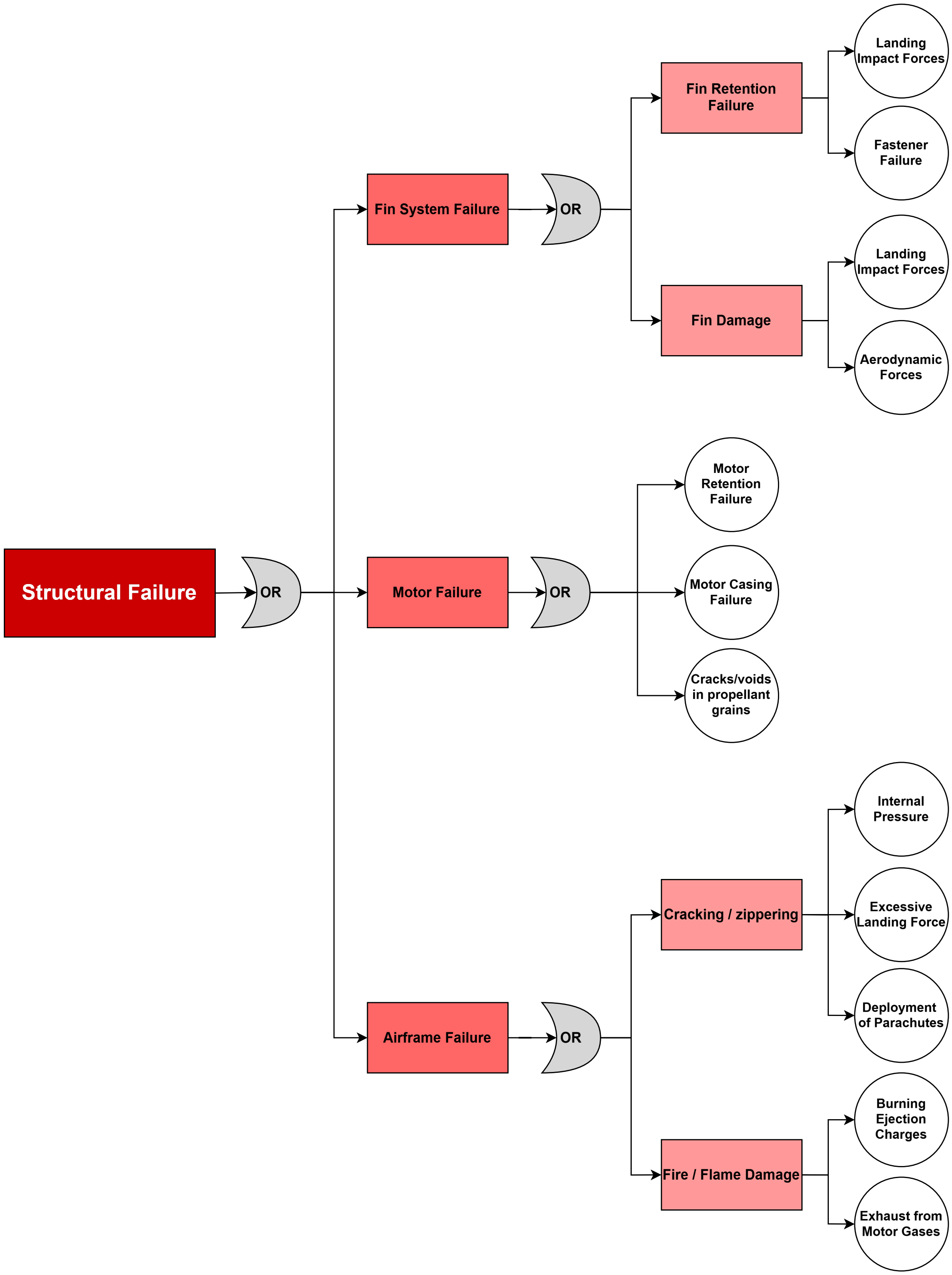


Figure 6.1: Structures FTA.

6.7.2 Recovery Fault Tree Analysis

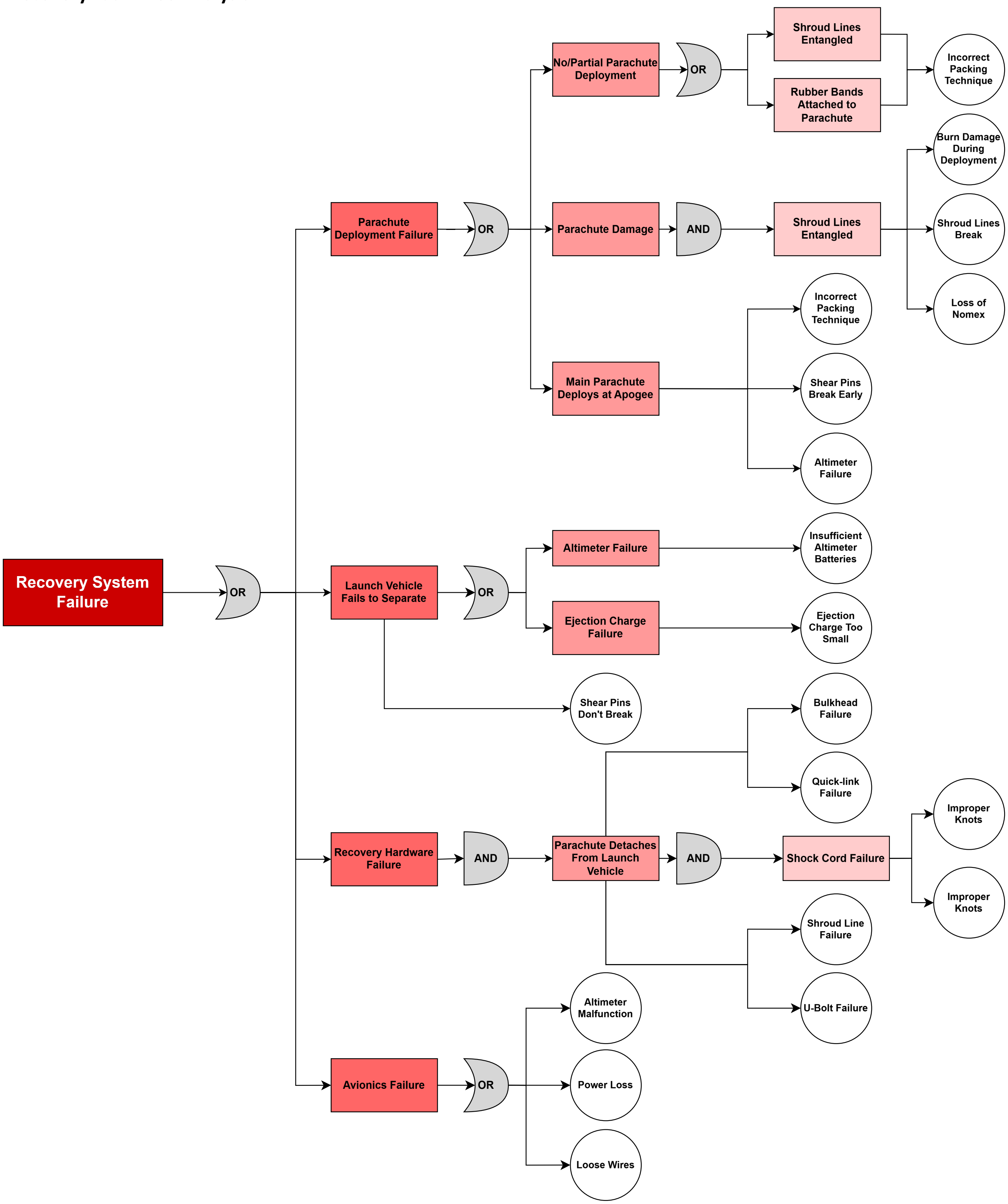


Figure 6.2: Recovery FTA.

6.7.3 Payload Fault Tree Analysis

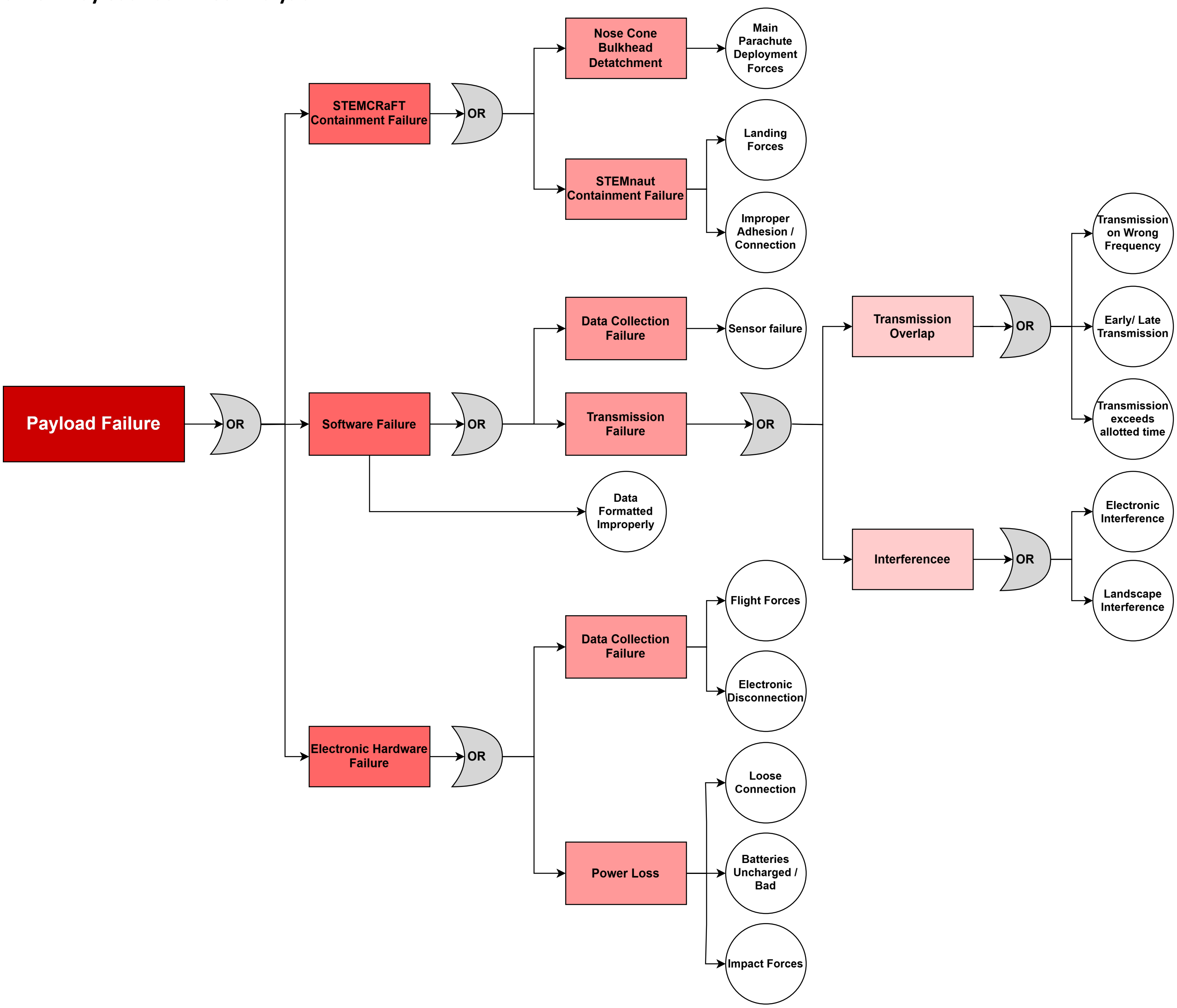


Figure 6.3: Payload FTA.

6.7.4 Air Brakes Fault Tree Analysis

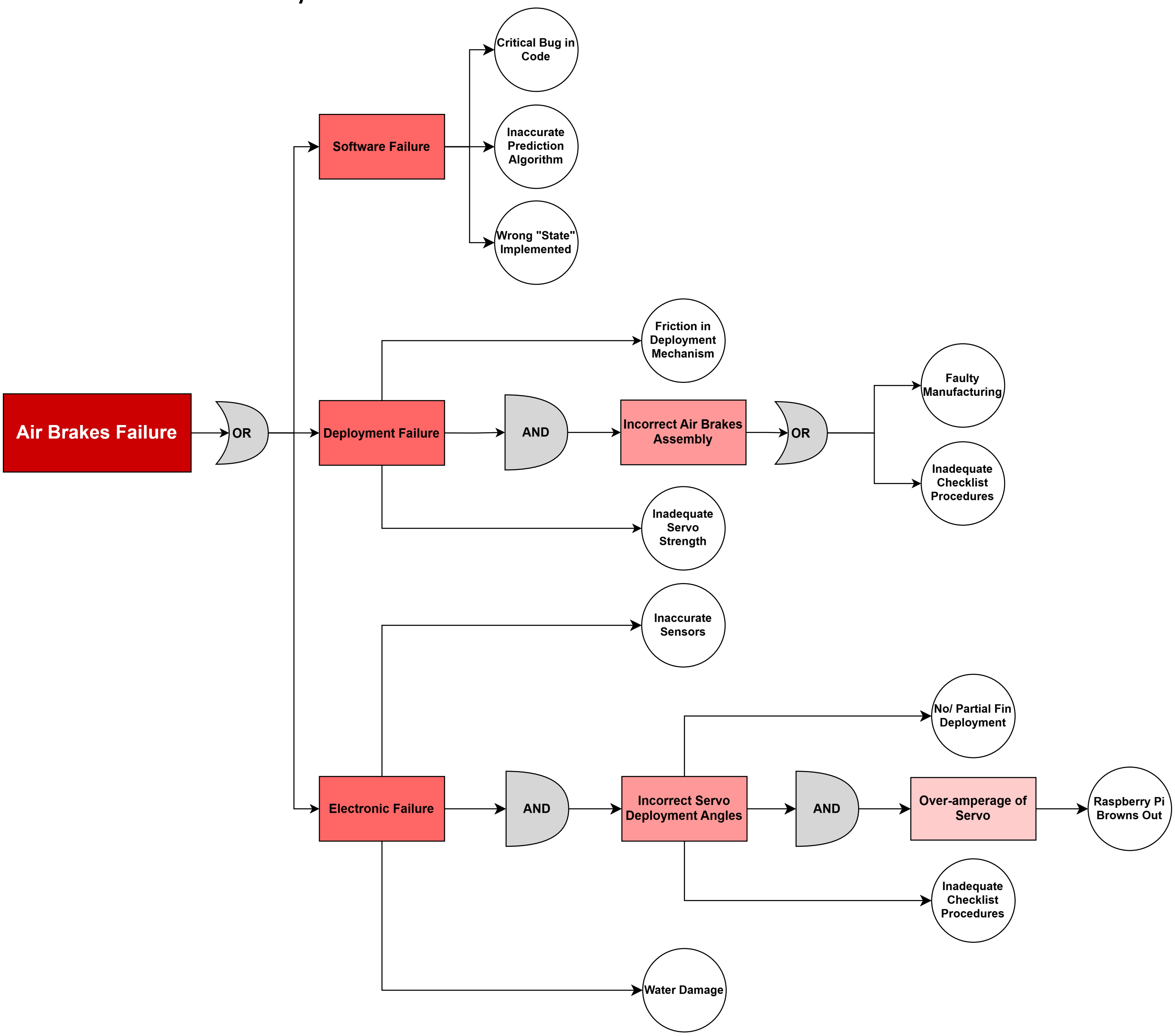


Figure 6.4: Air Brakes FTA.

7 Project Plan

7.1 Launch Vehicle Testing Suite

Table 7.1 identifies all of the tests required to prove the integrity of the final Launch Vehicle design. These tests will be completed prior to the Vehicle Demonstration Flight scheduled for February 22, 2025. These tests are also included in the project timelines in Section 7.5.

Table 7.1: Launch Vehicle Tests

Test	Requirement Verified	Date	Status
Subscale Ejection Test	NASA Req. 3.2, TDR RF.10, TDR RF.24	November 15, 2024	Verified
Subscale Dry Run	TDR LVF.2, TDR LVF.3	November 15, 2024	Verified
Subscale Demonstration Flight	NASA Req. 2.18	November 16, 2024	Verified
Moment of Inertia Test	TDR LVD.1	February 10, 2025	Not Verified
Nose Cone Bulkhead Tensile Test	TDR LVD.1	January 28, 2025	Not Verified
AVAB Bay Tensile Test	TDR LVD.1	January 28, 2025	Not Verified
Rivet Shear Loading Test	TDR LVF.11	February 4, 2025	Not Verified
Shear Pin Shear Loading Test	TDR LVF.12	February 4, 2025	Not Verified
Fin Can Impact Test	TDR LVD.1	February 3, 2025	Not Verified
Altimeter Test	TDR RF.13	January 13, 2025	Not Verified
GPS Test	TDR RD.6	January 27, 2025	Not Verified
Parachute Deployment/ STEMnaut Containment Test	TDR RF.18	January 15, 2025	Not Verified
Full-scale Ejection Test	NASA Req. 3.2, TDR RF.10, TDR RF.24	February 14, 2025	Not Verified
Full-scale Dry Run	TDR LVF.2	February 14, 2024	Not Verified
Full-scale Demonstration Flight	NASA Req. 2.19, TDR PF.5, TDR PF.6, TDR PF.7, TDR PF.8, TDR PF.9, TDR PF.10, TDR PF.11, TDR PF.12, TDR PF.13	February 22, 2024	Not Verified

7.1.1 Subscale Ejection Test

Subscale ejection testing ensured that black powder charge sizes calculated with the ideal gas law were sufficient to separate the Launch Vehicle for parachute deployment. Ejection testing is necessary to verify that the analytical calculations are correct and accurate. This satisfies NASA Requirement 3.2 and Team Derived Requirement RF.24. This test was completed on November 15, 2024. Table 7.2 defines the success criteria for this test.

Table 7.2: Subscale ejection testing success criteria.

Success Criteria	Status
Complete separation at the connection point between the AVAB and Drogue Parachute Bay/ Fin Can	Verified
Complete separation at the connection point between the Nose Cone and AVAB	Verified
No damage to the Launch Vehicle	Verified
No damage to recovery materials or hardware	Verified

Controllable Variables

- Ejection charge size
- Test location
- Test set-up

Required Facilities, Equipment, Tools, and Software

- HPRC Lab
- Assembled Launch Vehicle
- Safety glasses
- Nitrile gloves
- Fireproof gloves
- Foam pads
- 9V battery
- Battery clip

Methodology

1. Assemble Launch Vehicle into launch day configuration with the following exceptions:
   (a) The AV and Air Brakes sleds are not placed inside of the AVAB, instead a mass simulator is used.
   (b) The e-match wires are not cut, but instead threaded through the Air Brakes fin slots for easy access from the exterior of the Launch Vehicle.
   (c) Only the primary blast caps are filled with black powder.
2. The Launch Vehicle is placed horizontally on a piece of foam outdoors such that the forward and aft ends of the vehicle are at least 3 ft. away from walls or obstructions.
3. Any walls directly in front of or behind the vehicle are protected with another piece of foam.
4. Ensure battery is not connected to the battery clip.
5. One designated team member, equipped with safety glasses, approaches the Launch Vehicle to secure the ejection testing wires to the wires labeled ”drogue” on the exterior of the vehicle.
6. The team member returns to a safe distance.
7. Ensure that everyone is wearing safety glasses, no one is standing behind or in front of the Launch Vehicle, and everyone is at least 20 ft. from the sides of the Launch Vehicle.
8. The team member conducts a verbal countdown starting from 5.
9. Upon completion of the countdown, the team member connects a 9V battery to the ejection testing wires, detonating the drogue ejection charge.
10. The team member and safety officer approach the vehicle and, with fireproof gloves, ensure adequate separation of the Launch Vehicle sections. The safety officer then dumps out the contents of each section and puts out any sparks.
11. Steps 4-10 are repeated with the ejection testing wires secured to the wires labeled ”main.”

Results

Ejection testing resulted in full separation of the Launch Vehicle for drogue and main parachute deployment. This demonstrated that the black powder charges were sufficiently sized to break the shear pins and deploy parachutes during descent. Ejection testing for the drogue parachute and main parachute were both successful, and black powder masses were noted for use in the Subscale Demonstration Flight.

7.1.2 Subscale Dry Run

The objective of the Subscale dry run was to verify that the Launch Vehicle could be properly integrated on launch day, and the written checklist procedures were fully complete and accurate. During dry run, the Launch Vehicle and payload, or simulated payload, were fully constructed into launch day configuration, excluding the use of energetics. Final measurements of the Launch Vehicle were conducted to determine weight, on-pad center of gravity, and motor burnout center of gravity. This test was completed on November 15, 2024.

Table 7.3: Subscale dry run success criteria.

Success Criteria	Status
Burn out center of gravity is measured to be forward of the Air Brakes slots	Verified
Static stability is greater than 2.0	Verified

Controllable Variables

- Center of gravity
- Launch Vehicle stability
- Checklist procedures
- Motor casing preparation

Required Facilities, Equipment, Tools, and Software

- Additional mass for the simulated motor
- All tools, components, and hardware listed in the Subscale Launch Day Checklist in Section 8.1

Methodology

Subscale dry run follows the Subscale Launch Day Checklist in Section 8.1, excluding the use of any energetics. Additionally, on-pad motor mass and burnout motor mass are simulated with distributed weights in the motor casing. On-pad motor mass is used to measure the static stability margin of the Launch Vehicle and ensure it is greater than 2.0. Burn out motor mass is used to measure the burn out center of gravity and ensure it is forward of the Air Brakes fins.

Expected Results

The Subscale dry run conducted prior to the Subscale Demonstration Flight was successfully completed, meeting all of the success criteria defined in Table 7.15. The dry run identified minor adjustments needed in the Launch Vehicle structure and Subscale checklist, all of which were corrected prior to launch.

7.1.3 Subscale Demonstration Flight

The objective of the Subscale Demonstration Flight was to verify that the aerodynamic design of the Launch Vehicle functioned as intended on a smaller scale. This test is essential for validating the Launch Vehicle's design, construction methods, recovery system, and integration prior to construction of the Full-scale Launch Vehicle. The Subscale Demonstration Flight also allowed the team to gather flight data for the NASA Student Launch payload and experimental payload, Air Brakes. A successful Subscale Demonstration Flight was completed on November 16th, 2024, which verifies NASA Requirement 2.18.

Table 7.4: Subscale Demonstration Flight success criteria.

Success Criteria	Status
Launch Vehicle exits launch rail	Verified
Altimeter records apogee altitude	Verified
Altimeter produces a complete flight profile graph	Verified
Launch Vehicle is recovered in a relaunchable configuration	Verified
Launch Vehicle deploys at least one parachute during descent	Verified
Launch Vehicle records landing location	Verified

Controllable Variables

- Motor selection
- Parachute selection
- Shock Cord selection
- Altimeter selection
- GPS selection
- Ejection charge sizing
- Launch Vehicle mass
- Launch Vehicle stability

Required Facilities, Equipment, Tools, and Software

- Tripoli Range Safety Officer
- NASA Student Launch Team Mentor
- Subscale Checklist
- 10-10 Launch Rail
- Launch system
- All other tools, components, and hardware listed in the Subscale Launch Day Checklist in Section 8.1

Methodology

Subscale launch day procedures are located in Section 8.1.

Expected Results

The Subscale Demonstration Flight was successful and met all of the success criteria defined in Table 7.4 and in NASA Requirement 2.18. This demonstration flight resulted in changes in the RMFS and Air Brakes design.

7.1.4 Moment of Inertia Test

The moment of inertia test determines the moment of inertia of the Launch Vehicle, which verifies the accuracy of flight simulations. Accurate moment of inertia measurements ensure that simulation inputs are reliable, which enables precise apogee predictions, as required by the competition.

Table 7.5: Moment of inertia success criteria.

Success Criteria	Status
Moment of inertia calculation is within 20 percent of the simulated value	Not Verified
Individual swing tests should remain within .5 kgm^2 of each other	Not Verified

Controllable Variables

- Length of support ropes
- Structural design of the swing
- Initial displacement
- Measurement equipment
- Duration of test
- Number of tests completed
- Launch vehicle configuration

Required Facilities, Equipment, Tools, and Software

- Moment of inertia swing
- Launch Vehicle accelerometer with 3 degree of freedom capability
- Computer to collect data
- USB compatible extension cord to attach accelerometer to computer without impeding axial displacement
- Tape to attach accelerometer to Launch Vehicle

Methodology

1. Construct the moment of inertia swing.
2. Verify the structural integrity of the swing to support the Launch Vehicle.
3. Attach the accelerometer to the Launch Vehicle at the center of gravity of the Launch Vehicle.
4. Connect the accelerometer to the computer for data collection.
5. Set an initial displacement of the Launch Vehicle so that it will rotate axially.
6. Record the displacement of the Launch Vehicle until it comes to rest.
7. Verify the collection of verifiable data.
8. Complete the test 5 times, repeating steps 3 through 7.
9. Process the displacement data saved from the experiment in MATLAB to yield the oscillation period for the moment of inertia calculation.

Expected Results

The results from the moment of inertia calculation should closely resemble the moment of inertia values yielded from Open Rocket simulations. If the experimental results vary significantly from the simulations, the simulations will be altered with the updated moment of inertia of the Launch Vehicle.

7.1.5 Nose Cone Bulkhead Tensile Test

The Nose Cone bulkhead tensile test will subject the structural components of the Nose Cone Bulkhead assembly to tensile loading using a universal testing machine. This test will verify that the assembly can withstand the maximum calculated shock force experienced during recovery, which ensures the Nose Cone and main parachute remain attached to the remainder of the Launch Vehicle.

Table 7.6: Nose Cone Bulkhead tensile test success criteria.

Success Criteria	Status
Assembly sustains a maximum tensile load greater than 410-lbf	Not Verified
Assembly maintains a factor of safety greater than 1.5	Not Verified
Centering ring maintains a factor of safety greater than 1.5	Not Verified

Controllable Variables

- Design of replacement Nose Cone
- Loading procedure
- Testing equipment
- Margin of safety
- Post-test analysis
- Bulkhead material
- Bulkhead thickness

Required Facilities, Equipment, Tools, and Software

- Universal tensile testing machine (MAE Structural Mechanics Lab)
- 2 x 1/4 in. steel quick links
- 2 x 5/16 in. zinc-plated steel U-bolts with mount plates
- 1 x 1/2 in. Nose Cone/ Payload Bay bulkhead
- 2 x 1/2 in. Baltic Birch plywood bulkheads
- 2 x 1/4-20 threaded rods
- 2 x 1/4-20 T-Nuts
- 2 x 1/4 in. steel hex nuts
- 2 x 1/4 in. steel washers
- Safety glasses
- Camera

Methodology

1. Attach one steel quick link to each U-bolt on either side of the Nose Cone bulkhead assembly.
2. Fix each quick link to the opposite jaws of the universal load testing machine.
3. Place bulkhead assembly in slight tension.
4. Begin recording via camera.
5. Increment the tensile load via 10-ft-lbf increments. Briefly pause after each load increment to listen and visually inspect the test article.
6. If any component fails prior to 410-lbf., stop testing, document, and revise design before testing again.
7. Continue increasing load until at least 410-lbf. is reached (1.5 factor of safety). Higher loading may be attempted if desired.
8. Remove test assembly from the machine and visually inspect all components.

Expected Results

The Nose Cone assembly is expected to sustain a load of at least 410-lbf. Analysis of the assembly has yielded satisfactory results. If any failures were to occur, it would likely be the birch plywood Nose Cone/ Payload Bay Bulkhead. In this case, it would be redesigned as a thicker centering ring or a different material.

7.1.6 AVAB Bay Tensile Test

The AVAB Bay tensile test will subject the structural components of the AVAB assembly to tensile loading using a universal testing machine. This test will verify that the assembly is able to sufficiently withstand the maximum calculated shock force from the recovery system during flight, with an appropriate factor of safety. Since the AVAB bulkheads are used to attach the main parachute and the drogue parachute to the remainder of the Launch Vehicle, this test will ensure the recovery system will not compromise the success of the flight.

Table 7.7: AVAB Bay tensile test success criteria.

