NC STATE UNIVERSITY

# Tacho Lycos

# 2026 NASA Student Launch

# Critical Design Review

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

January 7, 2026

## Common Abbreviations and Nomenclature

AIAA = American Institute of Aeronautics and Astronautics
APCP = Ammonium Perchlorate Composite Propellant
AV = Avionics
AVAB = Avionics and Air Brakes Bay
CAD = Computer Aided Design
CATO = Catastrophe at Take Off
CDR = Critical Design Review
CFD = Computational Fluid Dynamics
CG = Center of Gravity
CNC = Computer Numerical Control
CP = Center of Pressure
ECE = Electrical and Computer Engineering
ETF = Educational and Technology Fee
EYE = Engineer Your Experience
FAA = Federal Aviation Administration
FMEA = Failure Modes and Effects Analysis
FRR = Flight Readiness Review
GrAVE = Ground Activated Vehicle Ejector
GPS = Global Positioning System
GUI = Graphical User Interface
HAUS = Habitat for Agricultural Utilization Study
HPRC = High-Powered Rocketry Club
ID = Inner Diameter
IMU = Inertial Measurement Unit
INS = Inertial Navigation System
LED = Light Emitting Diode
LiPo = Lithium Polymer
LRR = Launch Readiness Review
LS = Likelihood Severity
MAE = Mechanical & Aerospace Engineering
NAR = National Association of Rocketry
NASA = National Aeronautics and Space Administration
NCSG = North Carolina Space Grant
NCSU = North Carolina State University
NFPA = National Fire Protection Association
NPK = Nitrogen, Phosphorus, and Potassium
OD = Outer Diameter
PCB = Printed Circuit Board
PDR = Preliminary Design Review
PDF = Payload Demonstration Flight
PEM = Penn and Manufacturing Corp.
PETG = Polyethylene Terephthalate Glycol
PLA = Polylactic Acid
PLAR = Post-Launch Assessment Review
PPE = Personal Protective Equipment
RSO = Range Safety Officer
RVM = Requirement Verification Matrices
SDS = Safety Data Sheets
SGA = Student Government Association
SL = Student Launch
STEM = Science, Technology, Engineering, and Mathematics
TRA = Tripoli Rocketry Association
UHMWPE = Ultra-high-molecular-weight polyethylene
VDF = Vehicle Demonstration Flight
ZOMBIE = Z-axis Orienting Mechatronic Botanical Investigative Excavator

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## 1.1 Team Summary

Table 1.1: Team Information

| Information Required | Details |
|---|---|
| **Team Name** | Tacho Lycos |
| **Mailing Address** | 1840 Entrepreneur Drive, Raleigh, NC 27606 |
| **Name of Mentor** | Jim Livingston |
| **TRA Number** | 02204 |
| **Certification Level** | TRA Level 3 Certification |
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| **Phone Number** | (910) 612-5858 |

## 1.2 Launch Vehicle Summary

Table 1.2: Vehicle Motors, Sections, and Recovery System

<table>
<tr><th colspan="7">Flight Performance and Configuration</th></tr>
<tr><td><b>Declared Target Apogee</b></td><td colspan="6">4600 (ft)</td></tr>
<tr><td><b>Primary Motor Choice</b></td><td colspan="6">L1390G</td></tr>
<tr><td><b>Secondary Motor Choice</b></td><td colspan="6">L1520T</td></tr>
<tr><td><b>Rail Size</b></td><td colspan="6">144 (in), 1515 launch rail</td></tr>
<tr><th colspan="7">Vehicle Section Breakdown</th></tr>
<tr><td><b>Section</b></td><td><b>Length</b></td><td><b>Dry Mass</b></td><td><b>Wet Mass</b></td><td><b>Ballasted</b></td><td><b>Burnout</b></td><td><b>Landing</b></td></tr>
<tr><td><b>Nosecone / Payload Bay</b></td><td>32.6 (in)</td><td>11.20 (lbs)</td><td>11.20 (lbs)</td><td>11.20 (lbs)</td><td>11.20 (lbs)</td><td>11.20 (lbs)</td></tr>
<tr><td><b>Main Bay/Avionics Bay</b></td><td>29 (in)</td><td>7.82 (lbs)</td><td>7.82 (lbs)</td><td>7.82 (lbs)</td><td>7.82 (lbs)</td><td>7.82 (lbs)</td></tr>
<tr><td><b>Drogue Bay/Air Brakes Bay/ Fin Can</b></td><td>49.3 (in)</td><td>12.14 (lbs)</td><td>20.69 (lbs)</td><td>20.69 (lbs)</td><td>16.34 (lbs)</td><td>16.34 (lbs)</td></tr>
<tr><td><b>Totals</b></td><td>110.09 (in)</td><td>31.15 (lbs)</td><td>39.7 (lbs)</td><td>39.7 (lbs)</td><td>35.3 (lbs)</td><td>35.3 (lbs)</td></tr>
<tr><th colspan="7">Recovery System</th></tr>
<tr><td><b>Parachute</b></td><td colspan="3"><b>Specification</b></td><td><b>Descent</b></td><td><b>Main</b></td><td><b>Backup</b></td></tr>
<tr><td><b>Main Parachute</b></td><td colspan="3">Fruity Chutes 120 in. Iris Ultra Compact parachute</td><td>13.33 (fps)</td><td>2.75 (g) of BP</td><td>3.66 (g) of BP</td></tr>
<tr><td><b>Drogue Parachute</b></td><td colspan="3">15 in. in-house fabricated elliptical parachute</td><td>129.66 (fps)</td><td>2.92(g) of BP</td><td>3.89(g) of BP</td></tr>
<tr><th colspan="7">Altimeter Details</th></tr>
<tr><td><b>Brand</b></td><td colspan="2"><b>Model</b></td><td colspan="2"><b>Main Deployment</b></td><td colspan="2"><b>Drogue Deployment</b></td></tr>
<tr><td>Silicdyne</td><td colspan="2">Fluctus</td><td colspan="2">550 (ft)</td><td colspan="2">Apogee</td></tr>
<tr><td>Altus Metrum</td><td colspan="2">EasyMini</td><td colspan="2">500 (ft)</td><td colspan="2">Apogee + 1s</td></tr>
</table>

## 1.3 Payload Summary

The payload is comprised of two major systems: ZOMBIE and GrAVE. ZOMBIE, or the Z-axis Orienting Mechatronic Botanical Investigative Extractor, is a self-righting lander which will collect and sample soil. GrAVE, or the Ground Activated Vehicle Ejector, is the system which deploys ZOMBIE after the launch vehicle has landed.

ZOMBIE will right using four deploying legs. Once upright, it will use an auger to drill into the soil. The system aims to collect at least 75 (ml) of soil for testing. The collected soil will be tested for Nitrate-Nitrogen content, electrical conductivity, and pH.

# 2 Changes Made Since PDR

## 2.1 Changes Made To Vehicle Criteria

Table 2.1: Changes Made to Vehicle

| Change Description | Justification | Affected Subsystem(s) |
|---|---|---|
| Launch vehicle mass increased to 39.7 lbs | Increase in subsystem masses | Vehicle Structures |
| Air Brakes and Avionics Bay threaded rods changed to 0.25 (in) stainless steel from 0.25 (in) 6061 aluminum | Increased factor of safety during recovery shock loading | Vehicle Structures |
| Forward main parachute recovery attachment point is an epoxied section of Kevlar shock cord in a carbon fiber guide rail instead of a U-bolt on a bulkhead | To provide a rigid attachment point that is not a removable bulkhead and allow for more space within the Nosecone for GrAVE | Vehicle Structures |
| Air Brakes and Avionics Bay U-bolts increased to 0.375 (in) thick stainless steel from 0.3125 (in) thick stainless steel | Increased factor of safety during recovery shock loading | Vehicle Structures |
| Nosecone tip utilizes a 3D printed PLA contoured washer instead of machined aluminum | reducing machining complexity | Vehicle Structures |
| Forward centering ring consists of two 0.125 (in) honeycomb Nomex cores | A reduced number of unique laminates and manufacturing complexity | Vehicle Structures |
| Non-in-flight separation points use steel screws instead of stainless steel | Increased factor of safety during recovery shock loading | Vehicle Structures |
| Air Brakes bay slot sizing and location adjusted within the fin can tube | Matching the design requirements set during the subscale launch vehicle | Vehicle Structures |
| Fin fillet sizes reduced to a 5% internal fillet and 4% external fillet from 10% and 6% | Reducing the mass of the fin can system | Vehicle Structures |
| Airframe laminates manufactured with heat shrink sleeve instead of peel-ply release | Increasing laminate compaction and smoother surface texture | Vehicle Structures |
| 120 (in) main parachute instead of a 96 (in) main parachute | Allows for a smaller drogue to be used and decreases kinetic energy upon landing | Vehicle Recovery |
| 15 (in) drogue parachute instead of an 18 (in) drogue parachute | Decreases overall descent time | Vehicle Recovery |
| 1/2 (in) instead of 5/8 (in) Kevlar shock cord | Reduces weight without compromising needed strength | Vehicle Recovery |
| 17 (ft) instead of 25 (ft) of shock cord will be used for main parachute deployment | Reduces weight and unnecessary length | Vehicle Recovery |
| 19 (ft) instead of 28.5 (ft) will be used for drogue parachute deployment | Reduces weight and unnecessary length | Vehicle Recovery |
| Primary drogue ejection charge will be 2.92 (g) and the secondary charge will be 3.89 (g), as opposed to 2.40 (g) and 3.90 (g), respectively | Updated volume estimates | Vehicle Recovery |
| Primary main ejection charge will be 2.75 (g) and the secondary charge will be 3.66 (g), as opposed to 2.30 (g) and 3.70 (g), respectively | Updated volume estimates | Vehicle Recovery |

## 2.2 Changes Made to Payload Criteria

Table 2.2: Changes Made to Payload

| Change Description | Justification | Affected Subsystem(s) |
|---|---|---|
| ZOMBIE height increased from 14 to 16.25 (in) | Allows for more space for internal systems | Payload Structures |
| ZOMBIE legs increased from 8 to 10 (in) and strut connection point moves from 1.4 to 1.75 (in) | Maintain correct moment arm required for self-righting after the height increase | Payload Structures |
| ZOMBIE linkages change from PLA linear shape to aluminum L shape and linkage-collar connection points move inwards | Allows for greater moment arm for the lead screw motor to act on while pushing out the legs while maintaining linkage stiffness | Payload Structures |
| ZOMBIE body split into smaller interconnected sections | Allows for easier access and faster prototyping | Payload Structures |
| ZOMBIE top plate will be composite plate instead of PLA | Composite plate is needed to withstand the forces during launch | Payload Structures |
| GrAVE flight computer changed from Arduino Nano to Raspberry Pi Zero | Greater processing power, simplified coding interface, and the addition of a camera slot allows for recording of the Air Brakes | Payload Electronics |
| GrAVE battery changed from 2S to 4S LiPo | The increased voltage allows for the operation of the chosen motors in GrAVE | Payload Electronics |
| Parker Lord CX5 IMU replaced for integrated INS system | An INS provides greater control of data, reliability of data collection, and space savings for Full-scale design | Payload (Air Brakes) |
| Raspberry Pi Hat is now a custom PCB | Allows for the addition of current sensing for all voltage regulations, debug LEDs for testing, better brownout protection and overall reliability | Payload (Air Brakes) |

## 2.3 Changes Made to Project Plan

Table 2.3: Changes Made to Project Plan

| Change Description | Justification | Affected Subsystem(s) |
|---|---|---|
| A more in-depth development timeline was finalized | This will allow the Project Management Subteam to accurately monitor progress, and ensure the team completes their VDF and PDF successfully | All Teams |
| Moved the painting of the full-scale launch vehicle to occur one week after the attempted VDF/PDF on February 21st, 2025. | To ensure the Vehicle Team and Payload have an adequate buffer period before the VDF/PDF | All Teams |
| Added Payload and Vehicle Structures subteam PERT charts to the Development Timeline | Allow teams to better visualize simultaneous progress, to ensure that construction gets completed before VDF/PDF | Vehicle Structures, Payload, Project Management |
| Team Derived Requirements LVD 8, RF 2, PF 4, PF 7 and PD 1 were removed. | Team-derived requirements were refined by removing or consolidating items that were redundant, unverifiable, or to similar to higher-level NASA rules, improving clarity, traceability, and verifiability without reducing safety or mission assurance. | All Teams |

# 3 Vehicle Criteria

## 3.1 Mission Statement

The primary mission of the Launch Vehicle is to deliver the payload to the declared apogee and return it to the ground within specified kinetic energy and descent time requirements. The Launch Vehicle's secondary objective is to house the Air Brakes system, the system which improves the accuracy of the launch vehicle's apogee in relation to the targeted declared apogee. The Launch Vehicle will be designed to enable a complete execution of the payload mission requirements with re-usability, reliability, and safety. Various criteria will be utilized to determine the launch vehicle's mission success in Table 3.1.

Table 3.1: Vehicle Success Criteria

| Success Level | Vehicle Criteria |
|---|---|
| Success | · The Launch Vehicle exhibits nominal performance during powered flight and coast phases<br>· Stage separation and recovery system deployment occur as intended at the designated altitudes<br>· The vehicle achieves an apogee within ±200 (ft) of the declared target altitude<br>· Landing occurs within the designated recovery area and within the allotted recovery timeframe<br>· The vehicle and payload sustain no structural or electrical damage<br>· All vehicle sections are successfully located and recovered<br>· The launch vehicle remains fully operational and capable of same-day relaunch |
| Partial Success | · Powered flight and coast phases proceed nominally<br>· Separation and recovery system deployment occur at the intended altitudes<br>· The vehicle achieves an apogee between 4,000 ft and 6,000 (ft)<br>· The vehicle experiences only minor landing damage and can be repaired and reflown within the same day. |
| Partial Failure | · Powered flight and coast phases proceed nominally<br>· The vehicle fails to achieve an apogee within the 4,000-6,000 (ft) range.<br>· Recovery system deployment is incomplete, tangled, or otherwise impaired<br>· The vehicle or payload sustains damage preventing same-day reflight.<br>· The vehicle lands outside the designated recovery area or in an inaccessible or hazardous location (e.g., tree, water, power line). |
| Failure | · The launch vehicle fails to leave the launch rail<br>· A catastrophic motor failure (CATO) occurs<br>· Premature separation occurs during powered flight or coast phase<br>· The vehicle fails to exceed an altitude of 3,500 ft<br>· The recovery system fails to separate or deploy<br>· Any other incident results in significant structural damage or total loss of the launch vehicle or primary payload. |

## 3.2 Design and Verification of Launch Vehicle

### 3.2.1 Finalized Vehicle Design

The final Launch Vehicle measures 110.9 (in) from the Nosecone tip to the aft end of the motor retainer 3.1. An outer body diameter of 6.12 (in) for airframe sections represents an 18.2:1 aspect ratio. The integrated launch rail mass of the launch vehicle is 39.7 (lb) with a vehicle burnout mass of 35.3 (lb). The launch vehicle includes six sections from the forward to aft end: (1) the Nosecone and Payload Bay, (2) the Main Parachute Bay, (3) the Avionics Bay, (4) the Drogue Parachute bay, (5) the Air Brakes bay, and (6) the Fin Can. The leading launch vehicle motor utilizes an Aerotech 75/3840 reloadable motor system with an L1390G motor.

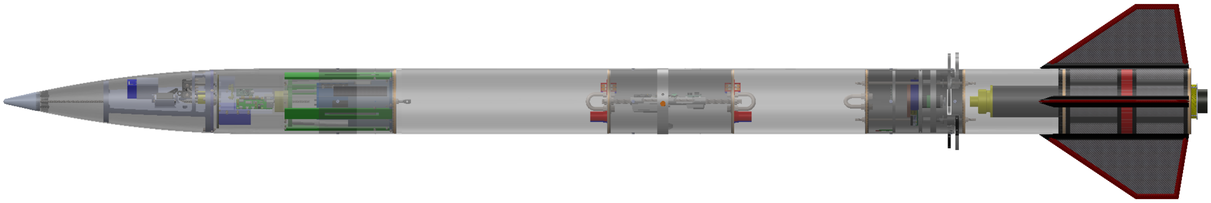


Figure 3.1: Assembled launch vehicle.

### 3.2.2 Separation and Energetic Locations

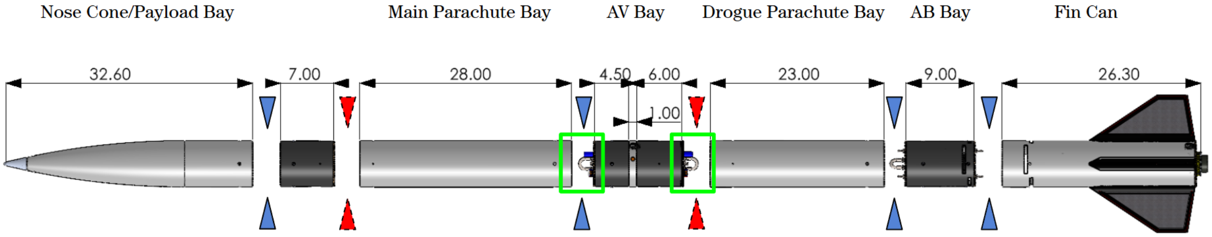


Figure 3.2: Dimensioned launch vehicle sections (in). In-flight separation points (red and dashed). Non-in-flight separation points (blue and solid). Location of energetics (green).

The final launch vehicle design includes two in-flight separation points and four non-in-flight separation points, Figure 3.2. The first in-separation point is for the drogue recovery system deployment between the aft end of the Avionics Bay Coupler and the forward end of the Drogue Parachute Bay. The secondary in-flight separation point is for the main recovery system deployment between the forward end of the Main Parachute Bay and the aft end of the Nosecone Coupler. Both of the in-flight separation points meet NASA requirements 2.5.1 and 2.5.3 for a coupling engagement length of 1X the inner diameter of the airframe body tubing for the Avionics Bay separation point and 0.5X the inner diameter of the airframe body tubing for the Nosecone Coupler point. The in-flight separation points are pinned utilizing four 4-40 nylon shear pins to prevent a premature separation due to drag forces, but low in strength to allow for precise separation with energetic charges at the main and drogue recovery event sequences. The nylon shear pins are evenly spaced radially and halfway in-between the coupling engagement of the section.

All four non-in-flight separation points meet NASA requirements 2.5.3 and 2.5.2 for minimum coupling engagement for the Nosecone, Avionics Bay, and Air Brakes bay coupling sections. The three forward non-in-flight separation points will be retained via press-fit stainless steel nuts in the coupler tubing, and stainless steel countersink screws for flush-mounting with the airframe. The airframe tubing will be countersunk to match the screw head. The points are designed for rapid removal and attachment during the vehicle assembly process. The forward non-in-flight separating sections are evenly spaced radially and located at the halfway point in-between the coupling engagement of the section.

### 3.2.3 Nosecone/Payload Bay

The Nosecone bay is a multi-purpose aerodynamic vehicle fairing and payload housing system, Figure 3.3. The nosecone ogive region is an approximate 4:1 length to diameter ratio; the length will be slightly less due to the blunted nosecone tip with a 0.25 (in) radius. The nosecone features a 9.00 (in) straight section for increased payload volume. The nosecone straight section and the ogive section are a single manufactured part. Towards the forward end of the nosecone, there will be an overlap between two different tubular fiberglass sleeve sizes to bridge the sizing of the minimum and maximum fiberglass sleeve dimensions. Sleeve overlap was chosen compared to utilizing two different nosecone sizes with a contoured coupler due to the reduced complexity of manufacturing three independent sections. It was determined that the minimal aerodynamic loss from the increased thickness at the overlap was minimal compared to the additional mass that would be gained from a three-part nosecone body. The increased thickness will be sanded and filled for a smooth aerodynamic surface. The tip will use a machined 6061 aluminum nosecone tip with a conical taper in Figure 3.4a, and a 3D printed contoured washer with steel screws for axial compression to keep the tip in place, Figure 3.4b. The aluminum tip will have a centrally drilled 0.375 (in) diameter hole with a 2.00 (in) depth for the payload to extend further from the vehicle payload bay. A 3D printed nosecone washer is used instead of an aluminum one due to the complex shape and machining complexity that would be required. The 3D printed washer will additionally utilize a high-infill and wall count in case of a landing impact with shear forces. Should forward ballast be necessary, aluminum pucks can be mounted to the payload's lead screw motor mounting plate.

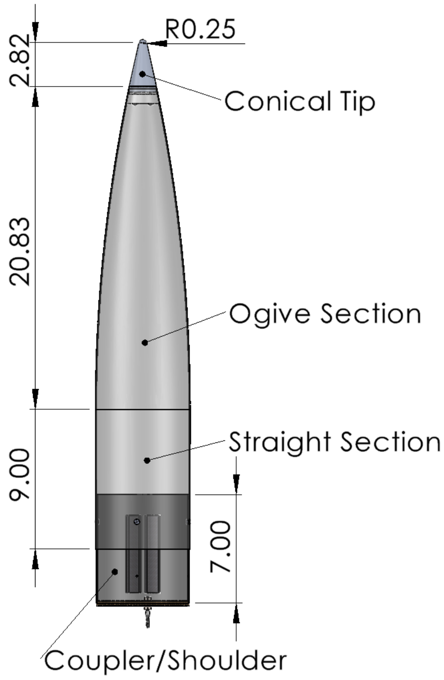


Figure 3.3: Annotated nosecone structure assembly.

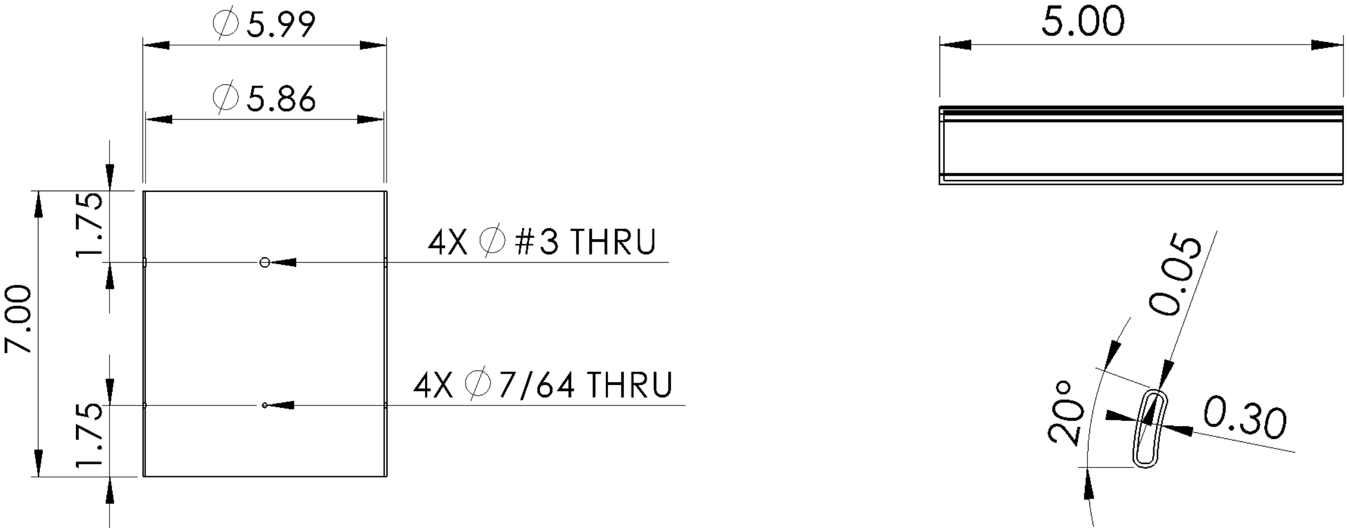
(a) Nosecone tip.