Success Criteria	Status
Assembly sustains a maximum tensile load greater than 410-lbf	Not Verified
Assembly maintains a factor of safety greater than 1.5	Not Verified

Controllable Variables

- Configuration of all structural components
- Loading procedure
- Testing equipment
- Margin of safety
- Post-test analysis
- Bulkhead material
- Bulkhead thickness

Required Facilities, Equipment, Tools, and Software

- Universal tensile testing machine (MAE Structural Mechanics Lab)
- 2 x 1/4 in. steel quick links

- 2 x 5/16 in. zinc-plated steel U-bolts with mount plates
- 2 x 1/2 in. Baltic Birch plywood bulkheads
- 4 x 1/4-20 threaded rods
- 12 x 1/4 in. steel hex nuts
- 12 x 1/4 in. steel washers
- Safety glasses
- Camera

Methodology

1. Attach one steel quick link to each U-bolt on either end of the AVAB bulkhead assembly.
2. Fix each quick link into the opposite jaws of the universal load testing machine.
3. Place bulkhead assembly in slight tension.
4. Begin recording via camera.
5. Increment the tensile load via 10-ft-lbf increments. Briefly pause after each load increment to listen and visually inspect the test article.
6. If any component fails prior to 410-lbf., stop testing, document, and revise design before testing again.
7. Continue increasing load until at least 410-lbf. is reached (1.5 factor of safety). Higher loading may be attempted if desired.
8. Remove test assembly from the machine and visually inspect all components.

Expected Results

The AVAB assembly is expected to sustain a load of at least 410-lbf. Finite element analysis of the assembly and real-world testing/performance of similar designs have yielded satisfactory results. If any failure were to occur, it would likely be the birch plywood bulkheads, and the system would be redesigned and retested.

7.1.7 Rivet Shear Loading Test

The rivet shear loading test will subject the rivets that are used to connect non-separating Launch Vehicle sections together during flight. This test will verify that the Launch Vehicle will not separate at non-separating connections during flight due to forces from launch, parachute deployment, or landing.

Table 7.8: Rivet shear loading test success criteria.

Success Criteria	Status
Rivet sustains a maximum tensile load of greater than 80-lbf	Not Verified
Rivet maintains a factor of safety greater than 2.0	Not Verified

Controllable Variables

- Configuration of all structural components
- Loading procedure
- Testing equipment
- Margin of safety
- Post-test analysis
- Number of rivets
- Rivet material
- Size of rivets

Required Facilities, Equipment, Tools, and Software

- Universal tensile testing machine (MAE Structural Mechanics Lab)
- Nylon rivet
- 1/8 in. thick 6061 aluminum shear loading test plates
- 2 x 1/4 in. steel quick links
- Safety glasses
- Camera

Methodology

1. Insert a test rivet into both holes in the shear loading test plates.
2. Fix each quick link into the opposite jaws of the universal load testing machine.
3. Place assembly in slight tension.
4. Begin recording via camera.
5. Increment the tensile load via 10-ft-lbf increments. Briefly pause after each load increment to inspect the rivet.
6. Continue to increase the load until failure.
7. Record the failure point and calculate the factor of safety.

Expected Results

The rivets are expected to withstand a load of at least 25-lbf and produce a factor of safety of at least 2 during flight and recovery events. If failures were to occur such that the test no longer satisfied the success criteria in Table 7.8, the number of rivets used would be increased.

7.1.8 Shear Pin Shear Loading Test

The shear pin shear loading test will subject the shear pins that are used to connect separating Launch Vehicle sections together during flight. This will verify that the Launch Vehicle does not prematurely separate before black powder detonation due to forces from launch, coast, or drogue parachute deployment.

Table 7.9: Shear pin shear load test success criteria.

Success Criteria	Status
Shear pins fail at 40 $\pm$5 lbs	Not Verified

Controllable Variables

- Configuration of all structural components
- Loading procedure
- Testing equipment
- Margin of safety
- Post-test analysis
- Number of shear pins
- Shear pin material
- Size of shear pins

Required Facilities, Equipment, Tools, and Software

- Universal tensile testing machine (MAE Structural Mechanics Lab)
- Nylon shear pin
- 1/8 in. thick 6061 aluminum shear loading test plates 2 x 1/4 in. steel quick links
- 2 x 1/4 in. steel quick links
- Safety glasses
- Camera

Methodology

1. Insert the test shear pin into both holes in the shear loading test plates.
2. Fix each quick link into the opposite jaws of the universal load testing machine.
3. place assembly in slight tension.
4. Begin recording via camera.
5. Increment the tensile load via 10-ft-lbf increments. Briefly pause after each load increment to inspect the rivet.
6. Continue to increase the load until failure.
7. Record the failure point and calculate the factor of safety.

Expected Results

The shear pins are expected to withstand a load of at least 35-lbf. If the shear pins do not fail at the expected loads, the number of shear pins used between separating sections will be changed. This would ensure that the Launch Vehicle still separates, but not prior to black powder detonation.

7.1.9 Fin Can Impact Test

The Fin Can impact test will simulate ground impact of the Fin Can components at the end of flight via drop testing. This test will evaluate the intersection of the fins and interior RMFS structure upon impacting the ground. A scrap piece of fiberglass airframe will be used as a stand-in for the Fin Can airframe to allow for extra weight to be affixed to the airframe to achieve the desired impact energy of 75 ft-lbs. This test verifies that the fins, RMFS, and Fin Can will survive the maximum kinetic energy impact determined by NASA Requirement 3.3.

Table 7.10: Fin Can impact test success criteria.

Success Criteria	Status
Fin can assembly suffers no damage	Not Verified
RMFS components suffer no damage	Not Verified
Fins suffer no damage	Not Verified

Controllable Variables

- RMFS configuration including attachment of weights and the scrap piece of airframe
- Impact angle
- Impact surface
- Drop methodology
- Test repetition

Required Facilities, Equipment, Tools, and Software

- Test stand base
- 1515 aluminum extruded rail with eye-bolt
- Barbell weights
- Bags of sand ballast
- Greater than 25 ft. of 550 para-cord
- 1 x 5/16 in. threaded rod
- 2 x 5/16 in. hex nuts
- 2 x 5/15 in. fender washers
- RMFS assembly and associated fasteners
- Fiberglass fins
- Tape measure
- Masking tape
- Safety glasses
- Camera

Methodology

1. Assemble the Fin Can test article by fastening the RMFS to the scrap airframe.
2. Affix the desired weights to the Fin Can via two plywood bulkheads and a 5/16 in. threaded rod running through the center of the Fin Can.
3. Retain the weights with 5/16 in. hex nuts and fender washers.
4. Measure the mass of the assembled test article.
5. Use kinematic equations to calculate the required height needed to generate 75 ft-lbs of kinetic energy prior to impact using test article mass.
6. Tie a length of cord to an eye-bolt on the test article, feed the remaining length of cord through the test stand rail eye-bolt.
7. Mark off the proper length of cord to meet the drop height requirement on the cord using masking tape.
8. Set up the test stand and ensure it is stable.

9. Ensure the impact area is clear and observers are at a safe distance away.
10. Slowly raise the Fin Can test article to the required height.
11. Begin recording.
12. Drop the test article by releasing the cord and allow the Fin Can to impact the ground.
13. Visually inspect for any damage and confirm the correct fin position and orientation.
14. Repeat the test as necessary to obtain various impact scenarios.

Expected Results

The Fin Can is expected to endure all impacts without damage or deformation to components. For vertical impact, the fin trailing edge tips are expected to partially dig into the ground. For horizontal and oblique impacts a purely elastic response is expected from the fin and runner system. If the fins sustain damage that would prevent a reflight of the Launch Vehicle, the thickness of the fins would be increased. If the RMFS sustains damage it will be redesigned to be more rigid with added supports and changes in material.

7.1.10 Altimeter Test

The altimeter test ensures that both the primary and secondary altimeters used on the Launch Vehicle operate properly and are programmed correctly before each launch. A flight will be simulated and the altimeters will be checked to verify that charges were sent for both drogue and main parachute deployment at the appropriate altitudes. This is necessary to ensure proper recovery of the Launch Vehicle on launch day.

Table 7.11: Altimeter Test Success Criteria

Success Criteria	Status
Drogue and main deployment LEDs light up at their appropriate times given the change in pressure in the chamber for the primary altimeter	Not Verified
Flight data of the test indicates that drogue and main charges deployed for the primary altimeter	Not Verified
Drogue and main deployment LEDs light up at their appropriate times given the change in pressure in the chamber for the secondary altimeter	Not Verified
Flight data of the test indicates that drogue and main charges deployed for the secondary altimeter	Not Verified

Controllable Variables

- Vacuum chamber conditions
- Orientation of altimeter in vacuum chamber
- Visual indication method
- Flight data verification method
- Testing repetition

Required Facilities, Equipment, Tools, and Software

- Perfect Flite StratologgerCF
- Altus Metrum EasyMini
- Computer with Perfect Flite Data Cap & AltosUI
- 9V battery
- 7.4V LiPo battery
- Pressure Chamber
- Plumbers Putty
- LED altimeter testing board

Methodology

1. Program the primary altimeter using the Perfect Flite Data Cap software.
2. Program the secondary altimeter using the AltosUI software.
3. Connect the primary or secondary altimeter to the LED board, with the red light being for the drogue charge and the yellow light being for the main charge.
4. Connect the 9V battery to the primary altimeter or the 7.4 LiPo battery to the secondary altimeter.

5. Place the altimeter, LED board, and battery in the pressure chamber.
6. Seal the pressure chamber with plumbers putty.
7. Place a cell phone on the Plexiglass cover of the vacuum chamber and start recording a video of the test.
8. Slowly bring the chamber pressure to the minimum vacuum pressure.
9. Observe the pressure chamber to verify the red LED lit up just after the pressure was brought down to the minimum.
10. Slowly bring the pressure chamber back up to atmospheric pressure.
11. As the chamber pressure increases, the yellow LED should light up.
12. Repeat steps 3-11 for both altimeters.
13. Connect the primary altimeter to a computer and view the flight profile using Perfect Flite Data Cap. The data should show the drogue charge signal was sent at ”apogee” and the main charge signal was sent at ”550 ft.”
14. Connect the secondary altimeter to a computer and view the flight profile using AltosUI. The data should show the drogue charge signal was sent 1 second after ”apogee” and the main charge signal was sent at ”500 ft.”

Expected Results

For each of the altimeters, it is expected that as the pressure reaches the minimum vacuum pressure, the red LED on the altimeter testing board will light up, indicating a successful drogue parachute deployment. It is also expected that as pressure is reintroduced into the pressure chamber, the yellow LED on the altimeter testing board will light up, indicating a successful main parachute deployment. The flight data chart for the primary altimeter should show that the drogue charge signal was sent at ”apogee” and the main charge signal was sent at ”550 ft.” The flight data chart for the secondary altimeter should show that the drogue charge signal was sent 1 second after ”apogee” and the main charge signal was sent at ”500 ft.” If the altimeters do not function as intended, the problem will be diagnosed and the altimeters will be retested. Otherwise, a different altimeter of the same type will be selected.

7.1.11 GPS Test

The GPS test will evaluate the Full-scale GPS’s transmission, battery life, and accuracy. The GPS must be able to transmit accurate coordinates on launch day as per NASA Requirement 3.13. The GPS is also required to be able to last at least 3 hours without losing functionality, as per NASA Requirement 2.5. These tests are necessary to verify all NASA Requirements regarding tracking devices.

Table 7.12: GPS Test Success Criteria

Success Criteria	Status
GPS receiver maintains a consistent and reliable connection with the Eggfinder Mini GPS transmitter within a radius of 1.5 miles	Not Verified
Eggfinder Mini GPS transmitter remains on and powered for at least 3 hours under typical usage conditions	Not Verified
The receiver consistently picks up the GPS signal from the Eggfinder Mini GPS transmitter as the distance increases	Not Verified

Controllable Variables

- Test location and environmental factors
- Maximum distance between GPS and receiver
- Test repetition
- Acceptable accuracy range

Required Facilities, Equipment, Tools, and Software

- Eggfinder Mini GPS Transmitter
- Receiver
- Two individuals
- Stopwatch/timer
- Phone
- Data logging device

Methodology

1. Ensure full battery life for GPS transmitter and receiver.
2. Power on GPS transmitter and receiver and start a stopwatch to record battery life.

3. Do not turn off the transmitter for the entirety of the test.
4. Connect the receiver to the transmitter.
5. One individual holds the receiver and stays in place outside.
6. The second individual holds the transmitter and will move to a known secondary location a set distance away from the starting point.
7. At the secondary location, the transmitter holder will use their mobile device to find the approximate distance from the receiver holder and record their latitude and longitude coordinates.
8. At the secondary location, the transmitter holder will use the transmitter to record their latitude and longitude coordinates.
9. The receiver holder will record the coordinates displayed on the receiver.
10. Repeat steps 5-8 for 3-7 repetitions while the receiver holder remains in the same location.
11. Transmitter holder returns to EB3 or the starting location.
12. At the starting location, the transmitter holder and receiver holder compare coordinates recorded by both the transmitter and receiver.
13. Accuracy is evaluated and any discrepancies are noted.
14. Turn off the receiver.
15. Verify that the GPS transmitter is on after completing the range test.
16. Allow the battery life to run out on the device and stop the stopwatch once the first battery dies.
17. Record the total time of the battery life.

Expected Results

The Eggfinder Mini GPS transmitter is expected to transmit consistently accurate data that is within 5-10 meters of the actual location. The Eggfinder Mini GPS transmitter is also expected to remain on and powered for at least 3 hours under typical usage conditions. Finally, the receiver is expected to consistently read the GPS signal from the Eggfinder Mini GPS transmitter. If there are significant differences in the results between the Launch Vehicle GPS data and external GPS data, the GPS will be altered and retested.

7.1.12 Parachute Deployment/ STEMnaut Containment Test

The parachute deployment and STEMnaut containment test will evaluate the folding techniques of the Full-scale main and drogue parachutes to ensure minimal shroud line entanglement during packing and recovery events. Additionally, the containment method of the STEMnaut housing will be validated during descent under parachute. The parachutes must fully deploy during flight to ensure accurate calculations of drag coefficients, enabling the descent velocity and kinetic energy requirements outlined in NASA Requirement 3.3 to be met.

Table 7.13: Parachute Deployment/ STEMnaut Containment Test Test Success Criteria

Success Criteria	Status
Parachutes demonstrate consistent and reliable deployment within an accectable time frame	Not Verified
Shroud line entanglement does not exceed specified threshold	Not Verified
STEMnaut containment housing remains undamaged with STEMnauts securely housed throughout the test	Not Verified

Controllable Variables

- Parachute folding technique
- Parachute condition
- Parachute packing method
- Parachute release method
- Drop site location and height
- STEMnaut housing and securement method
- Simulated weight attachment method
- Parachute measurement parameters
- Test repetition

Required Facilities, Equipment, Tools, and Software

- Full-scale main parachute
- Full-scale drogue parachute
- Full-scale main parachute nomex
- Full-scale drogue parachute nomex
- STEMnaut containment housing and STEMnauts
- Simulated payload flight conditions
- Tall building
- Recording equipment
- Stopwatch
- Scale
- Measurement tape

Methodology

1. Inspect parachutes for damage, knots in shroud lines, and fraying fabric.
2. Assemble the STEMnaut payload and secure the STEMnaut figurines in the containment housing.
3. Perform a pre-test check for the STEMnaut security and payload sled structural integrity.
4. Pack the main parachute using the ”Z-fold technique”.
5. Wrap the main parachute in a nomex cloth and secure it with a rubber band for transport.
6. Pack the drogue parachute using the ”Z-fold technique”.
7. Wrap the drogue parachute in a nomex cloth and secure it with a rubber band for transport.
8. Attach a small simulated weighted payload to the drogue parachute.
9. Attach the STEMnaut payload to the main parachute. Add an additional simulated weight to simulate the Launch Vehicle sections recovered under final main parachute recovery if needed.
10. Transport the items to the designated tall building.
11. Ensure that the drop site has no potential hazards above or below the release site.
12. Remove the rubber band from the parachute.
13. Start video recording from multiple viewpoints.
14. Throw the parachute system from the drop site to simulate recovery descent.
15. Monitor and record shroud line behavior, mark any notice of shroudline entanglement, time from release to full parachute deployment, time of descent, and height of drop distance.
16. Stop video recordings.
17. After the drop test, inspect the parachute for tangling, improper deployment, or damage. Note any observations.
18. Repeat steps 12-17 for both the main parachute and the drogue parachute.
19. For the main parachute, examine the STEMnaut containment housing for signs of impact stress or damage. Record observations.

Expected Results

The parachutes are expected to deploy without significant delay or shroud line entanglement. STEMnauts are also expected to remain within their containment housing and the housing is expected to sustain minimal to no damage. If the parachutes do not deploy appropriately or the STEMnauts are not contained, the parachute folding technique or the STEMnaut sled will be altered and retested.

7.1.13 Full-scale Ejection Test

Full-scale ejection testing will ensure that the black powder charges calculated are sufficient in separating the appropriate sections of the fully assembled Launch Vehicle for parachute deployment. This is necessary to verify a successful recovery during launch. Ejection charge sizes are calculated analytically based on ideal gas law but must be experimentally verified prior to launch in accords with NASA Requirement 3.2.

Table 7.14: Full-scale ejection testing success criteria.

Success Criteria	Status
Complete separation at the connection point between the AVAB and Drogue Parachute Bay/ Fin Can	Not Verified
Complete separation at the connection point between the Nose Cone and AVAB	Not Verified
No damage to the Launch Vehicle	Not Verified
No damage to the recovery materials or hardware	Not Verified

Controllable Variables

- Ejection charge size
- Test location
- Test set-up

Required Facilities, Equipment, Tools, and Software

- HPRC Lab
- Assembled Launch Vehicle
- Safety glasses
- Nitrile gloves
- Fireproof gloves
- Flat outdoor area
- Foam pads
- 9V battery
- Battery clip

Methodology

1. Assemble Launch Vehicle into launch day configuration with the following exceptions:
   (a) The AV and Air Brakes sleds are not placed inside of the AVAB, instead a mass simulator is placed in that section.
   (b) The e-match wires are not cut, but instead threaded through the Air Brakes fin slots for easy access from the exterior of the Launch Vehicle.
   (c) Only the primary blast caps are filled with black powder.
2. The Launch Vehicle is placed horizontally on a piece of foam such that the forward and aft ends of the Launch Vehicle are at least 3 ft. away from walls or obstructions and the forward end of the vehicle faces away from the wall.
3. Any walls in front of or behind the Launch Vehicle are protected with an additional piece of foam.
4. Ensure that the battery clips are not connected to any power source such as a battery.
5. Ensure that all members present for the ejection test are equipped with safety glasses.
6. One designated team member attached the battery clips to the ejection testing e-match wired labeled ”drogue.”
7. The designated team member backs at least 20 ft. away from the Launch Vehicle.
8. Ensure that everyone is wearing safety glasses, no one is standing behind or in front of the Launch Vehicle, and no one is within 20 ft. of the Launch Vehicle.
9. The designated team member begins a verbal countdown from 5.
10. Once the countdown reaches 0, the team member connects a battery to the ejection testing wires, detonating the drogue ejection charge.
11. With fireproof gloves, the team member and the safety officer approach the Launch Vehicle and ensure that the vehicle separated as expected and there is no damage to the Launch Vehicle.
12. Steps 4-11 are repeated with the ejection testing wires secured to the wires labeled ”main.”

Expected Results

The drogue and main sections of the Launch Vehicle will separate on the foam pulling the drogue and main parachutes out. This successfully demonstrates that the black powder charges are large enough to break the shear pins and deploy the parachutes during descent. If both tests are successful, the masses for the black powder are recorded and used during the next flight. In the event either the drogue or main separation charge is not large enough to separate the vehicle, the ejection test will be repeated for the that/those sections with an additional 0.2 grams of black powder added until successful separation.

7.1.14 Full-scale Dry Run

The Full-scale dry run will verify that the Launch Vehicle and the Launch Day Checklist are fully ready for launch. During dry run, the Launch Vehicle and payload will be fully constructed into launch day configuration using the Launch Day Checklist, excluding the packing or use of energetics. During the final checklist section of dry run, final measurements will be taken of the on-pad static stability, burn out center of gravity, and weight of the Launch Vehicle. Final measurements will be conducted using simulated weights to represent the on-pad motor mass and burn out motor mass.

Table 7.15: Subscale dry run success criteria.

Success Criteria	Status
Burn out center of gravity is measured to be forward of the Air Brakes slots	Not Verified
Static stability is greater than 2.0	Not Verified

Controllable Variables

- Center of gravity
- Launch Vehicle stability
- Checklist procedures
- Motor casing preparation

Required Facilities, Equipment, Tools, and Software

- Additional mass for the simulated motor
- All tools, components, and hardware listed in the Launch Day Checklist in Section 6.2. Note: checklist procedures may change as the Full-scale Launch Vehicle is developed.

Methodology

Full-scale dry run will follow a similar procedure to the Launch Day Checklist included in Section 6.2, however, it will utilize Full-scale components. Due to this, some checklist procedures such as the amount of black powder, number of shear pins, and payload assembly will vary from the Subscale checklist. During dry run, on-pad motor mass is used to measure the static stability margin of the Launch Vehicle and ensure it is greater than 2.0, as required by NASA Requirement 2.14. Burn out motor mass is used to measure the burn out center of gravity to ensure that it is forward of the Air Brakes fin slots, as required by NASA Requirement 2.16.

Expected Results

A Full-scale dry run will be conducted prior to any Full-scale launch. Given the project plan's inclusion of numerous integration tests leading up to dry run, it is expected that all components will correctly fit within the Launch Vehicle during the test. Additionally, simulations conducted during the design and construction phases of the Full-scale Launch Vehicle indicate that the static stability is expected to be above 2.0 and the burn out center of gravity is expected to be several in. forward of the Air Brakes fin slots. If any of the success criteria are not met, dry run will be redone before launch.

7.1.15 Full-scale Demonstration Flight

The objective of the Full-scale Demonstration Flight is to verify the Launch Vehicle's stability, the structural integrity of Launch Vehicle components, the recovery system, and the team's ability to prepare the Launch Vehicle for flight. The demonstration flight also validates the Launch Vehicle's ability to safety retain the constructed payload, and ensures the payload performs as designed. A Vehicle Demonstration Flight and a Payload Demonstration Flight are required by NASA Requirements 2.19.1 and 2.19.2. Both flights are planned for February 22, 2025.

Table 7.16: Full-scale Demonstration Flight success criteria.

Success Criteria	Status
Launch Vehicle departs launch rail travelling vertically until motor burnout	Not Verified
Launch Vehicle deploys at least one parachute during descent	Not Verified
Launch Vehicle endures minimal damage such that it could be relaunched in the same day	Not Verified
Altimeter flight profile data is complete	Not Verified
Quality pictures of the as landed configuration of all sections of the Launch Vehicle are taken	Not Verified
Payload is safely retained throughout the duration of the flight	Not Verified
Payload systems preform as designed	Not Verified

Controllable Variables

- Ejection charge sizing
- Launch Vehicle mass
- Launch Vehicle stability
- Payload configuration

Required Facilities, Equipment, Tools, and Software

- Tripoli Range Safety Officer
- NASA Student Launch Team Mentor
- Full-scale Checklist
- 15-15 Launch rail
- Launch system
- All other tools, components, and hardware listed in the Launch Day Checklist in Section **??**.

Methodology

The procedure for the Full-scale Demonstration Flight will follow the Launch Day Checklist located in Section 6.2. The procedure may be altered to include launch day set-up of the competition payload.

Expected Results

For the Vehicle Demonstration Flight and Payload Demonstration Flight, the Launch Vehicle is expected to contain a working payload and Air Brakes system. The Launch Vehicle is expected to weigh 35.78 lbs, have a static stability of 2.06, reach a maximum velocity of 653.75 fps, reach an apogee of 4800 ft., and descend in 76.4 sec. The drogue parachute is expected to deploy at apogee and the main parachute is expected to deploy at 550 ft. Under the main parachute, the Launch Vehicle is expected to land with a maximum kinetic energy of 54.969 Ft-lbs. The Launch Vehicle is expected to include a working GPS and payload system that transmits all eight pieces of data determined in the NASA Student Launch Handbook. If the Vehicle Demonstration Flight is deemed unsuccessful, the Launh Vehile will be altered and relaunched on the back-up launch date.

7.2 Payload Testing Suite

Table 7.17 identifies all of the tests required to prove the integrity of the final Payload and Air Brakes design. These tests will be completed prior to the Payload Demonstration Flight scheduled for February 22, 2025. These tests are also included in the project timelines in Section 7.5.

Table 7.17: Payload Tests

Test	Requirement Verified	Date	Status
Payload Data Collection Test	TDR PF.5, TDR PF.6, TDR PF.7, TDR PF.8, TDR PF.9, TDR PF.10, TDR PF.11, TDR PF.12, TDR PF.13	January 25, 2025	Not Verified
Payload Flight Simulation Transmission Test	TDR PF.1	February 14, 2025	Not Verified
Remote Override Test	TDR PF.1	February 14, 2025	Not Verified
Data Transmission Verification	TDR PF.1	January 31, 2025	Not Verified
Battery Capacity Verification	TDR PF.9	January 30, 2025	Not Verified
Nose Cone with STEMCRaFT Impact Test	TDR PF.7	February 6, 2025	Not Verified
Air Brakes Deployment Test	TDR ABF.1, TDR ABF.2	February 13, 2025	Not Verified
Air Brakes Flight Simulation Test	TDR ABF.4, TDR ABF.5	January 31, 2025	Not Verified
Air Brakes Effectiveness Flight Test	TDR ABF.1, TDR ABF.2, TDR ABF.3, TDR ABF.4	January 25, 2025	Not Verified

7.2.1 Payload Data Collection Test

The Payload data collection test has an objective of confirming the data collection abilities of various on board sensors through a flight identical to that of the competition flight. This test will take place on January 25th, prior to the Payload Demonstration Flight, and is necessary for completion of the payload challenge. The data collection subsystem will be mounted in the Nose Cone alongside the rest of the payload hardware. The accuracy of the collected data will be verified using externally collected data points.

Table 7.18: Payload data collection test success criteria.

Success Criteria	Status
Recorded sensor data falls within the acceptable range of externally verified data	Not Verified
Data is recorded throughout the flight without any sensors failing to record data points	Not Verified

Controllable Variables

- Initialization timing
- Configuration of onboard sensors
- Data validation standards
- Choice of externally collected data points
- Date of verification flight/ environmental conditions
- Data collection subsystem integration into payload

Required Facilities, Equipment, Tools, and Software

- Payload sensors
  - BNO085 Inertial Measurement Unit
  - DPS310 Barometric Pressure Sensor
  - SAM-M10Q GPS Chip Antenna Module
- Payload
  - Raspberry Pi
  - ESP32
- Calibrated external sensors
- Windows laptop
- VS Code Software

Methodology

1. Mount the data collection subsystems onto the payload sled inside of the Nose Cone.
2. Initialize payload software at the launch pad immediately prior to launch.
3. Detach software such that the payload can perform its data collection independently of any ground station during flight.
4. Launch and recover the Launch Vehicle and payload.
5. Inspect the data collected during the launch and compare it to the data from independent sensors to verify the accuracy of the recorded data.

Expected Results

The sensors are expected to record full data points that are able to be compared to external sensor data for verification. Flight log data is also expected to be recorded that may assist in the use of flight simulations between the Payload Demonstration Flight and the Competition Flight. These results will determine what changes need to be made before PDF and the competition flight.

7.2.2 Payload Flight Simulation Transmission Test

The payload flight simulation transmission test will verify the reliability of the finite state machine through the use of prior flight data, which allows for simulations to be performed without an actual flight. The specific conditions for processing through various states will be fined tuned to match the setup of the payload. The simulations will be performed within a controlled environment, where the only function performed by the payload is transmission.

Table 7.19: Payload flight simulation transmission test success criteria.

Success Criteria	Status
Payload computers properly identify various states of the Launch Vehicle's flight	Not Verified
Payload transmits data for less than 5 minutes, determined autonomously	Not Verified
Payload transmits the desired data points	Not Verified

Controllable Variables

- Previous flight data source
- Payload configuration
- Finite state machine conditions

- Transmission end time
- Data format
- Power supply

Required Facilities, Equipment, Tools, and Software

- Payload and all associated subsystems
  - Transmission subsystem
  - Data collection subsystem
  - Payload computers
- Previous flight data in .xlsx format
- Ground station capable of receiving APRS signal (RTL-SDR dongle)
- Laptop with required RF reception software

Methodology

1. Assemble the payload in a controlled environment, including sensors, payload computers, and transmission setup.
2. Configure the payload to read data from a previously logged flight, as opposed to live sensor data.
3. Initialize the payload to begin tracking the previous flight data and progressing between states as necessary.
4. Wait until the previous flight data reaches the point where the Launch Vehicle has landed to verify that it begins transmitting.
5. Ensure that transmission begins and concludes within the 5 minutes allotted period.
6. Read and record the transmission signal via a nearby ground station that may receive APRS signal.
7. Inspect the transmitted data for accuracy by comparing it against manual analysis of the previous flight data.