(b) Dimensioned nosecone tip washer.

Figure 3.4: Nosecone tip.

**Nosecone Coupler**

The coupler tubing joining the nosecone straight section and the main parachute bay measures 7.00 (in), Figure 3.5a. The length is 0.50 (in) longer than NASA requirement 2.5.3 for nosecone coupling lengths on each side to ensure the sections couple properly. The purpose of the nosecone coupler is to provide additional payload volume and to serve as the forward main recovery attachment point. The recovery attachment point is a permanently fixed Kevlar shock cord in a dual-purpose carbon fiber guide rail measuring 5.00 (in) long, presented in Figure 3.5b. The carbon fiber guide rails are 0.05 (in) thick walls with a custom contoured surface matching the inner diameter of the coupler and offset 0.50 (in) from the forward end of the nosecone bulkhead. There will be two carbon fiber guide tubes on opposite sides of the coupler tube. The payload system will use the rails for guiding the payload out of the nosecone upon landing and deployment. 5.00 (in) of the main recovery system's Kevlar shock cord will be epoxied into the carbon fiber guide rails for the forward main recovery retention method.



(a) Dimensioned nosecone coupler.

(b) Payload guide rails.

Figure 3.5: Nosecone bay components.

**Nosecone Bulkhead**

The nosecone bulkhead includes a stepped interface to provide a sealing surface, protecting the payload components, Figure 3.6. The nosecone bulkhead is manufactured with 0.04 (in) thick S2 fiberglass face sheets on the opposing sides with two 0.125 (in) honeycomb Nomex cores and a 0.01 (in) thick fiberglass face sheet in between. The bulkhead has a 0.25 (in) hole cut out for a 0.25 (in) threaded hangar eyebolt. The eyebolt serves as the hold to pull the bulkhead off the nosecone during the main recovery sequence discussed in Section 3.5.2. On the opposing slide is the slot cut out for the Kevlar shock cord routing.

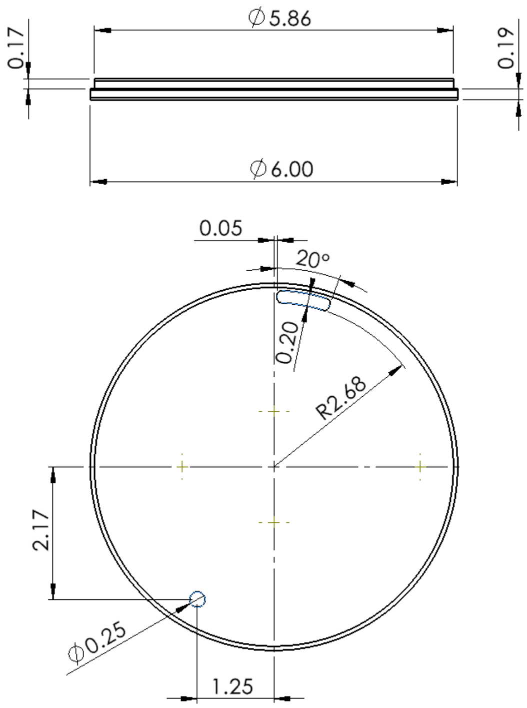


Figure 3.6: Dimensioned nosecone bulkhead.

### 3.2.4 Main Parachute Bay

The main parachute bay houses the main parachute recovery system in a 28.0 (in) long section of fiberglass tubing, coupling the nosecone/-payload bay to the avionics bay, Figure 3.7a and Figure 3.7. All airframe outer body tubing dimensions measure a 6.00 (in) inner diameter and a 6.12 (in) outer diameter. The forward end of the main parachute bay includes four 4-40 holes drilled with even radial spacing for the nylon shear pins to keep the section retained for the in-flight-separation point. The aft end of the bay has four 0.15625 (in) holes drilled and countersunk for the countersunk 6-32 steel screws to fasten the non-in-flight separation point with the avionics bay. An internal coupler band is epoxied 3.70 (in) from the forward end of the bay. Measuring 0.50 (in) long, the internal band prevents the nosecone bulkhead from falling into the bay.

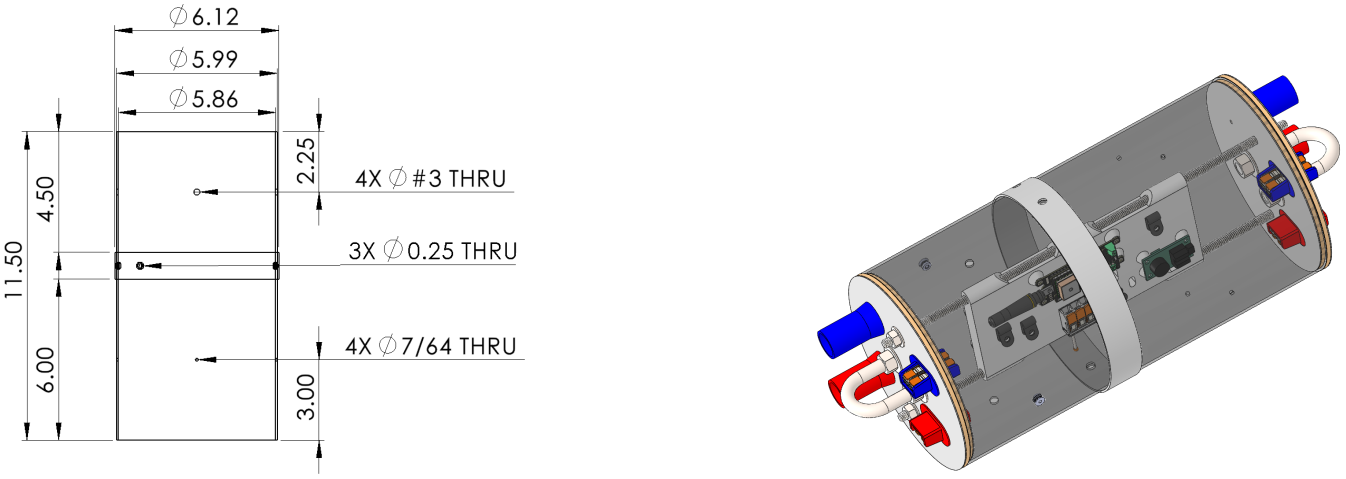
(a) Dimensioned main parachute bay.

(b) Main parachute bay.

Figure 3.7

### 3.2.5 Avionics Bay

The avionics bay houses the avionics systems in an 11.5 (in) fiberglass coupler with a 1.00 (in) fiberglass switchband epoxied with the aft end 6.00 (in) from the aft end of the coupler tube, Figure 3.8a. All launch vehicle coupler tubing uses a 5.99 (in) outer diameter and a 5.87 (in) inner diameter. Removable bulkheads on the forward and aft ends of the avionics bay transfer vehicle recovery and compressive loads through the threaded rods, compressing the system. The bulkheads also provide sealing from the energetic charges, protecting the avionics systems. The avionics boards include control of energetic recovery deployment events, launch vehicle tracking, and altitude recording. The avionics bay includes recovery attachment points for the forward end of the drogue shock cord and the aft end of the main shock cord on the bulkheads, Figure 3.8b. The switchband includes two 0.1875 (in) holes drilled centrally and through the coupler to provide altimeter pressure ports and access to the pull-pin arming switch. The middle of the switchband on the interior of the coupler will include a 0.50 (in) square wooden block with 0.25 (in) thickness for a wooden screw to mount the aft airfoiled 1515 rail guide. The rail buttons are located 48.0 (in) of separation from each other. The forward end of the avionics bay is a non-in-flight separation point with four 6-32 stainless steel press-fit nuts located 2.25 (in) from the forward end of the coupler and evenly spaced radially. The aft end of the avionics bay is an in-flight separation point with four 4-40 holes drilled for nylon shear pins to be placed.



(a) Dimensioned avionics bay coupler.

(b) Assembled avionics bay.

Figure 3.8

**Avionics Bulkheads**

The avionics bay bulkheads are machined with a step for interfacing the coupler centrally without alignment issues, Figure 3.9. The nosecone bulkhead is manufactured with 0.04 (in) thick S2 fiberglass face sheets on the opposing sides with two 0.125 (in) honeycomb Nomex cores and a 0.01 (in) thick fiberglass face sheet in between. All bulkheads and centering rings use a common material core for the lightweight and high-strength properties compared to solid wood or composite laminates. Stainless steel 0.375 (in) thick u-bolts with a 1.375 (in) center-to-center distance will provide recovery attachment for the recovery systems. The U-bolt is centrally located on the bulkhead to reduce stress concentrations with the addition of washers to spread the shear loading. Located at a 90-degree radial offset from the u-bolt holes will be the threaded rod through-holes that compress the bulkheads to the avionics bay for recovery load transfer through the launch vehicle. Stainless steel 0.25 (in) threaded rods transfer the load with washers and nuts for spreading out the shear loading. The threaded rod holes will be mounted 3.00 (in) center-to-center, allowing for the same avionics sled from the subscale launch vehicle to be mounted for the full-scale launch vehicle, simplifying designs. A pair of 0.125 (in) holes will be drilled in each bulkhead for mounting the energetic charge wells. Slots are to be machined for mounting the 3D printed inline WAGO lever terminals, allowing for pass-through of the energetic deployment signal to the e-matches. The 3D printed inserts will be epoxied into the bulkheads and the inline WAGOs will be epoxied into the inserts for rigidity during flight.

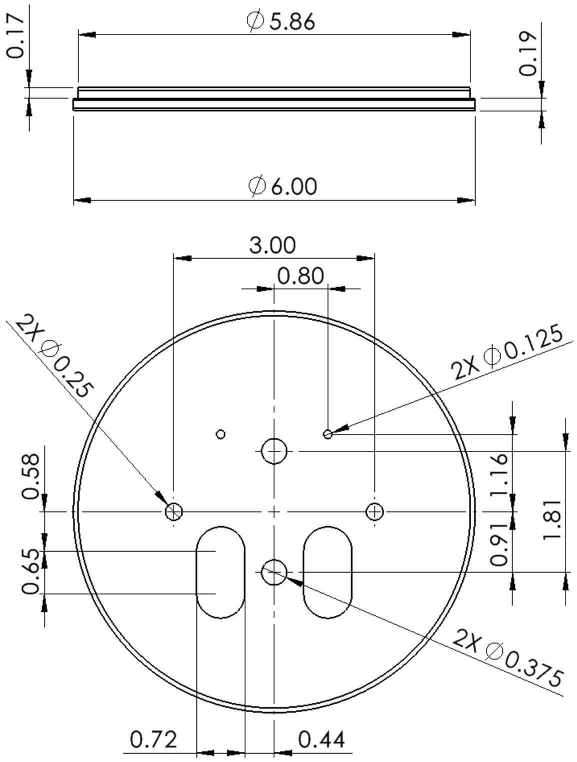
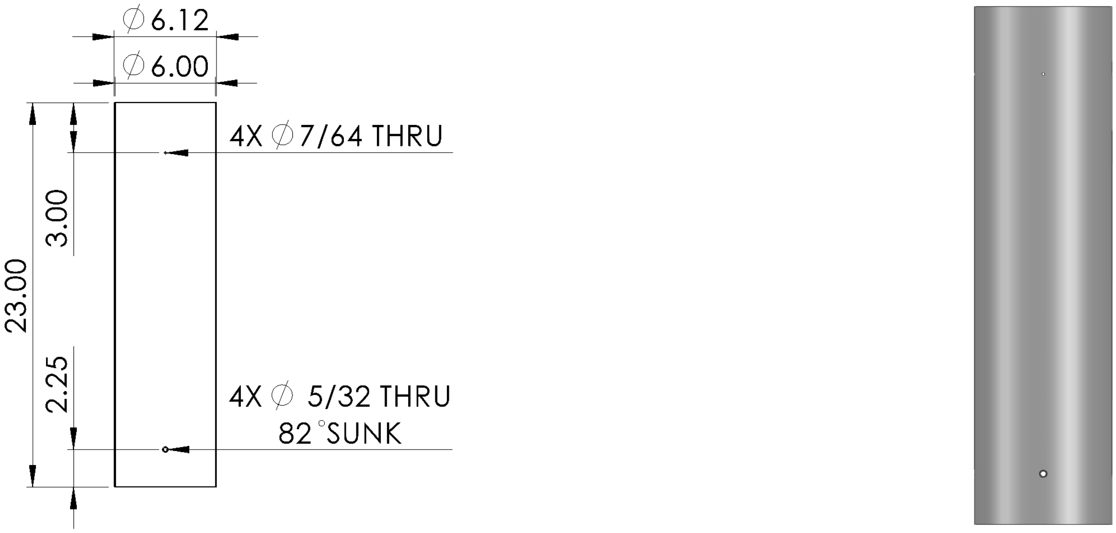


Figure 3.9: Dimensioned avionics bay bulkhead.

### 3.2.6 Drogue Parachute Bay

The drogue parachute bay houses the main parachute recovery system in a 23.0 (in) long section of fiberglass tubing, coupling the avionics bay to the Air Brakes bay, Figure 3.10a and Figure 3.10b. The forward end of the drogue parachute bay includes four 4-40 holes drilled with even radial spacing for the nylon shear pins to keep the section retained for the in-flight separation point. The aft end of the bay has four 0.15625 (in) holes drilled and countersunk for the countersunk 6-32 steel screws to fasten the non-in-flight separation point with the Air

Brakes bay.



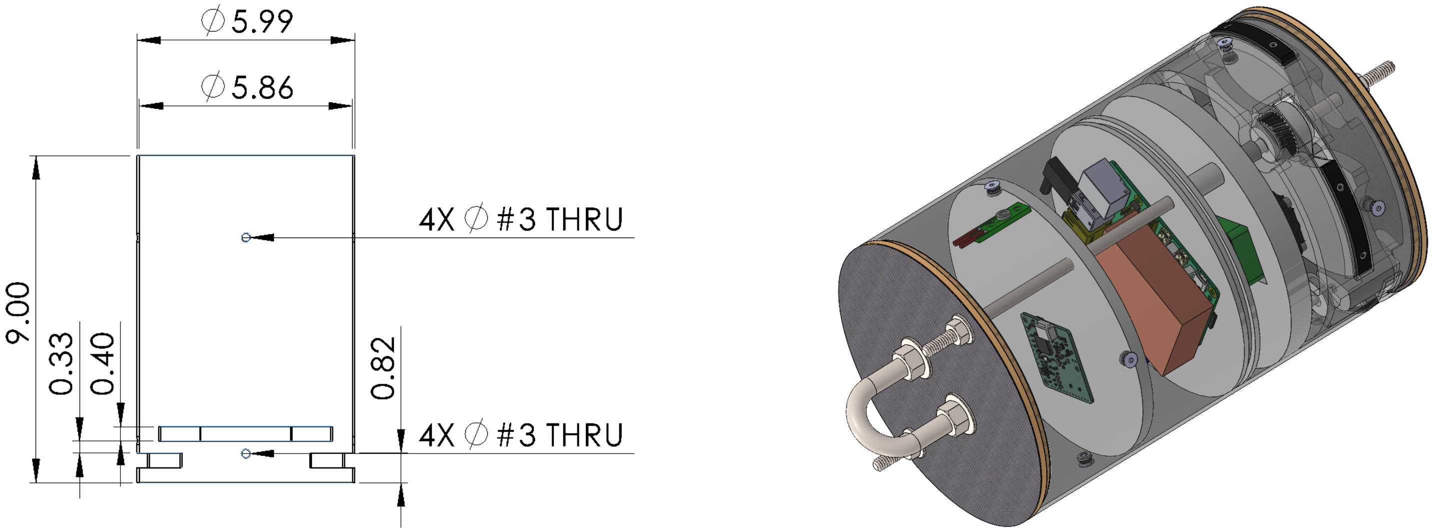
(a) Dimensioned drogue parachute bay.

(b) Drogue parachute bay side view.

Figure 3.10: Drogue parachute bay.

### 3.2.7 Air Brakes Bay

The Air Brakes bay houses the active drag system in a 9.00 (in) fiberglass coupler, Figure 3.11a and Figure 3.11b. Removable bulkheads on the forward and aft ends of the Air Brakes bay transfer vehicle recovery and compressive loads through the threaded rods, compressing the system. The bulkheads also provide sealing from the energetic charges, protecting the electronics onboard. The Air Brakes bay includes a recovery attachment point at the forward bulkhead for the aft end of the drogue recovery shock cord. The forward and aft end of the avionics bay are non-in-flight separation points. The forward end uses four 6-32 stainless steel press-fit nuts located 2.25 (in) from the forward end of the coupler and evenly spaced radially. The aft end of the Air Brakes bay uses 6-32 steel screws mounted in the 3D printed Air Brakes body.



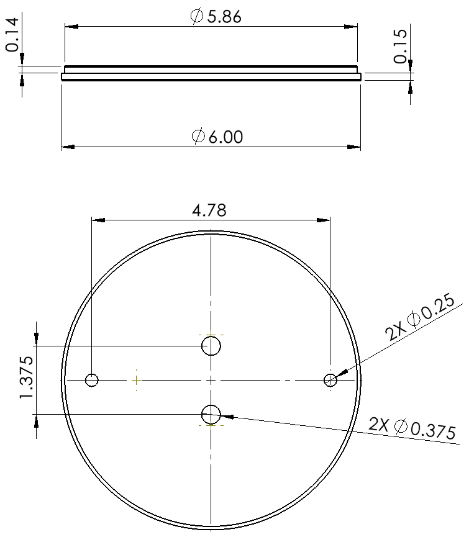
(a) Dimensioned Air Brakes bay coupler.

(b) Assembled bay.

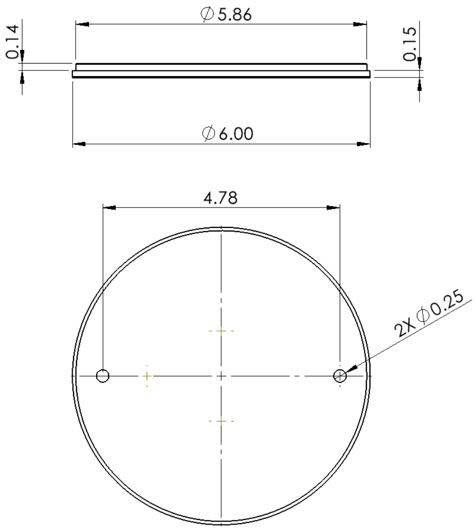
Figure 3.11: Air Brakes bay.

#### Air Brakes Bulkheads

The avionics bay bulkheads are machined with a step for interfacing the coupler centrally without alignment issues, Figure 3.12a and Figure 3.12b. The nosecone bulkhead is manufactured with 0.03 (in) thick carbon fiber face sheets on the opposing sides with two 0.125 (in) honeycomb Nomex cores and a 0.01 (in) thick carbon fiber face sheet in between. A stainless steel 0.375 (in) thick u-bolt with a 1.375 (in) center-to-center distance will provide a recovery attachment for the recovery systems. The U-bolt is centrally located on the bulkhead to reduce stress concentrations with the addition of washers to spread the shear loading. Located at a 90-degree radial offset from the u-bolt holes will be the threaded rod through-holes that compress the bulkheads to the avionics bay for recovery load transfer through the launch vehicle. Stainless steel 0.25 (in) connecting rods with threaded ends transfer the load with washers and nuts for spreading out the shear loading. The threaded rod holes will be mounted 4.78 (in) center-to-center.



(a) Dimensioned forward Air Brakes bulkhead.



(b) Dimensioned aft Air Brakes bulkhead.

Figure 3.12: Forward and aft Air Brakes bay bulkheads.

### 3.2.8 Fin Can

The fin can includes an epoxied passive fin stability system constructed of a carbon fiber motor mount, two centering rings, a motor retainer, a central alignment ring, four fins, and the aft rail guide, Figure 3.13. The fins, centering rings, and motor mount are permanently affixed to the fin can tube with internal and external fillets connecting the subsystems. The fillets connecting the subsystem components will be specified at their location for sizing. The internal fillets will be sized to a 5% radius relative to the length of the root chord. The external fillets will be sized to a 4% radius based on the root chord length. The increased internal fillets help counter the moments applied to the fin can from the lateral pressures at high angles of attack.

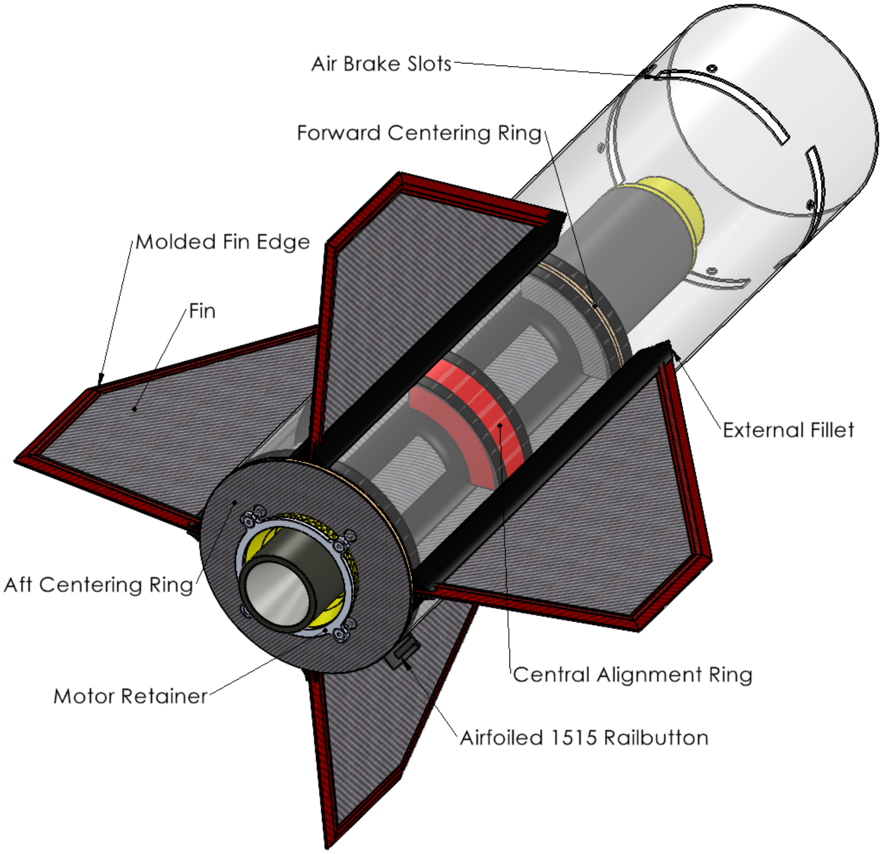


Figure 3.13: Assembled fin can.

### Fin Can Tube

The fin can tube is a 25.5 (in) long section of fiberglass, Figure 3.14. The fin can tube includes slots for the passive fin stability system, the slots for the active drag system, and thrust transfer through the launch vehicle. The forward end of the fin can tube has four slots cut for the active drag system. The two pairs of slots are cut offset to increase the fin area and to reduce the stress concentrations experienced by the body tubing. The forward body tube also includes countersink holes cut for a non-in-flight separation point connecting to the Air Brakes bay.

The aft end of the bay includes four evenly spaced slots radially for the passive fin stability system. The fin slots will initially be cut through the aft end of the tube for the mostly assembled fin system to slide into the tube, before being epoxied together at the aft end once the fin assembly is complete. The fin can tube is anticipated to experience the greatest stress concentrations from the passive and active drag system slots. The aft end of the tube will include a hole with a 0.50 (in) square wooden block with 0.25 (in) thickness for a wooden screw to mount the aft airfoiled 1515 rail guide. The wooden block will be epoxied with fillets to provide ample bonding.

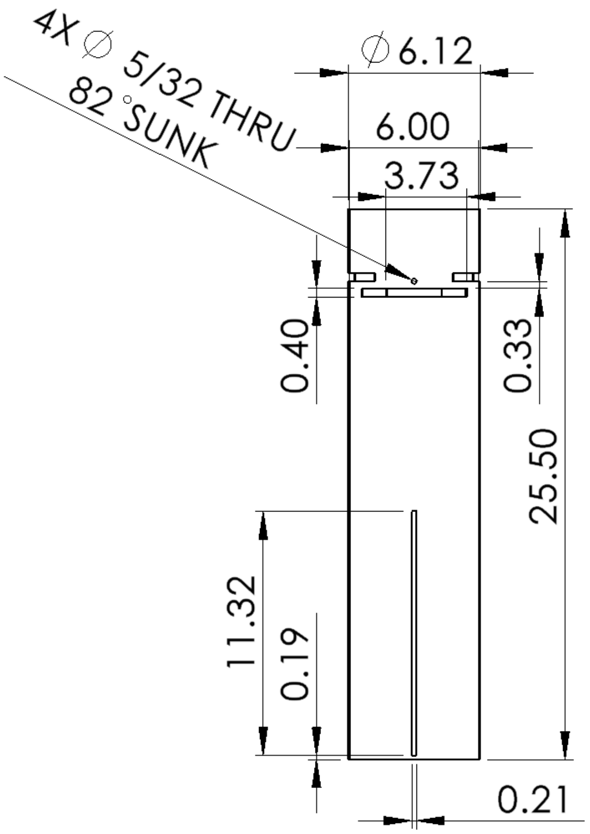


Figure 3.14: Dimensioned fin can tube.

### Motor Mount Tube

The motor mount tube connects the fins, centering rings, and motor into a single structural assembly, facilitating load transfer from the motor's axial compressive forces into the launch vehicle structure while also providing lateral bending support from the fins at high angles of attack. This integration ensures efficient load distribution through the fin can and improves overall structural stiffness.

The motor mount tube consists of a 12.0 (in) long carbon fiber tube with a 2.975 (in) inner diameter and a wall thickness of 0.03 (in), as shown in Figure 3.15.

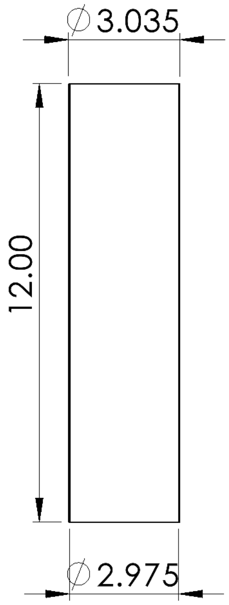
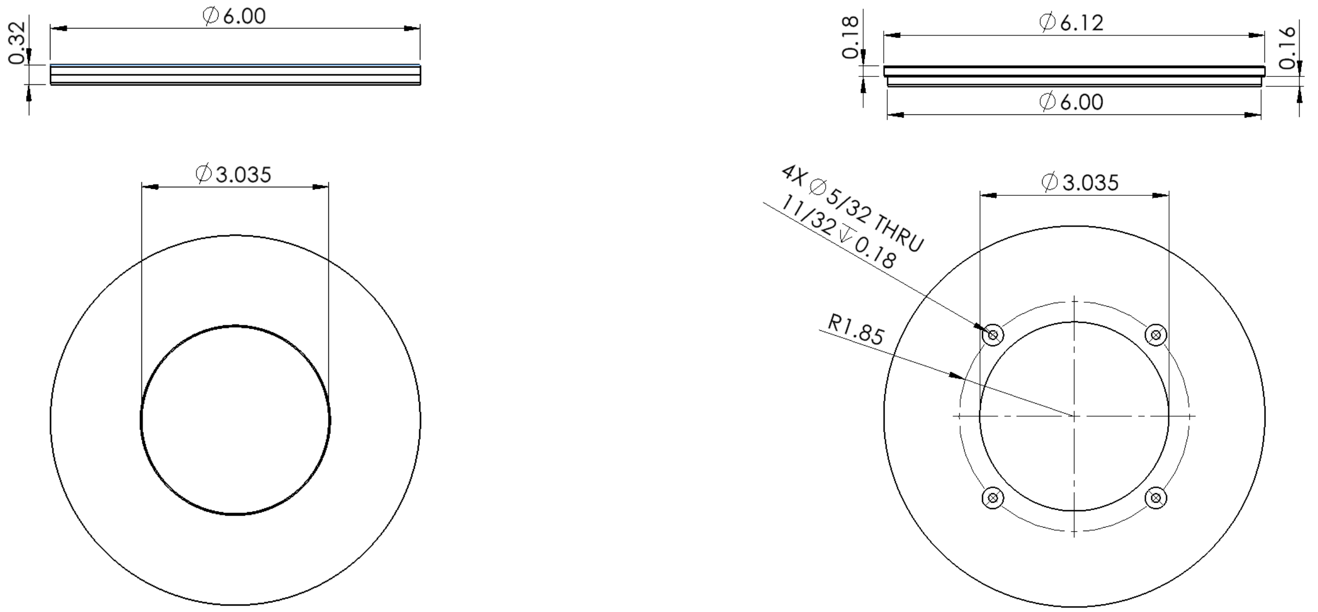


Figure 3.15: Dimensioned motor mount tube.

### Centering Rings

The forward and aft centering rings are constructed with double-thick honeycomb Nomex cores with carbon fiber face sheets. The forward centering ring is epoxied 11.5 (in) from the top of the motor mount tube, Figure 3.16a. The aft centering ring includes a stepped interface to connect to the aft end of the fin can tube; the motor mount is also located flush with the aft end of the aft centering ring, Figure 3.16b.



(a) Dimensional drawing forward centering ring.

(b) Dimensional drawing aft centering ring.

Figure 3.16: Forward and aft composite centering rings.

The middle centering ring is for alignment, as it is a 3D printed 1.00 (in) thick PLA ring with slots to match the fins, Figure 3.17. The alignment ring will be used as the initial bond between the fins and the fin system for proper radial and axial alignment of the system.

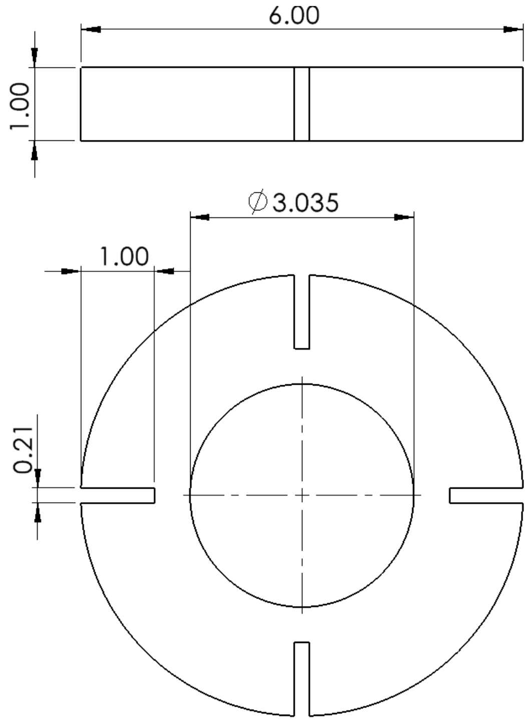
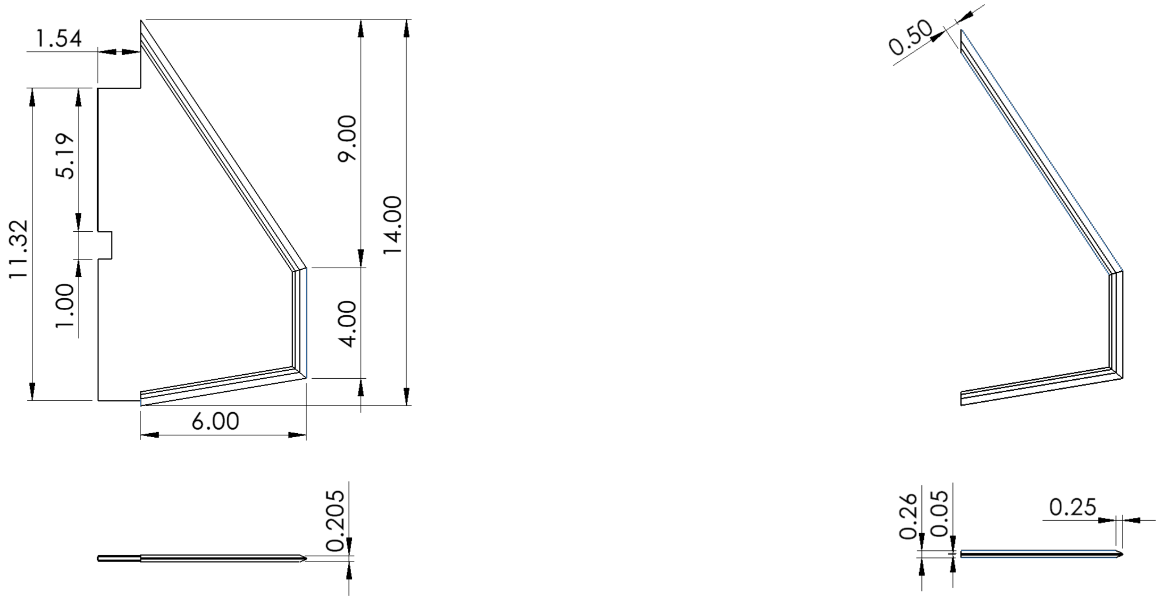


Figure 3.17: Middle centering ring.

### Fins

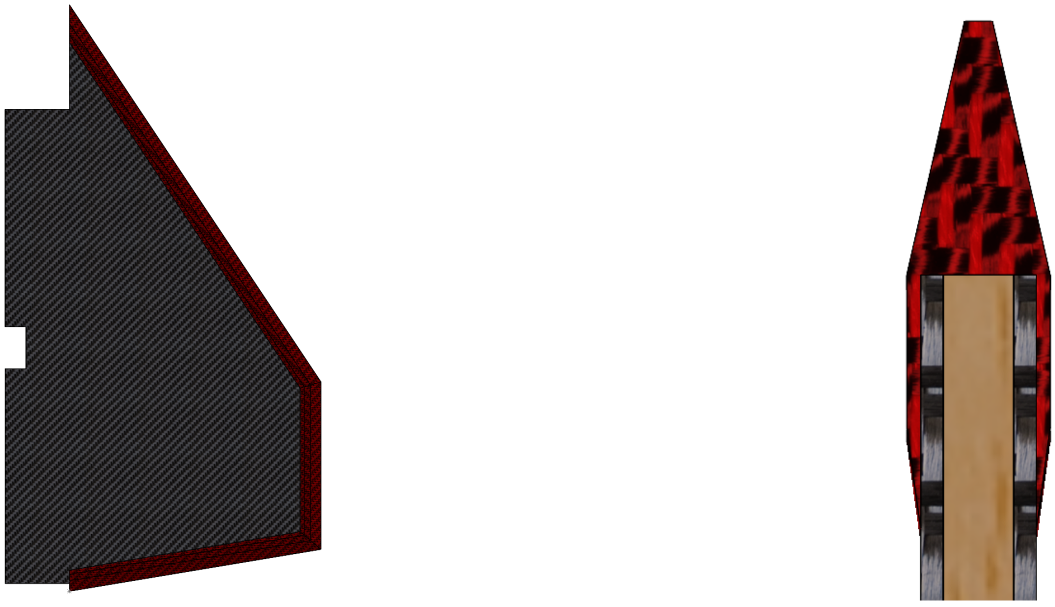
The fins provide the passive stability for the launch vehicle during ascent. The fins are placed with the aft end of the root chord lining up flush with the aft end of the fin can tube. Due to the aft centering ring having a stepped interface to match the outer dimension of the fin can tube, the fins are not located directly at the aft of the launch vehicle. Fin tabs provide an interface with mounting to the motor mount tube and the centering rings. The fins are constructed of a single 0.125 (in) honeycomb Nomex core with 0.04 (in) thick carbon fiber face sheets, Figure 3.18a and Figure 3.19a. To provide edge protection to the fins, a molded carbon fiber fairing will be bonded to the fin leading, trailing, and tip edges with a molded chamfered edge and 0.25 (in) of bonding on each side of the edges, Figure 3.18b and Figure 3.19b.



(a) Side profile.

(b) Molded fin edge fairing.

Figure 3.18: Dimensioned fin views.



(a) Side profile.

(b) Molded edge fairing cross section.

Figure 3.19: Fin views.

### Suitability of Design

An aft swept trapezoidal fin design has been selected for the launch vehicle. The aft swept fins provide reduced drag, velocity losses, and turbulence due to the pressure differences seen across the fin. To aid in decreasing turbulence along the aft end of the fin, an aerodynamic fairing was constructed along the leading and trailing edges along with the tip chord length. This helps decrease turbulence along the trailing by keeping air flow attached while it flows over the fins' edges. This also aids in further drag reduction for the entire vehicle. The final design incorporates these factors while maintaining ease of manufacturing, durability, and reliability.

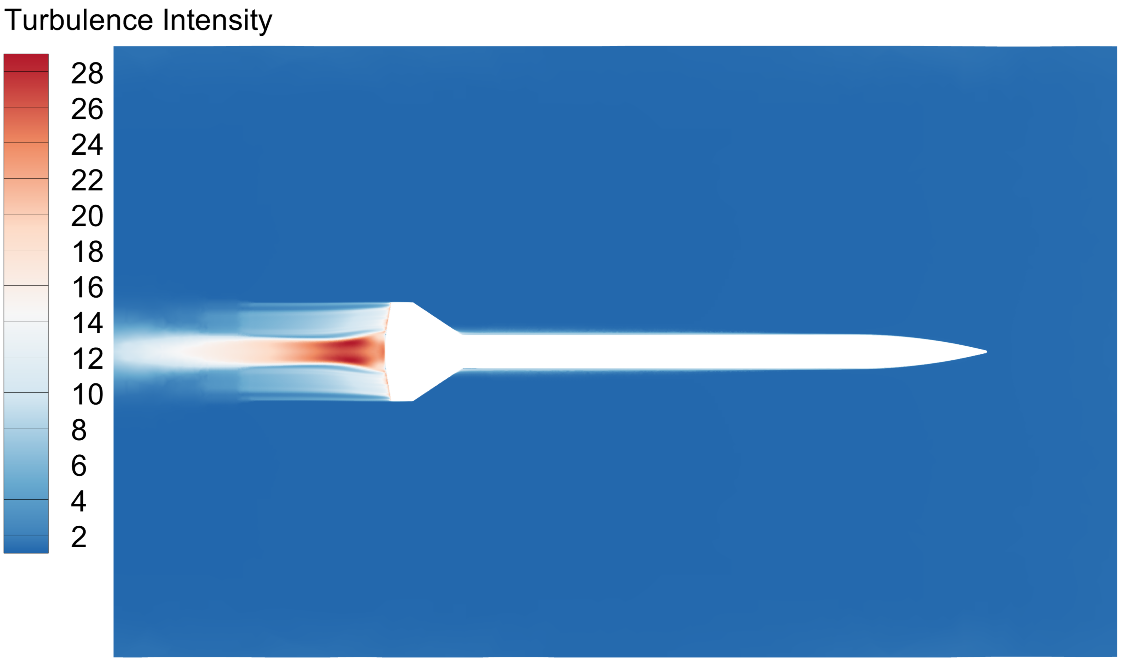


Figure 3.20: Final fin turbulence intensity contour across fins.

Shown in Figure 3.20 above is a contour of Turbulence Intensity ratio across the entire vehicle. As aforementioned, compared to the preliminary design, the turbulence along the trailing has substantially decreased leading to 1.53 (lbf) of drag per fin due to the addition of the fairing and fillets along the root chord of the fin. Overall, the fins balance durability and aerodynamic performance. The design meets all required performance and re-usability criteria for the launch vehicle based on impact testing, aerodynamic simulations, and subscale test flight performance.

### Motor Retainer

The motor retainer is sized for the aft closure of an AeroTech 75 (mm) reloadable motor assembly. The retainer is made from 0.125 (in) 6061 aluminum with four holes and countersunk 8-32 stainless steel screws for compaction and retention to the body of the launch vehicle, Figure 3.21a and Figure 3.21b. The screws are retained via stainless steel nuts epoxied into the aft centering ring. The motor retainer design was chosen over a commercially available Aeropack due to lower weight and smaller costs associated with a single flat plate.

(a) Dimensioned motor retainer.

(b) View of the completed model.

Figure 3.21: Motor Retainer.

### 3.2.9 Design Integrity

#### Avionics and Air Brakes Bulkheads

Significant shock loading during the main parachute deployment event is calculated to 414 (lbf). Roark's Formulas for Stress and Strain (7th Edition), Table 11.2, Case 1e, will be used to calculate the minimum thickness for a flat circular plate of constant thickness, [18]. Finite Element Analysis is not used in bulkhead structural analysis due to the complex and varied material properties required for a sandwich composite assembly, along with the numerous interactions and load conditions that occur. The bulkheads are simplified during these calculations, assuming the bulkhead is of constant diameter, based on the inner stepped bulkhead diameter. The shock loading will be converted to a purely shear loading over the circumference of a central 0.375 (in) diameter hole, mimicking the u-bolt thickness. Threaded rod attachment points will be disregarded. The simplifications taken will provide a conservative load estimate. A 5.0 factor of safety is applied to account for the possibility of a deployment with a tangled drogue or no drogue with much more significant shock loadings, Table 3.2.

Table 3.2: Bulkhead thickness input parameters

| $a(in)$ | $b(in)$ | $r_0(in)$ | $w(\frac{\text{lbf}}{\text{in}})$ | $\nu$ | $\sigma_{CF}(psi)$ | $\sigma_{FG}(psi)$ |
|---|---|---|---|---|---|---|
| 2.93 | 0.1875 | 0.1875 | 1757 | 0.330 | 23800 | 17000 |

Table 3.3: Bulkhead thickness output parameters

| **Bulkhead** | $M_{ra}$ **(**$\frac{\text{in-lbf}}{\text{in}}$**)** | $Q_a$ **(**$\frac{\text{lbf}}{\text{in}}$**)** | $t_{\text{bulkhead}}$ **(in)** |
|---|---|---|---|
| Carbon Fiber | -170 | -112 | 0.245 |
| S2 Fiberglass | -170 | -112 | 0.207 |

Due to manufacturing constraints on the thickness of the honeycomb Nomex core and nearly matching the previously tested three-point bending tests, the carbon fiber bulkheads will come out to a 0.29 (in) thickness and 0.32 (in) for the fiberglass bulkheads. The increased thicknesses provide a large factor of safety to account for unanticipated recovery mishaps, allowing for a complete vehicle recovery should increased shock loadings be experienced, Table 3.3. Due to the shock loading at 414 (lbf) exceeding the maximum vehicle thrust, an analysis for the fin can centering rings was not concluded. Due to the presence of two composite centering rings matching the thickness of the bulkheads, the motor thrust is distributed along both structural centering rings and through the fins, generating a lower stress environment compared to the bulkheads. The centering ring thickness was kept constant and not reduced for weight reasons due to a simpler manufacturing process requiring fewer unique layups. The lower stress helps account for unanticipated harsh landings at off-angles from the fins on rigid or non-rigid landing surfaces. The motor retainer is not anticipated to experience loading other than the weight of the assembled motor on the launch pad. There are no ejection charge pressures due to the separation between the fin can and the drogue bay via the Air Brakes bay. The 0.125 (in) thick motor retainer with 6061 aluminum.

#### Airframe Tubing

The fin can tube is anticipated to experience the most significant loading due to the large lateral pressure generated by the fins during flight, and the slots in the forward end of the tube are cut for the Air Brakes fins. To verify the integrity of the system, a hand calculation and finite element analysis (FEA) will be used to analyze the system. The hand calculation follows Richard Nakka's Experimental Rocketry website guide for "Rocket Body Design Considerations", combining vehicle aerodynamic and compressive flight loads [9], and Figure 3.4.

Table 3.4: Vehicle body tubing input parameters

| $\alpha(^\circ)$ | $v(\frac{ft}{s})$ | $\rho(\frac{slug}{ft^3})$ | $G-force$ | $r_{OD}(in)$ | $t_{wall}(in)$ | $F_T(lbf)$ | $m_{rocket}(lbm)$ | $\sigma_{laminate}(psi)$ |
|---|---|---|---|---|---|---|---|---|
| 10.0 | 626 | 0.00238 | 9.00 | 3.0582 | 0.0582 | 370.9 | 39.7 | 16000 |
| $C_t(in)$ | $C_r(in)$ | $b(in)$ | $Sweep(in)$ | $N_{fins}$ | $CG(in)$ | $C_D$ | $L_{nosecone}(in)$ | $L_{LeadingEdge}(in)$ |
| 4.00 | 14.0 | 12.0 | 9.50 | 4 | 64.6 | 0.559 | 23.5 | 50 |

$$\sigma_{concentration} = \sigma\sqrt{2(\sqrt{\frac{E_x}{E_y}} - \nu) + \frac{E_x}{G}} \quad (1)$$

After factoring the stress concentrations generated via two Air Brakes fin slots in line with each other, a 1.1 factor of safety is achieved, 1. It is noted that the conditions provided in Table 3.4 are significant overestimates in anticipated vehicle flight conditions. Flight under conditions beyond what can be expected when accounting for lower in-flight mass during motor burn, vehicle max pressure at a different time from the max vehicle thrust, and an angle of attack requiring a greater than 100 (ft/s) gust condition, the vehicle airframe tubing integrity is verified at all flight conditions.

SolidWorks Simulation is used in combination with the composite material choices for component analysis. The fin can tube design file is uploaded with the vehicle's max compressive force calculated to 418 (lbf), and a lateral normal force component determined in the hand calculation to be 138 (lbf). The body is rigidly fixed at the aft end with no additional fixtures. The primary considerations for inputs are the 16000 (psi) compressive strength determined from previous fiberglass tube compressive tests [4], and the elastic modulus in the x and y directions.