Expected Results

It is expected that the stage requirements will be finalized and fine tuned to the specific launch configuration. It is also expected that the payload will transmit accurate flight data. If initial simulations expose flaws in the state progression requirements, they will be fixed, then the test will be rerun.

7.2.3 Remote Override Test

The payloads remote override system will be verified via initializing the payload, and forcing the finite state machine both forwards and backwards. This will ensure that the remote override functions as desired and allows the payload to be controlled remotely. This testing will be performed with the payload fully assembled and with sufficient obstruction and distance to simulate launch conditions

Table 7.20: Remote override test success criteria.

Success Criteria	Status
Remote override command successfully jumps from pre-transmission state to transmission state	Not Verified
Remote override command successfully jumps from post-transmission state to transmission state	Not Verified
Remote override command successfully jumps from transmission state to shutdown state	Not Verified

Controllable Variables

- Previous flight data source
- Payload configuration
- Payload software state being interrupted
- Ground station configuration
- Distance between payload and ground station
- Obstruction between payload and ground station

Required Facilities, Equipment, Tools, and Software

- Payload and all associated subsystems
  - Transmission subsystem
  - Payload computers
- Previous flight data in .xlsx format
- Ground station with the following capablities
  - Capable of receiving APRS signal (RTL-SDR dongle)
  - Capable of transmitting UHF commands to XBee

Methodology

1. Assemble the payload in a controlled environment, including sensors, payload computers, and transmission setup
2. Configure the ground station in order to transmit UHF commands, and begin monitoring APRS data on the 2M band
3. Relocate the assembled payload and ground station to the desired testing locations, with sufficient distance and obstruction to replicate launch field conditions.
4. Initialize payload software to begin simulating a flight using the prior flight data.
5. Upon reaching the desired state to be overridden, use the ground station to send the command, which will be received by the XBee.
6. Use the ground station to monitor for any transmission, or lack of transmission, dependent on the state being overridden.
7. Shutdown and recover the payload and review data logs to ensure the payload received commands as expected.

Expected Results

Upon transmitting a command for the payload to begin transmission, the payload should begin immediately transmitting data. In the case of a shutdown command, the payload should cease all transmission, and have no active functions. This test verifies that the team will be able to reliably deliver commands to the payload during the competition, and that the payload will function accordingly to the command being sent. If any of the success criteria is not met, the payload software will be altered and the test will be rerun.

7.2.4 Data Transmission Verification

The payload data transmission will be verified by simulating a launch using prior flight data, and receiving the transmission on a handheld receiver. This ensures that the transmitted data is in the expected format, and is capable of being received at expected launch day conditions. This testing will be performed at conditions similar to those expected on launch day, with a minimum distance and minor obstruction from landscape.

Table 7.21: Data transmission test success criteria.

Success Criteria	Status
Receiver is able to connect and receive transmitted data at desired distance	Not Verified
All data points are transmitted and received properly using handheld receiver	Not Verified
STEMCRaFT completes transmission after 5 minute period with no further signals	Not Verified

Controllable Variables

- Previous flight data source
- Payload flight software
- Payload encoding software (Direwolf)
- SA828 Configuration
- Distance between STEMCRaFT and receiver
- Obstruction between STEMCRaFT and receiver
- 2M handheld radio

Required Facilities, Equipment, Tools, and Software

- Payload and all associated subsystems
  - Transmission subsystem
  - Data collection subsystem
  - Payload computers
- Previous flight data in .xlsx format
- Ground station capable of receiving APRS signal (RTL-SDR dongle)
- Laptop with required RF reception software
- NiceRF software

Methodology

1. Assemble the payload in a controlled environment, including sensors, payload computers, and transmission setup.
2. Configure the ground station to begin monitoring APRS data on the 2M band.
3. Relocate the assembled payload and ground station to the desired testing distance.
4. Initialize payload software to begin simulating a flight using the prior flight data

5. Use the ground station to monitor the 2M band for APRS transmission.
6. Once the transmission is received, inspect the received transmission to verify that all data is contained, and is formatted properly.
7. Recover and shutdown the payload, and ground station.

Expected Results

The data transmitted should be received by the RF receiver at the desired distance and obstruction level. Additionally, the data should be received in the desired RF format, with no data missing from the transmission. These results will verify that the transmission from the STEMCRaFT is properly configured for the desired NASA receivable format. If the transmission fails, the test will be rerun until the success criteria are met.

7.2.5 Battery Capacity Verification

The battery capacity, as defined in the team-defined requirements, will be verified via a battery rundown test on the payload. This test will allow the payload to sit in standby state for a set amount of time, and a post-landing shutdown state for a set amount of time. This verifies that the battery capacity of the payload is sufficient for launch day conditions and delays. This testing will be performed with the payload fully assembled and initialized within a controlled environment.

Table 7.22: Battery capacity verification success criteria.

Success Criteria	Status
STEMCRaFT remains operational for 3+ hours after initialization and while in idle state	Not Verified
STEMCRaFT remains operational for 15+ minutes after landing and while in shutdown state	Not Verified
Battery levels of both payload LiPos remain above the recommended minimum operating level	Not Verified

Controllable Variables

- Payload software
- LiPo charge level
- Individual electronic power settings
  - DPS310
  - BNO085
  - SAM-M10Q GPS
  - Onboard Fan

Required Facilities, Equipment, Tools, and Software

- Payload and all associated subsystems
  - Transmission subsystem
  - Data collection subsystem
  - Payload computers
- Software designed to last desired testing period
- LiPo battery charging station
- Multimeter
- Laptop

Methodology

1. Assemble the payload in a controlled environment, including sensors, payload computers, and transmission setup.
2. Verify the chares of both LiPo batteries located on the STEMCRaFT are at maximum capacity.
3. Initialize battery capacity test payload software.
4. Allow payload to function for the entire duration of the testing software.
5. Recover and shutdown the STEMCRaFT, unplugging the LiPo batteries.
6. Verify the charge of the LiPo batteries remains above the minimum voltage for safe operation.

Expected Results

The recovered battery charge should remain above the minimum voltage after the 15+ minute simulation period. The power draw of specific electronics may be adjusted as necessary should the payload batteries not have a sufficient lifespan. This test will verify that the payload electronics may remain functional for a time period sufficient for competition. If the battery charge is not sufficient at the conclusion of the test, the battery will be changed and the test will be rerun.

7.2.6 Nose Cone with STEMCRaFT Impact Test

The Nose Cone impact test will simulate the ground impact of the Nose Cone assembly, including the STEMCRaFT, under the main parachute at the end of the flight via drop testing. This test evaluates the structural integrity of the Nose Cone, STEMCRaFT, and the payload retention system. The goal is to ensure that the STEMCRaFT and all of its electronics remain operational and undamaged, with no loosening or disconnections of components.

Table 7.23: Nose Cone impact test success criteria.

Success Criteria	Status
Nose Cone structure suffers no damage	Not Verified
STEMCRaFT housing suffers no damage	Not Verified
STEMCRaFT remains secured inside the Nose Cone	Not Verified
No internal electronics become loose or disconnected	Not Verified

Controllable Variables

- Nose Cone weight
- Impact angle
- Impact surface type
- Drop methodology

Required Facilities, Equipment, Tools, and Software

- Drop test stand
- Fully assembled Nose Cone with STEMCRaFT inside
- Tape measure
- Masking tape
- Safety glasses
- Camera for documentation

Methodology

1. Assemble the STEMCRaFT and all internal electronics within the housing.
2. Assemble the Nose Cone, securing the STEMCRaFT inside using the retention system.
3. Affix additional ballast to simulate full Nose Cone mass if necessary.
4. Measure the total mass of the assembled Nose Cone.
5. Use kinematic equations to calculate the drop height needed to achieve 37 ft-lbs of kinetic energy with the Nose Cone mass.
6. Attach a length of cord to an eye-bolt on the Nose Cone, threading the remaining cord through the test stand rail eye-bolt.
7. Mark the required cord length corresponding to the drop height with masking tape.
8. Set up the test stand and ensure stability.
9. Clear the impact area and position all observers at a safe distance.
10. Slowly raise the Nose Cone to the required height.
11. Begin recording.
12. Release the cord, allowing the Nose Cone to free-fall and impact the ground.
13. Visually inspect the Nose Cone for damage.
14. Remove the Nose Cone bulkhead and inspect the STEMCRaFT for damage or displacement.
15. Verify the functionality of all electronics in the STEMCRaFT.
16. Disassemble the STEMCRaFT and inspect the electronic components and STEMnauts for damage or displacement.
17. Repeat the test as necessary to cover different impact angles and scenarios.

Expected Results

The Nose Cone is expected to endure all impact scenarios without structural damage or deformation. The STEMCRaFT should remain intact, with no cracks, fractures, or loosened fasteners. All electronics must remain securely in place and fully operational. The STEMnauts are expected to stay retained inside their housing. Minor scuffing or abrasion on the Nose Cone tip is permissible, but any other damages would result in redesign of the STEMCRaFT.

7.2.7 Air Brakes Deployment Test

The Air Brakes deployment test will simulate the expected aerodynamic forces on the Air Brakes fins by attaching weights to simulate drag. This will ensure that the fins are able to deploy and will not break during flight. It is necessary to verify that the fins will not break to ensure the Launch Vehicle flies straight.

Table 7.24: Air Brakes deployment test success criteria success criteria.

Success Criteria	Status
Air Brakes fully deploy without stalling the servo	Not Verified
The servo does not pull more amps than a 2 cell LiPo can provide	Not Verified
The Air Brakes mechanism remains functional	Not Verified

Controllable Variables

- Method of simulating drag force
- Weight attachment points
- Servo selection in the Air Brakes assembly
- Air Brakes assembly design including gears, tolerances, and material choice
- Method of data collection
- Test repeatability

Required Facilities, Equipment, Tools, and Software

- Air Brakes system
- Weights
- Weight attachment method
- Power supply to measure the servo power draw

Methodology

1. Assemble the Air Brakes system.
2. Determine the expected drag force on the Air Brakes fins during flight.
3. Attach weights to the fins to simulate drag forces.
4. Inspect deployment mechanics and measure servo power draw during deployment.

Expected Results

The Air Brakes fins are expected to fully deploy and retract with the weights attached. The servo motor should operate smoothly, with no stalling or interruptions during the deployment process, and remain within the limits of the LiPo battery's capacity. If the Air Brakes do not deploy the Air Brakes design will be altered.

7.2.8 Air Brakes Flight Simulation Test

The Air Brakes flight simulation test will model the Launch Vehicle's ascent with and without Air Brakes deployment to determine the expected reduction in ascent speed and overall control authority throughout the flight. This will initially assist with target altitude prediction, and subsequently validate the apogee prediction software.

Table 7.25: Air Brakes flight simulation test success criteria.

Success Criteria	Status
Decent rate is decreased by at least 5%	Not Verified
Apogee is significantly reduced with Air Brake deployment	Not Verified

Controllable Variables

- Air Brakes deployment engaged/disengaged
- Launch Vehicle physical properties such as mass and drag coefficient
- Environmental parameters used in the simulation

- Launch parameters used in the simulation
- Air Brakes design parameters
- Time step used in the simulation

Required Facilities, Equipment, Tools, and Software

- Simulation software (OpenRocket, MATLAB, or custom-built simulator)
- Rocket specifications for the simulation
- Air Brakes specifications for the simulation
- Design inputs for the simulation

Methodology

1. Use previous flight data to develop a simulation environment replicating the rocket's flight profile.
2. Input physical properties of the Launch Vehicle including mass, size, and drag coefficient.
3. Simulate flights with the Air Brakes engaged and disengaged.
4. Record and compare ascent rates, apogee, and stability between various simulations.

Expected Results

The simulation with Air Brakes deployed is expected to result in a decreased descent rate in comparison with the the simulation without Air Brakes deployed. Additionally, the Launch Vehicle is expected to stabilize during descent due to the deployed Air Brakes fins.

7.2.9 Air Brakes Effectiveness Flight Test

The Air Brakes effectiveness flight test will evaluate how effectively the Air Brakes reduce apogee and ascent velocity. The physical test will include launching a Subscale or Full-scale version of the Launch Vehicle equipped with the Air Brakes payload. Data from onboard sensors will validate ascent rate reductions and overall performance compared to simulated flights. If the Air Brakes are deemed ineffective, the design of the fins will be altered.

Table 7.26: Air Brakes effectiveness flight test success criteria.

Success Criteria	Status
The Launch Vehicle is successfully recovered	Not Verified
Decent rate is decreased by at least 5%	Not Verified
Apogee is significantly reduced with Air Brake deployment	Not Verified

Controllable Variables

- Air Brake deployment timing
- Air Brake deployment speed
- Air Brake deployment mechanism
- Launch Vehicle mass
- Sensor calibration
- Flight conditions including wind speed and launch angle
- Post-flight data analysis

Required Facilities, Equipment, Tools, and Software

1. Launch site
2. Air Brakes system and components
3. Launch Vehicle and all other tools, components, and hardware listed in the Launch Day Checklist in Section 6.2

Methodology

- Prepare the Launch Vehicle and Air Brakes system for launch.
- Install onboard sensors for tracking ascent rate, acceleration, and orientation.
- Conduct a controlled flight with Air Brakes deployed.
- Retrieve and analyze flight data post launch.

Expected Results

The Launch Vehicle is expected to be launched and recovered successfully where the measured ascent rate and apogee of the Launch Vehicle are expected to be decreased. Additionally, the actual flight is expected to resemble the simulated flight conducted in Section 7.2.8. If the Air Brakes do not function as intended on launch day the launch will be redone at the next possible launch date.

7.3 Requirements Compliance

To assist in managing requirement compliance, each requirement is evaluated based on its overall completion. This rating is then given a color based score: Fully Verified, Partially Verified, In Progress, Not Verified, or Not Applicable. A more thorough description of the organizational options can be seen below.

- Fully Verified: The verification required for this requirement is complete. All of the success criteria has been met.
- Partially Verified: One or more of the success criteria has been met. However, one criteria is still in progress or non-applicable.
- In Progress: The verification process has begun, but is not completed.
- N/A: The team does not expect to utilize this requirement for successful completion for the project. An example is the requirement requiring explicit permission to utilize the secondary motor option.

The tables below illustrate the completion status of requirements for the project, categorized as NASA-defined requirements (Table 7.27) and team-derived requirements (Table 7.28).

Table 7.27: NASA Requirements Completion Status

Fully Verified	Partially Verified	In Progress	Not Verified	N/A
35.77% (49)	45.26% (62)	4.38% (6)	12.41% (17)	2.19% (3)

Table 7.28: Team-Derived Requirements Completion Status

Fully Verified	Partially Verified	In Progress	Not Verified	N/A
26.5% 31	53.85% 63	17.95% 21	0	1.71% 2

7.3.1 Competition Requirements

Table 7.29: 2024-2025 General Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** Documentation of student participation in construction and flight preparation. **(2)** Compliance with NASA SL Handbook requirements verified through inspection.	**(1) Review:** Include team member roster in report documentation, along with safety pledge. **(2) Review:** Include a requirement verification matrix or table in all report documentation.	Verified	Project Manage-ment	**(1)** Academic Pledge & Student Sign Off **(2)** See Section 7.3 for Requirement Compliance Matrices
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, 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.	**(1)** Inclusion of a successful project plan in all report documents. **(2)** Inclusion of a budget report in all report documents.	**(1) Review:** Include multiple project plans for all subsystems in all report documentation. **(2) Review:** Include detailed budget reports in all report documentation.	Verified	Project Manage-ment	**(1)** See Section 7.5 for the team's updated project plan and subsystem construction timelines. **(2)** See Section 7.4 for the team's updated budget plan and resource allocation.
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.	Team members complete registration for NASA Gateway system prior to Nov. 29th, 2024	**Inspection:** Inspect the NASA Gateway profile for completed registrations prior to roster identification.	Verified	Project Manage-ment	Team Lead submitted the team roster for attendance to the Huntsville Launch. All submitted members completed the NASA Gateway registration.

Table 7.29: 2024-2025 General Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
1.3.1	Team members 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.	**(1)** Huntsville roster will be compared with meeting sign in sheets. **(2)** Roster only includes individuals actively engaged enough to have a fully completed NASA Gateway profile.	**(1) Inspection:** Inspect meeting sign in sheets and confirm team member participation before Huntsville selection. **(2) Inspection:** Inspect team roster and confirm team member Gateway registration prior to final submittal to NASA.	Verified	Project Manage-ment	**(1)** Subsystem leads only selected the most active club members for the Huntsville launch roster. **(2)** Every member chosen for the Huntsville roster are registered in Gateway.
1.3.2	Team members SHALL include one mentor.	The Team Lead will invite the mentor(s) 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.	**(1)** Mentor identified in report documentation is invited to Huntsville **(2)** Mentor attends Huntsville Launch	**(1) Inspection:** Verify that a Huntsville invitation is sent to the mentor identified in report documentation. **(2) Demonstration:** Verify mentor's attendance at the Huntsville Launch.	**(1)** Verified **(2)** In Progress	Project Manage-ment	**(1)** See Section 1.1.2 for identified team mentor and Huntsville roster for their invitation. **(2)** Not completed yet.
1.3.3	Team members 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.	**(1)** Adult educators identified in report documentation is invited to Huntsville. **(2)** Notice of competition dates and location sent to adult educators.	**(1) & (2) Review:** Confirm that the appropriate amount of adult educators are listed in report documentation and Huntsville travel roster.	Verified	Project Manage-ment	**(1)** See Section 1.1.2 for identified adult educator and Huntsville roster for their invitation.

Table 7.29: 2024-2025 General Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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, 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.	**(1)** Team "Outreach Officer" identified in the proposal report document. **(2)** Outreach Officer reports participant and event details to Team Lead and corresponding NASA officials.	**(1) Review:** Confirm Outreach Officer is identified in proposal report documentation. **(2) Demonstration:** Outreach Officer takes photos / records all contact information and event details for all outreach events. Information is shown to Team Lead and sent to NASA officials.	**(1)** Verified **(2)** In Progress	Project Management	**(1)** See Section 1.6 of Proposal documentation for identified Outreach Officer. **(2)** See STEM Engagement Reports sent to NASA.
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, will document club progress and events across multiple social media platforms. Platforms consist of Instagram, Facebook, X, TikTok, and LinkedIn.	**(1)** Team "Social Media Officer" identified in the proposal report document **(2)** Social Media Officer posts major team progress updates across all social media platforms. **(3)** Social media platforms identified in report documentation.	**(1) Review:** Confirm Social Media Officer is identified in proposal report documentation. **(2) Demonstration:** Social Media Officer posts about all major design and construction milestones. **(3) Review:** Confirm team social media platforms are identified in proposal report documentation.	**(1)** Verified **(2)** In Progress **(3)** Verified	Project Management	**(1)** See Section 1.6 of Proposal documentation for identified Social Media Officer. **(2)** All major team progress updates are posted to multiple social media platforms. **(3)** See Appendix 8.3.1 for identified team social media platforms.

Table 7.29: 2024-2025 General Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
1.6	Teams SHALL email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of PDR, CDR, or FRR milestone documents will NOT be accepted. Teams that fail to submit the PDR, CDR, or FRR milestone documents will be eliminated from the project.	The Team Lead will email/ submit all deliverables to the NASA project management team by the deadline specified in the NASA SL handbook. The Webmaster, identified in Section 1.6, will receive the deliverables and upload it to the NCSU HPRC website by the specified deadline.	**(1)** Team Lead emails/ submits milestone deliverables by the appropriate deadline. **(2)** Team "Webmaster", identified in proposal report documentation, uploads milestone deliverables to the team website.	**(1) Demonstration:** Milestone deliverables are submitted on time and team continues in competition progress. **(2) Review:** Confirm Webmaster is identified in proposal report documentation.	**PDR/CDR:** Verified **FRR:** N/A	Project Manage-ment	**(1)** PDR & CDR milestone deliverables uploaded to team website and submitted by Team Lead by the specified deadline. **(1)** See Appendix 8.3.1 for the NCSU HPRC website information. **(2)** See Section 1.6 of Proposal documentation for identified Webmaster.
1.7	Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) will be provided action items to be completed following their review and will be required to address action items in a delta review session. After the delta session, the NASA management panel will meet to determine the teams' status in the program, and the teams will be notified shortly thereafter.	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.	**(1)** Team completes all milestone review documents and submits prior to the deadline if required. **(2)** Action items are addressed in milestone presentations if required.	N/A	N/A	Project Manage-ment	N/A
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.	Team Lead submits NASA milestone deliverables in PDF format.	**Review:** Verify project deliverable submissions are in PDF format.	**PDR/CDR:** Verified **FRR:** N/A	Project Manage-ment	Submitted CDR, PDR and proposal documentation in PDF format.
1.9	In every report, teams will 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.	Milestone report includes a table of contents.	**Review:** Verify milestone report submissions have a table of contents.	**PDR/CDR:** Verified **FRR:** N/A	Project Manage-ment	See this report documentation and previous milestone submissions.
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.	Milestone reports & presentations include page numbers at the bottom of every page.	**Review:** Verify milestone report and presentation submissions have page numbers at the bottom of every page.	**PDR/CDR:** Verified **FRR:** N/A	Project Manage-ment	See this report documentation and previous milestone submissions.

Table 7.29: 2024-2025 General Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** Team Lead selects a meeting room and provides all computer equipment necessary. **(2)** All video teleconference equipment is tested prior to the official presentation time. **(3)** Cellular phones are used as a last resort.	**(1) Demonstration:** Design review occurs in a private meeting room. **(2) Demonstration:** Audio and recording equipment function as designed during design review. **(3)** N/A	**PDR:** Verified **CDR/FRR:** N/A	Project Manage-ment	**(1) & (2) PDR:** Demonstrated successful video teleconferencing capabilities. Received an "expected professionalism" score. **CDR & FRR Presentation:** N/A
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 will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 – 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day 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.	**(1)** Launch Vehicle is designed to launch on pads provided by the NASA SLs launch services provider. **(2)** Subscale is designed to launch on pads provided by the Tripoli Launch Field similar to the launch pad used at the Huntsville launch	**(1) Demonstration:** Successful Subscale, VDF, and PDF launches on approved and related launch pads. **(2) Review:** Successful Subscale launch and launch pad information included in CDR documentation.	**Subscale:** Verified **Full-scale Design:** Verified	Aerodynam-ics & Structures	**(1)** See Section 3.2 for current Launch Vehicle design and propulsion system. **(2)** See Section 3.3 for proof of successful Subscale flight. Launch pad specifications can be found in Section 3.3.3.

Table 7.29: 2024-2025 General Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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 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.	**(1)** All milestone reports identify the team's mentor and their contact information (NASA Req. 1.13). **(2)** Travel stipend will be requested for the team's mentor for travel to the Huntsville Launch.	**(1) Review:** Confirm mentor name and contact information is listed in all report documentation. **(2) Demonstration:** Mentor attends Huntsville launch with travel stipend.	**(1) PDR/CDR:** Verified **FRR:** N/A **(2)** In Progress	Project Manage-ment	**(1)** See Section 1.1.2 for identified mentor. **(2)** Mentor agreed to attend Huntsville launch. Team Lead will request stipend.
1.14	Teams SHALL track and report hours spent on milestones.	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.	**(1)** Integration Lead updates a team member hour chart weekly. **(2)** Hours spent per milestone is included in all report documentation.	**(1) Demonstration:** Excel sheet with team member weekly hours is included in appendix. **(2) Review:** Verify that hours spent per milestone is included in report documentation.	**PDR/CDR:** Verified **FRR:** N/A	Integration & Project Manage-ment	**(1)** See Appendix 8.3.1 for weekly hour excel sheet. **(2)** See Section 1.1.4 for hours spent on this specific milestone