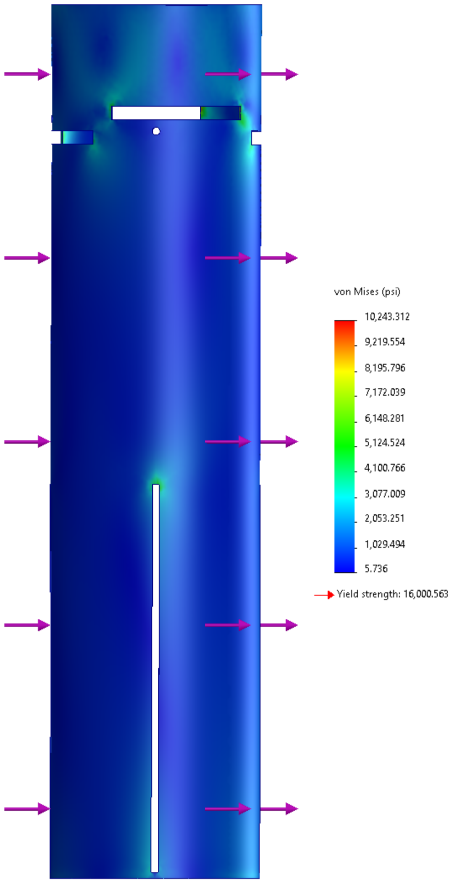


Figure 3.22: Solidworks fin can tube FEA.

From the simulation, a calculated 1.56 factor of safety is determined, Figure 3.22. Between both of the analysis methods, the stresses seen in the airframe body tubing will not exceed the strength of the fiberglass tubing during flight compressive and lateral forces.

**Avionics and Air Brakes Recovery Loads**

The avionics and Air Brakes bays are anticipated to experience a 414 (lbf) axial loading during the main parachute recovery sequence. To provide recovery retention for the vehicle, the shock loading will transfer from the shock cord through to 3500 a 3500-lbf-rated u-bolt. The load then transfers to two 1/4-20 (in) stainless steel threaded rods, compacting the bulkheads from each section together to the respective section couplers. The maximum allowable load on the rods is calculated with a tensile loading and the threaded rod minimum diameter of 0.196 (in) to a factor of safety of 16.2, 2.

$$FoS = \frac{F/A}{\sigma_{max}} \tag{2}$$

The load from the shock loading is then transferred to the airframe via four 6-32 black-oxide alloy steel countersink screws in shear. The shear loading uses the 414 (lbf) shock load spread evenly between the four pinned sections with a 0.104 (in) minimum section diameter to achieve a 9.40 factor of safety, 2. The maximum stress for the section multiplies the yield tensile stress by a factor of 0.60 to conservatively estimate the yield shear strength for the material.

### 3.2.10 Launch Vehicle Weight Estimates

Table 3.5: Section Weight Estimates

| Nosecone/Payload Bay | |
|---|---|
| Component | Weight [lbs.] |
| Machined Tip | 0.15 |
| Nosecone Body | 1.98 |
| Nosecone Coupler | 0.69 |
| Payload | 8.00 |
| Bulkhead | 0.18 |
| Eyebolt | 0.20 |
| **Section Subtotal** | **11.20** |

| Main Parachute Bay | |
|---|---|
| Component | Weight [lbs.] |
| Main Parachute | 1.25 |
| Shock Cord | 0.96 |
| Soft Links | 0.06 |
| Airframe | 2.31 |
| **Section Subtotal** | **4.58** |

| Avionics Bay | |
|---|---|
| Component | Weight [lbs.] |
| Avionics & Threaded Rods | 1.32 |
| 2 x U-bolts | 0.40 |
| 2 x Bulkheads | 0.36 |
| Airframe | 1.16 |
| **Section Subtotal** | **3.24** |

| Drogue Parachute Bay | |
|---|---|
| Component | Weight [lbs.] |
| Drogue Parachute | 0.125 |
| Shock Cord | 0.96 |
| Soft Links | 0.06 |
| Coupler | 1.90 |
| **Section Subtotal** | **3.05** |

| Air Brakes Bay | |
|---|---|
| Component | Weight [lbs.] |
| Air Brakes & Threaded Rods | 3.35 |
| U-bolt | 0.20 |
| 2 x Bulkheads | 0.32 |
| Coupler | 0.85 |
| **Section Subtotal** | **4.72** |

| Fin Can | |
|---|---|
| Component | Weight [lbs.] |
| Fins | 1.05 |
| Epoxy Fillets | 0.55 |
| Centering Rings and Thrust Plate | 0.27 |
| Motor Retainer | 0.13 |
| Motor Tube | 0.27 |
| Airframe | 2.11 |
| Loaded Motor | 8.55 |
| **Section Subtotal** | **12.92** |

Table 3.6: Summary Weight Estimate

| Section | Weight [lbs.] |
|---|---|
| Nosecone/Payload Bay | 11.20 |
| Main Parachute Bay | 4.58 |
| Avionics Bay | 3.24 |
| Drogue Parachute Bay | 3.05 |
| Air Brakes Bay | 4.72 |
| Fin Can | 12.92 |
| **Launch Vehicle Total** | **39.70** |

### 3.2.11 Material Selection

#### Airframe Tubing

All airframe tubes will use 8.9 (oz/yd$^2$) satin weave S2 fiberglass as the fiber material with US Composites 635 Slow 2:1 as the matrix material. S2 fiberglass was chosen for its superior strength properties over electrical-grade fiberglass with a near 30% increase in strength and stiffness, [8]. Fiberglass was chosen over carbon fiber materials due to the Air Brakes and avionics bays that contain transmitting components to remove the need for an external antenna on the launch vehicle. The climate resistance of fiberglass is favored for the varying launch conditions, along with a near-zero thermal expansion coefficient, removing the possibility of launch vehicle components not interfacing properly on cold or hot launch days. The airframes will be roll-wrapped from 0/90 plain weave. It is calculated that six layers of fiberglass will be used for the outer airframe tubing, while seven layers will be used for the coupling tubes to match and increase the section moment of area.

The nosecone laminate utilizes 9.6 (oz/yd$^2$) electrical-grade fiberglass due to the material availability for tubular sleeved fabrics. The grade of fiberglass utilized for the nosecone is acceptable due to the lower stresses at the forward end of the launch vehicle relative to the aft end closer to the vehicle's center of pressure. The nosecone is constructed with 6 layers of tubular light fiberglass sleeving with two different diameters to bridge the gap between the minimum stretch of a 6.00 (in) diameter sleeve and the maximum stretch of a 2.75 (in) diameter sleeve. There will be a minimum of 3.00 (in) length of overlap between the sleeves for increased structural rigidity.

**Bulkheads and Centering rings**

The vehicle bulkheads will utilize a common core 0.125 (in) honeycomb Nomex core with varying face sheet materials and layer counts. The fiberglass face sheets use 8.9 (oz/yd$^2$) satin weave S2 fiberglass, the carbon fiber face sheets use 3.74 (oz/yd$^2$) 1K plain weave. Each bulkhead includes two cores for the stepped interface with multiple layers on each face sheet and a singular laminate in between the cores to provide abrasion resistance for the lip of the bulkhead that interfaces with the ends of the couplers. The avionics bay and nosecone bulkheads will utilize fiberglass bulkheads. The Air Brakes bay bulkheads will be manufactured with carbon fiber face sheets due to the Air Brake's avionics requiring transmission at the launch pad and not continuously during flight at significant distances. The centering rings match the layer count and material as the Air Brakes bulkheads to minimize unique layups. The aft centering ring includes a stepped interface to match the outer airframe tubing; the forward centering ring does not include a stepped interface. The precise number of layers and weave type is specified in Table 3.7.

Table 3.7: Bulkhead, fin, and centering ring laminate orientations

| Component | Layup Sequence | | | | |
|---|---|---|---|---|---|
| Avionics & Nosecone Bulkheads | 4 x [0/90] FG | Honeycomb Nomex Core | 1 x [0/90] FG | Honeycomb Nomex Core | 4 x [0/90] FG |
| Air Brakes Bulkheads | 5 x [0/90] CF | Honeycomb Nomex Core | 1 x [0/90] CF | Honeycomb Nomex Core | 5 x [0/90] CF |
| Forward and Aft Centering Ring | 5 x [0/90] CF | Honeycomb Nomex Core | 1 x [0/90] CF | Honeycomb Nomex Core | 5 x [0/90] CF |
| Fins (Symmetric About Honeycomb Nomex) | 1 x [-45/+45] Spread CF | 1 x [0/90] CF | 2 x [-45/+45] CF | 1 x [0/90] CF | 2 x [-45/+45] CF |

**Fins**

The fins incorporate the 0.125 (in) honeycomb Nomex core with carbon fiber face sheets for increased strength compared to the fiberglass airframe components. The [0/90] carbon fiber plies are 3K 5.7 (oz/yd$^2$) plain weave, the [-45/+45] plies are 2.94 (oz/yd$^2$) stitched weave, the outer ply is a 12K (oz/yd$^2$) spread tow plain weave. The [-45/+45] plies are doubled compared to the [0/90] plies due to the lower density and thickness of each ply. The usage of multiple ply angles is to provide a near quasi-isotropic laminate to resist loads in various directions. The fins are positioned farther from the transmitting components, reducing the possibility of transmission interference and improving telemetry tracking of the launch vehicle. The laminate sees an increase in ply count with one less layer of honeycomb Nomex core compared to the bulkheads due to the desire for decreased cross-sectional area with lower drag in mind. The increased layers account for all aerodynamic loads anticipated. The most significant load anticipated is the landing from the impact kinetic energy. To provide protection on impact, the molded fin edges are constructed from chopped 1.0 (in) segments of carbon fiber tow with dyed fiberglass strands to provide an isotropic material, withstanding impacts from various directions. Fin flutter calculations were not completed due to the lack of shear modulus material properties for the fins. It would not be possible to make an assumption for the properties due to the complex manufacturing compared to solid carbon fiber laminates. The molded edge is bonded to the edges and has a small offset from the edge on the face sheet of the fins for ample bonding space. The fin tabs with a large fillet radius on the interior of the launch vehicle, connected to the motor mount tube and centering rings, provide a large reaction force to reduce the moment when large loadings impact the fins. Ply orientation and count are specified in Table 3.7.

**Motor Mount Tube**

The motor mount tube is constructed from 3 layers of 3K 5.7 (oz/yd$^2$) plain weave carbon fiber. The tube experiences primarily compressive forces from the motor thrust, which is also spread to the airframe from the aft centering ring. Due to the primarily axial forces, the motor tube does not need a significantly thick laminate for the vehicle's integrity to be met. Since the motor tube is in the aft end of the fin can, far from transmitting electronics, carbon fiber is preferred for the lower weight and higher strength, with no need to be electrically transparent.

**Payload Guide Rail**

The payload guide rails are constructed from 5 layers of 3K 5.7 (oz/yd$^2$) plain weave carbon fiber. The tube experiences primarily shear forces from the main recovery event. The tube is sufficiently thick to remove the possibility of shear failure by providing a large adhesive area for bonding.

## 3.3 Vehicle Manufacturing

### 3.3.1 Airframe Laminates

Vehicle airframe and coupler tubing will be manufactured via roll-wrapping with a wet layup. Mandrels will be prepped with sanding for a smooth surface, followed by a thin sheet of clear mylar wrapped around the mandrel to provide a releasing material for which the composite laminate can release. Dry S2 8.9 (oz/yd$^2$) satin-weave fiberglass will be wrapped over a mandrel and impregnated with the US Composites 635 thin epoxy system over multiple layers. Airframe tubes will use 6 layers of fabric wrapped about the outer diameter of the mandrel, and coupler tubes will use an additional 7th layer. Following the laminate saturation, the tubes will be compressed from a heat-shrink tubing to remove excess epoxy from the laminate and provide a smooth aerodynamic surface. A cross-section of the construction is provided in Figure 3.23.

The tubing laminates will be cut to length on a miter saw with a fine-tooth carbide-tipped blade. A slow cutting speed combined with high blade RPM will be used to not fray the ends or overheat the laminate. Fin slots will be cut into the fin can tube with a Dremel using a high RPM diamond-coated blade.

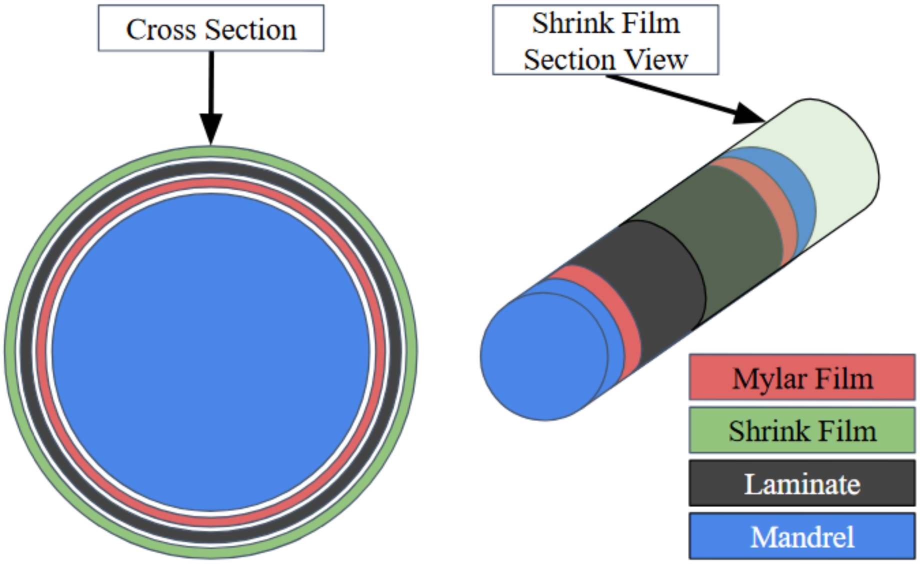


Figure 3.23: Tube laminate procedure.

### 3.3.2 Plate Laminates

All plate laminates will utilize a common wet-layup and vacuum bag procedure. Laminates are laid up in a bottom-up method following the cross-section presented in Figure 3.24. Cloth will be wet-out layer by layer with a central honeycomb Nomex core. The composite face sheets will be covered in a peel-ply fabric to provide a consistent surface finish that allows excess resin to soak through to the perforated release film and into the breather material on the top-facing face sheet. The bottom layer of perforated release film facilitates the release of the laminate from the tooling surface, addressing previous issues encountered when using only peel-ply. Following the application of a vacuum bag over the top of the laminate breather and sealant on the sides, a vacuum is pulled to release excess epoxy from the laminate. The fin laminates will use pre-cut honeycomb Nomex to the desired shape for accurate dimensions to allow for the precise attachment of the molded fin fairings.

The bulkhead, thrust plate, and centering ring laminates will utilize a double sandwich section. The initial face sheet will have a core placed on top, before a singular layer of face sheet, then another core before the final face sheet is laid up. The final sandwich composite will be CNC routed to the proper size. During the CNC routing process, holes will be drilled for the threaded rods, U-bolts, and inline Wago block flanges. The routed out holes will allow for drilled out holes with tighter tolerances.

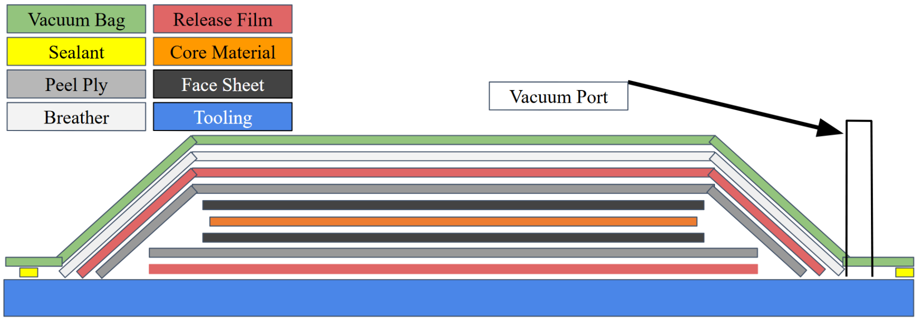


Figure 3.24: Plate laminate procedure.

### 3.3.3 Nosecone Laminate

Due to the complex curvature of the nosecone ogive shape, the nosecone laminate will utilize a three-dimensional sleeve shape of fiberglass. The sleeve fiberglass compacts and extends as the nosecone diameter shrinks along its length towards the tip. To account for the shrink from a 6 (in) diameter to a 1.75 (in) diameter aluminum tip, the nosecone will include two different diameter sleeves. Combining a 6 (in) and a 2.75 (in) diameter sleeve will allow for overlap between the central section of the nosecone and the end.

### 3.3.4 Composite Drilling

There will be multiple sets of holes drilled into the airframes and plate materials. The airframes will use a 1/8 (in) drill for through-holes for a 4-40 nylon shear pin pass through. A 3D printed alignment jig will ensure a perfect radial and axial placement of the holes. The coupler and airframe body tubing will be drilled through at the same time for perfect alignment.

The 6-32 stainless steel press-fit inserts will be mounted into the coupler tubing. The outer diameter section of the insert will be located on the inside of the coupler tubing. A # 3 gauge drill bit will be used in the coupler tubing for press-fitting the insert into place. A 5/32 (in) drill fit will be drilled into the airframe tubing with an 82° countersunk hole for the flush mount countersink screws for rigid non-in-flight separation points.

Any additional holes drilled for a vent hole, pressure port, arming switch, or various holes will follow the same procedure for safe and effective drilling. A small bead of water will be applied to the point of contact, reducing the dust from composite materials entering the air. A vacuum and proper PPE will be used during drilling procedures for safety. All parts are to be rigidly clamped with a sturdy drill press or power drill, ensuring they do not chatter or alter the anticipated hole size.

### 3.3.5 Fins

Fins will be rough cut from the fabricated laminate using a Dremel with a high RPM and a diamond-coated blade. Following an initial pass, the fins will be clamped together for sanding on a belt sander until the honeycomb Nomex is exposed on all sides, verifying the final dimension of the fin before the molded fin fairing is attached. The female fairing mold will be 3D printed from PLA plastic at a fine quality for reduced marks. Partall Paste #2 will be applied as per the manufacturer's guidelines to provide a releasing agent between the mold and the epoxy in the chopped carbon fiber tow. A mixture of chopped carbon fiber tow strands and epoxy will be mixed in a cup with an approximate 60:40 ratio of epoxy to carbon fiber, with excess epoxy to fill the gaps between fibers. The mixture will be applied into the female mold until flat with the edge of the mold with minimal open spaces. The filled mold will be pushed onto the corresponding edges of the fin and taped down to ensure coverage. Marks will be made to verify that the mold is sufficiently placed on the fin. A light sanding is anticipated after the mold is released between the fairing and the fin face sheet connections.

### 3.3.6 Fin Can

Initial fin can construction begins with the assembly of the motor tube and two forward centering rings. The centering rings will be epoxied without fillets initially. The completed fins will be epoxied into the assembly next, with internal fillets applied between the fins and the motor tube, along with the centering rings to the motor tube. The fins will be aligned primarily with the middle PLA centering ring with the matching slots; any additional alignment will be completed with a secondary fin alignment jig. The fin can tube will be dremeled with four evenly spaced slots from the aft end of the tube to the location of the fin's forward tab height. The motor mount system would then be epoxied into the fin can tube with fillets applied to the aft end of the middle centering ring and the forward end of the forward centering ring. The aft rail button, thrust plate, and the external fin fillets will be applied in the final epoxy assembly for the fin can. The aft rail button is structurally attached using the same method, a small wooden block with epoxy and small fillets. The internal and external fillets will be applied with tape for symmetrical fillets. The open aft end of the tube fin slots between the thrust plate and the fins' aft root chord location will be filled with epoxy. All structural fillets will be made with System Three Gelmagic epoxy for its no-sag properties with a 20-minute working time.

## 3.4 Subscale Flight Results

### 3.4.1 Flight Predictions

**Motor Selection**

The selected motor for the subscale launch was the AeroTech J520W motor. Table 3.8 below highlights all the motor details and specifications.

Table 3.8: Subscale motor specfications and details

| Motor | Propellant Mass (slug) | Total Mass (slug) | Total Impulse (lbf·s) | Average Thrust (lbf) | Maximum Thrust (lbf) | Burn Time (s) | Casing | Length (in) |
|---|---|---|---|---|---|---|---|---|
| J520W | 0.0261 | 0.0519 | 150.91 | 109.57 | 202.94 | 1.4 | RMS-38/1080 | 19.76 |

**Simulated Flight Profiles**

Below in Figures 3.25 and 3.26 are the simulated flight profiles without and with Air Brakes deployment, respectively. Further, Table 3.10 highlights the apogee reported, time to apogee, rail exit velocity, and total flight time without and with Air Brakes deployment.

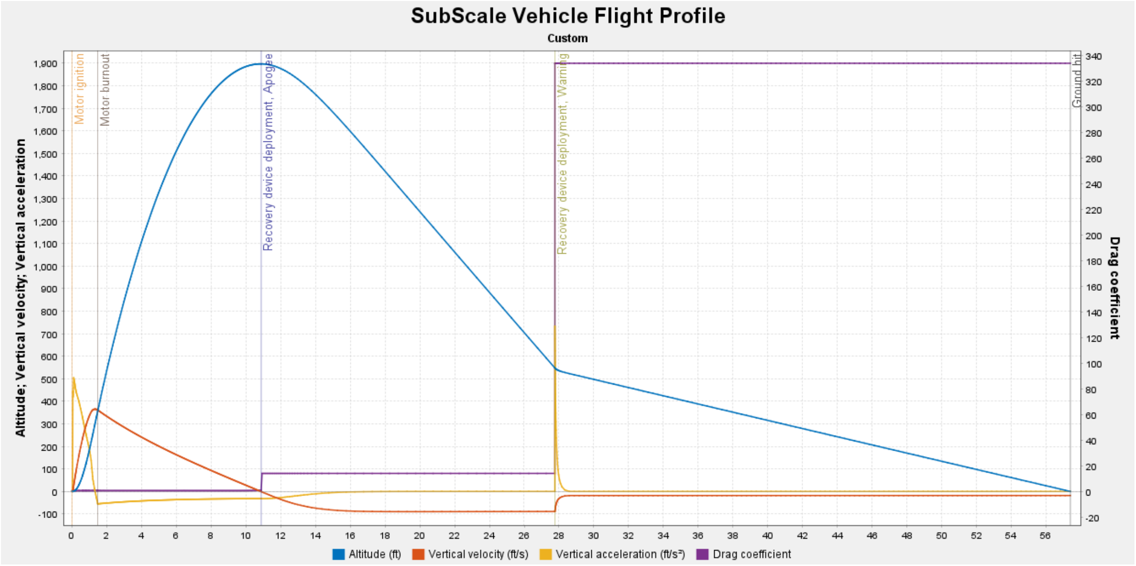


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Figure 3.25: Subscale launch vehicle simulated trajectory without Air Brakes deployment.

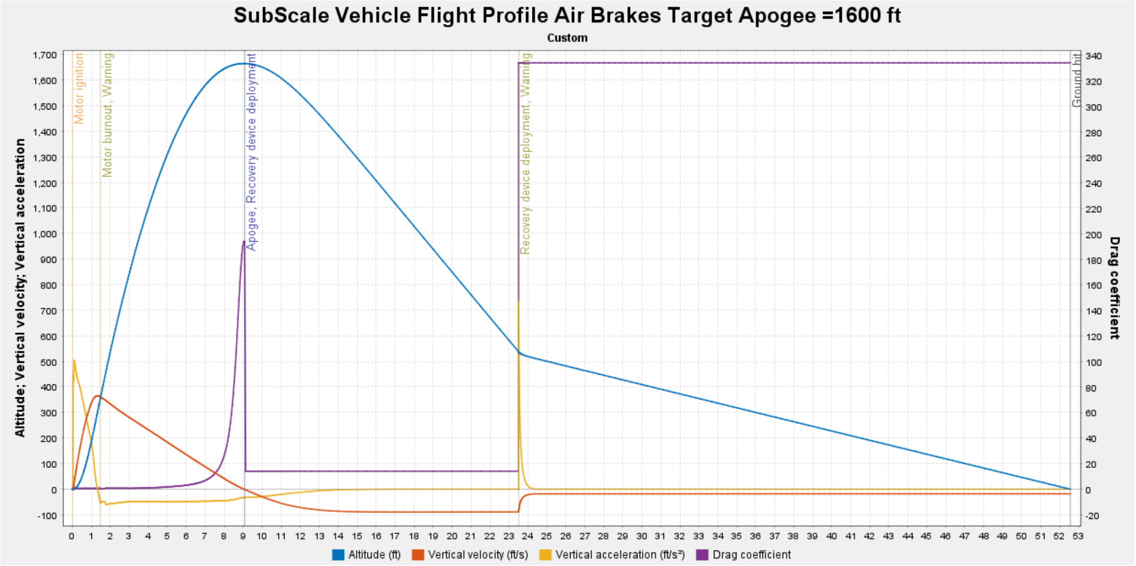


Figure 3.26: Subscale launch vehicle simulated trajectory with Air Brakes deployment.

Table 3.9: Subscale flight predictions without and with Air Brakes deployment.

| Air Brakes Deployment | Apogee | Time to Apogee | Rail Exit Velocity |
|---|---|---|---|
| No | 1897 (ft) | 10.9 (s) | 90.7 ft/s |
| Yes | 1664 (ft) | 9.03 (s) | 90.7 ft/s |

Figure 3.26 is the most realistic flight profile for the given launch day, which reports a predicted apogee of 1664 (ft). The simulations were run with a ground temperature of 64 (°F), a ground pressure of 99800 (Pa), launch rail cantilever of 5°, and day of flight wind profile and conditions shown in Figures 3.27 and 3.28 below.

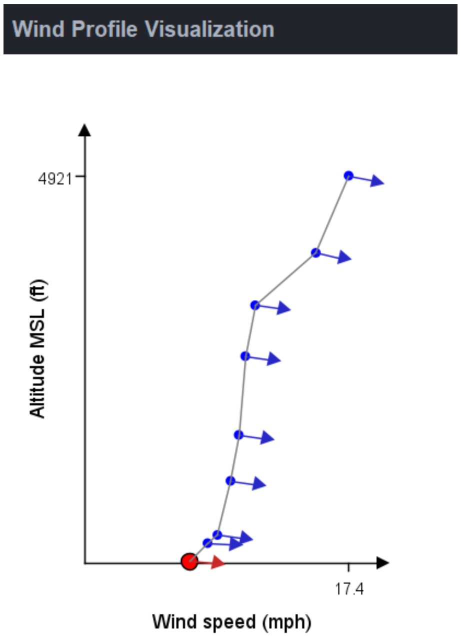


Figure 3.27: Subscale day of launch profile.

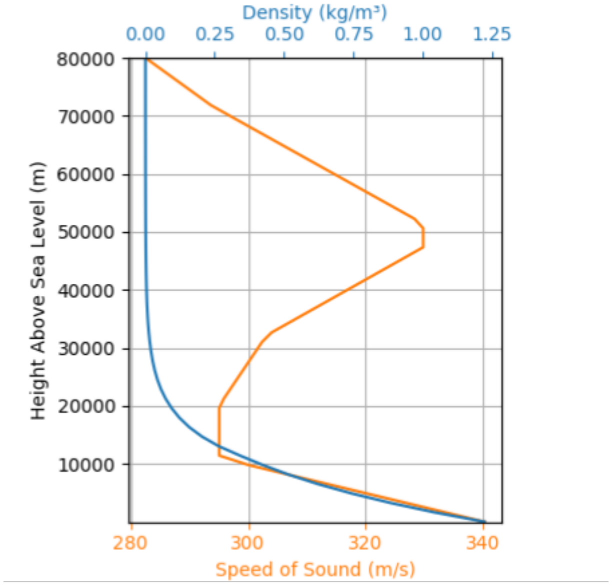


Figure 3.28: Subscale day of launch density profile.

**Static and Burnout CG Verification**

To ensure the subscale vehicle complies with NASA requirement 2.13 to maintain any protuberance outside the vehicle behind the center of mass throughout the entire flight, the static and burnout center of gravities were calculated and measured. Figure 3.29 below shows the OpenRocket view of the vehicle with the static CG calculated at 46.60 (in) from the nosecone. The calculated burnout CG location is 44.82 (in).

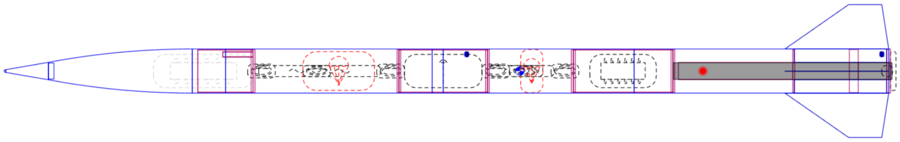


Figure 3.29: Subscale OpenRocket view with static CG at 46.72 (in).

These calculated and measured values are tabulated in Table 3.10 in which the CG always remains forward of the Air Brakes protuberance location at 58.5 (in) measured away from the nosecone, ensuring compliance with NASA Requirement 2.13.

Table 3.10: Static and Burnout CG Locations

| | Calculated | Measured |
|---|---|---|
| Static CG | 46.72 (in) | 46.6 (in) |
| Burnout CG | 44.94 (in) | 44.82 (in) |

Figure 3.30: Subscale launch.

Figure 3.31 shows the altitude over time for the subscale vehicle launch. Both the primary and secondary altimeters provided consistent altitude data. Around 11 (sec), a sudden drop in altitude is seen. This is correlated to a spike in pressure in the AV Bay, indicating a leak of ejection charge gas into the AV Bay. The leak was likely due to poorly sealed WAGO connectors on each bulkhead.

To prevent ejection charge gases from leaking into the AV Bay on the full-scale vehicle, modifications will be made to the WAGO mounting method, ensuring a complete seal at every connection. Electrical tape will also be placed over top of the WAGOs, preventing any gases from traveling through the connectors themselves.

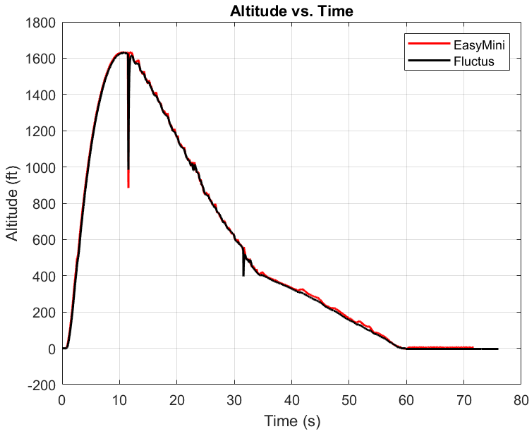
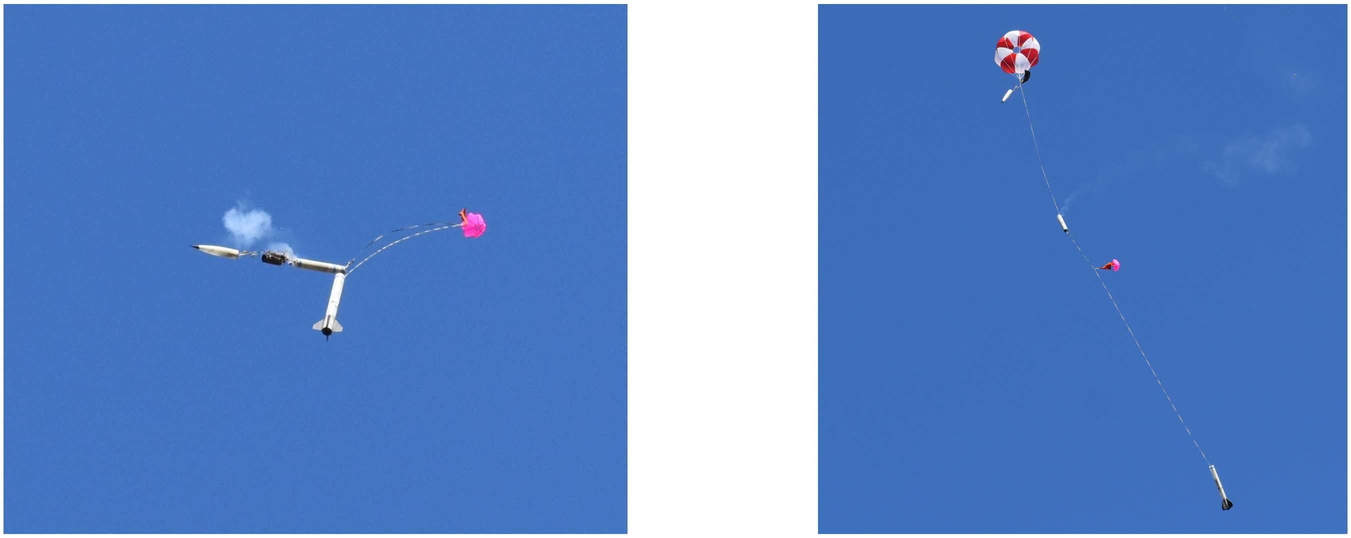


Figure 3.31: Primary and secondary altimeter altitude data.

### 3.4.2 Landing Configuration

Figure 3.32 shows the subscale launch vehicle during descent. The recovery system performed as expected, with the drogue deploying at apogee and the main parachute deploying at 550 (ft). In Figure 3.32a, the main parachute is being ejected from the vehicle, and Figure 3.32b shows the resulting successful deployment.



(a) Main parachute deployment.

(b) Descent under main parachute.

Figure 3.32: Deployment configurations.

An observed discrepancy was that the vehicle's descent rate under drogue was significantly lower than predicted. The measured drogue descent velocity was 54 (fps), compared to a predicted value of 91 (fps), resulting in a longer descent time. This behavior is attributed to the fin can falling in a horizontal orientation during portions of the drogue descent rather than maintaining a vertical orientation directly under the drogue parachute. This configuration increased the effective area normal to the descent direction, thereby producing higher aerodynamic drag. For the full-scale vehicle, the increased fin can mass is expected to encourage a more stable, vertical orientation during drogue descent, mitigating this issue.

Figures 3.33, 3.34, and 3.35 show the landing configuration of the launch vehicle.

Figure 3.33: Subscale Nosecone landing configuration.

Figure 3.34: Subscale Main Bay and AV Bay landing configuration.

Figure 3.35: Subscale Fin Can landing configuration.

The launch vehicle's recovery system behaved as expected, with the drogue parachute remaining attached to the fin can and aft end of the AV Bay, and the main parachute attached to the forward end of the AV Bay and Nosecone. All vehicle sections remained properly connected via the shock cord system throughout deployment, descent, and landing. No structural or component damage was observed upon landing, and no tangling of shock cords or parachutes occurred at any point during recovery. Altimeter data indicated a landing descent rate of 17.4 (fps) and a total descent duration of 61.9 (s), with an overall drift of approximately 36 (ft) from the launch pad.

### 3.4.3 Scaling Factors

The subscale launch vehicle is an approximate 2/3 scale of the final vehicle design with values presented in Table 3.11. The outer diameter of the subscale launch vehicle was scaled from 6.12 (in) to 4.00 (in). The fin can tube, main parachute bay, and drogue parachute bay were increased in length compared to the 2/3 scaling. The fin can tube was increased due to a larger 38/1080 Aerotech reloadable casing as the subscale flight vehicle motor casing of choice. The parachute bays were increased in size to ensure ample recovery volume relative to the sections. The full-scale launch vehicle's nosecone includes an extended 9.00 (in) airframe diameter region for payload volume. The subscale vehicle will be shortened to a 3.00 (in) section due to the reduced payload size in the subscale vehicle. The reduced payload size additionally ensures that the subscale vehicle length does not exceed the 3/4 scaling factor.

| Parameter | Subscale | full-scale | Scale |
|---|---|---|---|
| Length (in) | 80.1 | 110 | 72.8% |
| Diameter (in) | 3.98 | 6.12 | 65.0% |
| CG (in) | 46.6 | 66.1 | 70.5% |
| CP (in) | 63.1 | 85.2 | 74.1% |
| Stability (cal) | 4.15 | 3.13 | - |
| Launch Mass (lbm) | 12.1 | 36.9 | 32.8% |

Table 3.11: Subscale vs full-scale Rocket Comparison

### 3.4.4 Subscale Manufacturing

Much of the materials for the subscale launch vehicle were designed similarly to the full-scale launch vehicle to keep the process consistent between vehicles. The airframe tubing uses the same S2 fiberglass cloth and roll-wrapping method with the difference in using peel-ply on the outer surface rather than a heat-shrink tubing. The nosecone remains constant with tubular fiberglass sleeve and no outer layer consolidation due to the complex shape. All of the bulkhead, centering ring, and fin material kept the 0.125 (in) honeycomb Nomex core with fiberglass or carbon fiber face sheets depending on the location. The layups used less layers compared to the full-scale vehicle due to lower aerodynamic and recovery loading conditions. The leading, trailing, and tip edges of the fins did not use a molded fin fairing but instead left a wooden edge. Small wooden strips were placed into the layup at the edges to reduce the manufacturing time and complexity for the subscale launch vehicle.

### 3.4.5 Analysis of Subscale Flight

#### Launch Day Flight Profile and Errors Analysis

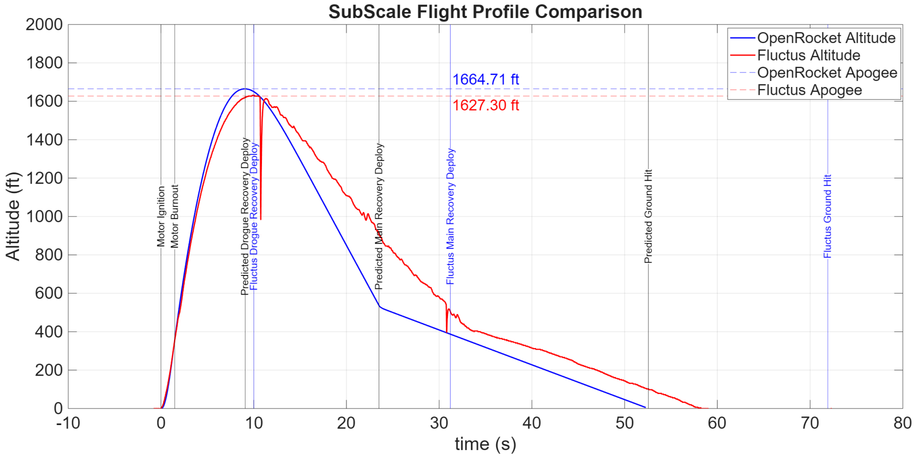


Figure 3.36: Subscale launch profile comparison between simulation and primary altimeter.

Figure 3.37: Air Brakes deployment during ascent.

Figure 3.36 shows the simulated trajectory with Air Brakes deployment and the primary altimeter data. The Fluctus reported an apogee of 1627 (ft), while the simulation predicted an apogee of 1664 (ft), indicating a 2.27% reduction in apogee. In both instances, Air Brakes were deployed as intended, as shown in Figure 3.37. The launch conditions were nearly identical and the launch time was similar. The percent error is relatively small, which bodes well for the fidelity of the simulations conducted. However, on launch day, a sudden gust of wind caused the vehicle to veer upwind, thereby reducing apogee and increasing overall flight times. Table 3.13 highlights all differences measured and errors experienced in the predicted values. To ensure that as many variables as possible are accounted for on the Fullscale vehicle, Monte Carlo simulations will be employed to understand better how varied initial conditions affect flight times, landing locations, and apogee. This is further explored in Section 3.6.6 using a table that lists the parameters varied and their corresponding standard deviations.

Table 3.12: Subscale Error Analysis

| | Flight | Prediction | Percent ErrorFlight vs Prediction |
|---|---|---|---|
| Apogee (ft) | 1627 | 1664 | 2.27% |
| Time to Apogee (s) | 10.01 | 9.03 | 9.79% |
| Main Parachute Deployment (s) | 31.2 | 23.51 | 24.65% |
| Time to Ground (s) | 71.91 | 52.66 | 26.77% |

Moreover in Figure 3.38 shows the landing location distribution from a small Monte Carlo simulation run of the Subscale vehicle along with Google Earth view of the simulated trajectory in RocketPy in Figure 3.39.

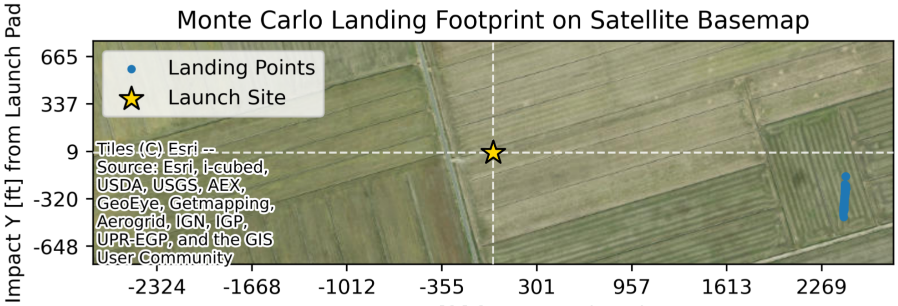


Figure 3.38: Subscale landing locations from Monte Carlo simulations.

Figure 3.39: Subscale Google Earth view of simulated trajectory.

### Drag and Cd Calculation

Using data collected from the subscale launch flight, the vehicle's Cd can be measured and compared with that derived from CFD analysis in ANSYS Fluent. The derivation applies only during the coast phase of flight, as the primary forces acting on the vehicle are limited to weight and drag. Equation 3 shows that the relationship between weight, acceleration, and drag force can be approximated via Newton's Second Law of motion for the launch vehicle. Equation 4 is the total drag force when Air Brakes is deployed. M is burnout mass, acceleration, a, is given from the Fluctus data, gravitation acceleration is constant and represented by g, $F_{d,roc}$ is the drag force for the rocket, and $F_{d,AB}$ is the Air Brakes drag force.

$$F_{d,roc} = -m(g + a) \tag{3}$$

$$F_{total} = F_{d,roc} + F_{d,AB} \tag{4}$$

Once $F_d$ can be calculated, Equation 5 shows $C_d$ can be calculated.

$$C_d = \frac{2\,F_{\text{total}}}{\rho\,v^2\left(S_{\text{ref,rocket}} + S_{\text{ref,airbrakes}}\right)}. \tag{5}$$

Table 3.13 tabulates the peak $C_d$ at Mach 0.32 garnered from the equations above and the percent difference to the calculation. The frontal area with Air Brakes deployed was found to be 22.9 (in$^2$). The Estimated value is 1.17% greater than the estimated showing additional confidence in the simulation strategy and results.

Table 3.13: Subscale Error Analysis

| $C_d$ Estimated | $C_d$ Predicted | Percent Difference |
|---|---|---|
| 0.512 | 0.506 | 1.17% |

### 3.4.6 Fullscale Design Modifications

The Subscale flight proved the general viability of the vehicle and Air Brake designs. Air Brakes deployed as intended, along with more than adequate data acquisition. The primary modification to the full-scale recovery system, informed by subscale flight results, involves resizing the drogue and main parachutes. The subscale vehicle experienced a significantly longer descent time than predicted, prompting a reduction in the full-scale drogue parachute diameter from an 18 (in) elliptical canopy to a 15 (in). Additionally, the full-scale recovery system has been updated to incorporate a 120 (in) Fruity Chutes Iris Ultra Compact parachute in place of the previously selected 96 (in) Iris Ultra. Collectively, these modifications are intended to provide increased flexibility in meeting descent time requirements.

Moreover, simulation accuracy needs to be tightened due to a small difference from simulated and flight apogee. Apogee prediction worked as intended to deploy Air Brakes but a second Subscale flight is required to further test the INS integration along with a tuned RK4 apogee prediction method. The apogee prediction changes are further explained in Section 5.4.3. The current design will continue to be independent of ballast weight due to the amount of control authority the current Air Brake fin design affords the launch vehicle.

## 3.5 Recovery Subsystem

The recovery system employs a dual-event deployment sequence consisting of a drogue and main parachute. The first event is initiated at apogee, where the primary altimeter triggers the primary drogue black powder charge located on the aft side of the avionics bay. One second later, the secondary altimeter fires its redundant drogue charge. The resulting pressure rise within the drogue bay breaks the shear pins securing the fin can to the drogue bay, allowing the sections to separate and the drogue parachute to deploy. The launch vehicle then descends in a controlled manner under drogue until the second recovery event is initiated.

The main parachute is deployed at 550 (ft), when the primary altimeter ignites the primary main separation charge on the forward end of the AV bay. At 500 (ft), the secondary altimeter activates its redundant main charge. These charges pressurize the main parachute bay, breaking the shear pins that attach it to the nosecone and allowing the main parachute to deploy. The vehicle then descends under the main chute for the remainder of flight.

In this configuration, a Silicdyne Fluctus serves as the primary altimeter and an Altus Metrum EasyMini functions as the secondary altimeter. The Fluctus' integrated GPS module provides vehicle tracking. The recovery hardware includes an 18 (in) custom elliptical drogue parachute and a 96 (in) Fruity Chutes Iris Ultra Compact main parachute.

### 3.5.1 Concept of Operations

The concept of operations is divided into four distinct phases. Phase 1 corresponds to vehicle ascent, Phase 2 to descent under the drogue parachute, Phase 3 to descent under the main parachute, and Phase 4 to landing. Prior to launch, both the primary and secondary altimeters are powered on at the launch pad by removing the pull-pin switch. The primary altimeter connects to the handheld ground station and associated software, through which igniter continuity and GPS transmission are verified, and manual arming is performed. The recovery team verifies ejection charge continuity on the secondary altimeter via its status beeps. The vehicle is cleared for launch only after all recovery avionics have been confirmed to be fully operational.

During Phase 1, upon reaching apogee, the primary altimeter triggers the first deployment event by igniting the primary drogue ejection charge, followed one second later by ignition of the secondary drogue charge by the secondary altimeter. This deployment separates the vehicle between the Drogue Bay and the Avionics Bay (AV Bay), allowing drogue parachute deployment. The vehicle then descends under the drogue parachute with the forward section maintaining a minimum separation of 8 (ft) above the drogue bay.