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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)** Apogee ranges between 4,000-6,000 ft. AGL during VDF and PDF flights. **(2)** Simulations predict apogee within the 4,000-6,000 ft. range.	**(1) Test:** Apogee flight data during VDF and PDF flights confirm the altitude is within the 4,000-6,000 ft. range. **(2) Analysis:** Use OpenRocket and RockSim simulations to predict the expected altitude range.	**(1) Test:** In Progress **(2) Analysis:** Verified	Aerodynamics, Structures	**(1)** Planned VDF and PDF flights in Table 7.42 **(2)** See Section 3.6.2 for final Full-scale Launch Vehicle simulations.
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.	**(1)** Simulations provide a predicted apogee altitude. **(2)** Target altitude is explicitly stated in the CDR milestone documentation.	**(1) Analysis:** Use simulations (OpenRocket and RockSim) to predict the apogee. **(2) Inspection:** Inspect CDR report to confirm inclusion of the target altitude.	Verified	Aerodynamics	**(1)** See Section 3.6.2 for the apogee simulations. **(2)** See Section 1.2.1 for target altitude.
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 no non-cosmetic damage and have the ability to launch twice in the same day without repairs or needed modifications.	**(1)** Launch vehicle can be flown twice in one day without requiring major repairs. **(2)** Launch vehicle is inspected after recovery.	**(1) Inspection:** Physically inspect all sections post-flight to ensure no damage. **(2) Inspection:** Include recovery photos in appropriate report documentation.	**Subscale:** Verified **Full-scale:** In Progress	Recovery, Structures	**(1)** Subscale Launch Vehicle flown twice in one day. See recovery photos for Subscale launch in Figures 3.35, 3.36. **(2)** See Section 3.5.1 for planned recovery system design.
2.4	The Launch Vehicle SHALL have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	The Aerodynamics Lead and Recovery Lead will design a Launch Vehicle and recovery system that has a maximum of four independent sections.	The Launch Vehicle has three independent sections that are tethered together.	**Inspection:** Inspect the Launch Vehicle design to verify the number of independent sections and confirm that they are tethered together.	Verified	Aerodynamics, Recovery	See Figure 3.2 for final Launch Vehicle configuration.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	The coupler/airframe shoulders at in-flight separation points are 12 in. long.	**Measurement:** Measure the coupler/airframe shoulder design to ensure they meet the 12-inch length requirement.	Verified	Aerodynam-ics & Structures	See Figure 3.2 for final Launch Vehicle configuration.
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.	The coupler/airframe shoulders at in-flight separation points are at least 9 in. long.	**Measurement:** Measure coupler/airframe shoulder design to verify the 9-inch length requirement.	Verified	Aerodynam-ics & Structures	See Figure 3.2 for final Launch Vehicle configuration.
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 Nose Cone shoulders to be at least 0.5 body diameter in length. The Structures Lead will construct the Nose Cone shoulders per the Aerodynamics Leads design.	Nose Cone shoulders located at in-flight separation points are 3 in long.	**Measurement:** Measure Nose Cone shoulder design to ensure they meet the length requirement.	Verified	Aerodynam-ics & Structures	See Figure 3.2 for final Launch Vehicle configuration.
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.	The Launch Day Checklist ensures full preparation within 2 hours.	**Review:** Verify the Launch Day Checklist allows for all tasks to be completed within the 2-hour preparation window.	Verified	Integration, Project Manage-ment, Safety	See Appendix 8.1 for Subscale checklist.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	Vehicle design can remain in launch-ready configuration for at least 3 hours without failure or vital battery outages.	**Analysis:** Analyze the Launch Vehicle design and operational procedures to ensure it supports 3 hours in launch-ready configuration without failure. Review all batteries to confirm they remain operational in launch-ready state for 3 hours.	In Progress	Project Manage-ment, Safety	**(1)** For payload battery analysis see Section 4.2.1 and Tables 4.3 and 4.4. **(2)** Future payload battery capacity verification test found in Section 7.2.5 .
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.	The vehicle is capable of being launched with a 12-volt firing system.	**Test:** Test the firing system with the selected motor igniter to ensure compatibility with a 12-volt direct current system during Subscale, VDF, and PDF.	**Subscale:** Verified **VDF/PDF:** In Progress	Project Manage-ment, Structures	**(1) Subscale:** See Section 3.3.3 for Subscale launch pad information. **(2)** See Section 3.2.12 for final Launch Vehicle motor selection.
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.	**(1)** The vehicle only requires a standard 12-volt firing system to initiate launch. **(2)** No additional external circuitry or special equipment is required.	**(1) Review:** Verify that the vehicle only requires the standard 12-volt firing system to initiate launch. **(2) Demonstration:** Demonstrate with Subscale, VDF, and PDF that no external circuitry or special equipment is required for launch initiation.	**(1) Review:** Verified **(2) Demon-stration:** In Progress	Project Manage-ment, Structures	**(1)** See Section 3.2.12 for final Launch Vehicle motor selection. **(2) Subscale:** See Section 3.3.3 for Subscale launch pad information.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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 ematches and igniters used are commercially available and that the Launch Vehicle does not use hand-dipped igniters.	Ematches or igniters used are commercially available.	**Inspection:** Inspect ematches and/or igniter types to confirm compliance with commercial standards.	Verified	Project Manage-ment, Recovery, Safety	**(1)** See the Recovery and Avionics section in budget table, Table 7.38, for Electric Match vendor. **(2) Full-Scale:** See Full-Scale Draft Checklist, Section 6.2, Steps 1.2–1.22, for procedures on the use of commercial e-matches.
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.	**(1)** The motor is certified by NAR, TRA, or CAR. **(2)** The motor is commercially available.	**(1) Review:** Verify the motor's certification status with NAR, TRA, or CAR. **(2) Review:** Confirm the motor's commercial availability through the manufacturer's website or documentation.	Verified	Aerodynam-ics, Project Manage-ment	**(1)** See the motor vendor under Full-scale Structure in the budget table, Table 7.38. **(2)** See final motor selection in Section 1.2.2.
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.	Final motor choice is declared by the PDR milestone.	**Review:** Verify that the final motor choice is included in the PDR documentation and future documentation.	Verified	Aerodynam-ics	See Section 1.2.2 for final Launch Vehicle motor selection. See PDR document for inclusion of final Launch Vehicle motor selection.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	Motor changes after PDR will not be made.	N/A	N/A	Project Manage-ment	No verification required yet.
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.	The vehicle uses a single motor propulsion system.	**Inspection:** Inspect the propulsion system design to confirm that only one motor is used.	Verified	Aerodynam-ics	See Section 3.2.11 and 3.2.12 for final Launch Vehicle propulsion system design.
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.	The motor selected does not exceed a total impulse of 5,120 Newton sec.	**Analysis:** Analyze motor specifications and confirm that the motor's total impulse is within the 5,120 N·s limit.	Verified	Aerodynam-ics	The total impulse of the L1520T motor is 3715.9 Ns and can be seen in Table 3.3.
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.	No pressure vessel is included in the Launch Vehicle design.	**Inspection:** Confirm the design does not include any pressure vessels.	Verified	Structures	See Section 3.2 for final Launch Vehicle design.
2.13.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) SHALL be 4:1 with supporting design documentation included in all milestone reviews.	The Structures Lead will not include a pressure vessel in the Launch Vehicle design.	No pressure vessel is included in the Launch Vehicle design.	**Inspection:** Confirm the design does not include any pressure vessels.	Verified	Structures	See Section 3.2 for final Launch Vehicle design.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	No pressure vessel is included in the Launch Vehicle design.	**Inspection:** Confirm the design does not include any pressure vessels.	Verified	Structures	See Section 3.2 for final Launch Vehicle design.
2.13.3	The full pedigree of the tank SHALL be described, including the application for which the tank was designed and the history of the tank. This 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.	No pressure vessel is included in the Launch Vehicle design.	**Inspection:** Confirm the design does not include any pressure vessels.	Verified	Structures	See Section 3.2 for final Launch Vehicle design.
2.14	The Launch Vehicle SHALL have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	The Aerodynamics Lead will design the Launch Vehicle to have a minimum static stability margin of 2.0 at the point of rail exit.	The Launch Vehicle stability margin ranges between 2.0 and 2.9.	**Analysis:** Analyze the stability margin calculations and verify with simulations (OpenRocket and RockSim) to ensure it falls within the 2.0 to 2.9 range.	Verified	Aerodynam-ics	See Section 3.6.8 and Table 3.17 for Launch Vehicle stability margin.
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.	The Launch Vehicle thrust to weight ratio is greater than 5.0:1.0.	**Analysis:** Perform thrust-to-weight ratio calculation using motor specifications and rocket design.	Verified	Aerodynam-ics	The thrust-to-weight ratio with the selected motor is 9.05:1.0. See Table 3.4 for the calculations.
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.	Structural protuberances are located at least 1 inch aft of the burnout center of gravity.	**Inspection:** Inspect the design to confirm the location of structural protuberances relative to the burnout center of gravity.	Verified	Aerodynam-ics	See Table 3.16 for burnout center of gravity and Air Brake locations.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** Rail exit velocity is ≥ 52 fps during flight testing. **(2)** Simulations predict ≥ 52 fps rail exit velocity.	**(1) Test:** Measure velocity using onboard sensors during Subscale, VDF, and PDF launches. **(2) Analysis:** Validate design and motor selection with OpenRocket and RocketPy.	**(1) Test:** In Progress **(2) Analysis:** Verified	Aerodynamics	**Analysis:** Velocity off the rail is calculated to be 81.5 fps for an L1520T motor and can be seen in Table 3.5.
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.	**(1)** The Subscale model is successfully launched and recovered. **(2)** Subscale flight data is documented in the CDR. **(3)** Subscale motor has a minimum motor impulse class of E. **(4)** Subscale flight is determined to be successful by the NASA review panel.	**(1) Test:** Verify the Subscale launch and recovery through recorded data or other acceptable evidence. **(2) Review:** Confirm that the flight data is documented in the CDR. **(3) Review:** Verify the motor's impulse class of E through CDR documentation. **(4) Review:** Confirm that the flight is determined to be successful by the NASA review panel.	**(1) Test:** Verified **(2) Review:** Verified **(3) Review:** Verified **(4) Review:** In Progress	Aerodynamics, Project Management	**(1)** See Figures 3.35 and 3.36 for Subscale recovery photos. **(2)** See Figures 3.32 and 3.33 for Subscale flight data (analyzed). **(3)** See Section 3.3.2 and Table 3.10 for Subscale motor specifications. **(4)** See Section 3.3.3 for Subscale results.
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.	**(1)** The Subscale model is similar in design to the Full-scale model. **(2)** The Subscale model performs similarly to the Full-scale model, excluding Full-scale use.	**(1) Review:** Review design documents and performance data to confirm the similarity between the Subscale and Full-scale models. **(2) Test:** Confirm similarity through testing of the Subscale model.	Verified	Aerodynamics, Structures	**(1)** See Section 3.3.1 and Figure 3.27 for Subscale design. **(2)** See Section 3.3.3 for results of the Subscale flight.
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.	**(1)** The altimeter is installed correctly and operational. **(2)** Altitude data is recorded by the altimeter.	**(1) Inspection:** Physically inspect the altimeter installation to confirm it is properly installed and operational. **(2) Test:** Verify that apogee altitude data is recorded during flight.	Verified	Recovery	**(1)** See Section 3.3.1 for Subscale design. See Appendix 8.1 for the Subscale Launch Day Checklist and proper installation procedures. **(2)** See Section 3.3.3 for results of the Subscale flight.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	A new Subscale rocket is constructed specifically for this project year.	**Review:** Verify design and construction records to ensure the Subscale rocket is newly built for this project year.	Verified	Aerodynam-ics, Structures	See Section 3.3.1 and Figure 3.27 for unique Subscale rocket design.
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.	Proof of successful flight provided and properly formatted in CDR.	**Review:** Confirm the inclusion of proof in CDR.	Verified	Project Manage-ment	See Section 3.3.3 and Figures 3.32, 3.33, 3.35, and 3.36 for proof of a successful Subscale launch.
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 altimeter flight profile graphs are not available, the Recovery Lead will submit a quality photo showing successful launch, recovery events, and landing events as proof for a successful flight.	**(1)** Subscale altimeter data is included and complete in CDR OR **(2)** Quality photos showing successful launch, recovery events, and landing are included in CDR	**Inspection:** Inspect the altimeter flight profile graphs to ensure they are complete and included in the CDR.	Verified	Recovery	See Figures 3.32 and 3.33 for Subscale launch Stratologger and EasyMini altimeter flight profile graphs.
2.18.4.2	Quality pictures of the as landed configuration of all sections of the Launch Vehicle SHALL be included in the CDR report. This includes, but is not limited to: 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.	Clear, quality photos of all sections of the Launch Vehicle in the landed configuration are included in the CDR.	**Inspection:** Review photo quality and ensure that all sections of the Launch Vehicle are covered in the photos included in the CDR.	Verified	Project Manage-ment, Recovery	See Figures 3.35 and 3.36 for Subscale launch landing configuration photos.
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.	Subscale rocket dimensions are ≤75% of the Full-scale rocket's dimensions.	**Measurement:** Measure the actual dimensions of the Subscale rocket and compare them to the Full-scale rocket's dimensions to ensure they are ≤75%.	Verified	Structures	See Section 3.3.1 and Figure 3.27 for Subscale rocket design. See Table 3.9 for the scaling factor of each section.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** The Full-scale rocket is successfully launched and recovered in its final flight configuration. **(2)** Full-scale Rocket meets NASA Requirements 2.19.1.1 - 2.19.1.9.	**(1) Demonstration:** Verify the Launch Vehicle completes a successful launch and recovery event. **(2) Inspection:** Ensure that all hardware functions properly and meets NASA Requirements 2.19.1.1 - 2.19.1.9.	In Progress	Project Manage-ment	**(1)** Not yet completed. **(2)** See Verification Results for NASA Requirements 2.19.1.1 - 2.19.1.9.
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.	The vehicle and recovery system operate as designed.	**Review:** Inspect flight data from VDF to confirm that the vehicle and recovery system functioned properly (correct deployment of the drogue and main chutes, etc).	Not Verified	Integration, Project Manage-ment	Not yet completed.
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.	**(1)** Design and construction process documented via photos & CAD models. **(2)** Newly constructed rocket, designed and built for this years challenge.	**(1) Review:** Verify that multiple construction and CAD models are included in report documentation. **(2) Review:** Verify that report documentation have new and purposeful appendices and references.	**Design:** Verified **Construc-tion:** In Progress	Aerodynam-ics, Structures	**(1)** See Section 3.2 for a complete Launch Vehicle design summary. **(2)** See References and Appendices.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** A mass simulator is securely integrated into the Launch Vehicle if the payload is not flown during the VDF. **(2)** The mass simulator accurately replicates the payload mass and center of gravity (CG) properties. **(3)** The flight dynamics of the vehicle with the mass simulator meet performance expectations (apogee predictions align within acceptable error margins).	**(1) Inspection:** Verify secure integration of the mass simulator and inspect its design to match payload mass and CG specifications if using a mass simulator. **(2) Analysis:** Use simulations (OpenRocket or RockSim) to confirm the mass simulator's impact aligns with predicted outcomes for the payload configuration if using a mass simulator. **(3) Test:** Conduct a VDF with the mass simulator and compare apogee and flight stability with simulation predictions to ensure acceptable performance if using a mass simulator.	Not Verified	Payload, Structures	Not yet completed.
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.	**(1)** The mass simulator is positioned within the Launch Vehicle at the same approximate location as the missing payload to ensure accurate center of gravity (CG) replication. **(2)** The vehicle's center of gravity (CG) with the mass simulator matches the expected CG with the payload within an acceptable margin of error.	**(1) Inspection:** Confirm the placement of the mass simulator in the same approximate location as the missing payload. **(2) Measurement:** Measure the center of gravity (CG) of the Launch Vehicle with the mass simulator and compare it to the expected CG with the payload.	Not Verified	Structures	Not yet completed.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** Air brakes are installed and integrated into the rocket for the VDF. **(2)** Air brakes are fully functional and actively manage the vehicle's total altitude during the flight.	**(1) Inspection:** Verify the Air Brakes are installed and operational before the VDF. **(2) Test:** Observe the Air Brakes' performance during the VDF to confirm proper deployment and functionality.	Not Verified	Payload, Project Management	Not yet completed.
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.	**(1)** The competition launch motor is installed and flown during the Vehicle Demonstration Flight (VDF). **(2)** If the competition motor cannot be used, a waiver is submitted and approved by NASA for an alternative motor. **(3)** The alternative motor performs similarly to first motor choice.	**(1) Inspection:** Verify that the competition motor is installed in the Launch Vehicle before the VDF launch. **(2) Inspection:** Confirm the submission and approval of the waiver for an alternative motor, if applicable. **(3) Analysis:** Compare thrust and impulse data for the alternative motor to ensure compliance with competition requirements if required.	In Progress	Aerodynamics, Project Management	**(3)** See Section 3.2.12 for first and alternative motor comparison.
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.	**(1)** The Full-scale Launch Vehicle is flown with the maximum ballast configuration during the Vehicle Demonstration Flight (VDF). **(2)** No additional ballast is added without a re-flight of the vehicle. **(3)** The ballast configuration used during the VDF is verified to match the maximum ballast planned for the competition flight.	**(1) Inspection:** Confirm the ballast configuration before the VDF to ensure the correct amount of ballast is used. **(2) Inspection:** Ensure that no additional ballast is added after the VDF unless a re-flight is conducted. **(3) Measurement:** Measure the ballast weight and configuration during the VDF and compare it to the planned competition ballast configuration.	**Design:** Verified **Demonstration:** N/A	Aerodynamics, Project Management	**Design:** See Section 3.2.15 for the Launch Vehicle weight breakdown and Section 3.6.4 for maximum ballast.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** No modifications are made to the Launch Vehicle or its components after the Full-scale demonstration flight. **(2)** Any proposed modifications are approved by NASA management or the RSO before being implemented.	**(1) Inspection:** Verify that no modifications are made to the Launch Vehicle or components after the Full-scale demonstration flight. **(2) Inspection:** Confirm the approval of any modifications by NASA management or the RSO.	Not Verified	Project Manage-ment	Not yet completed.
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.	FRR report includes proof of a successful Full-scale demonstration flight (including flight profile graphs, apogee, etc.).	**Inspection:** Confirm that the flight data provided (apogee, stability) aligns with simulations and is included in FRR.	Not Verified	Project Manage-ment	Not yet completed.
2.19.1.8.1	Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet Requirement 2.19.1.8. 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.	**(1)** Altimeter flight profile data is provided in the FRR report with accompanying altitude and velocity versus time plots. **(2)** The flight profile graph includes data from liftoff through landing.	**(1) Inspection:** Verify that the altimeter flight profile data is included in the FRR report. **(2) Inspection:** Confirm that the altitude and velocity versus time plots cover the entire flight from liftoff to landing.	Not Verified	Recovery	Not yet completed.
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.	**(1)** High-quality pictures of all sections (nosecone, recovery system, airframe, booster) in the as-landed configuration are included in the FRR report. **(2)** The pictures are clear, detailed, and capture the full vehicle configuration post-landing.	**(1) Inspection:** Review the FRR report to ensure that high-quality pictures of the landed configuration are included. **(2) Inspection:** Verify that all required sections (nosecone, recovery system, airframe, booster) are clearly represented.	Not Verified	Project Manage-ment, Recovery	Not yet completed.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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 is submitted in .csv or .xlsx format.	**(1)** Raw altimeter data is submitted in either .csv or .xlsx format. **(2)** The data is complete and includes all necessary information for flight analysis.	**(1) Inspection:** Verify that the raw altimeter data is submitted in the correct format (.csv or .xlsx). **(2) Inspection:** Check the completeness and quality of the raw data for analysis.	Not Verified	Project Manage-ment, Recovery	Not yet completed.
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.	**(1)** The Vehicle Demonstration flight is completed by the FRR submission deadline. **(2)** If a re-flight is required, it is completed with an FRR Addendum submitted by the Addendum deadline. **(3)** Extensions are only requested for re-flights and not for the first-time flight.	**(1) Inspection:** Confirm the completion of the Vehicle Demonstration flight by the FRR submission deadline. **(2) Inspection:** Ensure that an FRR Addendum is submitted if a re-flight occurs.	Not Verified	Project Manage-ment	Not yet completed.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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 their competition launch.	**(1)** The rocket experiences a stable ascent and smooth recovery events. **(2)** The payload is retained as designed throughout the flight until deployment (if applicable).	**(1) Demonstration:** Proof of successful Payload Demonstration Flight shown in FRR document. **(2) Inspection:** Post-flight payload retention verification proof shown in FRR document.	Not Verified	Payload, Project Manage-ment, Structures	Not yet completed.
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 does not jettison.	**Inspection:** Payload is designed not to jettison.	**Design:** Verified **Demon-stration:** N/A	Integration, Payload	**Design:** See Section 4.2.2 for the payload structural design.
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.	**(1)** The payload flown matches the finalized design. **(2)** The payload is active and functional during flight.	**(1) Inspection:** Inspect payload design prior to PDF. **(2) Demonstration:** Demonstrate proper collection and transmission during PDF flight, providing proof in FRR.	**Design:** Verified **Construc-tion:** In Progress **Demon-stration:** N/A	Payload, Project Manage-ment	Not yet completed.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** All required data from the original Vehicle Demonstration Flight is complete. **(2)** The data is accurate and included in the FRR package by the deadline.	**Review:** Confirm VDF data is detailed and complete in FRR report document.	Not Verified	Project Manage-ment	Not yet completed.
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.	The Payload Demonstration Flight is successfully completed before the FRR Addendum deadline.	**Demonstration:** PDF submitted by FRR addendum deadline.	Not Verified	Project Manage-ment	Not yet completed.
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.	A complete FRR Addendum is submitted by the deadline if required.	**Demonstration:** Submitted FRR addendum if required.	Not Verified	Project Manage-ment	Not yet completed.
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.	The FRR Addendum is submitted on time.	**Demonstration:** Submitted FRR addendum if required.	Not Verified	Project Manage-ment	Not yet completed.
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.	**(1)** The petition is submitted to the NASA RSO. **(2)** Permission is granted by the NASA RSO, with no outstanding safety concerns.	N/A	N/A	Project Manage-ment	N/A

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** The team's name and contact information are visible. **(2)** The information is retrievable from all required sections of the vehicle without opening or separating components.	**Inspection:** Inspect the internal Launch Vehicle air frame for contact information and include photos in documentation.	Not Verified	Project Management	Not yet completed.
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.	**(1)** All Lithium Polymer batteries are brightly colored and clearly marked as fire hazards. **(2)** Batteries are sufficiently protected from ground impact.	**Inspection:** Inspection of all LiPo batteries for protection and labels.	**Design:** Verified **Construction:** In Progress	Project Management, Safety	**Design:** LiPo Batteries are located in compartments in the recovery avionics, payload, and Air Brakes sleds. Prior to Subscale launch day vehicle integration, all LiPo batteries were wrapped in bright tape and labeled.
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.	The selected motor/s is not a forward firing motor/s.	**Inspection:** Verify propulsion system design meets requirement.	Verified	Aerodynamics	See Section 1.2.2 for final motor selection.
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.	A motor is selected that does not expel titanium sponges.	**Inspection:** Verify propulsion system design meets requirement.	Verified	Aerodynamics	See Section 1.2.2 for final motor selection.
2.23.3	The Launch Vehicle SHALL not utilize hybrid motors.	The Aerodynamics Lead will design the Launch Vehicle to not utilize hybrid motors.	A hybrid motor is not used in the Launch Vehicle propulsion system.	**Inspection:** Verify propulsion system design meets requirement.	Verified	Aerodynamics	See Section 1.2.2 for final motor selection.
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.	A cluster of motors is not used in the Launch Vehicle propulsion system.	**Inspection:** Verify propulsion system design meets requirement.	Verified	Aerodynamics	See Section 1.2.2 for final motor selection.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** The Launch Vehicle incorporates a motor retainer or retention device. **(2)** Friction fitting is not utilized for motor retention.	**Inspection:** Verify propulsion system design meets requirement.	Verified	Structures	See Section 3.2.11 for motor retainer design.
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)** All flight simulations show a max velocity under Mach 1. **(2)** During all flight operations, the Launch Vehicle does not exceed Mach 1.	**(1) Analysis:** Analyze the velocity of Launch Vehicle in OpenRocket and RockSim throughout the entirety of its flight. **(2) Demonstration:** Demonstrate requirement with Subscale, VDF, and PDF.	**Subscale:** Verified **Full-scale:** In Progress	Aerodynamics	**(1)** See the blue line in Figures 3.46, 3.47, and 3.48 for the vertical velocity of the rocket in three different simulation softwares. **(2)** See Table 3.15 for max velocity during Full-scale simulated flight.
2.23.7	Vehicle ballast SHALL not exceed 10% of the total unballasted weight of the rocket, as it would sit on the pad (i.e., a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).	The Aerodynamics Lead will design the Launch Vehicle such that the vehicle ballast does not exceed 10% of the total unballasted weight of the rocket.	The total vehicle ballast is ≤10% of the unballasted weight of the rocket.	**(1) Measurement:** Calculate total rocket weight and total designed ballast weight. **(2) Inspection:** Inspect total ballast weight flown during VDF and PDF.	**Design:** Verified **Demonstration:** N/A	Aerodynamics	**(1)** See Section 3.6.4 for approximate ballast calculations.
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.	**(1)** Each transmitter operates at ≤250 mW of power during the flight. **(2)** The power output is verified through testing.	**Test:** Verify power output via electronic tests prior to flights/launches.	**Design:** Verified	Payload, Recovery	Not yet completed.

Table 7.30: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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)** All transmitters operate on unique frequencies to prevent interference with other teams. **(2)** A handshake/passcode system or equivalent is implemented to mitigate interference. **(3)** No excessive interference is detected during testing or operations.	**(1) Inspection:** Confirm the ability to change frequencies and/or handshake/passcode systems during transmitter setup in payload design. **(2) & (3) Test:** Conduct interference tests to verify that no excessive interference is caused to or received from other teams.	**Design:** Verified **Demon-stration:** In Progress	Payload, Recovery	Not yet completed.
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.	**(1)** Materials consist primarily of lightweight metals and non-metal materials. **(2)** Dense metals are used only where necessary for structural integrity.	**(1) Review:** Review material selection documentation to confirm the primary use of lightweight metals and non-metal materials. **(2) Review:** Review high stress locations and verify heavy metals are used sparingly in the designated area.	**Design:** Verified **Construc-tion:** In Progress	Structures	**(1)** See Section 3.2 for material selection of Launch Vehicle. **(2)** See Section 3.2.9 for Fin Can design. Fin Can is the location of the most metal in the Launch Vehicle.

Table 7.31: NASA 2024-2025 Recovery Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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 parachute will be deployed at apogee and the main parachute deployed above 500 ft.	**(1)** Drogue parachute is deployed at apogee. **(2)** Main parachute is deployed at an altitude above 500 ft.	**(1) Demonstration:** Demonstrate drogue parachute deployment at apogee with Subscale, VDF, and PDF. **(2) Demonstration:** Demonstrate main parachute deployment above 500 ft with Subscale, VDF, and PDF.	**Subscale:** Verified **Full-Scale:** In Progress	Recovery	**Subscale:** See Figures 3.32 and 3.33 for the primary and secondary Subscale altimeter graphs. **Full-scale:** See Section 3.5 and Figure 3.39 for final recovery system design.

Table 7.31: NASA 2024-2025 Recovery Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	Main parachute deployment occurs at or above 500 ft.	**(1) Demonstration:** Demonstrate with Subscale, VDF, and PDF. **(2) Analysis:** Analysis of Avionics Bay electronics and flight data.	**Subscale:** Verified **Full-Scale:** In Progress	Recovery	**Subscale:** See Figures 3.32 and 3.33 for the primary and secondary Subscale altimeter graphs. **Full-scale:** See Section 3.5 and Figure 3.39 for final recovery system design.
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.	The apogee event contains a delay of no more than 2 sec.	**(1) Demonstration:** Demonstrate with Subscale, VDF, and PDF. **(2) Analysis:** Analyze the altimeter flight data for Subscale, VDF, and PDF.	**Subscale:** Verified **Full-Scale:** In Progress	Recovery	**Subscale:** See Figures 3.32 and 3.33 for the primary and secondary Subscale altimeter graphs. **Full-scale:** See Section 3.5 and Figure 3.39 for final recovery system design.
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.	Launch Vehicle is not designed to use motor ejection for primary or secondary deployment.	**Inspection:** Inspect the Launch Vehicle motor retention and drogue parachute deployment design.	**Design:** Verified	Recovery	See Section 3.5 and Figure 3.39 for final recovery system design that does not include motor ejection.
3.2	Each team shall perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the Subscale and Full-scale vehicles.	The Recovery Lead will perform ground ejection tests prior to every vehicle launch.	Ground ejection tests will be successfully performed for all recovery events for Subscale, VDF, and PDF launches.	**Demonstration:** Perform the ground ejection test and record the successful test for inclusion in the CDR and FRR milestones.	**Subscale:** Verified **Full-Scale:** In Progress	Recovery	**Subscale:** Subscale ejection tests was successful and proof of successful launch can be found in Section 3.3.1. **Full-scale:** See the recovery timeline in Table 7.43 for planned Full-scale ejection tests.

Table 7.31: NASA 2024-2025 Recovery Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	Each individual Launch Vehicle section lands with a kinetic energy below 65 ft-lbs.	**Analysis:** Analysis of kinetic energy at landing via altimeter flight graphs.	**Design:** Verified **Construc-tion:** In Progress	Recovery	See Section 3.6.9 and Table 3.19 for the calculated kinetic energies of each individual section at landing.
3.4	The recovery system SHALL contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events.	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.	The recovery system design includes two separate commercially available barometric altimeters.	**Inspection:** Inspect recovery system design prior to construction.	**Design:** Verified **Construc-tion:** In Progress	Recovery	**(1) Subscale:** The Subscale rocket included two different altimeters. See Figures 3.32 and 3.33 for the primary and secondary altimeter plots. **(2) Full-scale:** See Figures 3.44 and 3.45 for the designed primary and secondary altimeter wiring diagrams in the AVAB.
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.	The recovery system design includes two separate commercially available batteries, one for each individual altimeter.	**Inspection:** Inspect Avionics Bay power supply design.	**Design:** Verified **Construc-tion:** In Progress	Recovery	See Figures 3.44 and 3.45 for the primary and secondary wiring diagrams with separate power sources (batteries).
3.6	Each altimeter SHALL be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	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.	Pull pin switches are used on launch day to arm altimeters.	**Inspection:** Inspect Launch Vehicle switchband prior to launch.	**Design:** Verified **Construc-tion:** In Progress	Recovery	See Section 3.5 for final recovery system design and Figures 3.44 and 3.45 for the altimeter arming configuration. See Launch Day Checklist, Section 6.2.

Table 7.31: NASA 2024-2025 Recovery Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	Pull pin switches are ON for the entirety of the flight.	**(1) Inspection:** Inspect Launch Vehicle switchband and arming switch. **(2) Inspection:** Inspect altimeter flight graph after landing.	**Design:** Verified **Construc-tion:** In Progress	Recovery	**(1)** See Launch Day Checklist Section 6.2 and Section 3.5.5 for altimeter arming.
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.	Recovery electronics are independent of all payload electronic circuits.	**Inspection:** Inspect Avionics Bay GPS and altimeter circuits.	**Design:** Verified **Construc-tion:** In Progress	Recovery	See Section 3.5 for final recovery system and avionics design.
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.	Shear pins are used and broken during all Full-scale and Subscale flights.	**Inspection:** Inspect Launch Vehicle separation points before and after launch.	**Design:** Verified **Construc-tion:** In Progress	Recovery	See Section 3.2.2 and Figure 3.2 for separation points of the Launch Vehicle and connection hardware.
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.	Only forged/cast eye bolts are used in the recovery system.	**Inspection:** Inspect eye bolts prior to design and installation.	**Design:** Verified **Construc-tion:** In Progress	Recovery	A forged eye bolt is secured to the motor-casing and connects the drogue parachute to the Launch Vehicle. The utilized bolt has been inspected and is not bent or damaged.
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.	**(1)** Max drift distance and main parachute at apogee scenario remains within the given perimeter. **(2)** All Subscale, VDF, and PDF flights land within the given perimeter.	**(1) Analysis:** Calculate max drift distance under high wind and main at apogee. **(2) Demonstration:** Demonstrate landing radius with Subscale, VDF, and PDF.	**Subscale:** Verified **Full-Scale:** In Progress	Recovery	**(1)** The max drift distance at 20 mph winds is 2085.18 ft. See Section 3.6.11 for Full-scale drift distance calculations. **(2)** Subscale drifted 304 ft. from the launch pad (Section 3.3.3).

Table 7.31: NASA 2024-2025 Recovery Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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)** Parachutes are sized to bring down the Launch Vehicle in <80 sec. **(2)** All Subscale, VDF, and PDF flights land before 80 sec.	**(1) Analysis:** Descent times for selected parachutes are lower than 80 sec. **(2) Demonstration:** Demonstrate descent time with Subscale, VDF, and PDF.	**Subscale:** Verified **Full-Scale:** In Progress	Recovery	**(1)** See Section 3.5.2 for Full-scale parachute selection and opening shock calculations. See Section 3.6.10 for the calculated descent time. **(2)** Subscale landed in 35.75 sec. (Section 3.3.3.
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.	**(1)** GPS transmits launch pad coordinates while on launch pad. **(2)** GPS shows approximate rocket location after touch-down.	**(1) Inspection:** Inspect Launch Day Checklist for confirmed continuity. **(2) Demonstration:** Document GPS coordinates at launch and at landing in documentation.	**Subscale:** Verified **Full-Scale:** In Progress	Recovery	**(1)** See Appendix 8.1 for Subscale Launch Day Checklist. **(2)** The onboard GPS system during the Subscale launch determined that the rocket drifted 304 ft. (Section 3.3.3).
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.	**(1)** The rocket is designed to come down in three sections that are tethered together. **(2)** The rocket contains one GPS in the AVAB.	**(1) Review:** Confirm recovery design is all tethered together in report documentation. **(2) Inspection:** Ensure a GPS is included in the designed AVAB.	Verified	Recovery	**(1)** See Section 3.5 and Figure 3.39 for the recovery system design. **(2)** See Section 3.5.5 and Figures 3.42 and 3.43 for AVAB electronics design.
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.	**(1)** GPS transmits coordinates on the launch pad. **(2)** Accurate GPS data from launch to recovery.	**(1) Inspection:** Inspect Launch Day Checklist for confirmed continuity. **(2) Inspection:** Confirm complete and accurate GPS data is included in report documentation.	**Subscale:** Verified **Full-Scale:** In Progress	Recovery	**(1) Subscale:** GPS continuity checked in step 8.22 of Subscale Launch Day Checklist (See Appendix 8.1). **(2)** The onboard GPS system during the Subscale launch determined that the rocket drifted 304 ft. (Section 3.3.3).

Table 7.31: NASA 2024-2025 Recovery Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** All recovery electronics work as intended during the entire duration of any launch. **(2)** Launch data is complete from launch to landing.	**(1) Demonstration:** Demonstrate successful flight with Subscale, VDF, and PDF. **(2) Inspection:** Confirm complete recovery system electronics data from every flight.	**Subscale:** Verified **Full-Scale:** In Progress	Recovery	**(1) Subscale:** See Section 3.3 for Subscale flight results. **(2) Subscale:** See Section 3.3.3 and Figures 3.32 and 3.33 for Subscale recovery system electronics figures.
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.	**(1)** Altimeters are located in a separate compartment or physically located separately from other electronics. **(2)** Altimeters work as designed during all tests and flights.	**(1) Inspection:** Inspect altimeter design location and constructed compartment. **(2) Demonstration:** Show multiple successful flights and data collections with Subscale, VDF, and PDF.	**Design:** Verified **Subscale:** Verified **Full-scale:** In Progress	Recovery	**(1)** See Section 3.5.5 and Figures 3.42 and 3.43 for the altimeter locations. **(2)** See Figures 3.32 and 3.33 for the Subscale altimeter data.
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.	**(1)** AVAB design includes a specific ”shield” mechanism. **(2)** Recovery system electronics work as designed during tests and flights.	**(1) Inspection:** Inspect design documentation and ensure some form of shield is placed between recovery electronics and other on-board transmitting devices. **(2) Demonstration:** Show multiple successful flights with the final shield mechanism.	**(1) Inspection:** Verified **(2) Demon-stration:** N/A	Recovery	**(1)** See Section 3.5.5 and Figure 3.42 for the AVAB design. **(2)** Not yet completed.
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.	**(1)** AVAB design includes a specific ”shield” mechanism. **(2)** Recovery system electronics work as designed during tests and flights.	**(1) Inspection:** Inspect design documentation and ensure some form of shield is placed between recovery electronics and other on-board devices. **(2) Demonstration:** Show multiple successful flights with the final shield mechanism.	**(1) Inspection:** Verified **(2) Demon-stration:** N/A	Recovery	**(1)** See Section 3.5.5 and Figure 3.42 for the AVAB design. **(2)** Not yet completed.

Table 7.31: NASA 2024-2025 Recovery Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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.	**(1)** AVAB design includes a specific "shield" mechanism. **(2)** Recovery system electronics work as designed during tests and flights.	**(1) Inspection:** Inspect design documentation and ensure some form of shield is placed between recovery electronics and other on-board devices. **(2) Demonstration:** Show multiple successful flights with the final shield mechanism.	**(1) Inspection:** Verified **(2) Demonstration:** N/A	Recovery	**(1)** See Section 3.5.5 and Figure 3.42 for the AVAB design. **(2)** Not yet completed.

Table 7.32: NASA 2024-2025 Payload Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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 to safely house four STEMnauts. A microcontroller will collect and store data for transmission. Safety reviews will be conducted.	**(1)** STEMnaut flight capsule safely retains four STEMnauts during flight. **(2)** STEMnaut flight capsule transmits relevant data to a NASA-owned receiver. **(3)** STEMnaut flight capsule is deemed safe and complies with FAA and legal requirements.	**(1) Demonstration:** Conduct test flights and confirm the capsule safely retains four STEMnauts during flight. **(2) Test:** Verify the capsule's data transmission system during PDF. **(3) Demonstration:** Conduct test flights to demonstrate that the capsule is safe and complies with legal requirements.	In Progress	Payload Team	**(1) Planned Structures Tests:** Parachute Deployment/STEMnaut Containment Test and FEA of Payload Sled (Section 7.2). **(2) Planned Collection & Transmission Tests:** Payload Data Collection Test, Payload Flight Simulation Transmission Test, Remote Override Test, and Data Transmission Verification (Section 7.2). **(3)** See Section 7.2 for planned payload flight tests to demonstrate compliance with legal requirements.

Table 7.32: NASA 2024-2025 Payload Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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 time of landing, maximum velocity, landing velocity, G-forces sustained, temperature, apogee reached, battery status, and orientation of STEMnauts.	**(1)** Payload capsule includes sensors to record a minimum of 3 (maximum of 8) data pieces. **(2)** Payload capsule includes transmission devices to transmit chosen data.	**(1) Review:** Verify design documentation to ensure 3 to 8 data points are included. **(2) Review:** Verify design documentation to confirm the inclusion of transmission devices.	Verified	Payload Team	**(1)** See Section 4.2.1 for Payload Capsule electronic data collection design. See Figure 4.3 for the electronics diagram. **(2)** See Section 4.2.1 for Payload Capsule electronic data transmission design. See Figure 4.3 for the electronics diagram.
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 ensure no protrusions beyond a quarter inch prior to apogee.	The Payload Capsule design does not include any protrusions.	**Review:** Verify design documentation to confirm no protrusions are present in the payload design.	Verified	Payload Structural Integration	See Section 4.2.2 for final Payload Capsule. See Section 4.2.2 and 4.2.2 for the Payload capsule integration design.
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 team will design for transmissions to the FTM-300DR receiver on the 2-M band.	**(1)** Payload transmits on the 2-M band. **(2)** Payload has the ability to change transmission frequency.	**(1) Review:** Verify payload design transmits on the 2-M band and is included in CDR documentation. **(2) Review:** Verify payload design includes the capability to change the transmission frequency.	**(1) Review:** Verified **(2) Review:** Not Verified	Payload Team	**(1)** See Section 4.3.1 for final payload CONOPS and transmission design on the 2-M band. **(2)** Not yet verified.
4.2.4	All transmissions SHALL start and stop with team member call sign.	The system will be programmed to initiate and terminate transmissions with the team member call sign.	**(1)** Payload can change call signs. **(2)** Payload starts and stops transmission with the inputted call sign.	**(1) Review:** Verify design documentation to confirm that the payload is capable of changing call signs. **(2) Demonstration:** Test the payload system to ensure transmissions start and stop with the inputted call sign.	**(1) Review:** Verified **(2) Demon-stration:** Not Verified	Payload Systems	See Section 4.2.1 for the selected transmitter device. See Figure 4.3 for a transmitter integration diagram. See Section 4.2.3 for transmission software information.
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 submit a list of selected data points to NASA by the deadline.	A list of data points to be transmitted is submitted by the March 17 deadline	**Inspection:** Verify submission of the data list to NASA by reviewing the submission confirmation or email.	In Progress	Payload Team	See Section 4.2 for current data point collection design.

Table 7.32: NASA 2024-2025 Payload Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
4.2.6	Teams SHALL transmit with a maximum of 5W and transmissions SHALL not occur prior to landing.	The team ensures no transmissions before landing and that power does not exceed 5W.	**(1)** Transmissions occur only after landing. **(2)** Transmission power does not exceed 5W	**(1) Inspection:** Verify that transmission timing is programmed to start after landing through design documentation or testing data. **(2) Test:** Confirm transmission power does not exceed 5W through operational testing or review of payload specifications.	**Design:** Verified **Construction:** In Progress	Payload Electronics & Systems	See Section 4.2.1 for the selected transmitter device. See Figure 4.3 for a transmitter integration diagram. See Section 4.2.3 for transmission software information.
4.2.6.1	Teams SHALL not transmit on the specified NASA frequency on launch day prior to landing.	The team ensures no transmission on the NASA frequency prior to landing.	**(1)** No transmission on the specified NASA frequency prior to landing. **(2)** Payload code has minimum period that the payload must be armed before progressing to a landed state to prevent accidental transmission. **(3)** Non-NASA communicating transceivers must not be on the 2m band.	**Inspection:** Verify the design documentation to ensure the system is programmed to prevent transmission on the NASA frequency prior to landing.	**Design:** Verified **Construction/Test:** In Progress	Payload Electronics & Software	See Section 5.2.1 and Section 4.2.3 for current payload software and electronics design.
4.3.1	Black powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.	The Payload Team does not design a jettisoning payload.	The payload design does not jettison.	**Inspection:** Review the payload design documentation to ensure no jettison mechanism is included.	Verified	Payload Team & Safety	See Section 4.2.2 for current non-jettisoning payload design.
4.3.2	Teams SHALL abide by all FAA and NAR rules and regulations.	The Safety Team reviews all systems for compliance.	All systems comply with FAA and NAR rules.	**Inspection:** Review the safety documentation and system designs to verify compliance with FAA and NAR rules.	**Design:** Verified **Construction:** In Progress	Safety	See Section 6.5.2 for the safety analysis of the current payload design.
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 a jettisoning payload.	The payload does not jettison.	**Inspection:** Review the payload design documentation to ensure no jettison mechanism is included.	Verified	Payload Systems & Safety	See Section 4.2.2 for current non-jettisoning payload design.

Table 7.32: NASA 2024-2025 Payload Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
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 a UAS or jettisoning payload.	The payload does not jettison.	**Inspection:** Review the payload design documentation to ensure no jettison mechanism is included.	Verified	Payload Systems & Safety	See Section 4.2.2 for current non-jettisoning payload design.
4.3.5	Teams flying UASs SHALL abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112–95 Section 336; see https://www.faa.gov/uas/faqs).	The Payload Team does not design a UAS or jettisoning payload.	The payload does not jettison.	**Inspection:** Review the payload design documentation to ensure no jettison mechanism is included.	Verified	Safety	See Section 4.2.2 for current non-jettisoning payload design.
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 a UAS or jettisoning payload.	The payload does not jettison.	**Inspection:** Review the payload design documentation to ensure no jettison mechanism is included.	Verified	Payload Team	See Section 4.2.2 for current non-jettisoning payload design.

Table 7.33: 2024-2025 Safety Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
5.1	Each team shall use a launch and safety checklist.	The Team Lead will create a checklist for launch day activities and include it in the CDR and FRR report.	A detailed launch and safety checklist is created and documented for all Subscale, VDF, PDF, and Huntsville launches.	**Review:** Confirm detailed launch and safety checklists are included in the CDR and FRR reports.	**Subscale:** Verified **Full-scale:** In Progress	All Subsystems	See Appendix 8.1 for the Subscale Launch Day Checklist.
5.2	Each team shall identify a student safety officer.	The team will nominate a Safety Officer, identified in the proposal document.	A student Safety Officer is nominated and identified in all report documentation.	**Review:** Verify that the Safety Officer's name and responsibilities are included in milestone documents.	**Proposal/CDR:** Verified **FRR:** N/A	Project Management, Safety	See Section 6.1 for Safety Officer identification.
5.3.1.1	The Safety Officer SHALL monitor team activities during design.	The Safety Officer or a member of the Safety Team will attend design activities to enforce safety protocols.	Safety Protocols are enforced during all design activities.	**Inspection:** Confirm monitoring through attendance records and safety documentation.	**Subscale:** Verified **Full-scale:** In Progress	Project Management, Safety	See Section 6.1 for Safety Officer and Safety Team responsibilities.
5.3.1.2	The Safety Officer SHALL monitor team activities during construction.	The Safety Officer or a member of the Safety Team will attend construction activities to enforce safety protocols.	Safety Protocols are enforced during all construction activities.	**Inspection:** Confirm monitoring through activity logs and adherence to documented safety protocols.	**Subscale:** Verified **Full-scale:** In Progress	Project Management, Safety	See Section 6.1 for Safety Officer and Safety Team responsibilities.

Table 7.33: 2024-2025 Safety Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
5.3.1.3	The Safety Officer SHALL monitor team activities during assembly.	The Safety Officer or a member of the Safety Team will enforce safety protocols during all Launch Vehicle assemblies.	Safety protocols are enforced during all assembly activities.	**Inspection:** Confirm monitoring through assembly records and adherence to documented safety protocols.	**Subscale:** Verified **Full-scale:** In Progress	Project Manage-ment, Safety	See Section 6.1 for Safety Officer and Safety Team responsibilities.
5.3.1.4	The Safety Officer SHALL monitor team activities during ground testing.	The Safety Officer or a member of the Safety Team will enforce safety protocols during ground testing.	Safety protocols are enforced during all ground testing.	**Inspection:** Confirm monitoring through ground testing records and adherence to documented safety protocols	**Subscale:** Verified **Full-scale:** In Progress	Project Manage-ment, Safety	See Section 6.1 for Safety Officer and Safety Team responsibilities.
5.3.1.5	The Safety Officer SHALL monitor team activities during Subscale launch tests.	The Safety Officer or a member of the Safety Team will ensure adherence to safety protocols during Subscale launches.	Safety protocols are enforced during Subscale launches.	**Inspection:** Confirm monitoring through Subscale Launch Day Checklist records	Verified	Project Manage-ment, Safety	See Appendix 8.1 for the Subscale Launch Day Checklist.
5.3.1.6	The Safety Officer SHALL monitor team activities during Full-scale launch tests.	The Safety Officer or a member of the Safety Team will ensure adherence to safety protocols during Full-scale launches.	Safety protocols are enforced during Full-scale launches.	**Inspection:** Confirm monitoring through Full-scale Launch Day Checklist records and launch attendance records	Not Verified	Project Manage-ment, Safety	See Section 6.2 for draft of Full-scale Launch Day Checklist.
5.3.1.7	The Safety Officer SHALL monitor team activities during the competition launch.	The Safety Officer or a member of the Safety Team will ensure adherence to safety protocols during the competition launch.	Safety protocols are enforced during the competition launch.	**(1) Inspection:** Confirm monitoring through competition Launch Day Checklist records **(2) Inspection:** Confirm Safety Officer attendance with Huntsville roster	**(1) Inspection:** Not Verified **(2) Inspection:** Verified	Project Manage-ment, Safety	**(1)** See Section 6.2 for the draft of Full-scale Launch Day Checklist. **(2)** See Huntsville roster.
5.3.1.8	The Safety Officer SHALL monitor team activities during recovery.	The Safety Officer or a member of the Safety Team will enforce safety protocols during recovery activities.	Safety protocols are enforced during all recovery operations.	**Inspection:** Confirm monitoring through outreach attendance records and adherence to documented safety protocols.	In Progress	Project Manage-ment, Safety	See Section 6.1 for Safety Officer and Safety Team responsibilities
5.3.1.9	The Safety Officer SHALL monitor team activities during STEM engagement.	The Safety Officer or a member of the Safety Team will ensure adherence to safety protocols during STEM activities.	**(1)** Safety protocols are enforced during STEM engagement activities. **(2)** All participants remain safe and unharmed.	**(1) Inspection:** Safety and mitigation protocols are included in report documentation. **(2) Demonstration:** STEM engagement reports do not include injury notifications.	**(1) Inspection:** Verified **(2) Demon-stration:** In Progress	Project Manage-ment, Safety	**(1)** See Section 6.1 for STEM Engagement FMEA analysis. **(2)** No incidents or injuries have occurred during STEM engagement events.

Table 7.33: 2024-2025 Safety Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
5.3.2	The Safety Officer SHALL implement team-developed procedures.	The Safety Officer will implement and verify all procedures for construction, assembly, launch, and recovery.	Multiple procedure lists for required team practices are created and distributed to subsystem leads.	**Inspection:** Inspect the team's safety handbook for safety procedures.	Verified	Safety	The team lab space includes folders for each subsystem of safety protocols and procedures.
5.3.3	The Safety Officer SHALL manage team's hazard analyses and procedures.	The Safety Officer will manage and maintain the team's hazard analyses and safety data.	Team hazard analysis and procedures in all report documentation.	**Inspection:** Inspect report documentation for hazard analyses and procedures.	Verified	Safety	See Sections 6.4 and 6.5 for subsystem FMEAs and hazard analyses.
5.3.4	The Safety Officer SHALL assist in writing hazard analyses and procedures.	The Safety Officer will assist in creating hazard analyses and procedures for safety.	**(1)** Hazard analyses and procedures are written for each subsystem. **(2)** The Safety Officer reviews each subsystem hazard analysis.	**Inspection:** Inspect report documentation for hazard analyses and procedures.	Verified	Safety	**(1)** See Sections 6.4 and 6.5 for subsystem FMEAs and hazard analyses. **(2)** Safety Officer assisted in the creation of the FMEAs and hazard analyses.
5.4	Teams SHALL abide by local rocketry club's RSO rules.	The Safety Officer will verify compliance with local rules.	**(1)** The team is informed about the local rocketry club's RSO rules. **(2)** The team adheres to the local rocketry club's RSO rules during all phases of the rocket's design, construction, and launch events.	**(1) Review:** Confirm appropriate information was communicated to all team members. **(2) Demonstration:** Demonstrate compliance with all local RSO rules by successfully launching the final Subscale and Full-scale rocket design. Include successful launch documentation in milestone reports.	**(1) Review:** Verified **(2) Demon-stration:** In Progress	Safety	**(1)** See Appendix 8.4 for the HPRC Safety Handbook. **(2)** See Section 3.3 for Subscale flight overview.
5.5	Teams SHALL abide by FAA rules.	The Safety Officer will train the team on safety protocols and ensure compliance with FAA rules.	**(1)** The team is informed about relative FAA rules and regulations prior to design process. **(2)** The team follows all FAA rules and regulations during the design, construction, and flight phases.	**(1) Review:** Confirm appropriate information was communicated to all team members. **(2) Demonstration:** All Subscale, VDF, and PDF flights are flown and follow FAA rules.	**(1) Review:** Verified **(2) Demon-stration:** In Progress	All Subsystems	**(1)** See Appendix 8.4 for the HPRC Safety Handbook. **(2)** See Section 3.3 for Subscale flight overview.

7.3.2 Team Derived Requirements

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	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 occurring. As referenced in Section 3.2.14, the Full-scale Launch Vehicle will be composed of primarily G12 fiberglass. This requirement must be followed when drilling the shear pin holes, pressure port holes, rivet holes, and switchband holes.	**(1)** Pilot holes are drilled before final holes for all required tasks. **(2)** Blue masking tape is applied properly before drilling.	**(1) Inspection:** Inspect the fiberglass tubes to verify the presence of pilot holes. **(2) Inspection:** Inspect the application of blue masking tape before the final hole.	**Subscale:** Verified **Full-scale:** In Progress	Structures	The Subscale was successfully built using this method. Full-scale fabrication, as described in Sections 3.4.7 and 3.4.9, will also use this method for Subscale flight results.	Full-scale construction will begin on January 6th.
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.	All rocket components (excluding motor and black powder) are assembled and integrated successfully during the dry run.	Demonstration: Observe the team conducting the full ”dry run” assembly, ensuring all parts integrate correctly without requiring extra materials.	**Subscale:** Verified **Full-scale:** In Progress	Structures, Team Man-agement	See Appendix 8.1 for the Subscale Launch Day Checklist.	Dry run utilizes the official Launch Day Checklist. Subscale dry run is officially completed.
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 allowables can be found in Section 7.4.1 (Funding Plan).	**(1)** Components are verified to fit correctly during every construction phase. **(2)** No additional materials are required due to fitment errors.	**(1) Demonstration:** Observe test fittings during each construction phase to confirm all components fit and align as required. **(2) Inspection:** Inspect the fit and tolerances after test fitting procedures are completed.	**Subscale:** Verified **Full-scale:** In Progress	Integration, Structures	Subscale components integrated seamlessly and required no additional material.	Full-scale construction will begin on January 6th.

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req. No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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.	Epoxy areas are undisturbed for 24 hours.	**Inspection:** Inspect the epoxy areas to ensure they remain undisturbed during the curing period.	**Subscale:** Verified **Full-scale:** In Progress	Structures	Epoxied components are left in a corner of the lab with a note detailing start and end date and time.	The Subscale Launch Vehicle performed well and had no epoxy related failures.
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.	**(1)** Jigs are used for all cuts into circular tubing. **(2)** Tubes remain steady during cutting procedures.	**(1) Demonstration:** Demonstrate the use of a jig during cutting to ensure tubing does not roll. **(2) Inspection:** Inspect the final vehicle assembly and verify straight edges.	**Subscale:** Verified **Full-scale:** In Progress	Structures	**(1)** During component manufacturing, jigs are planned to be used for circular cuts and holes (See Section 3.4). **(2) Subscale:** Subscale components integrated seamlessly, with straight edges and well toleranced holes.	Full-scale construction will begin on January 6th.
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 7.4.	**(1)** All parts are secured using clamps during drilling. **(2)** Holes are aligned as intended without shifting.	**(1) Inspection:** Inspect the clamping setup on the drill press. **(2) Inspection:** Inspect the final vehicle assembly for properly aligned holes.	**Subscale:** Verified **Full-scale:** In Progress	Structures	**(1)** See Section 3.4 for the Full-scale manufacturing procedure. **(2)** Subscale components integrated seamlessly.	Full-scale construction will begin on January 6th.
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.	Measurements are signed off by both the Integration Lead and Structures Lead prior to cutting.	**Inspection:** Inspect the Launch Vehicle for proper measurements.	**Subscale:** Verified **Full-scale:** In Progress	Integration, Structures	**(1)** See Section 3.4 for the Full-scale manufacturing procedure. **(2)** Subscale components integrated seamlessly.	Full-scale construction will begin on January 6th. All measure-ments have been doubly verified so far.

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req. No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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 7.45, 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.	**(1)** Ballast can be removed without damaging the rocket. **(2)** Adjustments to stability margins are possible using the removable ballast.	**Inspection:** Inspect the installation of ballast to verify removability and adjustability.	**Design:** Verified **Construc-tion:** In Progress	Structures	See Section 3.2.3 for the final ballast system in the Full-scale Launch Vehicle.	Full-scale construction will begin on January 6th.
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 fasteners into the 6061-T6 aluminum and wood 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 7.4.	**(1)** Fasteners are tightened using hand tools only. **(2)** RMFS threads remain undamaged after fastening.	**(1) Demonstration:** Demonstrate fastening using only hand tools. **(2) Inspection:** Inspect fasteners and threads to ensure no torque or torque-multiplying devices were used.	**Subscale:** Verified **Full-scale:** In Progress	Structures	**(1)** See Appendix 8.1 for Subscale checklist directions and adherence. **(2)** Subscale RMFS assembled correctly.	Full-scale construction will begin on January 6th.
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 3.6.2, also support the performance and coding software for the Air Brakes payload discussed in Section 5.2.3.	**(1)** Apogee results from three programs agree within acceptable margins. **(2)** Discrepancies between results are documented and justified.	**(1) Analysis:** Compare results from three separate analysis programs to verify consistency and accuracy. **(2) Review:** Review the results to ensure they meet NASA Requirement 2.1.	Verified	Aerodynam-ics	**(1) Analysis:** See Sections 3.6.1 and 3.6.2 for final altitude analysis in 3 separate programs.	
LVF.11	Rivets SHALL sustain a maximum tensile load greater than 80 lbf and have a factor of safety greater than 2.	The rivets must be stronger than the shear pins by a factor of 2 to ensure non-separating sections don't separate during the ejection of black powder charges.	Rivets break after a tensile load of 80 lbf.	**Test:** Perform a tensile load test that determines the strength of the purchased and utilized rivets.	In Progress	Structures	See Section 7.1.7 for the procedure of the Rivet Shear Loading Test	**Scheduled test date:** February 4th.

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req. No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
LVF.12	Shear pins SHALL sustain a maximum tensile load of 40 +/- 5 lbf.	This rating ensures the designated sections separate during the ejection of black powder charges.	The shear pins break at 40 +/- 5 lbf.	**Test:** Perform a tensile load test that determines the strength of the purchased and utilized shear pins.	In Progress	Structures	See Section 7.1.8 for the procedure of the Shear Pin Shear Loading Test	**Scheduled test date:** February 4th.
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.	**(1)** Simulations and/or test results demonstrate positive margins with a safety factor of 1.5. **(2)** Potential issues are identified and addressed before integration.	**(1) Analysis:** Perform Ansys/CAD simulations and numerical calculations. **(2) Test:** Conduct structural testing to validate the analysis results and safety factor compliance.	**(1)** Verified **(2)** In Progress	Aerodynamics	**(1) Analysis:** See Section 3.2.13 for Launch Vehicle Ansys results. **(2) Test:** See Section 7.1 for planned Launch Vehicle tests.	
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 7.42, there is no time allotted for rebuilding airframes in the case of material failure.	Tubing material is purchased from a reputable supplier.	**Review:** Review supplier for rocket tubing.	Verified	Structures	See Table 7.38 for the Full-scale purchase list and vendors.	
LVD.3	The Subscale version of the NASA SL competition rocket SHALL be constructed using Blue Tube.	Due to budget constraints outlined in Section 7.4, Blue Tube is the most cost effective material for Subscale Launch Vehicle body tube.	Blue Tube material is used for all Subscale body tubes.	**(1) Inspection:** Inspect the Subscale rocket to verify the use of Blue Tube material. **(2) Review:** Review purchase records and documentation to confirm compliance.	Verified	Structures	**Subscale Materials:** See Section 7.4 for the budget and Table 7.38 for the Subscale material purchases	

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req. No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
LVD.4	The Full-scale version of the NASA SL competition rocket SHALL be constructed using fiberglass tubing.	As outline in Section 3.2.14, 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.	Fiberglass tubing is used for all Full-scale body tubes.	**(1) Inspection:** Inspect the Full-scale rocket to verify the use of fiberglass tubing. **(2) Review:** Review material selection and verify compliance with design requirements.	Verified	Structures	**Full-scale Materials:** See Section 7.4 for the budget and Table 7.38 for the Full-scale material purchases.	Full-scale construction will begin on January 6th.
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 4.1.1. Due to the estimated length of the antenna, the payload needs to be in the Nose Cone of the rocket. Thus, the Nose Cone needs to be made of radio-transparent material to not hinder RF transmissions.	Nosecone material allows for uninterrupted RF signal transmission.	**Inspection:** Inspect the nosecone for compliance with structural and material requirements.	Verified	Structures	**Full-scale:** Fiberglass is confirmed RF transparent in Section 3.2.3	**Subscale:** Blue Tube is confirmed RF transparent.
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.	**(1)** Four fins are installed and identical in dimensions. **(2)** Fins are evenly spaced at 90° intervals around the rocket tube.	**(1) Inspection:** Inspect the rocket to verify four identical fins are installed and evenly spaced. **(2) Measurement:** Measure fin dimensions and spacing to confirm compliance.	Verified	Structures	See Section 3.2.10 for Full-scale fin design and Section 3.4.10 for Full-scale fin fabrication.	
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 being calculated as 2.12-2.14, the center of gravity of the Launch Vehicle must be forward of the center of pressure to ensure a positive static stability margin.	**(1)** Static stability margin at rail exit is calculated as 2.0 or greater. **(2)** Center of gravity is forward of the center of pressure.	**(1) Analysis:** Use simulation software to calculate and verify the center of gravity and center of pressure locations. **(2) Review:** Review simulation results to ensure the static stability margin meets requirements.	Verified	Aerodynam-ics	See Section 3.6.8 and Table 3.17 for the static stability margins and calculation method.	Results come from 3 different aerody-namic simulation softwares.