When the vehicle descends to an altitude of 550 (ft), the primary altimeter initiates the main parachute deployment by igniting the primary main ejection charge, followed at 500 (ft) by the secondary altimeter igniting the redundant main charge. The main parachute is subsequently deployed, allowing the vehicle to transition into the main descent phase. During this stage, all vehicle sections remain separated by at least 8 (ft) to prevent entanglement and damage.

The vehicle continues to descend under the main parachute until it reaches the ground. The recovery system is designed such that the vehicle lands without structural damage. The vehicle is designed to land with a maximum kinetic energy of less than 65 (ft-lbf) upon impact, a total descent duration under 80 (s), and a maximum horizontal drift distance of less than 2,500 (ft).

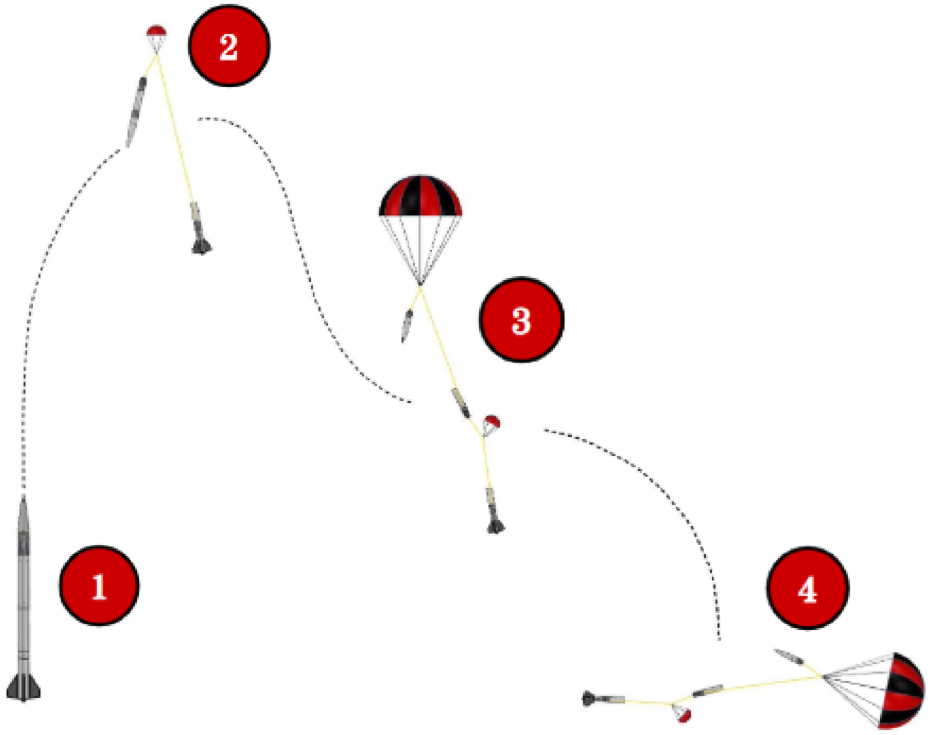


Figure 3.40: Recovery system CONOPS.

### 3.5.2 Recovery Hardware

**Parachutes**

For the drogue parachute, a custom 15 (in) elliptical parachute with an estimated drag coefficient of 1.5 has been selected. In PDR, an 18 (in) elliptical parachute was chosen, however due to updated mass estimates the Team has decided to decrease to a 15 (in) drogue. The drogue assembly will be housed in the Drogue Parachute Bay, located aft of the AV Bay. A Nomex blanket will protect the parachute from the drogue ejection charges. The selected parachute provides a descent rate that satisfies NASA requirements 3.10 and 3.11, concerning drift distance and descent time. Based on a mass of 35.35 (lbm), the calculated descent velocity under drogue, neglecting body drag, is 129.66 (fps).

For the main parachute, the Team has selected a 120 (in) Fruity Chutes Iris Ultra Compact with a drag coefficient of 2.2. The change in parachute selection since PDR was made because of updated vehicle mass estimates. The parachute will be contained within a deployment bag for protection and organized deployment. The main assembly will be stored in the Main Parachute Bay, positioned forward of the AV Bay. The deployment bag ensures reliable deployment by securing the canopy and shroud lines until ejection. The shroud lines will be z-folded and retained within external straps on the bag, allowing them to fully extend during deployment and minimizing the potential for line entanglement. Similar to the Nomex blanket used for the drogue system, the deployment bag protects the parachute from the main ejection charges.

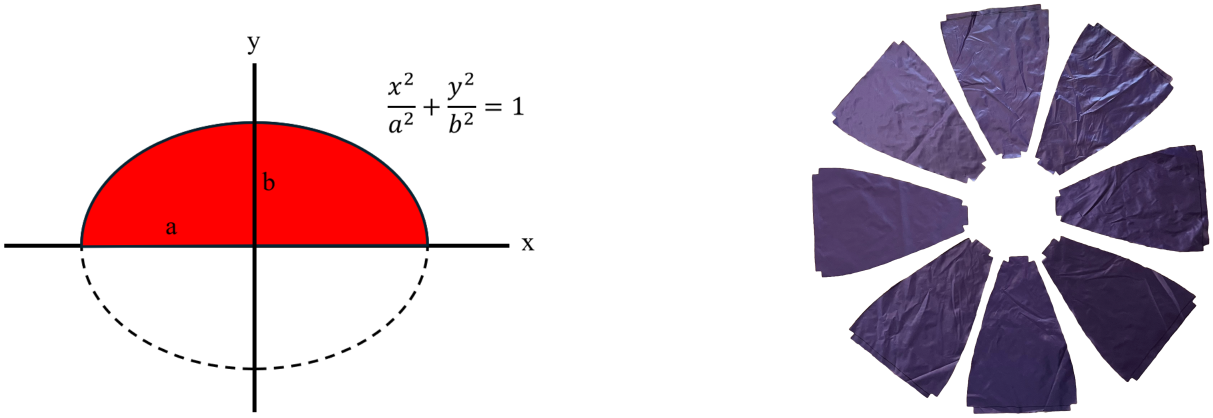
The main parachute was selected due to accessibility and its demonstrated compatibility with the 15 (in) drogue parachute. This configuration ensures the heaviest section of the vehicle lands with less than 65 (ft-lbf) of kinetic energy while landing in under 80 (s), satisfying bonus criteria for both requirements. Additionally, this recovery system guarantees that the vehicle will remain within 2,500 feet of the launch pad during descent. For calculations regarding kinetic energy, descent time, and drift distance, see sections 3.6.7, 3.6.8, and 3.6.9, respectively.

**Parachute Design**

As mentioned in section 3.5.2, the Team will fabricate a custom drogue parachute for the launch vehicle. Based on descent velocity, descent time, and kinetic energy calculations, shown in sections 3.6.7, 3.6.8, and 3.6.9, a 15 (in) drogue parachute size has been selected. The parachute will have an elliptical canopy, which reduces the required amount of material while maintaining similar performance to a hemispherical canopy.

The parachute will have an aspect ratio of $\frac{b}{a} = 0.707$, shown in Figure 3.41a. An aspect ratio of 0.707 balances curvature from the crown to the skirt, which leads to a more uniform membrane stress distribution. This shape balances meridional and hoop stresses, reducing peak loads at common failure points like the apex and skirt. As a result, the canopy experiences lower maximum stress and improved structural reliability during deployment and descent.

A 3 (in) spill hole is included in the design. A spill hole can lessen the shock loads on the parachute during deployment, as well as improve stability during descent. The spill hole accounts for approximately 4% of the canopy area. The parachute is designed with eight gores, shown in Figure 3.41b, providing a smooth inflated geometry and structural integrity.



(a) Elliptical design.

(b) 15 (in) parachute gores.

Figure 3.41: Drogue parachute design.

**Parachute Material Selection**

The custom parachute will be sewn using calendared ripstop nylon fabric. Calendared nylon has a tensile strength of 24.7 (lbf/in) compared to nylon with a polyurethane coating, which has a tensile strength of 18.9 (lbf/in). Figure 3.42 depicts the difference between a typical fabric weave and a ripstop weave. In ripstop fabric, thicker yarns are woven at regular intervals ranging from 0.2 to 0.3 (in)[16]. These thicker threads, shown in blue, act as reinforcing ribs that possess significantly higher tensile strength compared to the surrounding yarns. This structural arrangement increases the fabric's resistance to tear propagation, effectively preventing small tears from expanding and thus improving the overall durability and reliability of the material.

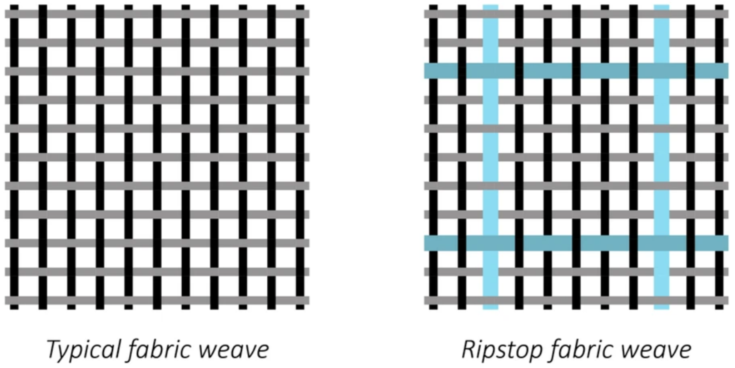


Figure 3.42: Typical fabric weave vs. ripstop fabric weave.[16]

100% bonded nylon thread will be used to sew the parachute. Bonded nylon thread offers high tensile strength, flexibility, and excellent resistance to abrasion, chemicals, and environmental factors such as moisture and UV exposure. It maintains its performance under the repeated stresses of parachute deployment and heavy loads typical in rocketry applications. In contrast, cotton thread, while soft and easy to handle, is more prone to breaking under tension and degrades quickly when exposed to moisture, abrasion, or prolonged use.

Kevlar is a popular choice for parachute shroud lines due to its excellent abrasion resistance and thermal stability, which help ensure the lines remain intact under the harsh conditions of launch vehicle deployment and descent. Kevlar is extremely durable and is easier to sew and handle compared to materials like ultra-high-molecular-weight polyethylene. This ease of sewing can result in more reliable and secure attachment points. Additionally, Kevlar's ability to resist cuts and wear better protects the shrouds from damage caused by sharp edges or rough surfaces.

A variation of the traditional flat-felled seam will be used. A flat-felled is strong and durable, fabric edges are folded and sewn together in such a way that all raw edges are fully enclosed within the seam. Typically, one seam allowance is trimmed narrower, and then the wider edge is folded over it before being stitched down, creating a flat, clean finish with two rows of topstitching. This technique produces an exceptionally strong and durable seam capable of withstanding substantial tensile loads and abrasion, making it a favored choice in rocketry applications. For parachutes, flat-felled seams are ideal because they minimize bulk while preventing fabric fraying and seam failure during the high stresses of deployment and descent. The secure, enclosed edges reduce the risk of seam unraveling and distribute loads evenly. The variation of the flat-felled seam that will be used is shown in Figure 3.43b.


(a) Traditional flat-fell seam.

(b) Flat-fell seam variation.

Figure 3.43: Flat-fell seam variations.

**Parachute Opening Shock**

In order to calculate the maximum opening shock force the recovery system will experience, the inflation time of the parachute must be obtained. The largest force acting on the launch vehicle will be when the main parachute is deployed, slowing the launch vehicle from 129.66 (fps) to 13.33 (fps). Equation 6 is used to estimate the inflation time,

$$t_{infl} = \frac{nD}{v_d} \tag{6}$$

where $t$ is the time it takes for the parachute to inflate, $n$ is the canopy fill constant, $D$ is the nominal diameter of the parachute, and $v_d$ is the descent velocity at the time of opening. Using an approximated canopy fill constant of 4, a nominal diameter of 120 (in), and a descent velocity of 129.66 (fps), the parachute inflation time is calculated to be 0.3085 (s). The expected shock force on the shock cord is then calculated using Equation 7,

$$F_{shock} = \frac{m\Delta v}{t_{infl}} \tag{7}$$

where $F_{shock}$ is the shock force, $m$ is the dry mass of the launch vehicle, $\Delta v$ is the change in velocity, and $t_{infl}$ is the previously calculated inflation time. Using a dry mass of 35.35 (lbm), a change in velocity of 116.33 (fps), and an inflation time of 0.3085 seconds, the maximum force the shock cord will experience is 414 (lbf).

**Recovery Harness**

1/2 (in) Kevlar shock cord will be used to keep each section of the launch vehicle connected during descent. 5/8 (in) shock cord was initially selected in PDR, however, the additional strength provided by the 5/8 (in) cord is unnecessary. Thicker shock cord also increases the mass of the recovery system significantly. Kevlar shock cord was chosen for its strength rating of 6000 (lbf) and its resistance to tearing and heat abrasion.

The length of the shock cord plays an important role in preventing collisions between vehicle sections during descent. A longer shock cord allows for gradual absorption of separation forces, reducing the risk of damage such as zippering. Per team-derived requirement RD 6, there is to be a minimum of 8 (ft) separation between each vehicle section during descent. To accommodate this requirement, a system of equations is used to calculate the required length of shock cord.

Figure 3.44a depicts the descent configuration of the launch vehicle following the deployment of the drogue parachute. In the diagram, $D_1$ denotes the distance between the AV Bay U-bolt and the drogue parachute connection point, while $D_2$ represents the distance from the fin can U-bolt to the same parachute connection. The chosen parachute connection point is positioned 24 (in) from the AV Bay connection, ensuring it is closer to the AV Bay end. Considering these lengths along with the combined length of the forward sections of the launch vehicle, $L_{FWS}$, and the length of shock cord contained within the fin can, $D_{FC}$, the total drogue shock cord length, $L_{drogue}$, can be determined using the following system of equations.

$$L_{drogue} = D_1 + D_2 \tag{8}$$

$$D_2 = 4D_1 \tag{9}$$

$$D_2 - D_{FC} = D_1 + L_{FWS} + 96 \text{ (in)} \tag{10}$$

Using a $L_{FWS}$ of 59.50 (in) and a $D_{FC}$ of 23.00 (in), the minimum length of shock cord needed to satisfy all requirements is 226.6 (in), or 18.88 (ft). A shock cord of length 19 (ft) will be used for drogue deployment.

Figure 3.44b illustrates the configuration of the launch vehicle during descent following the main parachute separation event. Consistent with the requirements applied during drogue parachute descent, a minimum separation distance of 8 (ft) must be maintained between all vehicle sections. Specifically, this necessitates a minimum spacing of 8 (ft) between the tip of the nosecone and the upper attachment point of the Main Parachute Bay.

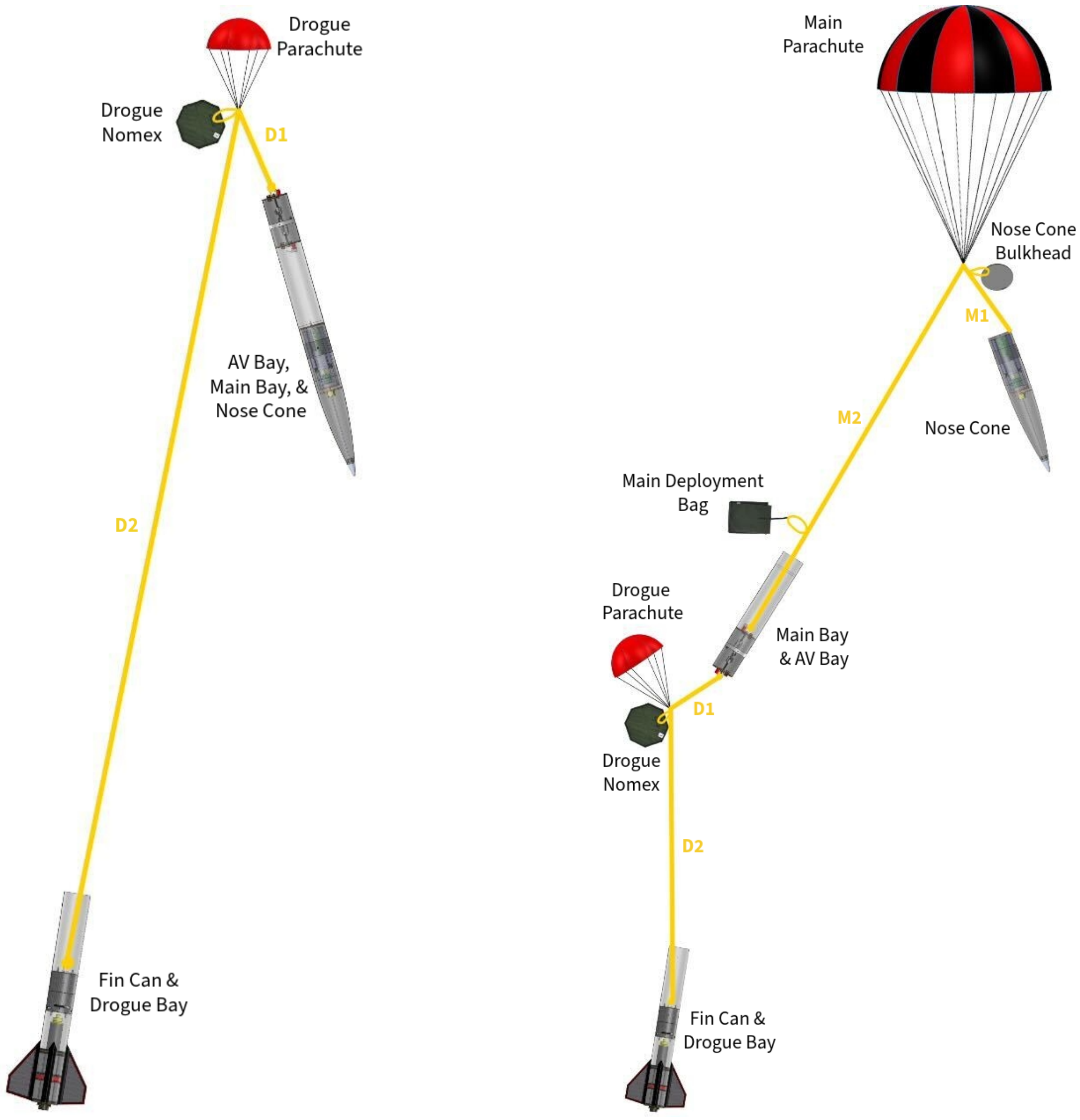
In the figure, $M_1$ denotes the distance between the nosecone U-bolt and the parachute attachment point, while $M_2$ represents the distance between the Main Parachute Bay U-bolt and the parachute connection. Analogous to the drogue shock cord configuration, the parachute attachment point is positioned 24 (in) from the nosecone connection. Using these constraints along with the known nosecone length, $L_{NC}$, and the length of main shock cord contained within the Main Parachute Bay, $M_{MPB}$, the total main shock cord length, $L_{main}$, is calculated using the following system of equations.

$$L_{main} = M_1 + M_2 \tag{11}$$
$$M_2 = 4M_1 \tag{12}$$
$$M_2 - M_{MPB} = M_1 + L_{NC} + 96 \text{ (in)} \tag{13}$$

Using a nosecone length of 31.50 (in) and the length of shock cord contained within the Main Parachute Bay being 28.00 (in), the required length of shock cord is 203.5 (in), or 16.96 (ft). A length of 17 (ft) of shock cord will be used for the main parachute deployment. Table 3.14 summarizes the minimum lengths of the shock cord required to satisfy team-derived requirement RD 6.

Table 3.14: Minimum shock cord lengths

| **Drogue Configuration** | |
|---|---|
| **D1** | 24 (in) |
| **D2** | 202.6 (in) |
| **Total Length** | 226.6 (in) |
| **Main Configuration** | |
| **M1** | 24 (in) |
| **M2** | 179.5 (in) |
| **Total Length** | 203.5 (in) |



(a) Drogue deployment configuration.

(b) Main deployment configuration.

Figure 3.44: Deployment configurations.

Commercial soft, shown in Figure 3.45, links will be used to connect the shock cord to the launch vehicle attachment points. In this setup, the shock cord is attached to the launch vehicle's U-bolt via the soft link, replacing traditional metal quick links. The shock cord itself is secured with a bowline knot to the soft link. The parachute is also connected to the shock cord by a soft link, using an alpine butterfly knot.

Figure 3.45: Kevlar soft link.

### Nosecone Attachment

In order to accommodate the Team's payload design, a unique recovery attachment will be employed for the launch vehicle's Nosecone. A 24 (in) length of 1/2 (in) Kevlar shock cord, previously denoted as $M_1$, will be routed through one of two carbon fiber tubes mounted in the Nosecone shoulder. The custom carbon fiber tubes double as guide rails for the Team's payload. Each tube will be epoxied to the side of the shoulder, ensuring a secure attachment point. A knot will be tied at the forward end of the tube, preventing the shock cord from slipping out. Epoxy will be used to fill any remaining volume in the tube. Figure 3.46 illustrates the intended attachment.

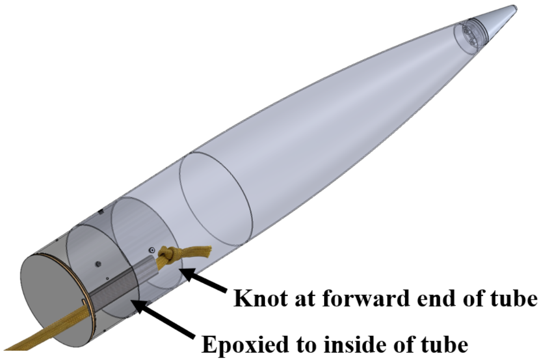


Figure 3.46: Nosecone attachment.

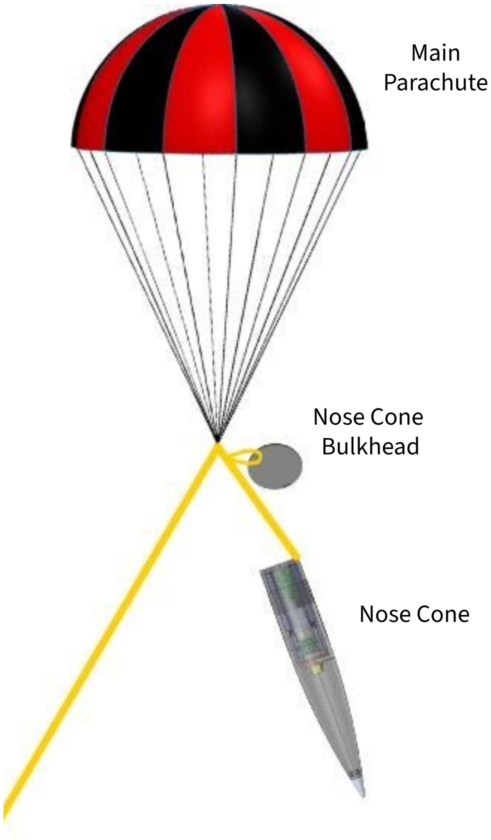


Figure 3.47: Nosecone Bulkhead.