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req. No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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, including 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 plate as determined in Section 3.2.14.	**(1)** The thrust plate is constructed from 6061 Aluminum. **(2)** The thrust plate evenly distributes thrust across the airframe body.	**(1) Inspection:** Inspect the material and placement of the thrust plate. **(2) Analysis:** Perform simulation testing to validate even distribution of force.	Verified	Structures	**(1) Inspection:** See Section 3.2.11 for thrust plate material. (2) Analysis: See Section 3.2.13 for thrust plate Ansys simulation.	
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.	**(1)** At least two centering rings are installed and secure the motor casing. **(2)** Centering rings maintain alignment of the motor casing with the center of gravity.	**(1) Inspection:** Inspect the installation of centering rings to verify quantity and placement. **(2) Demonstration:** Observe motor installation to confirm alignment and structural support.	**Subscale:** Verified **Full-scale:** In Progress	Structures	See Section 3.2.11 for Full-scale motor casing design.	Full-scale construction will begin on January 6th.
LVD.10	The Full-scale NASA SL competition rocket SHALL have a stability margin between 2.0 and 2.9 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 2.9 reduces the likelihood of undesired weather cocking which would decrease the accuracy of the mission performance predictions in Section 3.6.	Stability margin at rail exit is calculated between 2.0 and 2.9.	**Analysis:** Use simulation software to calculate stability margins at rail exit.	Verified	Aerodynamics	See Table 3.17 for the Full-scale stability margins.	Three different softwares were utilized.
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.	Maximum velocity is calculated to remain below Mach 0.75.	**Analysis:** Simulate the rocket's trajectory to verify the maximum velocity remains below Mach 0.75.	Verified	Aerodynamics	See Table 3.15 for maximum velocity of Full-scale Launch Vehicle.	

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req. No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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.	Materials are purchased from a reputable supplier.	**Review:** Review supplier for rocket materials.	Verified	Structures	See Table 7.38 for Full-scale budget purchases.	
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.	**(1)** All participating members complete the safety quiz and score 100%. **(2)** No tools are accessed by any member prior to quiz completion. **(3)** Records are maintained for all quiz completions.	**(1) Demonstration:** Observe quiz administration and ensure members score 100%. **(2) Inspection:** Check lab records to confirm no unauthorized tool usage. **(3) Review:** Verify compliance through Safety Officer documentation.	In Progress	Safety Team, Structures	See Appendix 8.4 for the Safety Quiz and Appendix 8.4 for the HPRC Safety Handbook.	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)** A safety officer or safety team member is always present during construction phases. **(2)** All members near tool use wear proper PPE. **(3)** PPE compliance aligns with Section 6.4.1 and 6.5 hazards.	**(1) Inspection:** Perform spot checks during construction phases to verify the presence of safety personnel. **(2) Test:** Observe team members for proper PPE usage. **(3) Review:** Review safety logs and PPE compliance records.	In Progress	Safety Team	See Appendix 8.4 for the Safety Quiz and Appendix 8.4 for the HPRC Safety Handbook.	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.	No gloves, rings, or bracelets are worn by any member while operating the drill press.	**Demonstration:** Monitor drill press operations to ensure compliance.	In Progress	Safety Team	See Appendix 8.4 for the Safety Quiz and Appendix 8.4 for the HPRC Safety Handbook.	Safe construction practices are maintained daily.

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req. No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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.	All members tie back hair and loose clothing before operating the drill press.	**Demonstration:** Observe team members preparing to use the drill press to verify safety compliance.	In Progress	Safety Team	See Appendix 8.4 for the Safety Quiz and Appendix 8.4 for the HPRC Safety Handbook.	Safe construction practices are maintained daily.
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 in Section 7.3.2 for team derived Launch Vehicle requirements.	**(1)** The drill press area is free of all hazards prior to and during operation. **(2)** No obstructions or unsafe objects are present in the vicinity of the drill press.	**Inspection:** Inspect the drill press area before operations.	In Progress	Safety Team	See Appendix 8.4 for the Safety Quiz and Appendix 8.4 for the HPRC Safety Handbook.	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.	**(1)** All members operating the drill press wear safety glasses. **(2)** No incidents related to flying debris occur.	**(1) Demonstration:** Observe members during drill press operations to confirm safety glasses usage. **(2) Review:** Check compliance against Appendix 8.4 guidelines.	In Progress	Safety Team	**(1)** See Appendix 8.4 for the Safety Quiz and Appendix 8.4 for the HPRC Safety Handbook. **(2)** No flying debri-related incidents.	Safe construction practices are maintained daily.

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req. No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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 7.46. 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.	**(1)** Gloves are worn during all epoxy use. **(2)** Safety protocols are followed in the event of epoxy skin contact.	**(1) Inspection:** Observe members during epoxy use for proper PPE compliance. **(2) Review:** Verify incident reports and logs for proper protocol adherence.	In Progress	Safety Team	**(1)** See Appendix 8.4 for the Safety Quiz and Appendix 8.4 for the HPRC Safety Handbook. **(2)** No epoxy-related incidents.	Safe construction practices are maintained daily.
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 6.4.3, and reduce the number of educated individuals working on the project.	**(1)** All team members wear particle masks and proper PPE during fiberglass manipulation. **(2)** Operations take place outdoors or in ventilated areas. **(3)** A lab vacuum is utilized during fiberglass cutting.	**(1)** Demonstration: Monitor fiberglass manipulation sessions to confirm PPE compliance. **(2)** Inspection: Ensure operations occur in ventilated environments. **(3) Review:** Verify vacuum usage through observation.	In Progress	Safety Team	See Appendix 8.4 for the Safety Quiz and Appendix 8.4 for the HPRC Safety Handbook.	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 7.5. Thus, maintaining a safe environment encourages productivity and allows the team to work efficiently.	**(1)** All members wear gloves, particle masks, and safety glasses during filler use. **(2)** Team members in the vicinity wear particle masks. **(3)** No exposure-related incidents occur.	**(1) & (2) Inspection:** Observe filler application sessions to verify PPE compliance. **(3) Review:** Check incident logs for compliance and effectiveness of safety protocols.	In Progress	Safety Team	**(1) & (2)** See Appendix 8.4 for the Safety Quiz and Appendix 8.4 for the HPRC Safety Handbook. **(3)** No exposure-related incidents.	Safe construction practices are maintained daily.

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req. No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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 7.5. Proper ventilation and PPE ensures that the painting process can proceed without interruptions.	**(1)** All members wear gloves and masks during spray painting. **(2)** Spray painting occurs only in ventilated areas. **(3)** No respiratory incidents are reported.	**(1) Demonstration:** Monitor spray painting sessions for proper PPE compliance. **(2) Inspection:** Verify painting occurs in ventilated spaces. **(3) Review:** Check incident logs for compliance and effectiveness of safety protocols.	In Progress	Safety Team	**(1) & (2)** See Appendix 8.4 for the Safety Quiz and Appendix 8.4 for the HPRC Safety Handbook. **(3)** No respiratory incidents.	Safe construction practices are maintained daily.
LVS.11	All motor construction SHALL occur under the supervision of the Team Mentor or an individual with at least an L2 certification.	Motor assembly is extremely important for the success of a rocket launch. An incorrectly assembled motor could lead to a CATO of the rocket, which could result in personnel injuries and mission objective failure.	An L2 (or higher) certification holder or the Team Mentor is present during motor assembly either on or before Launch Day.	**Inspection:** Verify that motor assembly occurs under the supervision of valid personnel. Include the name of the supervisor in checklist documentation.	**Subscale:** Verified **Full-scale:** In Progress	**Full-scale:** See the draft of the Launch Day Checklist for checklist assurance of L2 (or higher) certification holder verification.	Subscale motor assembly occurred on the day prior to the Subscale launch day and under the supervision of a club affiliated L2 (or higher) certification holder.	
Design 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.	**(1)** All leftover epoxy is disposed of in the communal waste container. **(2)** Epoxy in the waste container cures for 24 hours before being discarded. **(3)** No epoxy is improperly disposed of in sinks or other unauthorized areas.	**(1) Inspection:** Regularly check the epoxy waste container to ensure proper usage. **(2) Inspection:** Check epoxy prior to disposal. **(3) Demonstration:** Observe epoxy disposal practices during lab sessions.	Verified	Safety Team, Structures	See Appendix 8.4 for the Wake County Waste Disposal Guidelines and Appendix 8.3.1 for the signed safety contract. See Appendix 8.4 for the HPRC Safety Handbook which includes epoxy disposal procedures.	Environmentally safe construction practices are maintained daily.

Table 7.34: 2024-2025 Team-Derived Structures Requirements

Req. No.	Requirement Statement	Justification	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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 HPRC Safety Handbook (Appendix 8.4). Regular vacuuming also helps maintain equipment functionality and prolongs the lifespan of the lab's tools and workspace.	**(1)** Fiberglass shards and dust are captured using the shop-vac after any cutting, sanding, or drilling. **(2)** No residual fiberglass debris is found in the workspace. **(3)** The shop-vac is maintained and functional.	**(1) Demonstration:** Observe fiberglass cleanup procedures to confirm shop-vac usage. **(2) Inspection:** Perform post-task checks to ensure the workspace is free of fiberglass debris. **(3) Inspection:** Verify that the shop vac works prior to usage.	Verified	Safety Team	See Appendix 8.4 for the Wake County Waste Disposal Guidelines and Appendix 8.3.1 for the signed safety contract. See Appendix 8.4 for the HPRC Safety Handbook which includes fiberglass disposal procedures.	Environmentally safe construction practices are maintained daily.

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	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.	Team members inspect AV bay wires during launch day assembly.	**Inspection:** Inspect the Launch Day Checklist for the instruction of this visual inspection.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Subscale:** See Appendix 8.1 for the Subscale Launch Day Checklist. **Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	
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.	Team members "tug" AV bay wires during launch day assembly.	**Inspection:** Inspect the Launch Day Checklist for the instruction of this tactile inspection.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Subscale:** See Appendix 8.1 for the Subscale Launch Day Checklist. **Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
RF.3	Each cell of the LiPo SHALL be charged to above 4.0 V per cell.	The maximum charge for a LiPo cell is 4.2V. Charging the cells to 4.0V 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.	Battery life is checked during Launch Day Checklist and is confirmed to be above 4.0 V per cell.	**Inspection:** Inspect the Launch Day Checklist for the confirmation of battery life.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Subscale:** See Appendix 8.1 for the Subscale Launch Day Checklist. **Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	
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.	Battery life is checked during Launch Day Checklist and is confirmed to not be 0.03V above 4.1V.	**Inspection:** Inspect the Launch Day Checklist for the confirmation of battery life.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Subscale:** See Appendix 8.1 for the Subscale Launch Day Checklist. **Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	
RF.5	All utilized batteries SHALL 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 7.46, or data collection failure.	LiPo's are tested prior to launch day.	**Inspection:** Verify that LiPo testing is included in the recovery timeline prior to all launches.	In Progress	Recovery	Scheduled battery tests can be found in the Recovery timeline, Table 7.43.	Currently only two battery tests are officially planned, with one backup test day. More tests will be added as needed for launches.
RF.6	All 9V alkaline batteries SHALL be above 9.00 V.	Fully charged batteries are responsible for multiple electronics in the AV bay as clarified in Section 3.5.5. These batteries must be fully charged because a low voltage results in a lack of current draw in the batteries. Additionally, verifying that all batteries are fully charged help the team meet NASA Requirement 2.6 and Requirement RD.3.	Voltage output of all utilized batteries are above 9V.	**Inspection:** Confirm battery voltage prior to use and instruction is included in Launch Day Checklists.	In Progress	Recovery	**Subscale:** See Appendix 8.1 for the Subscale Launch Day Checklist. **Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
RF.7	All batteries in the Launch Vehicle SHALL be removed during cleaning of the Launch Vehicle 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.	All batteries are removed from the Launch Vehicle after the rocket is successfully recovered.	**Inspection:** Inspect the Launch Day Checklist for the confirmation of battery removal.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Subscale:** See Appendix 8.1 for the Subscale Launch Day Checklist. **Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	
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.	**(1)** Packaged black powder is the exact amount used in the prior ejection test for the rocket. **(2)** Black powder is packaged in a sealed and labeled container.	**(1) Measurement:** Calculate black powder measurements and test these values during ejection testing. **(2) Inspection:** Inspect transport materials and ensure containers and anti-static bags are well stocked.	Verified	Recovery	**(1)** See Section 3.6.12 for black powder calculations. **(2)** See Section 7.4 for budget outline.	See Table 7.43 for Full-scale ejection testing schedule.
RF.9	The secondary black powder charge SHALL be at least 0.3 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 7.5.	Secondary black powder charge is at least 0.3 grams larger than the primary black powder charge.	**Inspection:** Verify that the secondary black powder charge is at least 0.3 grams greater than the recorded primary black powder measurement.	Verified	Recovery	See Section refsec:Ejection Charge Sizing for the black powder calculations for Full-scale.	Prior to ejection testing, the Drogue parachute deployment has a primary charge of 2.75 g and a secondary charge of 3.25 g. The main parachute deployment has a primary of 3.02 g and a secondary of 3.52 g.

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
RF.10	The primary ejection charge SHALL be calculated and verified by ejection tests.	The primary charge must be calculated 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 RF.22.	**(1)** Black powder calculated in report documentation. **(2)** A successful ejection test occurs prior to all Subscale & Full-scale launches.	**(1) Inspection:** Inspect report documentation for black powder calculations. **(2) Demonstration:** Demonstrate successful ejection tests prior to all launches of a competition vehicle.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**(1)** See Table 7.43 for the planned ejection tests dates and recovery timeline. **(2)** Successful Subscale ejection test has been performed.	The VDF ejection test is scheduled for February 10th.
RF.11	All black powder calculations SHALL be done using the Ideal Gas Law.	Black powder calculations are performed using Equation 3.6.12 in Section 3.6.12. This equation is from a reputable source and derived from Ideal Gas Law. Verifying the location and method of the equation reduces calculation and human error.	Black powder equations are based on the Ideal Gas Law.	**Inspection:** Verify that the website used for black powder calculations is from a reputable source.	Verified	Recovery	See Section 3.6.12 for black powder calculations.	Black powder calculation reference included in references.
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 and lightly shaken 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 Equation 3.6.12, is utilized. Additionally, it ensures no leakage for safety and environmental reasons (See RF.8 and RS.1).	**(1)** Black powder charges fit inside designated blast caps. **(2)** Black powder charges are secured with filling and blue tape. **(3)** Black powder charges are turned upside-down to test black powder containment.	**Inspection:** Verify that the Launch Day Checklist includes these procedures.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Subscale:** See Appendix 8.1 for the Subscale Launch Day Checklist. **Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	
RF.13	Altimeters SHALL be tested prior to every launch by simulating flight. Flight will be simulated by placing the altimeter in a vacuum chamber and slowly decreasing the pressure to simulate an increase in altitude and then slowly decreasing the pressure to simulate the descent of the vehicle.	Altimeters are selected in Section 3.5.5 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.	Altimeters are tested prior to all launches.	**Test:** Altimeter test is included in report documentation.	In Progress	Recovery	See Section 7.1.10 for planned altimeter test. See the recovery timeline, Table 7.43, for the dates of the planned altimeter tests.	Current test dates are January 13th and January 15th.

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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 3.5.5, 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.	Altimeter continuity beeps don't overlap on launch pad.	**Inspection:** Verify that the Launch Day Checklist arms one altimeter at a time.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Subscale:** Continuity beeps did not overlap on launch day. **Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	**Checklist Steps:** 2.21 - 2.22, 3.21 - 3.22.
RF.15	Prior to launch day packing, all parachutes SHALL be inspected to visually verify that there are no holes, tears, or missing stitches.	Holes, tears, and missing stitches in the parachutes impact the parachute calculations made in Section 3.5.2. These deformities can decrease the effectiveness of the parachute and increase the kinetic energy values past what is allowed in NASA Requirement 3.3.	Parachutes do not have holes or missing stitches on launch day.	**Inspection:** Inspect all parachutes owned by the team and items used for this year's competition rocket.	Verified	Recovery	All team-owned parachutes have been cataloged and all damaged parachutes have been discarded.	Non-damaged parachutes have been selected in the final recovery design.
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 3.5.2. Parachute failure would result in the total failure of mission objectives and delay timelines established in Section 7.5.	Shroud lines are not frayed and are properly connected to parachutes on launch day.	**Inspection:** Inspect all parachutes owned by the team and items used for this year's competition rocket.	Verified	Recovery	All team-owned parachutes have been cataloged and all damaged parachutes have been discarded.	Non-damaged parachutes have been selected in the final recovery design.
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.	Parachutes are packed under the supervision of a qualified individual.	**Inspection:** Inspect the Launch Day Checklist for this supervision requirement.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	**Checklist Section:** 4, 6

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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.15 is met.	Parachutes are folded with the shroud line seams facing inward.	**Inspection:** Inspect parachute folding and ensure seam location.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	
RF.19	Prior to launch the Nomex cloths SHALL be inspected for holes. If any inconsistencies are found, another Nomex cloth SHALL be utilized.	Nomex clothes 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 3.5.2.	Utilized Nomex cloths are free of large holes, tearing, and frayed edges.	**Inspection:** Verify that Nomex cloths are quality checked prior to launch.	Verified	Recovery	See Appendix 8.2 for Launch Day packing list.	All team-owned Nomex cloths meet requirement standards.
RF.20	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.	Shock cord is accordion folded.	**Inspection:** Verify that the shock cord is accordion folded and is verified in Launch Day Checklist.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	**Checklist Step:** 4.2, 6.7 - 6.9.
RF.21	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.	Shock cord only uses self-tightening knots.	**Inspection:** Verify that only self-tightening knots are used in the shock cord.	Verified	Recovery	All team-owned shock cord has been cataloged and only contains self-tightening knots.	
RF.22	Prior to every launch of a NASA SL competition vehicle, the team SHALL perform an ejection test to verify ejection charges in the Launch Vehicles complete launch configuration.	Ejection charges calculated with Equation 3.6.12 in Section 3.6.12 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 and the changes in masses that affect how the Launch Vehicle separates.	A successful ejection test is performed prior to all Subscale and Full-scale launches.	**Demonstration:** Perform a successful ejection test for all Launch Vehicles.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**(1)** See Table 7.43 for the planned ejection tests dates and recovery timeline. **(2)** Successful Subscale ejection test has been performed.	The VDF ejection test is scheduled for February 10th.

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
RF.23	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 3.6.12. This also mitigates the forces from the ejection charges on the recovery equipment.	**(1)** Biodegradable insulation is used for packing material in the Launch Vehicle. **(2)** Insulation is placed between parachutes and black powder charges.	**(1) Inspection:** Verify that biodegradable insulation is included in the Launch Day Packing List. **(2) Inspection:** Verify that insulation is placed with the black powder charges and parachutes.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	**Checklist Step:** 4.22, 6.28
RF.24	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.	**(1)** Photos are taken of the Launch Vehicle prior to the start of recovery events. **(2)** Altimeters are disarmed.	**Inspection:** Ensure the procedure for disarming altimeters and taking recovery photos is included in the recovery section of the Launch Day Checklist.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	**Checklist Step:** 9.4
RF.25	Prior to launching a NASA SL competition rocket, GPS coordinates of the launch site SHALL be recorded.	Recording GPS requirements helps verify that we are meeting NASA Requirement 3.11 .	GPS coordinates are written down.	**Inspection:** Verify that the GPS coordinates are recorded in Launch Day Checklist.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	**Checklist Step:** 8.4
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 .	GPS coordinates are written down.	**Inspection:** Verify that the GPS coordinates are recorded in Launch Day Checklist.	**Sub-scale:**Verified **Full-scale:** In Progress	Recovery	**Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	**Checklist Step:** 9.13
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 isn't accidentally disconnected during flight.	Tape is applied to threaded quick-links.	**Inspection:** Verify that the tape is applied during Launch Day checklist.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Full-scale:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	**Checklist Step:** 4.20, 6.12, 6.22, 6.25

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
Design Requirements								
RD.1	Terminal block connections SHALL only be made with commercially available electrical connectors or soldered connections.	JST connectors or soldered connections ensure reliable and secure electrical connections. Secure connections are needed to maintain proper power and current configuration.	**(1)** Electrical connectors and soldered connections are available in the team's avionics bench. **(2)** Terminal block connections are made with commercially available connections or solder.	**(1) Inspection:** Inspect avionics bench for required materials. **(2) Inspection:** Verify connections are made with either commercially available products or solder.	In Progress	Recovery	**(1)** See Table 7.38 for the teams purchase list and the inclusion of JST connectors and solder. **(2)** All recovery avionics assembly is performed by or under the supervision of the Recovery Lead.	Full-scale construction to start in the spring semester.
RD.2	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 damage to the Launch Vehicle and improper deployment of the parachutes which would could result in a complete failure of the recovery system.	Shock cord length allows for at least 10 ft. of distance between sections.	**Inspection:** Verify that the calculated shock cord length between sections is greater than 10 ft.	Verified	Recovery	See Section 3.5.3 for shock cord calculations and length.	Drogue shock cord = 264 in. Main shock cord = 192 in.
RD.3	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 generate a strong anchor point for the recovery system.	Shock cord is attached to "U-bolt" bulkheads.	**Inspection:** Inspect recovery attachment design.	Verified	Recovery	See Section 3.5.2 for parachute attachment design and recovery process.	Also in Launch Day Checklist Section 6.2.
RD.4	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.	Due to the drift distances, shown in Table 3.20, a GPS range of 1.5 miles is required to find the rocket once it lands. Additionally, it helps to verify NASA Requirement 3.11.	**(1)** GPS has a range of 1.5 miles. **(2)** GPS has a battery life greater than 4 hours.	**(1) Test:** Test GPS range and accuracy. **(2) Analysis:** Analyze GPS specifications and power requirements.	In Progress	Recovery	**(1)** See Section 7.1.11 for the planned GPS test. **(2)** See Section 3.5.5 for the GPS specifications.	
RD.5	All recovery harness 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.	Threaded quick-links are used to attach recovery equipment.	**Inspection:** Check Launch Day Checklist and recovery attachment design.	Verified	Recovery	**(1)** See Section 6.2 for Launch Day Checklist. **(2)** See Figures 3.6, 3.10, and **??** for recovery attachment design.	

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
RD.6	The maximum descent velocity of any section of any 2025 NASA SL Launch Vehicle SHALL be less than 110 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 which leads could make the Launch Vehicle violate NASA Requirement 3.3.	**(1)** Parachutes are selected to remain under the maximum descent velocity. **(2)** The Launch Vehicle descent velocity is <110 f/s during Subscale, VDF, and PDF launches.	(1) Analysis: Calculate appropriate parachute size and verify landing velocity. (2) Demonstration: Demonstrate and prove requirement success using data from launches.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**(1) Analysis:** • KE at landing (Table 3.19. • Descent Velocity (Table 3.15. **(2)** The Subscale descent rate was 22.55 fps (See Section 3.3.3).	
Safety Requirements								
RS.1	All black powder SHALL be transported to the launch field in a tightly sealed containers which are placed into 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 due to small static electric currents. To prevent early ejection or explosion of black powder, the powder must be stored in a sealed container located in an explosive containment box. This is for personnel and equipment safety. More information can be found in Section 6.4.	**(1)** Black powder charges are sealed in separate containers. **(2)** Black powder containers are transported in anti-static bags. **(3)** Anti-static bags are transported inside a flame-proof explosive containment box.	**Inspection:** Launch Day Packing List includes black powder in containers and anti-static bags.	**Subscale:** Verified **Full-scale:** In Progress	Safety	**Full-Scale:** See Section 6.2 for the draft Full-Scale Launch Day Packing List.	VDF scheduled for Feb. 22nd.
RS.2	During the event of a CATO of the Launch Vehicle, the designated Safety Officer 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.	Recovery Lead and the designated Safety Officer are the first to approach the rocket during a CATO event.	N/A	N/A	Safety	N/A	The HPRC Safety Handbook includes CATO recovery details (Appendix 8.4).

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
RS.3	The safety officer and/or recovery lead SHALL be the first to approach the rocket and to "touch" the rocket during launch day 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. More information about potential black power hazards can be found in Tables 6.4 and 6.9.	**(1)** The Safety Officer/ Recovery Lead is first to approach the rocket. **(2)** Unblown black powder charges do not cause additional harm to the Launch Vehicle or personnel.	**(1) Inspection:** Launch Day Checklist details recovery procedures including personnel who approach the rocket after landing. **(2) Demonstration:** Personnel are not injured.	**Subscale:** Verified **Full-scale:** In Progress	Recovery, Safety	**Inspection:** See Section 6.2 for the draft Full-scale Launch Day Checklist.	This is also discussed in the safety briefing before each club launch. **Checklist Step:** 9.9
RS.4	All altimeters SHALL be turned off if they are still functioning during CATO event or field recovery.	As stated in RS.2, there may be unexploded black powder still in the Launch Vehicle after a CATO. To reduce the risk off the black powder exploding, altimeters must be disarmed in the same manner that they must be disarmed after any flight.	All altimeters are disarmed after flight and black powder charges are not set off accidentally.	**Inspection:** Launch Day Checklist details recovery procedures including disarming altimeters prior to continuing with recovery checklist. **Inspection:** See HPRC Safety Handbook about safety procedures regarding a CATO (Appendix 8.4).	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Inspection:** See Launch Day Checklist Section 6.2	HPRC Safety Handbook is located in Appendix 8.4.
RS.5	All appropriate procedures to avoid the preemptive 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 the altitude at which parachutes were programmed to be deployed. Mitigation to Hazard TF.6 must then be followed to ensure preemptive ejection of black powder does not injure personnel.	In the event of a CATO, the Launch Vehicle is recovered with no additional damage to the subsystems of the Launch Vehicle and personnel are not injured.	**Inspection:** See HPRC Safety Handbook about safety procedures regarding a CATO (Appendix 8.4).	N/A	Safety	N/A	HPRC Safety Handbook is located in Appendix 8.4.

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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 Table 6.4 ("Hazards Encountered at Launch Sites" Section). 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.	The Launch Vehicle is recovered with no harm to personnel due to launch field conditions.	**Inspection:** Launch Day Checklist Section 6.2 details the required materials for field recovery.	**Subscale:** Verified **Full-scale:** In Progress	Safety	**Inspection:** See Launch Day Checklist Section 6.2	This is also discussed in the safety briefing before each club launch.
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. Safety risks concerning shroud lines can be found in Section 6.4.1.	The Launch Vehicle is recovered during field recovery with no damage to parachutes and no harm to personnel.	**Inspection:** Launch Day Checklist Section 6.2 details the proper procedure for recovery of parachutes during field recovery.	**Subscale:** Verified **Full-scale:** In Progress	Safety	**Inspection:** See Launch Day Checklist Section 6.2	This is also discussed in the safety briefing before each club launch.
RS.8	In the event that black powder charges did not fully ignite during Launch Vehicle recovery, the team SHALL take every precaution to remove the section for the field and transport it back to the team's lab for a controlled dismantle.	If ejection charged did not ignite during flight, there is a change they ignite on the field accidentally. Taking precautions to ensure that ejection charges do not ignite or spill from the AV Bay during/after recovery ensures that black powder does not litter the launch field.	Unblown ejection charges do not ignite after flight/ during recovery resulting in personal injury or launch field contamination.	**Inspection:** Launch Day Checklist Section 6.2 details the proper procedure for recovery of unblown ejection charges.	**Subscale:** Verified **Full-scale:** In Progress	Safety	**Inspection:** See Launch Day Checklist Section 6.2	

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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.	The packing insulation is biodegradable.	**(1) Inspection:** Inspect Launch Day Checklist and budget for biodegradable insulation. **(2) Inspection:** Ensure insulation is biodegradable and used during Launch Day Checklist.	**Subscale:** Verified **Full-scale:** In Progress	Recovery, Safety	**(1)** See Section 6.2 for the Launch Day Checklist. **(2)** See Table 7.38 for the Launch Vehicle budget.	**Checklist Step:** 4.22, 6.28
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 can be collected and properly disposed of after field recovery.	The rubber bands remain attached to the shock cord for the entire duration of the flight.	**(1) Inspection:** Verify Launch Day Checklist includes attaching rubber bands to shock cord. **(2) Inspection:** Verify that the rubber bands are still attached to the shock cord during recovery.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	See Section 6.2 for Launch Day Checklist.	**Checklist Step:** 6.8
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.	All components of the Launch Vehicle remain fully attached upon landing.	**(1) Inspection:** Inspect Launch Vehicle recovery design. **(2) Inspection:** Verify all recovery equipment is attached to the Launch Vehicle during field recovery.	Verified	Recovery	See Section 3.5.1 for the recovery design CONOPs.	See Figure 3.39 for a concept of operations for the recovery system.
RE.4	All recovery personnel SHALL exercise caution during field recovery to avoid damage to crops, vegetation, or sensitive areas by carefully observing their surroundings.	All launch fields utilized during the competition are active farmland. To minimize our team's environmental impact and respect the landowner's property, interactions with the field should be kept to an absolute minimum.	No visible damage to crops, vegetation, or sensitive areas is observed after recovery operations.	**(1) Demonstration:** Personnel successfully demonstrate adherence to protocols by avoiding damage to crops, vegetation, or sensitive areas. **(2) Inspection:** Post-recovery field inspections confirm no visible damage to crops, vegetation, or sensitive areas.	**Subscale:** Verified **Full-scale:** In Progress	Recovery	**Subscale:** Minimal damage to local launch field experienced. All recovery personnel walked in between rows and avoided plant life as much as possible.	