In order to both protect the Team's payload assembly from the main ejection charges and allow the payload to deploy from the Nosecone, the Nosecone Bulkhead will be removed during main deployment. During ascent and descent under drogue parachute, the Nosecone bulkhead will remain in place utilizing an internal switch-band mounted in the Main Parachute Bay. The Nosecone Bulkhead is attached, via a short length of shock cord, to the main parachute attachment point. When the main parachute is deployed, the bulkhead will be pulled off the Nosecone, exposing the payload. With this design, the payload will be protected from ejection charges, while also being able to deploy after landing.

### Factor of Safety

Table 3.15 shows each recovery component and its respective strength rating. The weakest component in the recovery system is the 120 (in) Fruity Chutes Parachute, with a strength rating of 2200 lbf. With an expected maximum shock force of 414 lbf, calculated in section 3.5.2, the recovery system has an overall factor of safety of 5.31.

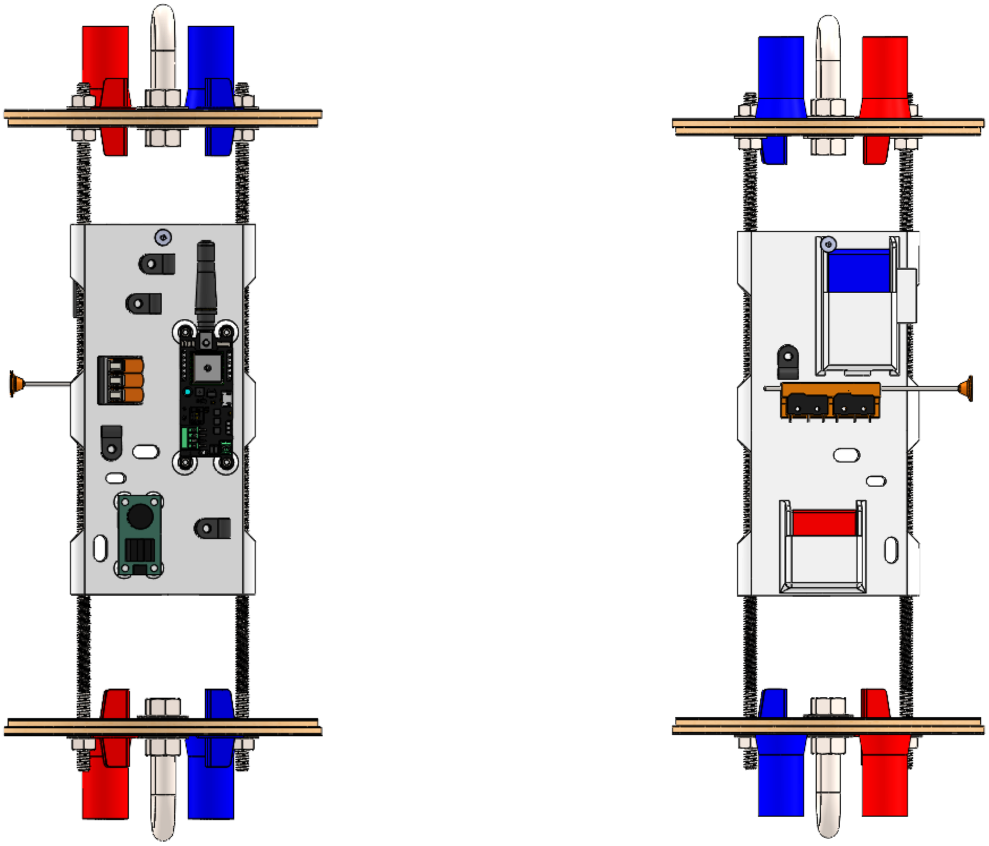
Table 3.15: Recovery components strength ratings

| Component | Strength Rating (lbf) |
|---|---|
| 120 (in) Fruity Chutes Iris Ultra Compact Parachute | 2200 |
| 4 x 6-32 (in) Steel Screws | 2440 |
| 3/8 (in) Stainless Steel U-bolt | 3500 |
| Fiberglass Bulkhead | 3540 |
| 2 X 1/4-20 (in) Stainless Steel Threaded Rods | 4220 |
| 1/8 (in) Kevlar Soft Link | 5130 |
| 1/2 (in) Kevlar Shock Cord | 6000 |
| Epoxied Nosecone Attachment | 10000 |

### 3.5.3 Recovery Electronics

### Avionics

Figure 3.48 shows the vehicle's AV Bay, located between the Drogue and Main Parachute Bays. This compartment houses all avionics components, including two altimeters, two batteries, and a double pull-pin arming switch. The avionics sled is manufactured using 3D printed PLA, allowing for ease of customization.



(a) AV sled (front view).

(b) AV sled (back view).

Figure 3.48: AV sled.

The Team selected the Silicdyne Fluctus as the primary altimeter, with the Altus Metrum EasyMini serving as the secondary altimeter. Both devices are mounted on the same face of the AV sled, as depicted in Figure 3.48a. Assembly is facilitated by 3D printed standoffs equipped with heat-set threaded inserts to ensure secure mounting. The sled integrates wire clamps that maintain cable organization and minimize interference by keeping all wiring flush with the sled surface. A WAGO splicing connector is utilized to distribute the Fluctus' common positive lead to the individual igniter circuits.

A battery for each altimeter and the double pull-pin switch are mounted on the back of the AV sled, seen in Figure 3.48b. The batteries are secured in place using 3D printed slots, as well as Velcro for additional security.

Figure 3.49 illustrates the wiring diagram for the Fluctus. This circuit operates independently from all other avionics systems and is powered by a 7.4 (V) 800 (mAh) LiPo battery. The Fluctus incorporates two terminal blocks, which secures wires to establish all electrical connections to the altimeter. The power connection is routed through the pull pin switch to enable controlled activation. Figure 3.50 shows the wiring layout for the EasyMini. This device operates on a dedicated 3.7 (V) 500 (mAh) LiPo battery. Similar to the Fluctus configuration, the EasyMini features two terminal blocks that secure the wires, forming all necessary electrical connections to the altimeter. Additionally, one of the pull-pin microswitches interfaces directly with the EasyMini's integrated switch.

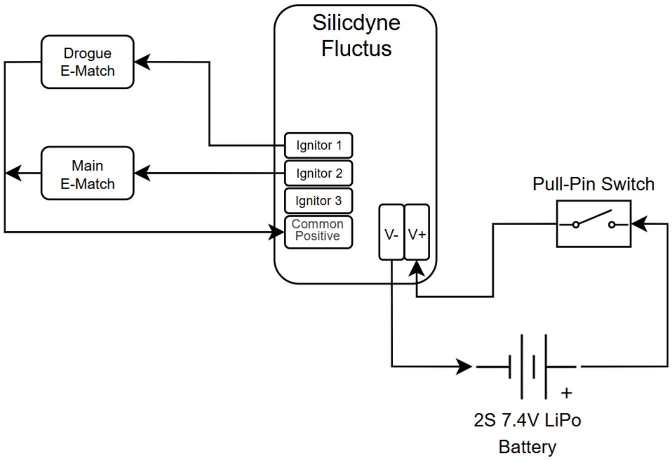


Figure 3.49: Primary altimeter wiring diagram.

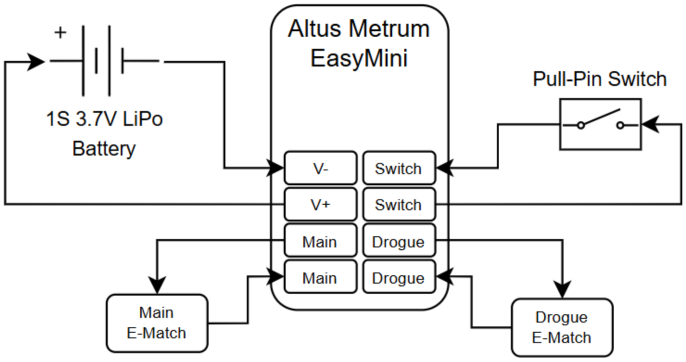


Figure 3.50: Secondary altimeter wiring diagram.

### Tracking

The built-in GPS unit on the Silicdyne Fluctus will be used to facilitate tracking of the launch vehicle. The tracker operates on a 900 (MHz) frequency band, meaning a HAM license is not required. The transmitting frequency will be 869.4625 (MHz) This device satisfies NASA requirement 3.12, in addition to meeting the minimum transmission range requirement of 5000 (ft). The tracker has an on-ground range of 6 (mi), which lies well within the size of the recovery zone. Fluctus documentation indicates that the transmitter draws 160 mW of power, satisfying NASA Requirement 2.20.8 [**?** ]. Using the Fluctus' integrated GPS simplifies the vehicles avionics system, eliminating an additional device and battery.

### Batteries

A 7.4 (V) 800 (mAh) LiPo battery will be used for the Fluctus, as recommended by the manufacturer. The Fluctus has a maximum power draw of 400 (mW), thus the operating time can be calculated using Equation 14,

$$t = \frac{QU}{P} \tag{14}$$

where $t$ is operating time, $Q$ is battery capacity, $U$ is battery voltage, and $P$ is device power. The 7.4 (V) LiPo battery will sustain the Fluctus for 14.8 hours.

The Altus Metrum EasyMini will be supplied power via a 3.7 (V) 500 (mAh) LiPo battery. With a nominal current draw of 10 (mA), the 3.7 (V) LiPo will be able to power the EasyMini for 185 hours. Both battery choices satisfy NASA Requirement 2.2, that devices should remain launch-ready for a minimum of 3 hours without losing functionality or any critical on-board components. All LiPo batteries used for avionics have a nominal discharge temperature range from -4 (°F) to 140 (°F), satisfying team-derived requirement RE 3.

### 3.5.4 Ejection Charges

Ejection charges are employed to separate the individual sections of the launch vehicle and initiate parachute deployment. The sequence begins when altimeters activate the Firewire Electric Matches housed within the charge wells at both ends of the AV Bay. The charge wells are fabricated using 3D printed PLA. Upon ignition, these e-matches light the black powder, which rapidly generates a high pressure environment inside the parachute bays. This elevated pressure produces sufficient force to break the shear pins, thus separating the launch vehicle sections. The pressure required to break the shear pins is calculated using Equation 15,

$$P = \frac{F}{A} \tag{15}$$

where $P$ is pressure, $F$ is the force required to break the shear pins, and $A$ is the cross-sectional area of the launch vehicle. Four 4-40 shear pins will be used to keep the sections of the launch vehicle in place until specified recovery events take place. The shear pins have a known strength of 76 (lbf). Knowing the shear strength of the shear pins and the cross-sectional area of the launch vehicle, 28.27 (in$^2$), the pressure required to break four shear pins is calculated to be 10.75 (psi). A factor of safety of 1.5 is applied to the pressure required to break the shear pins, giving a required pressure of 16.125 (psi). The mass of the black powder charge can then be calculated using the ideal gas law,

$$m = \frac{PV}{RT} \tag{16}$$

where $P$ is the pressure required to break the shear pins, $V$ is the volume of the section, $R$ is the gas constant for black powder, and $T$ is the temperature of the gas produced by black powder combustion.

777 FFFg black powder will be used for the ejection charges. This black powder has been selected based on its fine particle size, which promotes quick combustion, cleaner separation events, and minimal residual powder within the system. Thermodynamic parameters for black powder combustion include a gas constant of 22.16 (ft-lbf/lbm-°R) and an adiabatic combustion temperature of 3307 (°R). Volumetric assessments estimate the available empty space within the main parachute bay, including shock cord and parachute, at 330.26 (in$^3$), while the corresponding empty volume for the drogue parachute bay is calculated at 350.57 (in$^3$). In addition to the primary ejection charge, a secondary charge will be incorporated as a redundancy measure for both main and drogue separation events.

In alignment with Team Derived requirement RD 3, the secondary charge mass is determined using a factor of safety of 2 applied to the pressure required for shear pin failure. Table 3.16 summarizes the calculated values for both primary and secondary ejection charges for main and drogue parachute deployments.

Table 3.16: Ejection charge sizing

| Separation Event | Volume of Section | Primary Charge Mass | Secondary Charge Mass |
|---|---|---|---|
| Drogue Parachute Deployment | 350.57 (in$^3$) | 2.92 (g) | 3.89 (g) |
| Main Parachute Deployment | 330.26 (in$^3$) | 2.75 (g) | 3.66 (g) |

## 3.6 Mission Performance Predictions

### 3.6.1 Launch Day Target Altitude

The 2026 competition vehicle will have a target altitude of 4600 (ft) above ground level (AGL). This number is derived from CFD simulations, trajectory software, and an active Air Brake control system. The competition vehicle is designed to overshoot the declared apogee to preserve the Air Brakes system's control authority during the coast phase of flight, enabling the target altitude to be reached.

All trajectory simulations were run with a 144 (in) launch rail, 10 (mph) average wind speeds, and a 5deg launch rail cantilever. Apogee predictions meet NASA requirement 2.1 and allow for altitude ranges for Air Brake deployment. Section 3.6.3 explores the overall mission performance, and Section 3.6.6 shows the Air Brake deployment impact on altitude.

Table 3.17: Apogee Across Simulation Software

| Software | Apogee Without Air Brakes | Apogee with Air Brakes |
|---|---|---|
| OpenRocket | 4833 (ft) | 4600 (ft) |
| RocketPy | 4797 (ft) | 4591 (ft) |
| RASII Aero | 4987 (ft) | N/A |

Highlighted in table 3.17 is the apogee garnered with and without Air Brakes deployment. Both OpenRocket and RocketPy produce similar results in both scenarios, differing by only 0.74%. RASII Aero does not support external augmentation via code, so it was not used to predict Air Brakes Deployment. The following sections outline the analysis that led to this apogee, along with an error analysis to highlight differences observed in the calculations. Furthermore, Section 3.6.4 explains wind impacts on simulations with and without Air Brakes deployment.

### 3.6.2 Motor Selection

The selected motor for the 2026 launch vehicle is the AeroTech L1390G, and the backup motor is the AeroTech L1520T. Each motor is a single-motor propulsion system that satisfies NASA requirement 2.8. The L1390G is the primary choice due to its overall length, long burn time, and greater total impulse. This motor also meets NASA requirements 2.7 and 2.9. Shown in table 3.18 are the various specifications for the primary and backup motors, including the propellant and total mass, total impulse, average thrust, and others. Standard AeroTech igniters will be used satisfying NASA requirement 2.6.

Table 3.18: Motor Specifications and Details

| Motor | Propellant Mass (slug) | Total Mass (slug) | Total Impulse (lbf·s) | Average Thrust (lbf) | Maximum Thrust (lbf) | Burn Time (s) | Casing | Length (in) |
|---|---|---|---|---|---|---|---|---|
| L1390G | 0.1351 | 0.2657 | 887.77 | 312.48 | 370.89 | 2.6 | RMS-75/3840 | 20.86 |
| L1520T | 0.1270 | 0.2501 | 835.37 | 352.46 | 396.85 | 2.4 | RMS-75/3840 | 20.39 |

The initial thrusts, weights, and thrust-to-weight ratios are outlined in Table 3.19. The primary motor has a thrust-to-weight ratio of

7.78:1, and the backup motor has an 8.68:1 thrust-to-weight ratio. Both selections meet NASA requirement 2.12 for minimum thrust-to-weight ratio.

Table 3.19: Thrust and Weight Calculations Per Selected Motor

| Motor | Initial Thrust | Initial Weight | Thrust to Weight Ratio |
|---|---|---|---|
| L1390G | 317.43 (lbf-s) | 39.7 (lbf) | 7.78:1 |
| L1520T | 355.75 (lbf-s) | 39.1 (lbf) | 8.68:1 |

Furthermore, Table 3.20 details the apogee, time to apogee, and rail exit velocities of both motors. Both exceed NASA requirements 2.1, 2.12, and 2.14 for required apogee, rail exit velocity, and minimum rail exit velocity, respectively. Either motor will be well-suited for the launch vehicle, but the L1390G has a longer time-to-apogee, which is pivotal to the Air Brakes Control system.

Table 3.20: Motor Performance Comparison

| Motor | Apogee | Time to Apogee | Rail Exit Velocity |
|---|---|---|---|
| L1390G | 4833 (ft) | 17.4 (s) | 74.8 ft/s |
| L1520T | 4606 (ft) | 17 (s) | 79.8 ft/s |

The motors' thrust curves and trajectory simulations are displayed in figures 3.51 and 3.52, respectively.

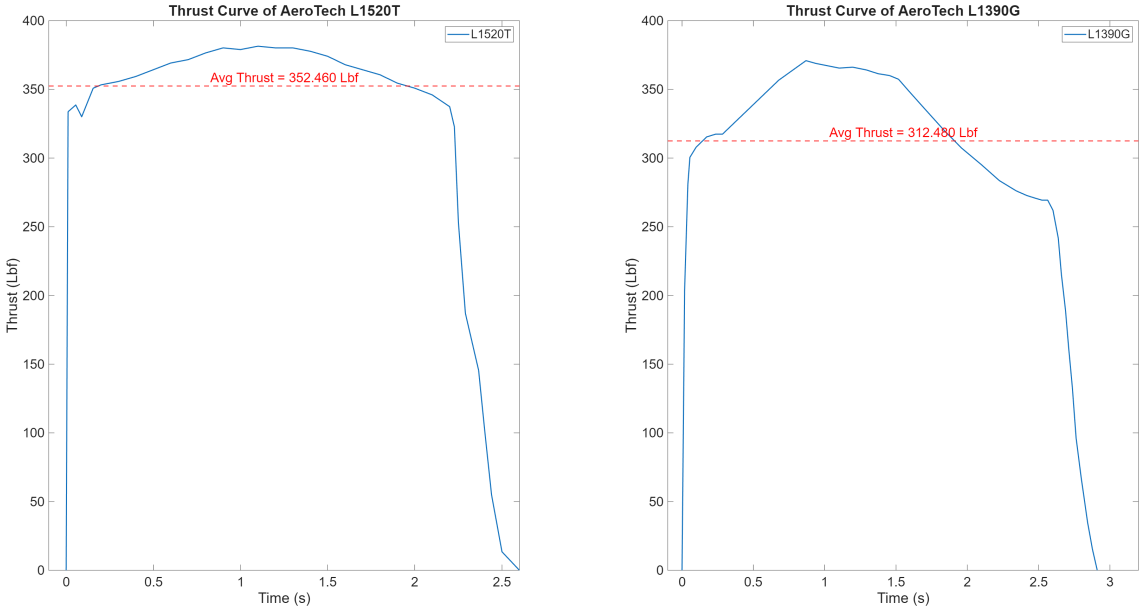


Figure 3.51: Primary and backup motor thrust curves.

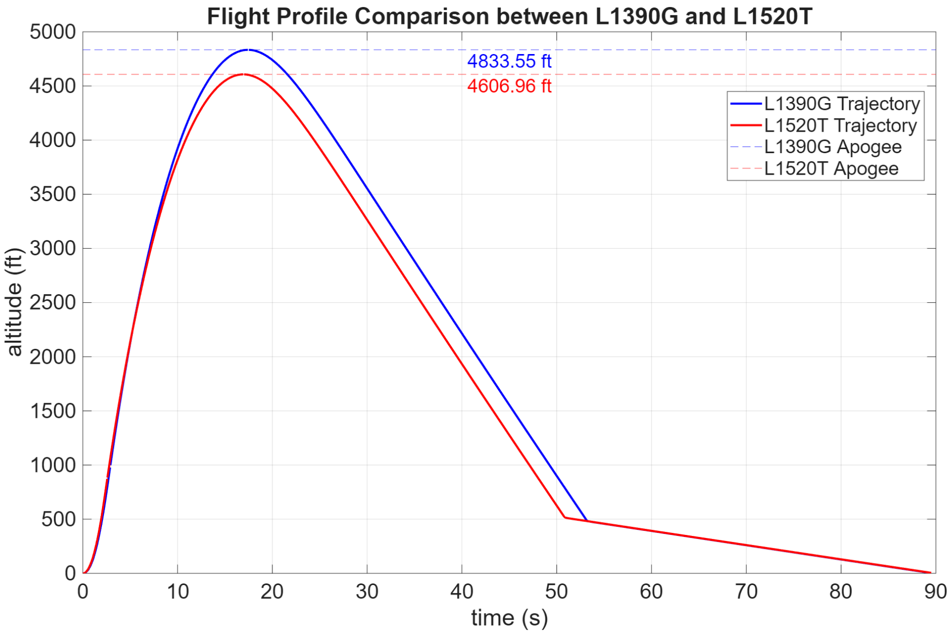


Figure 3.52: Primary and backup motors' flight profile.

### 3.6.3 Performance Analysis

#### Flight Profiles and Trajectory Analysis

As highlighted in Table 3.17 above, the Air Brakes system intends to decrease altitude by 200 ft to reach the target altitude. Shown in Figures 3.53, 3.54, and 3.55 are the flight profiles of the launch vehicle without the deployment of Air Brakes. These flight profiles show that all three software packages are comparable. OpenRocket offers the highest level of customization, trajectory-simulation fidelity, and external augmentation, while RocketPy enables the true apogee prediction algorithm to run within the simulation loop with ease. Hence, all mission performance results are reported using OpenRocket and RocketPy to allow comparisons and identify potential deviations. Both software will be employed to determine apogee and mission performance VDF and FRR.

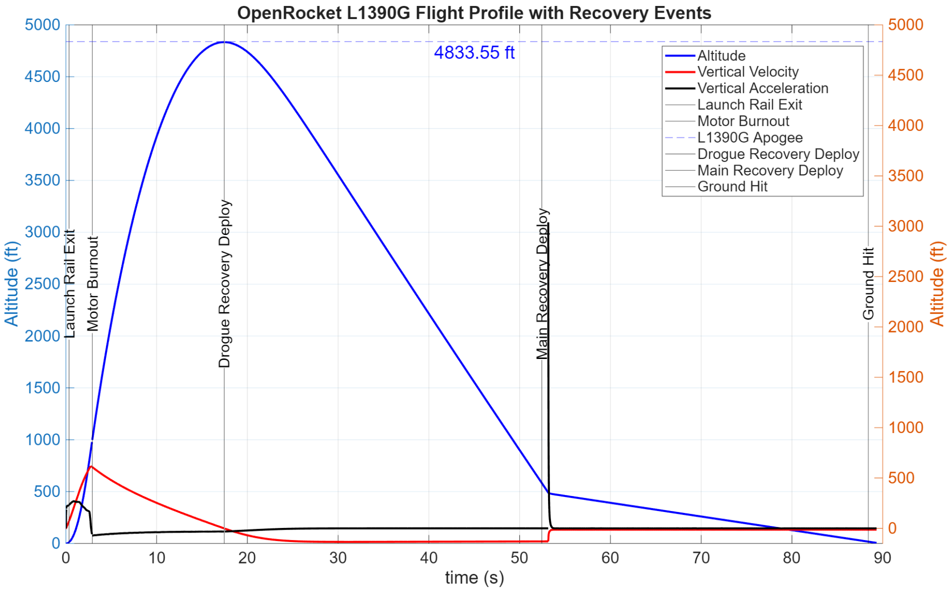


Figure 3.53: OpenRocket flight profile without Air Brakes deployment.