Table 7.35: 2024-2025 Team-Derived Recovery Requirements

Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
RE.5	The number of personnel involved in recovery SHALL be limited to a maximum of 3 individuals, not including subsystem leads, as determined by the recovery operations plan, to minimize environmental and agricultural impacts.	All launch fields utilized during the competition are active farmland. To minimize our team's environmental impact and respect the landowner's property, interactions with the field should be kept to an absolute minimum.	The number of people that recover the Launch Vehicle is limited to the personnel specified in the Launch Day Checklist	**Inspection:** Inspect Section 6.2 of Launch Day Checklist for required personnel	**Subscale:** Verified **Full-scale:** In Progress	Recovery	See Section 9 of the Launch Day Checklist	

Table 7.36: 2024-2025 Team-Derived Payload Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	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 7.4. 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.	**(1)** Test code is developed for payload functions. **(2)** Payload sensors are tested with test code prior to launch day. **(3)** A successful payload sensor test is completed prior to launch day.	**(1) Inspection:** Verify that test code is completed or planned to be completed prior to PDF. **(2) & (3) Demonstration:** Demonstrate successful test code prior to launch day.	In Progress	Payload Team	**(1)** Planned Tests/Test Codes: Payload Data Collection Test (Section 7.2.1) and Payload Flight Simulation Transmission Test (Section 7.2.2). **(2)** See Table 7.45 for the planned PDF launch date and payload development schedule.	Current PDF flight is scheduled on February 22nd, 2025 (along with VDF).
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.	A Payload Lead oversees the assembly and integration of the payload into the Launch Vehicle.	**Inspection:** Verify attendance on Launch Day Checklist.	**Subscale:** Verified **Full-scale:** N/A	Payload Team	**Subscale:** Section 6.2 for the draft Full-scale Launch Day Checklist.	Current PDF flight is scheduled on February 22nd, 2025 (along with VDF).

Table 7.36: 2024-2025 Team-Derived Air Brakes Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
PF.3	During the construction of any version of the competition payload, a member of the payload team 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.	A Payload Lead oversees the construction of the competition payload.	**Inspection:** Payload Leads organize payload meetings where all Payload Leads can attend.	**Subscale:** Verified **Full-scale:** In Progress	Payload Team	See Table 7.41 for payload meeting schedule.	Meetings scheduled and chosen by Payload Leads. Occurs weekly on Thursday's from 12:00 pm - 2:00 pm. Full-scale construction will start on January 9th.
PF.4	During the testing of any version of the competition payload, a member of the payload team SHALL be present.	See Requirement PF.3.	A Payload Lead oversees the testing of the competition payload.	**Inspection:** Payload Leads organize payload meetings where all Payload Leads can attend.	**Subscale:** Verified **Full-scale:** In Progress	Payload Team	See Table 7.41 for payload meeting schedule.	Meetings scheduled and chosen by Payload Leads. Occurs weekly on Thursday's from 12:00 pm - 2:00 pm. Full-scale testing will start January 30th.

Table 7.36: 2024-2025 Team-Derived Air Brakes Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
PF.5	Any soldering of electronics, wires, and sensors SHALL be done only under the supervision of a payload team member.	See Requirement PF.3.	A Payload Lead oversees the soldering of the competition payload.	**Inspection:** Payload Leads organize payload meetings where all Payload Leads can attend.	**Subscale:** Verified **Full-scale:** In Progress	Payload Team	See Table 7.41 for payload meeting schedule.	Meetings scheduled and chosen by Payload Leads. Occurs weekly on Thursday's from 12:00 pm - 2:00 pm. Full-scale construction will start January 9th.
PF.6	Any call-sign used during a flight is 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 call-sign without consent presents legal and moral issues.	**(1)** Payload is designed to accommodate changes in call-signs. **(2)** At least one member of the Payload Team has their own call-sign. **(3)** The owner of the utilized call-sign is present during tests and launch.	**(1) Inspection:** Verify payload design accommodates initialization changes. **(2) Inspection:** Inspect call-sign authorization for each Payload Lead. **(3) Demonstration:** Verify that call-sign attendance is checked in Launch Day Checklist.	**Design:** Verified **Demon-stration:** N/A	Payload Team	**(1)** See Section 4 for final payload design. **(3)** See Section 6.2 for rough draft of Full-scale Launch Day Checklist.	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.	**(1)** The payload housing is made of 3D printed material. **(2)** The 3D printed material has a minimum infill of 25%.	**(1) Inspection:** Confirm the payload housing design is primarily made of 3D printed material. **(2) Inspection:** Check that the 3D printer settings are set to an infill greater than or equal to 25% prior to printing payload housing parts.	**Subscale:** Verified **Full-scale:** In Progress	Payload Structural Integration Lead	See Section 4.2.2 for final Full-scale payload design.	**Full-scale design:** Verified Final components have yet to be 3D printed.

Table 7.36: 2024-2025 Team-Derived Air Brakes Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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.	**(1)** Wire connection methods are stocked and purchased prior to construction. **(2)** Payload electronic connections are secured using at least two methods.	**(1) Inspection:** Inspect budget section for purchased material. **(2) Inspection:** Inspect constructed payload and ensure two method connections.	**(1) In-spection:** Verified **(2) In-spection:** In Progress	Payload Electronics Lead	**(1)** See Table 7.38 for budget and purchased items. **(2)** See Full-scale draft checklist in Section 6.2 for payload assembly.	Construc-tion will begin on January 9th. First scheduled launch is on February 22nd.
PF.9	Payload battery SHALL be able to be active for over 3 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.4, to ensure that payload batteries meet this requirement, they must be able to sustain average payload power draw for 3 hours. Failure of the payload batteries would result in complete payload failure, as the challenge is entirely electronics based.	Payload battery is selected to maintain battery life for 3 hours at a average power draw.	**Analysis:** Analyze selected battery and perform an engineers estimate on battery life.	Verified	Payload Electronics Lead	For payload battery analysis see Section 4.2.1 and Tables 4.3 and 4.4. **(2)** Future payload battery capacity verification test found in Section 7.2.5 .	
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 7.4, replacing electrical components due to water damage is not feasible.	Payload housing can interact with water without much electronic damage.	**Demonstration:** Payload is launched at home field and has minimal electronic damage.	**Subscale:** Verified **Full-scale:** In Progress	Payload Structural Integration Lead	See Section 4.2.2 for final payload capsule design.	No specific water submersion tests planned. Verified based on results at home launch field. Will not launch in rain or extremely wet conditions.

Table 7.36: 2024-2025 Team-Derived Air Brakes Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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 PF.6. Therefore, call-signs cannot be hardcoded into the payload code.	**(1)** Call-sign is not hardcoded in payload software. **(2)** Call-sign can be changed on launch day.	**(1) Inspection:** Inspect payload software design and confirm that the call-sign is not hardcoded. **(2) Inspection:** Inspect payload software design and confirm that the call-sign can be changed.	**Design:** Verified	Payload Software Lead	See Section 4.2.3 for payload software design.	Software code currently in construction. Finalized code and hardware expected February 13th.
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.	Payload housing and electronics sled is primarily made of 3D printed material.	**Inspection:** Inspect payload design and material and confirm that it is will be primarily 3D printed.	Verified	Payload Structural Integration Lead	See Section 4.2.2 for payload capsule design. See Section 4.2.1 for electronic sled design and material list.	The payload sled used on the Subscale launch was fully 3D printed.
PD.4	Payload SHALL fit into the Nose Cone for both Subscale and Full-scale designs.	The Payload Team has selected a large antenna, detailed Figure 4.17c. 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.	Payload design fits into nose-cone of Launch Vehicle.	**(1) Measurement:** Measure the available space in the nose-cone and compare to payload design. **(2) Inspection:** Verify that the payload design fits in the nose-cone with acceptable tolerances.	**Design:** Verified	Payload Structural Integration Lead	**(1)** See Figure 3.3 for Nose Cone dimensions. See Figure 4.17c for payload height. **(2)** See Figure 4.24 for the exploded view of the Full-scale payload configuration. See Figure 4.25a for a proportioned image of the payload fitting inside the Nose Cone.	Full-scale and Subscale payload designs fit in CAD model of Launch Vehicle.

Table 7.36: 2024-2025 Team-Derived Air Brakes Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	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.	All data types offered are collected by the combination of payload sensors during flight.	**Demonstration:** Verify that the payload collects all possible data types, with some redundancy, after the demonstration flight.	**Test:** In Progress	Payload Electronics Lead	**(1)** Planned PDF flight is scheduled for February 22nd (Table 7.45). **(2)** See Section 4.2.1 for a list of utilized sensors and electronic schematic diagrams.	Sensor set-up schematic can be found in Figure 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 points to provide a fail safe. Additionally, two sensors increases the accuracy and reliability of the data.	**(1)** Payload electronics are designed to have redundancy. **(2)** Payload electronics collect data throughout the entirety of flight.	**(1) Inspection:** Inspect the payload sensor design to verify redundancy. **(2) Demonstration:** Confirm all desired data points are collected after flight.	**Design:** Verified **Test:** In Progress	Payload Electronics Lead	**(1)** See Section 4.2.1 for planned payload sensor redundancy **(2)** Payload flight demonstration test scheduled for February 22nd (Table 7.45).	Sensor set-up schematic can be found in Figure 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.	**(1)** Payload electronics are not affected by transmission signals throughout and after flight. **(2)** Payload electronic sleds electronics from transmission signal.	**(1) Demonstration:** Confirm payload electronics operate as expected after flight. **(2) Inspection:** Inspect the payload sled to confirm the use of shielding.	**Design:** Verified **Test:** In Progress	Payload Team	**(1)** Payload flight demonstration test scheduled for February 22nd (Table 7.45). Details on the planned payload transmission test occurs together and separately (Section 7.2.2. **(2)** See Section 4.4 for payload electronics shielding methods.	Successful on Subscale flight, Full-scale testing will start on January 30th.

Table 7.36: 2024-2025 Team-Derived Air Brakes Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
PD.8	The input power to all payload electronics SHALL not exceed 5V.	The selected electronics, detailed in Section 4.2.1, have fixed operating ranges. None of the selected component requirements exceed 5V.	The input power to all payload electronics allows them to work properly and collect data as designed.	**Demonstration:** Confirm the continuous operation of all payload electronics after flight .	**Design:** Verified **Test:** In Progress	Payload Electronics Lead	**(1)** See Section 4.2.1 for details regarding the input power of all payload electronics. **(2)** See Table 7.45 for planned Payload Demonstration Flight.	A voltage regulator is used to control input power.
PD.9	All sensors SHALL be capable of operating in 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 selected data points.	All payload sensors record data throughout the entirety of the Launch Vehicle flight.	**Demonstration:** Analyze all sensor data after flight to verify continuous operation.	**Design:** Verified **Test:** In Progress	Payload Electronics Lead	**(1)** See Section 4.2.1 for details on the operating ranges of all payload sensors. **(2)** Payload flight demonstration test scheduled for February 22nd (Table 7.45).	
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 4.3.1.	Pressure sensors record data within an accuracy of +/-200 Pa	Demonstration: Analyze the pressure data after flight to ensure accurate data collection.	**Design:** Verified **Test:** In Progress	Payload Electronics Lead	**(1)** See Section 4.2.1 for details on the accuracy of onboard pressure sensors. **(2)** Payload flight demonstration test scheduled for February 22nd (Table 7.45).	Pressure sensors have been chosen to meet this requirement.
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 4.2.1.	Temperature sensors record data within an accuracy of +/-2C.	**Demonstration:** Analyze the temperature data after flight to ensure accurate data collection.	**Design:** Verified **Test:** In Progress	Payload Electronics Lead	**(1)** See Section 4.2.1 for details on the accuracy of onboard temperature sensors. **(2)** Payload flight demonstration test scheduled for February 22nd (Table 7.45).	Temperature sensors have been chosen to meet this requirement.

Table 7.36: 2024-2025 Team-Derived Air Brakes Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
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.	**(1)** The IMU remains fully operational throughout the Launch Vehicle's flight. **(2)** The IMU collects accurate data throughout the Launch Vehicle flight	**Demonstration:** Analyze the IMU data after flight to ensure accurate data collection and verify continuous operation.	**Design:** Verified **Test:** In Progress	Payload Electronics Lead	**(1)** See Section 5.2.1 for details on the IMU configuration. **(2)** Payload flight demonstration test scheduled for February 22nd (Table 7.45).	Preliminary IMU testing has been successful.
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.	**(1)** Payload successfully transmits flight data at any location. **(2)** Payload is able to transmit flight data in any landing orientation.	**Test:** Test payload transmission at distances up to the maximum drift condition and at varying orientations.	**Design:** Verified **Test:** In progress	Payload Electronics Lead, Payload Software Lead	**(1)** See Sections 4.1 and 4.2 for final payload transmission design. **(2)** See the test procedures in Sections 7.2.2 and 7.2.4 for the planned payload transmission tests.	Initial trans-mission tests have to been conducted.
PD.14	Payload SHALL have a maximum weight of 5.5 lbs.	The payload is located in the Nose Cone of the Launch Vehicle. Due to Team Derived Requirement LVD.10, the stability of the Launch Vehicle must not exceed 2.9, which results from a maximum payload weight of 5.5 lbs.	The payload weights less than 5.5 lbs.	**(1) Design:** Design the payload structure and electronics such that the system weighs less than 5.5 lbs. **(2) Measurement:** Weigh the payload throughout construction and prior to launch.	**Design:** Verified **Construc-tion:** In Progress	Payload Structural Integration Lead	The final designed payload has an estimated weight of 2.2466 lbs. (Table 4.5).	The payload will be weighted with each additional contribution prior to integration into the Launch Vehicle.

Table 7.37: 2024-2025 Team-Derived Air Brakes Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
Functional Requirements								
ABF. 1	The Air Brakes fins shall be able to withstand 1.5 times the force of drag during deployment.	A safety factor of 1.5 is common in the aerospace industry and necessary to ensure safe deployment of a designed system.	Air Brake fins are tested to withstand 1.5 times the approximated value of drag.	**(1) Analysis:** Simulations and previous flight data is used to determine an approximate value of drag for this rocket configuration and motor selection. **(2) Test:** A loading test is performed with 1.5 times the estimated drag as the primary load factor.	In Progress	Payload Team	**(1) Analysis:** See Section 3.6.7 and Figure 3.52 for current Full-scale drag analysis. **(2) Test - Planned Air Brake VV&T:** Deployment Test, Flight Simulation Test, and Effectiveness Flight Test (Section 7.2).	
ABF. 2	All Air Brakes fins SHALL all deploy at the same time	To ensure the Launch Vehicle maintains a vertical trajectory and is not destabilized during flight. Asymmetric deployment of the Air Brakes can create unbalanced aerodynamic forces, that could endanger the vehicle's flight stability.	**(1)** All Air Brakes fins deploy at the same time. **(2)** Internal gears do not slip or break during deployment.	**(1) Demonstration:** Analyze post launch data to ensure the Launch Vehicle remained stable throughout flight. **(2) Demonstration:** Inspect the gearing system post launch to verify no gears are broken or misaligned.	**Subscale:** Verified **Full-scale:** In Progress	Payload Team	**(1) & (2) Demonstration:** Payload flight demonstration test scheduled for February 22nd (Table 7.45).	Additional Air Brakes deployment flight to occur on January 25th and during the Air Brakes Effective-ness Flight Test.
ABF. 3	The Air Brakes module SHALL be fixed to the airframe	Securing the Air Brakes module to the airframe ensures that the module does not shift during operation. Thus preventing the misalignment that could result in the fins rubbing against the airframe, preventing deployment, and stalling the servo.	**(1)** Air Brakes module is secured to the airframe by >1 connection point. **(2)** Air Brakes module remains in the same position for the duration of the launch.	**(1) Inspection:** Verify the design of the Air Brakes module has more than one connection point ot the airframe. **(2) Demonstration:** Verify proper deployment of the Air Brake fins and confirm that the Air Brake module did not shift during flight.	**Design:** Verified **Demon-stration:** In Progress	Payload Team	**(1) Inspection:** The Air Brakes include four nut slots to mount directly to switchband (Section 5.2.2). **(2) Demonstration:** VDF and PDF flights planned for February 22nd.	Awaiting Full-scale construction and demon-stration flight.

Table 7.37: 2024-2025 Team-Derived Air Brakes Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
ABF. 4	The Apogee Prediction algorithm SHALL have an accuracy of 4%	A 4% accuracy ensures the Apogee Preduction algorithm is working correclty to predict and adjust the apogee of the Launch Vehicle throughout flight.	The Apogee Prediction algorithm leads the Launch Vehicle to reach an apogee within 4% of the predicted apogee prior to flight.	**Demonstration:** Air Brakes are flown on the Subscale/ fullscale and the Apogee Prediction algorithm predicts the apogee withing a 4% accuracy.	**Design:** In Progress **Demon-stration:** In Progress	Payload Team	The Launch Vehicle reaches an apogee within 4% of the predicted apogee.	
ABF. 5	The Air Brakes fin deployment SHALL be tested prior to flight and after integration into the AVAB Bay on launch day	Testing the fin deployment ensures proper functionality and alignment of the Air Brakes system after integration into the AVAB Bay. It mitigates the risk of deployment failure due to assembly errors.	**(1)** Air Brake module is integrated into AVAB Bay and tested prior to launch day. **(2)** Air Brake fin deployment is tested inside of AVAB Bay prior to launch.	**(1) Inspection:** Verify that the Air Brake fin slots align with the slots in the AVAB Bay. **(2) Demonstration:** During Launch Day Checklist, Air Brakes are tested and they fully deploy with no interference from the fin slots or airframe.	In Progress	Payload Team	**Demonstration:** See Launch Day Checklist Section 6.2 for deployment test prior to flight.	**Checklist Steps:** 1.59 - 1.61 Awaiting Full-scale demonstra-tion flight.
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.	Air Brakes located aft of motor burnout CG.	**(1) Measurement:** Measure location of Air Brake fin slots and burnout CG location. **(2) Inspection:** Verify Air Brakes are located in the aft end of the AVAB design.	**Subscale:** Verified **Full-Scale:** Verified	Aerodynam-ics, Payload Team	**Subscale:** Burnout CG Verification can be seen in Figure 3.28. **Full-scale:** See Table 3.16 for Full-scale Air Brakes location compared to burnout CG.	**Subscale:** Complete **Full-Scale:** Finalized Design
ABD.2	The Air Brakes SHALL consist of four identical fins, equally spaced radially around the body of the rocket.	Four fins increases the aerodynamic drag of the entire rocket.	**(1)** Fins are symmetric. **(2)** Fins are evenly spaced around body tube.	**(1) Inspection:** Verify symmetric design. **(2) Inspection:** Verify fins are evenly spaced in Air Brake design.	**Subscale:** Verified **Full-Scale:** Verified	Payload Team	**Subscale:** Fin design remained the same as Full-scale. **Full-scale:** See Figure 5.8 for Full-scale Air Brakes fin design.	Awaiting Full-scale construc-tion.

Table 7.37: 2024-2025 Team-Derived Air Brakes Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results	Comments
ABD.3	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.	Air Brakes located in AVAB.	**Inspection:** Inspect AVAB design and confirm inclusion of Air Brakes.	**Subscale:** Verified **Full-Scale:** Verified	Payload Team, Recovery	**Full-scale:** See Section 5.2 for Full-scale Air Brakes design. See Section 3.2.6 and 3.2 for AVAB layout and structure.	Awaiting Full-scale construc-tion. Begins on January 9th.
ABD.4	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.	**(1)** At least two batteries are included in Air Brakes design. **(2)** Two separate power circuits are included in CDR documentation.	**(1) Inspection:** Verify required materials for Air Brakes design. **(2) Inspection:** Confirm two different power circuit designs are included in documentation.	**Design:** Verified	Payload Team	**(1) Inspection:** See Section 5.2.1 for selected batteries. **(2) Inspection:** See Figure 5.6 for the two power circuit designs.	Awaiting Full-scale construc-tion. Begins on January 9th.
ABD.5	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.	Two pull-pin switches are included in Air Brakes design.	**Inspection:** Confirm two pull-pin switches are included in Air Brakes design in CDR documentation.	**Design:** Verified	Payload Team	See Figure 5.6 for the Air Brakes electronic schematic.	Awaiting Full-scale construc-tion. Begins on January 9th.
ABD.6	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.	**(1)** Air Brakes software is a state-based model. **(2)** Multiple states are included in software (Standby, Motor burn, Coast, etc.)	**(1) Inspection:** Confirm Air Brakes software discussed in CDR documentation is a state-based model. **(2) Review:** Review discussion of software "states" in CDR documentation.	**Design:** Verified	Payload Team	**(1) Inspection:** See Section 5.2.3 for Air Brakes software. **(2) Review:** See Figure 5.11 for the diagram of the finite state machine (the discussed state's of the Air Brake software).	Software complete.

7.4 Budget

Table 7.38 details the year-long budget plan for the 2024 - 2025 competition year. The table is organized in columns of Item, Vendor, Quantity, Price Per Unit, and Total Item Price. The sum of all prices is highlighted in light gray at the end of each section. At the end of the budget section and highlighted in dark gray are 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, the items may change slightly as the design for our rocket is finalized. This could lead to changes in the items needed, the vendors used, and the total amount spent throughout the year.

Table 7.38: 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
	DS2685BLDP Servo Arm	ProModeler	1	$ 229.99	$ 229.99
	PLA Filament	AMOLEN	4	$ 14.99	$ 59.96
	PETG Filament	AMOLEN	4	$ 16.99	$ 67.96
	Payload Structural Materials	Etc	2	$ 70.01	$ 70.01
	Nuts, Screws, Eyebolts	McMaster-Carr	1	$ 12.71	$ 7.08
	Soldering Station	Pine Store	1	$ 165.00	$ 165.00
				Subtotal:	**$ 878.71**

Table 7.38: 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**

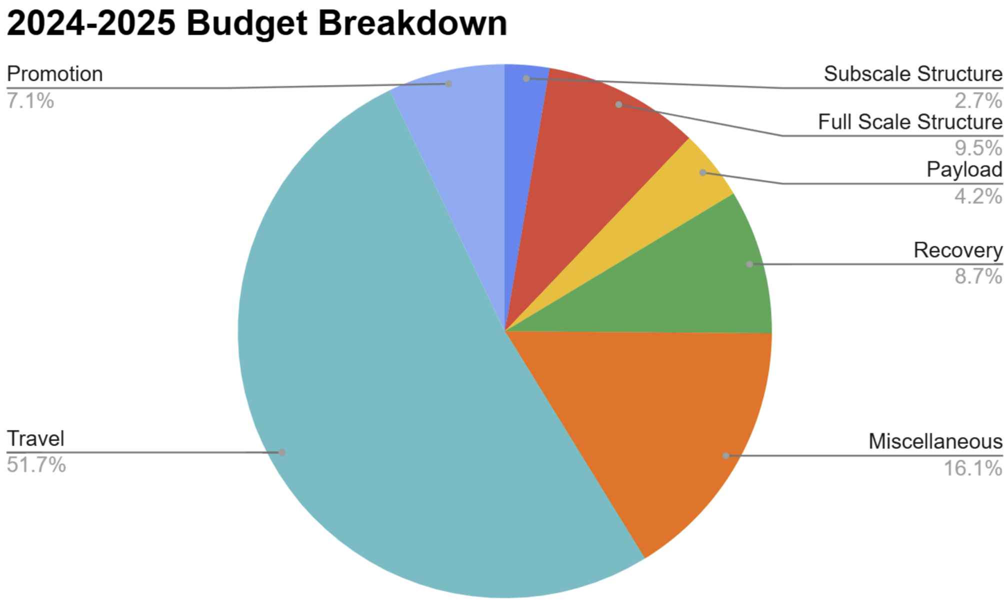


Figure 7.1: 2024-2025 Budget Breakdown.

7.4.1 Funding Plan

HPRC is supported by various funding sources from NC State University and the North Carolina Space Grant (NCSG). The following sections provides a detailed overview of each funding source and the specific allocations from each.

The NC State Student Government Association (SGA) allocates funds to over 600 campus clubs and organizations, including HPRC. At the beginning of each semester, clubs submit applications detailing their expected expenses. After submission, the clubs participate in a brief 15-minute interview with SGA representatives to discuss their activities, clarify budget specifics, and explain the value they provided to the university. Following this, the SGA allocates funds to each organization. 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 the current academic year, we requested $1,800 for the fall semester and $1,800 for the spring semester. Despite this request, the club is expected to receive the same $796 per semester as in previous years. In the fall, the student government funds are typically used primarily for the Subscale rocket, leaving little for backup parts or Full-scale materials. In the spring, SGA funds will be used for any necessary items, as long as all expenses are tracked with receipts.

NC State's College of Engineering Enhancement Funds, provided through the "Engineer Your Experience" (EYE) department, support extracurricular activities, particularly those related to travel. EYE will fully cover student travel costs to Huntsville. Based on the previous years' expenses for this trip, it is estimated that HPRC will receive around $8,000 for travel expenses this year.

The Educational and Technology Fee (ETF) is an NC State fund allocated for academic enhancement through student organizations. For the 2023-2024 academic year, HPRC received $2,500 from ETF, and the same amount is expected for this year. This funding is specifically designated for the travel and hotel expenses of the team's faculty advisors for the Huntsville trip.

In addition to funding from various NC State University sources, the North Carolina Space Grant (NCSG) is a significant contributor to HPRC's funding. The NCSG accepts funding proposals in the fall semester, with teams able to request up to $5,000 for participation in NASA competitions. After reviewing the submitted proposals, they notify the club of the awarded amount. In previous years, we received the maximum amount of $5,000, which will be available starting in November 2024. We are expected to receive the full $5,000 again this year, as in previous years. Requesting club items through Space Grant can be done in one of two ways. The first method involves using the MAE request form, where items are submitted for approval by the club advisor. Once approved, the items are ordered directly from the vendor. The second method is through the NC State Marketplace, which allows items to be ordered from a list of approved vendors using Space Grant funds, directly from the vendors' websites. Marketplace access is restricted to graduate students, so the treasurer typically collaborates with a graduate student in the club to place orders using their Marketplace access. While Marketplace is generally preferred due to its faster processing, it is limited by both its vendor selection and access restrictions for graduate students. As a result, both the Marketplace and MAE Purchase Request forms are used to order club items.

Regarding sponsorships, HPRC has previously been supported by companies such as Collins Aerospace, Jolly Logic, Fruity Chutes, and others. The club is actively seeking new sponsorships and re-engaging with past sponsors. We have observed that companies are more likely to offer in-kind donations rather than provide monetary sponsorship. The team anticipates receiving $3,200 inkind gifts this academic year, with the possibility of this amount increasing if we receive additional responses from other companies regarding gifts or sponsorships.

A summary of all these totals is provided in Table 7.39 below, which outlines the projected costs and incoming revenue for the 2024-2025 academic year.

Table 7.39: 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**

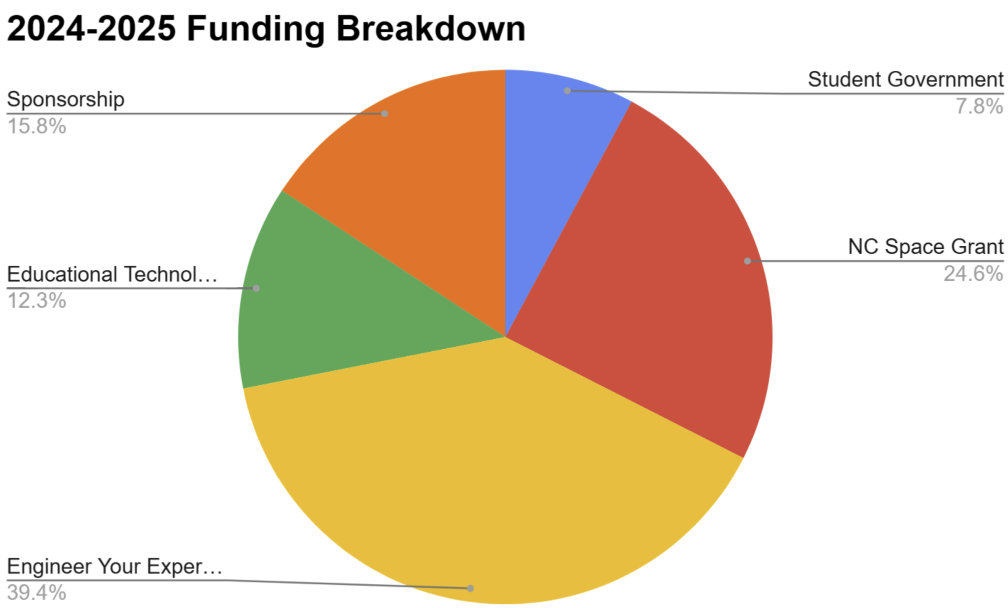


Figure 7.2: 2024-2025 Funding Breakdown.

NC STATE UNIVERSITY

7.5 Project Timelines

7.5.1 Competition Deliverables

Table 7.40: 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 23, 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

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2024-25 Student Launch Competition Gantt Chart

Task Name	Task Number	Start Week	End Week
RFP Released	1	W01	W01
Proposal	2	W02	W05
Awarded Proposals Announced	3	W08	W08
PDR Q&A	4	W09	W09
PDR	5	W06	W12
PDR Presentation	6	W13	W13
Gateway Registration	7	W09	W16
CDR Q&A	8	W17	W17
Huntsville Roster	9	W17	W19
CDR	10	W13	W22
CDR Presentation	11	W24	W24
Team Photos	12	W25	W27
FRR Q&A	13	W27	W27
FRR	14	W23	W32
FRR Presentation Window	15	W33	W35
FRR Addendum	16	W34	W36
Launch Week Q&A	17	W36	W36
Huntsville Launch Week	18	W38	W39
Competition Launch	19	W39	W39
PLAR	20	W40	W41

Figure 7.3: SL Competition Gantt chart.

7.5.2 Competition Development Timelines

Table 7.41 outlines the club weekly meeting schedule. Launch day activities occur on Saturdays and Sundays, depending on launch field availability and weather conditions. Dry run, ejection testing, and packing typically occur the Friday before launch to ensure everything is ready for launch day. Vehicle meetings are joint meetings between the structures, recovery, and aerodynamics subsystems to work on developing the Launch Vehicle and recovery system for the 2025 NASA Student Launch Competition. Payload meetings are joint meetings between all off the payload subsystem leads and Air Brakes personnel to work on developing both the competition and experimental payload. Integration meetings are joint meetings between the vehicle and payload subsystems to discuss measurements, changes to design, and development updates. These meetings ensure that the vehicle and payload subsystems work together and are using the same measurements. General body meetings are led by the team lead, and are used to provide updates from all subsystems to the club, along with providing club members necessary information about the competition. Officer meetings are led by the president and are used for club organization and management.

Table 7.41: Weekly Club Schedule

Sunday	7:00 am - 7:00 pm: Launch Day Activities
Monday	3:00 - 4:00 pm: Wolfworks Experimental Meeting 4:30 - 5:30 pm: Vehicle Meeting
Tuesday	3:00 - 4:00 pm: Wolfworks Experimental Meeting
Wednesday	4:30 - 5:30 pm: Vehicle Meeting
Thursday	12:00 - 2:00 pm: Payload Meeting 4:30 - 7:15 pm: Integration Meeting 7:30 - 8:30 pm: General Body Meeting
Friday	9:00 - 10:00 pm: Wolfworks Experimental Meeting 12:00 - 8:00 pm: Launch Day Packing
Saturday	7:00 am - 7:00 pm: Launch Day Activities

TACHO LYCOS

2024-25 Student Launch Competition Development Gantt Chart

				Aug			Sep				Oct				Nov					Dec				Jan
Task Name	Task Number	Start Week	End Week	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21
Brainstorming	1	W01	W05	1	1	1	1	1																
Vehicle Design	2	W04	W06				2	2	2															
Payload Design	3	W05	W14					3	3	3	3	3	3	3	3	3	3							
Subscale Parts Ordering	4	W06	W07						4	4														
Subscale Manufacturing	5	W08	W12								5	5	5	5	5									
Subscale Component Testing	6	W08	W12								6	6	6	6	6									
Subscale Ejection Testing	7	W10	W10										7											
Subscale Painting	8	W11	W11											8										
Subscale Launch	9	W12	W12												9									
Full-scale Parts Ordering	10	W14	W21														10	10	10	10	10	10	10	10
Payload Parts Ordering	11	W15	W21															11	11	11	11	11	11	11
Full-scale Manufacturing	12	W22	W24																					
Payload Manufacturing	13	W12	W24												13	13	13	13	13	13	13	13	13	13
Full-scale Component Testing	14	W25	W26																					
Recovery System Testing	15	W26	W28																					
Payload Testing	16	W25	W27																					
Full-scale Painting	17	W28	W30																					
VDF Launch	18	W28	W28																					
PDF Launch	19	W28	W28																					
Competition Launch	20	W38	W39																					

					Feb				Mar				Apr					May		
Task Name	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36	W37	W38	W39	W40	W41
Brainstorming																				
Vehicle Design																				
Payload Design																				
Subscale Parts Ordering																				
Subscale Manufacturing																				
Subscale Component Testing																				
Subscale Ejection Testing																				
Subscale Painting																				
Subscale Launch																				
Full-scale Parts Ordering																				
Payload Parts Ordering																				
Full-scale Manufacturing	12	12	12																	
Payload Manufacturing	13	13	13																	
Full-scale Component Testing				14	14															
Recovery System Testing					15	15	15													
Payload Testing				16	16	16														
Full-scale Painting							17	17	17											
VDF Launch							18													
PDF Launch							19													
Competition Launch																	20	20		

Figure 7.4: SL Development Gantt chart.

Competition Development PERT Charts

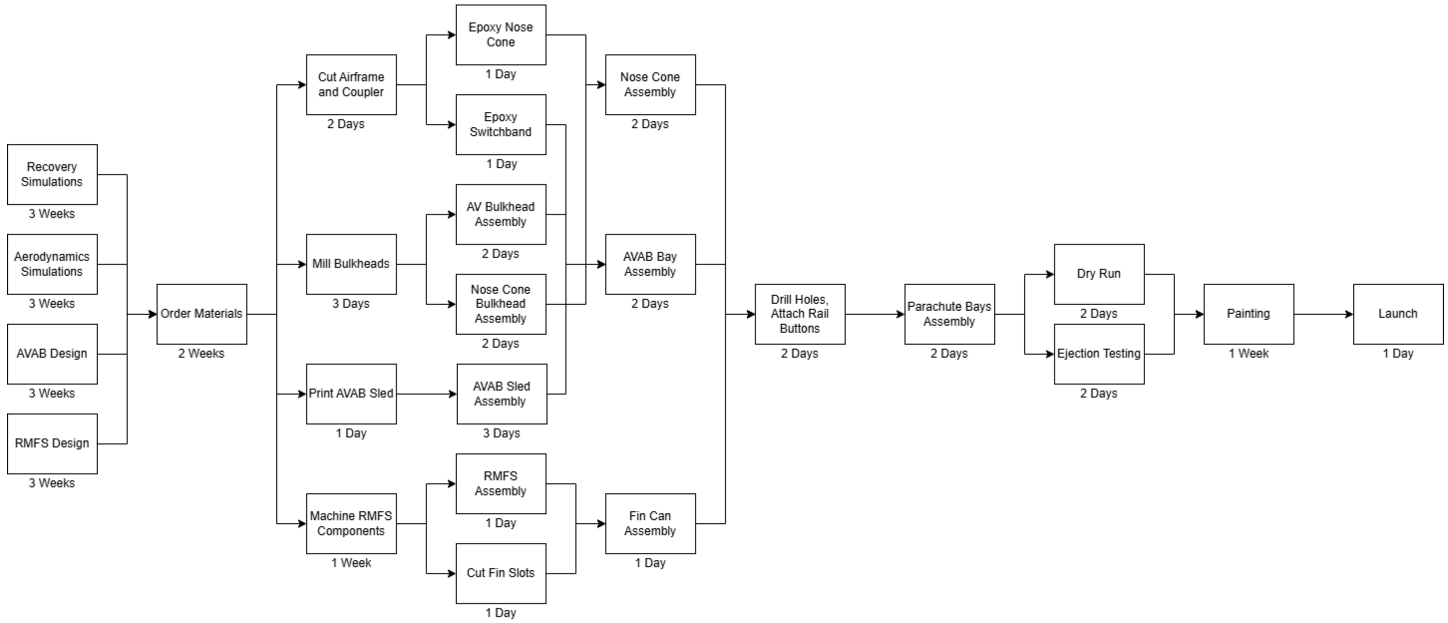

Figure 7.5: Full-scale Launch Vehicle PERT chart.

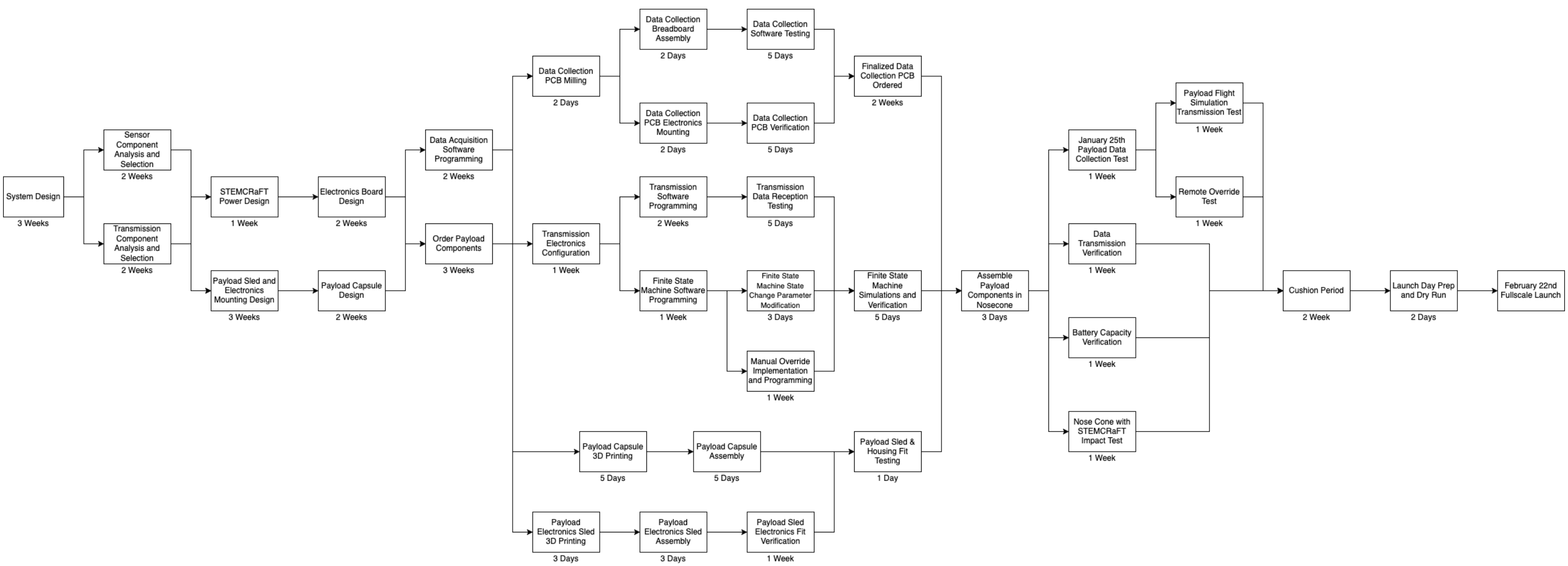

Figure 7.6: Payload PERT chart.

Structures Timeline

Table 7.42: 2024-2025 Structures Timeline

January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 • CDR soft deadline	2	3	4
5	6 • First day of class • Mill bulkheads • Clean airframe tubing • Cut threaded rods • Rough cut L-brackets • Print charge wells • Motor retainer and thrust plate waterjet requests • Test cut scrap tubing	7 • Machine RMFS fin runners • Machine L-brackets • 3D print marking guides	8 • CDR due • Epoxy AVAB switchband • Cut and shape fins • Drill bulkhead holes • Assemble bulkhead hardware • Machine RMFS Fin runners • Machine L-brackets	9 • Machine RMFS fin runners • 3D print marking guides	10	11
12	13 • Cut airframe • Drill airframe holes • Epoxy Nose Cone coupler & permanent bulkhead	14 • Air Brakes cutting jig • Machine thrust plate	15 • Drill airframe holes • Drill fin holes	16 • Cut Air Brakes slots • Machine thrust plate	17	18
19	20 • MLK Day	21	22 • Ballast system pouring	23	24	25
26	27 • Ballast system cutting	28 • AVAB/ Nose Cone bulkheads tensile testing	29 • Full-scale first assembly	30	31	

February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3 • Fin can drop testing	4 • Rivet/ shear pin shear testing	5	6	7	8
9	10 • Ejection testing	11 • No class	12 • Dry run	13	14	15
16	17 • Dry run	18	19 • Dry run	20	21	22 • VDF/PDF flight
23	24 • Post launch cleaning • Vehicle flight performance review • Painting • FRR writing	25 • Painting	26 • Painting • FRR writing	27 • Painting	28	

Table 7.42: 2024-2025 Structures Timeline

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			March			
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3 • Painting • FRR writing	4 • Painting	5 • Painting • FRR writing	6 • Painting	7	8 • Backup VDF/PDF flight
9	10 • Spring break	11 • Spring break	12 • Spring break	13 • Spring break	14 • Spring break	15
16	17 • FRR due • VDF Deadline • Painting	18 • Painting	19 • Painting • FRR presentation prep	20 • Painting	21	22
23	24 • FRR presentation prep	25	26 • FRR presentation prep	27	28	29
30	31					
			April			
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
6	7	8	9	10	11	12
13	14 • PDF deadline	15	16 • Huntsville dry run • Huntsville ejection testing	17	18	19
20	21	22 • Last day of class	23	24 • Finals	25 • Finals	26
27	28 • Finals	29 • Finals	30 • Finals • Huntsville			
			May			
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1 • Huntsville • Graduation	2 • Huntsville	3 • Launch day
4 • Huntsville	5	6	7	8	9	10
11	12 • PLAR writing	13	14 • PLAR review	15	16	17 • PLAR due
18	19	20	21	22	23	24
25	26	27	28	29	30	31

Recovery Timeline

Table 7.43: 2024-2025 Recovery Timeline

January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 • CDR soft deadline	2	3	4
5	6 • First day of class • CDR review	7 • CDR review	8 • CDR due	9	10	11
12	13 • CDR presentation preparation • Altimeter testing	14	15 • CDR presentation preparation • Parachute deployment testing	16	17	18
19	20 • MLK Day	21	22 • CDR presentation preparation	23	24	25
26	27 • GPS testing • Air Brakes code	28	29 • 3D print AV sled • Air Brakes code	30	31	
February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3 • AV sled assembly	4	5 • AV sled assembly • LiPo Testing	6	7	8
9	10 • AV sled AVAB integration • Air Brakes code • Full-scale ejection testing	11 • No class	12 • Air Brakes code • Full-scale dry run	13	14	15
16	17 • Air Brakes code • Test Batteries	18	19 • Air Brakes code	20	21	22 • VDF/PDF flight
23	24 • VDF flight analysis • Air Brakes code	25	26 • FRR writing • Payload support	27	28	
March						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3 • FRR writing • Payload support • Test Batteries	4	5 • FRR writing • Payload support	6	7	8 • Backup VDF/PDF flight
9	10 • Spring break	11 • Spring break	12 • Spring break	13 • Spring break	14 • Spring break	15

Table 7.43: 2024-2025 Recovery Timeline

16	17 • FRR due • FRR review	18	19 • Payload support • FRR presentation prep	20	21	22
23	24 • Payload support • FRR presentation prep	25	26 • Payload support • FRR presentation prep	27	28	29
30	31 • Payload support • FRR presentation prep					
April						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2 • Payload support • FRR presentation prep	3	4	5
6	7 • Payload support • FRR presentation prep	8	9 • Payload support • FRR presentation prep	10	11	12
13	14 • FRR addendum due	15	16 • Huntsville dry run • Huntsville ejection testing	17 • Launch Week Q&A	18	19
20	21	22 • Last day of class	23	24 • Finals	25 • Finals	26
27	28 • Finals • Test Batteries	29 • Finals	30 • Finals • Huntsville			
May						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1 • Huntsville • Graduation	2 • Huntsville	3 • Launch day
4 • Huntsville	5 • PLAR writing • Recovery handover	6	7 • PLAR writing • Recovery handover	8	9	10
11	12 • PLAR writing • Recovery handover	13	14 • PLAR writing • Recovery handover	15	16	17
18	19 • PLAR deadline	20	21	22	23	24
25	26	27	28	29	30	31

Aerodynamics Timeline

Table 7.44: 2024-2025 Aerodynamics Timeline

January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 • CDR soft deadline	2	3	4
5	6 • First day of class • CDR review	7	8 • CDR due	9	10	11
12	13 • CDR presentation prep • VV&T stand design	14	15 • CDR presentation prep • VV&T stand design	16	17	18
19	20 • MLK Day	21	22 • CDR presentation prep • Order parts for test stand	23	24	25
26	27 • Air Brakes code	28	29 • Air Brakes code	30	31	

February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3 • Air Brakes code • Build test stand	4	5 • Air Brakes code	6	7	8
9	10 • Air Brakes code • VV&T test	11 • No class	12 • Air Brakes code • VV&T test	13	14	15
16	17 • FRR writing • Air Brakes code • VDF flight predictions	18	19 • FRR writing • Air Brakes code	20	21	22 • VDF/PDF flight
23	24 • FRR writing • Air Brakes code • Analyze VDF	25	26 • FRR writing • Air Brakes code	27	28	

March						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3 • FRR writing	4	5 • FRR writing	6	7	8 • Backup VDF/PDF flight
9	10 • Spring break	11 • Spring break	12 • Spring break	13 • Spring break	14 • Spring break	15
16	17 • FRR due	18	19 • FRR presentation prep	20	21	22

Table 7.44: 2024-2025 Aerodynamics Timeline

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

Payload Timeline

Table 7.45: 2024-2025 Payload Timeline

January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1	2	3	4
5	6 • First day of class	7	8 • CDR Presentation • CDR Flysheet	9 • Discuss design plans/ updates	10 • Begin construction • Design remaining hardware components • Order required hardware	11
12	13		15	16 • Mill PCB • Order finalized designs • 3D print printed components	17	18
19	20	21	22	23 • Software • Configure transceiver • Select preliminary state transition requirements • Assemble payload hardware	24	25 • Payload data collection test
26	27	28	29	30 • First draft of payload • Battery capacity verification test	31 • Sensory accuracy testing • Air Brakes flight simulation testing	

February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6 • Nose Cone impact testing	7 • Transceiver functionality testing	8
9	10	11	12	13 • Finalized code and hardware • Air Brakes Deployment Test	14 • State machine • Launch day viability testing	15
16	17	18	19	20 • Dry run	21	22 • VDF/PDF flight
23	24	25	26	27 • FRR writing	28	

March						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6 • FRR writing	7	8 • Backup VDF/PDF flight

Table 7.45: 2024-2025 Payload Timeline

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

Project Management Timeline

Table 7.46: 2024-2025 Project Management Timeline

January						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 • CDR soft deadline	2	3	4
5	6 • First day of class	7	8 • CDR due • Subsclae flight due	9 • Set up FRR document	10	11
12	13	14	15	16	17	18
19	20 • MLK Day	21	22	23 • CDR presentation	24	25
26	27	28	29	30 • Determine date of team photos	31	

February						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5 • Write checklist	6 • Write checklist	7 • Write checklist	8 • Write checklist
9	10 • Team photos due • Write checklist	11 • No class • FRR Q&A • Write checklist	12 • Finalize checklist	13	14 • Full-scale dry run • Full-scale ejection testing	15
16	17	18	19	20	21 • Full-scale packing	22 • VDF/ PDF flight
23	24	25	26	27	28	

March						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7 • Backup packing	8 • Backup VDF/ PDF flight
9	10 • FRR soft deadline • Spring Break	11 • Spring Break	12 • Spring Break	13 • Spring Break	14 • Spring Break	15
16	17 • FRR due • VDF due	18 • Set up FRR addendum document	19	20	21	22
23	24	25	26	27	28 • Backup packing	29 • Backup PDF flight • Backup VDF reflight

Table 7.46: 2024-2025 Project Management Timeline

30	31					
April						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
6	7	8	9 • FRR addendum soft deadline	10	11	12
13	14 • FRR addendum due • PDF due • VDF reflight due	15 • Set up PLAR document	16 • Huntsville dry run • Huntsville ejection testing	17 • Launch week Q&A	18 • Huntsville ejection testing • Huntsville dry run	19
20	21	22 • Last day of class	23	24 • Finals	25 • Finals	26
27	28 • Finals • Huntsville packing	29 • Finals • Huntsville packing	30 • Finals • Travel to Huntsville			
May						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1 • Huntsville activities • Senior graduation • Seniors travel to Huntsville	2 • Huntsville activities	3 • Launch Day
4 • Backup Launch Day • Travel from Huntsville	5	6	7	8	9	10
11	12	13	14	15 • PLAR soft deadline	16	17
18	19 • PLAR due	20	21	22	23	24
25	26	27	28	29	30	31

7.5.3 Verification Testing Timeline

2024-25 Verification Testing Gantt Chart

TACHO LYCOS

Task Name	Task Number	Start Week	End Week	Nov					Dec				Jan					Feb			
				W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29
Subscale Ejection Test	1	W14	W14			1															
Subscale Dry Run	2	W14	W14			2															
Subscale Demonstration Flight	3	W14	W14			3															
Altimeter Test	4	W23	W23												4						
Parachute Deployment/ STEMnaut Containment Test	5	W23	W23												5						
Payload Data Collection Test	6	W24	W24													6					
Air Brakes Effectiveness Flight Tes	7	W24	W24													7					
Nose Cone Bulkhead Tensile Test	8	W25	W25														8				
AVAB Bay Tensile Test	9	W25	W25														9				
GPS Test	10	W25	W25														10				
Data Transmission Verification	11	W25	W25														11				
Battery Capacity Verification	12	W25	W25														12				
Air Brakes Flight Simulation Test	13	W25	W25														13				
Rivet Shear Loading Test	14	W26	W26															14			
Shear Pin Shear Loading Test	15	W26	W26															15			
Fin Can Impact Test	16	W26	W26															16			
Nose Cone with STEMCRaFT Impact Test	17	W26	W26															17			
Moment of Inertia Test	18	W27	W27																18		
Full-scale Ejection Test	19	W27	W27																19		
Full-scale Dry Run	20	W27	W27																20		
Payload Flight Simulation Transmission Test	21	W27	W27																21		
Remote Override Test	22	W27	W27																22		
Air Brakes Deploymnet Test	23	W27	W27																23		
Full-scale Demonstration Flight	24	W28	W28																	24	

Figure 7.7: SL testing Gantt chart.

7.5.4 Funding Timeline

2024-25 Competition Funding Gantt Chart

TACHO LYCOS

Task Name	Task Number	Start Week	End Week	Aug			Sep				Oct				Nov					Dec			Jan				Feb				Mar					Apr				May			
				W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36	W37	W38	W39	W40
E Council S24-F24	1	W01	W06	1	1	1	1	1	1																																		
Student Government S24-F24	2	W01	W14	2	2	2	2	2	2	2	2	2	2	2	2	2	2																										
E Council F24-S25	3	W10	W29										3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3											
Student Government F24-S25	4	W10	W30										4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4										
Space Grant 2023-2025	5	W12	W40												5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
EYE Funding	6	W24	W24																								6																
ETF Funding	7	W24	W24																								7																

Figure 7.8: SL Budget Gantt chart.

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8 Appendices

8.1 Additional Subscale Information

Subscale Launch Procedure / Checklist

Subscale Launch Day Checklist

8.2 Additional Full-Scale Information

Full-Scale Night Before Checklist

Full-Scale Night Before Checklist

Full-Scale Post-Launch Checklist

Full-Scale Post-Launch Checklist

8.3 Team / Club Documentation and Information

NC State University High-Powered Rocketry Club Constitution

NC State University High-Powered Rocketry Club Constitution

8.3.1 Social Media Accounts

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

Signed Safety Acknowledgment/Contract

Signed Safety Acknowledgment/Contract

- Details the safety agreement signed by team members for compliance.

Team Hour Tracker

	Abigail Kuppler	Katelyn Yount	James Holley	Aubri Sprouse	Trent Couse	Sam Patterson	Connor Swanson	Ryan Keever	Megan Rink	Tyler	Ben Radspinner	Total		
	Integration	Team Lead	Structures	Aerodynamics	Recovery	Payload	Payload	Payload	Safety	Treasurer	Outreach			Proposal Total
8/16 - 9/1	10	30	18	4	6	15	12	8	0	0	0	103		256.5
9/2 - 9/8	14	31	20	14	23	15	10	10	4.5	8	4	153.5		
9/9 - 9/15	3	5	12	4	15	8	8	8	0	0	0	63		PDR Total
9/16 - 9/22	5	8	12	6	9	16	6	6	0	0	0	68		1052
9/23 - 9/29	6	19	8	3	4	35	25	15	0	0	0	115		
9/30-10/6	11	8	10	3	10	4	3	7	0	0	0	56		
10/7 - 10/13	12	24	22	12	25	9	10	10	0	0	0	124		
10/14 - 10/20	36	40	30	22	35	10	20	16	0	0	0	209		
10/21 - 10/27	49	70	40	30	46	48	50	40	27	17	0	417		
10/28 - 11/3	2	4	6	2	2	8	3	4	0	0	0	31		CDR Total
11/4 - 11/10	6	6	15	2	15.5	7	10	5	0	0	0	66.5		1021
11/11 - 11/17	37	44	48	10	48.5	48	40	40	0	0	0	315.5		
11/18-11/24	2	4	6	4	2	5	4	3	0	0	0	30		
11/25-12/1	3	15	8	8	6	8	3	3	0	0	0	54		
12/2-12/8	4	6	4	15	3	3.5	3	3	0	0	0	41.5		
12/9-12/15	4	14	2	2	3	3.5	3	5	0	0	0	36.5		
12/16-12/22	9	14	2	1	2	2.5	2	5	0	0	0	37.5		
12/23/12/29	8	18	8	0	7	15	18	20	0	2	0	96		
12/30-1/5	19	36.5	28	20	16	20	32	25	0	0	0	196.5		
1/6-1/8	16	26	10	6	14	15	14	15	0	0	0	116		

- Details the number of hours each Team Lead and relative officer has worked for the CDR milestone (along with proposal and PDR).

8.4 Safety and Training Materials

NC State University High-Powered Rocketry Club Lab Safety Quiz

NC State University High-Powered Rocketry Club Lab Safety Quiz

- Contains the quiz questions used for training and certifying lab safety knowledge.

High-Powered Rocketry Club Safety Handbook

HPRC Safety Handbook

- Detailed safety guidelines and procedures for the NC State High-Powered Rocketry Club. Includes local RSO rules for Tripoli Rocketry and NAR.

Wake County Waste Disposal Guidelines and Resource Website

Wake County Waste Disposal Guidelines and Resource Website

- A resource website for proper disposal practices in compliance with county regulations.

Energetics Safety

Black Powder Safety Presentation

- A presentation going over the safe handling of energetics and black powder.

First Aid Kit

Safety Bin Inventory

- A detailed list of all of the safety equipment located in the lab's safety bins (first aid kit). Items are located in bins in the NCSU HPRC lab and are transported to the launch field.

Welding Training

Welding Training Handbook

- Document detailing the safe procedure for welding.

8.5 Technical Datasheets

West Systems 105/206 Epoxy Resin Datasheet

West Systems 105/206 Epoxy Resin Datasheet

- Technical information on the properties and use of epoxy resin for rocket construction.

8.6 Mental Health and Support Resources

Mental Health Resource Slide for HPRC General Body Meetings

- Includes resources and contacts for mental health support. Shared during weekly club meetings (General Body Meetings).