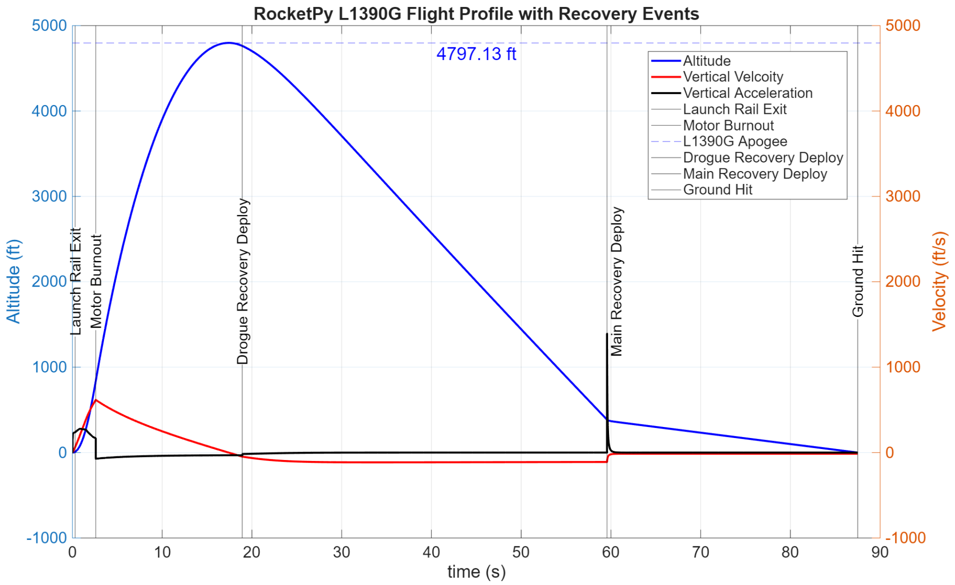


Figure 3.54: RocketPy flight profile without Air Brakes deployment.

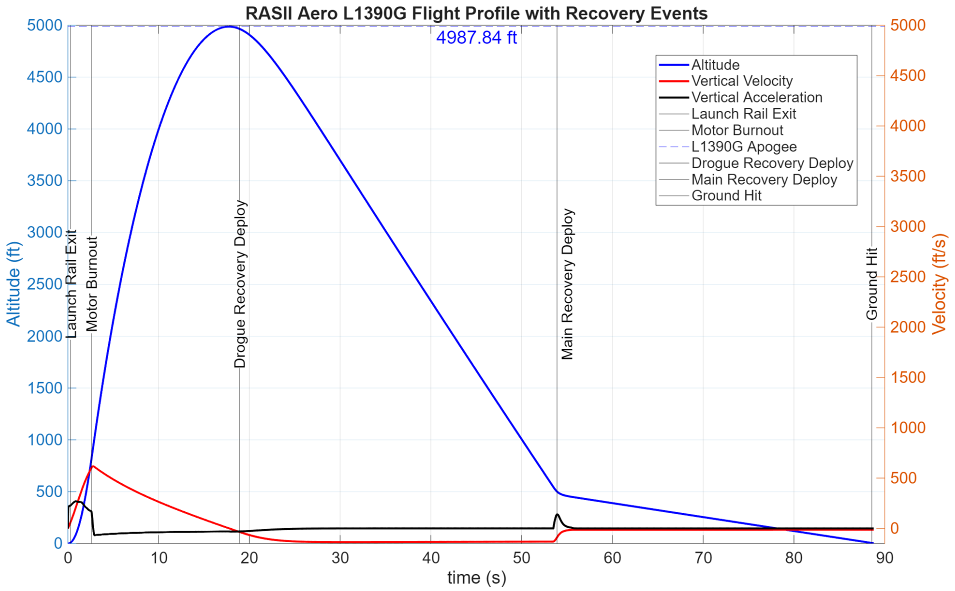


Figure 3.55: RASAero II flight profile without Air Brakes deployment.

Furthermore, Table 3.21 details the rail exit velocity, maximum velocity, and maximum Mach number across the simulation suites. OpenRocket reports a rail exit velocity of 74.8 ft/s, maximum velocity of 626 (ft/s), and maximum mach number of 0.56. RocketPy and RASII Aero differ from these values by an average of 2.3% and 0.47%, respectively. RASII shows a 1.28% increase in maximum velocity but similar maximum Mach number and rail exit velocity. RocketPy shows a decreased rail exit velocity and a rail exit velocity, but reports a 0.17% increase in the maximum Mach number. These values show that each flight software is comparable to the others within a small margin of error. The observed differences can be attributed to the simulation software's methodology for trajectory analysis and wind speed calculations.

Table 3.21: Velocity across states in flight

| Software | Rail Exit Velocity | Max Velocity | Max Mach |
|---|---|---|---|
| OpenRocket | 74.8 ft/s | 626 ft/s | 0.56 |
| RocketPy | 70.2 ft/s | 622 ft/s | 0.561 |
| RASII Aero | 74.7 ft/s | 634 ft/s | 0.56 |

**Verify Altitude Predictions** The Fehskens-Malewicki equations can be used to validate the apogee reported by both OpenRocket and RocketPy analytically. The equations are listed below. For clarification, $T$ is approximated to be the average thrust of the motor, $M$ is the mass of the rocket during liftoff, and $C_d$ is derived from CFD simulations.

The drag force is expressed by the constant K:

$$k = \tfrac{1}{2}\,\rho\, C_D\, A \tag{17}$$

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

$$q = \sqrt{\frac{T - Mg}{k}} \tag{18}$$

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

$$x = \frac{2kq}{M} \tag{19}$$

By using Equations 18 and 19, the maximum velocity of the launch vehicle is found through:

$$v_{\text{max}} = q\,\frac{1 - e^{-xt}}{1 + e^{-xt}} \tag{20}$$

At motor burnout, drag force and gravity become the main forces acting on the rocket. The altitude at motor burnout can be computed via:

$$Z_{\text{burnout}} = -\frac{M}{2k}\ \text{ln}\left(\frac{T - Mg - kv_{\text{max}}^2}{T - Mg}\right) \tag{21}$$

The total coast distance of the launch vehicle after burnout is calculated with:

$$Z_{\text{coast}} = \frac{M}{2k}\ \text{ln}\left(\frac{Mg + kv_{\text{max}}^2}{Mg}\right) \tag{22}$$

Lastly, the total apogee reached is the sum of equations 21 and 22.

$$Z_{\text{apogee}} = Z_{\text{burnout}} + Z_{\text{coast}} \tag{23}$$

The values, measurements, and results from equations 17 to 23 are depicted in table 3.22

Table 3.22: Constants and Results

| **Constant** | **Variable Name** | **Value** | **Units** |
|---|---|---|---|
| M | Power On Average Mass | 1.2339 | Slug |
| m | Power Off Average Mass | 0.9697 | Slug |
| $g$ | Gravitational Acceleration | 32.1719 | ft/s$^2$ |
| $t$ | Motor Burn Time | 2.6 | s |
| $T$ | Average Thrust | 312.4844 | lbf |
| $\rho$ | Air Density | 0.0764 | slug/ft$^3$ |
| $A$ | Launch Vehicle Frontal Area | 0.204 | ft$^2$ |
| $C_d$ | Drag Coefficient | 0.393 | NA |
| **Equation** | **Result** | **Units** | |
| $k$ | 0.000987 | slug/ft | |
| $q$ | 5657.59 | ft$^2$/s$^2$ | |
| $x$ | 0.256 | ft/s$^2$ | |
| $v_{\text{max}}$ | 583.95 | ft/s | |
| $Z_{\text{burnout}}$ | 819.174 | ft | |
| $Z_{\text{coast}}$ | 3908.22 | ft | |
| $Z_{\text{apogee}}$ | 4727.39 | ft | |

The results using the Fehskens-Malewick equations yield an apogee of 4727 (ft), which is a 2.23% reduction compared to the value seen in OpenRocket and slightly smaller than the apogee reported by RocketPy. This small difference can be attributed to the equations not accounting for launch rail length, wind speed and direction, launch rail cantilever, or assumptions made during the calculations. Moreover, this calculation underscores the fidelity of simulations conducted with this software, thereby ensuring accurate predictions.

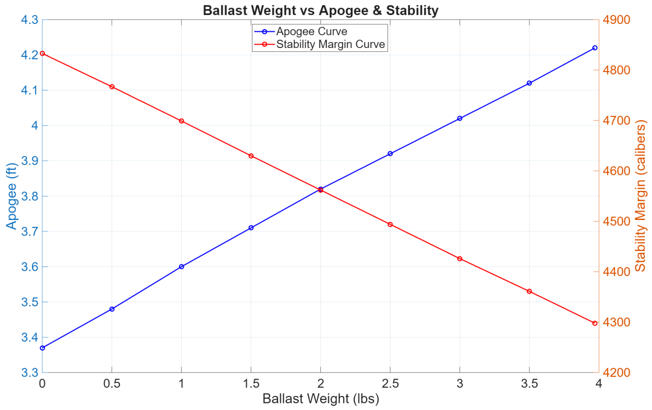
### 3.6.4 Alternate Impacts on Mission Performance

The reported apogee from prior simulations has 0 (lbs) of ballast and a predicted payload weight of 7.5 (lbs). These values were derived to keep the launch vehicle to maintain a static stability above 2.0 on the launch rail and to balance the advance of weather cocking effects seen at high stability margins. The next two sections outline the performance impacts of varying payload weight and ballast on stability and apogee.

#### Ballast Requirements and Payload Weight Impacts

Table 3.56b highlights how increasing the ballast weight will increase the stability of the launch vehicle and decrease apogee. The maximum allotted ballast weight is 10% of the launch vehicle's final weight, which works out to 3.97 (lbs). Any amount of ballast, up to the maximum, will allow the vehicle to meet NASA requirement 2.20.7, but the ballast weight must remain below 1.75 lbs to achieve the declared apogee. The current configuration uses 0 (lbs) of ballast, so none of the limitations mentioned currently apply. Figure 3.56a illustrates the overall effects increasing ballast weight has on vehicle stability and apogee. Increasing the ballast weight improves overall stability by shifting the center of gravity and weight distribution upward toward the nosecone.

Figure 3.56: Ballast Weight Impacts



(a) Ballast weight vs stability and apogee curves.

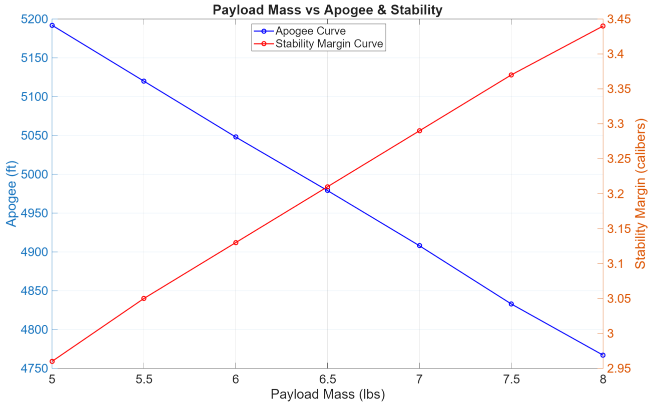
| Ballast (lbs) | Stability (cal) | Apogee (ft) |
|---|---|---|
| 0 | 3.37 | 4833 |
| 0.5 | 3.48 | 4767 |
| 1 | 3.6 | 4699 |
| 1.5 | 3.71 | 4630 |
| 2 | 3.82 | 4562 |
| 2.5 | 3.92 | 4493 |
| 3 | 4.02 | 4426 |
| 3.5 | 4.12 | 4361 |
| 3.97 | 4.22 | 4291 |

(b) Tabulated Values

#### Payload Weight Impacts

The Payload is approximately 7.5 lbs for this year's competition vehicle. This yields an apogee of 4833 (ft) and a stability margin of 3.37 (cal). As shown below in Figure 3.57a and Table 3.57b, the target apogee can be attainable for the launch vehicle up to the maximum allotted weight of the payload at 8 (lbs). This demonstrates the robust design of the launch vehicle and its ability to maintain mission performance, necessitating the deployment of Air Brakes. Static stability is currently high for the current configuration. It is manageable for any given Payload weight without ballast, since at a Payload weight of 5 (lbs), the stability is 2.96 (cal) and the apogee is 5192 (ft).

Figure 3.57: Payload Weight Impacts



(a) Payload weight vs stability and apogee.

| Payload Weight (lbs) | Stability (cal) | Apogee (ft) |
|---|---|---|
| 5 | 2.96 | 5192 |
| 5.5 | 3.05 | 5120 |
| 6 | 3.13 | 5048 |
| 6.5 | 3.21 | 4979 |
| 7 | 3.29 | 4908 |
| 7.5 | 3.37 | 4833 |
| 8 | 3.44 | 4767 |

(b) Tabulated Values

#### Wind Speed and Profile Impact

Overall wind speed and profiles are a concern for launch day. If wind speeds are above 20 (mph) the launch will be delayed. Since this is a bounding value, all simulations are run over average wind speeds from 0 to 20 (mph) in 5 (mph) increments. The increment was chosen to show a varied effect, but each flight software used supports day-of-launch conditions, so even higher-fidelity simulations will be run then. Without Air Brakes deployment in Table 3.23, the launch vehicle consistently overshoots the declared apogee, ensuring Air Brakes has some room to deploy. The Air Brakes deployment in Table 3.24 shows the vehicle reaching its target apogee either perfectly or with a small percentage difference. This speaks to the robust simulation methodology and apogee prediction done on the Air Brakes system. It is important to note that the reported apogee decreases with increasing wind speed, as in the case without deployment. This can be explained by an approximate apogee prediction algorithm that is run in OpenRocket, or by the vehicle's sustainability to weather cocking.

Table 3.23: Average Wind Speed Vs Apogee Without Air Brakes Deployment

| Wind Speed (mph) | Apogee (ft) |
|---|---|
| 0 | 4969 |
| 5 | 4913 |
| 10 | 4833 |
| 15 | 4747 |
| 20 | 4646 |

Table 3.24: Average Wind Speed Vs Apogee With Air Brakes Deployment

| Wind Speed (mph) | Apogee (ft) |
|---|---|
| 0 | 4600 |
| 5 | 4590 |
| 10 | 4564 |
| 15 | 4551 |
| 20 | 4524 |

To ensure the launch vehicle will reach its declared apogee, the target apogee can be altered in code to ensure that the difference, as described in the prior table, for any given wind speed can be accounted for. Table 3.25 documents the variation of target apogee to garner the 4600 (ft) declared altitude. These factors depend on the simulation settings described previously. On the day of launch, the wind profile for that day will be loaded, and the target apogee will be adjusted to reach the vehicle's declared altitude.

Table 3.25: Average wind speed vs apogee with Air Brakes deployment and target apogee

| Wind Speed (mph) | Apogee (ft) | Target Set (ft) |
|---|---|---|
| 0 | 4600 | 4600 |
| 5 | 4600 | 4625 |
| 10 | 4601 | 4635 |
| 15 | 4598 | 4655 |
| 20 | 4603 | 4675 |

### 3.6.5 Stability Margin Analysis

The stability margin of the launch vehicle is the distance between the CP and CG divided by the vehicle's outer diameter. Table 3.26 displays the CP, CG, and calculated stability margin from each simulation software used. Since OpenRocket dictates final prediction values, the static stability is 3.37 calibers.

Table 3.26: Center of Pressure, Center of Gravity, and Stability Margin by Software

| Software | Center of Pressure | Center of Gravity | Stability Margin |
|---|---|---|---|
| OpenRocket | 85.239 (in) | 64.629 (in) | 3.37 Calibers |
| RocketPy | 85.079 (in) | 63.425 (in) | 3.54 Calibers |
| RASII Aero | 85.19 (in) | 64.505 (in) | 3.40 Calibers |

Furthermore, Figures 3.58, 3.59, and 3.60 show the vehicle profiles in each software. A red dot denotes the center of pressure (CP), and a blue dot denotes the center of gravity (CG).

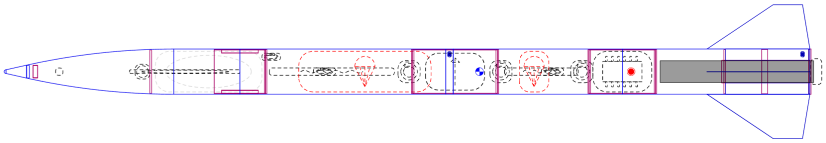


Figure 3.58: OpenRocket vehicle profile.

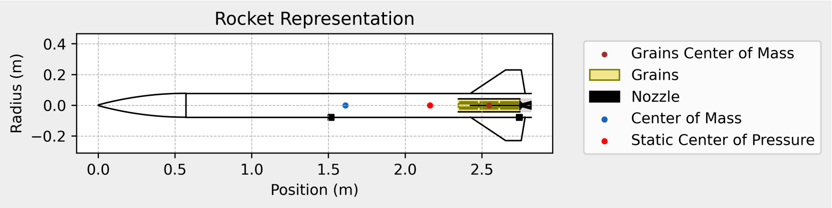


Figure 3.59: RocketPy vehicle profile.

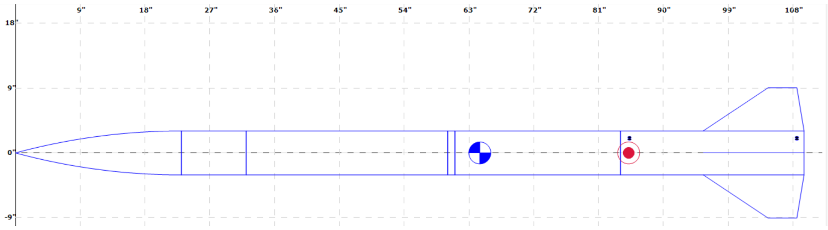


Figure 3.60: RASII Aero vehicle profile.

The Barrowman stability equations are employed to verify the CP and stability calculations from the simulation software. The derivation process is shown below.

$$C_{N_f} = \left[1 + \frac{R}{S+R}\right] \left[ \frac{4\,N \left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_f}{C_R + C_T}\right)^2}} \right] \tag{24}$$

$$X_f = X_B + \frac{X_R(C_R + 2C_T)}{3\,(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{C_R C_T}{C_R + C_T}\right] \tag{25}$$

$$X_{CP} = \frac{C_N X_N + C_F X_F}{C_N + C_F} \tag{26}$$

$$SM = \frac{X_{CP} - X_{CG}}{2R} \tag{27}$$

Using the equations above, in conjunction with OpenRocket estimates and measurements, Table 3.27 tabulates all values and results.

Table 3.27: Constants and Barrowman Results

| Constant | Variable Name | Value | Units |
|---|---|---|---|
| $(C_N)_N$ | Nosecone Coefficient | 2 | NA |
| $X_N$ | Nosecone Length Factor | 15.029 | (in) |
| $R$ | Body Radius | 3.085 | (in) |
| $S$ | Fin Span | 6 | (in) |
| $N$ | Number of Fins | 4 | NA |
| $d$ | Base of Nose Diameter | 6.12 | (in) |
| $L_F$ | Fin Midchord Line Length | 9 | (in) |
| $C_R$ | Fin Root Chord Length | 14 | (in) |
| $C_T$ | Fin Tip Chord Length | 4 | (in) |
| $X_B$ | Nose to Root Chord LE length | 94.5 | (in) |
| $X_R$ | Tail to Root Chord LE length | 10.817 | (in) |
| $X_{CG}$ | Center of Gravity (OpenRocket) | 64.63 | (in) |
| **Equation** | **Result** | **Units** | |
| $(C_N)_f$ | 8.52 | NA | |
| $X_f$ | 101.39 | in. | |
| $X_{CP}$ | 84.97 | in. | |
| $SM$ | 3.32 | Calibers | |

From these calculations, the CP is estimated to be 84.97 (in) from the tip of the launch vehicle. In combination with the estimated CG location from OpenRocket at 64.629 (in), the stability margin is 3.32 (cal). This is a 1.48% difference from OpenRocket's reported stability of 3.37 (cal). This shows a high level of accuracy from the simulated parameters. Moreover, this value ensures compliance with NASA Requirement 2.11. To verify that the center of gravity matches the calculated value, a CG check is performed after full assembly, either before launch day or on launch day. The vehicle is balanced on a rope until it sits level, and that balance point is recorded as the CG. In most cases, this closely matches the simulated value because CG is driven by the weight distribution, which is a relatively predictable factor once the build is finalized. Once the CP and CG are determined, the stability is calculated using Equation 27, with 2R equal to the vehicle's outer diameter.

### 3.6.6 Air Brakes Analysis

#### Drag Quantification

To start, Figure 3.61 highlights the Drag vs Extension Level vs Mach Number of the Air Brakes system. Across both configurations, drag increases with Mach, but the air brakes provide a clear step change in magnitude when deployed. With full deployment, the drag rises from 17.35 (lbf) at Mach 0.25 to 96.42 (lbf) at Mach 0.55, while the non-deployed baseline (0) increases from 5.95 (lbf) to 34.67 (lbf) over the same range. At a fixed Mach number, deployment increases drag by roughly a factor of 2.8. This shows that the air brakes maintain meaningful authority throughout the modeled regime, with the largest absolute drag gains occurring at higher Mach, where dynamic pressure is higher, thereby directly supporting tighter apogee control during the fastest portion of flight.

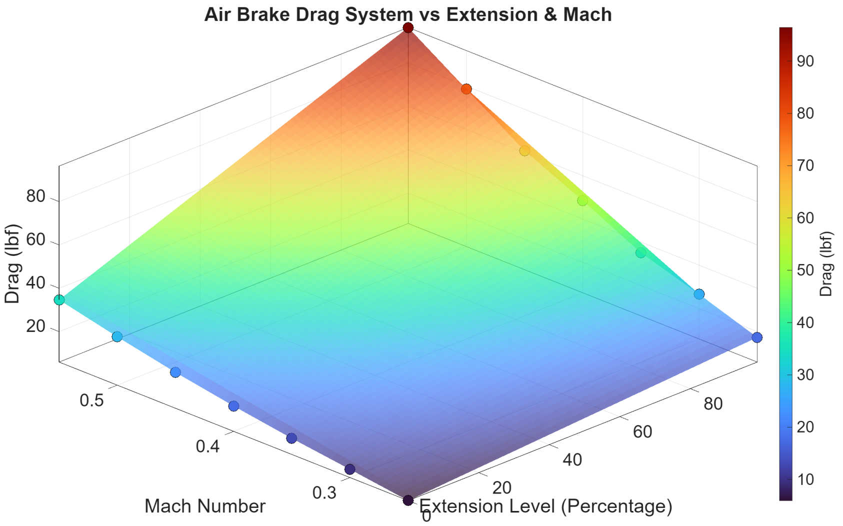


Figure 3.61: Drag vs Extension Level vs Mach Number of the Air Brakes system.

### Monte Carlo Simulations

Shown in Table 3.29 are the results of 2000 Monte Carlo simulations run in both OpenRocket and RocketPy. The initial conditions and the values varied are tabulated in Table 3.28. OpenRocket reports an average of 4823 (ft) with a standard deviation of 11.3 (ft), while RocketPy reports a 1.22% lower average but with a higher standard deviation compared to OpenRocket. The same results hold when Air Brakes are deployed in the system, with OpenRocket yielding a 0.55% lower result than RocketPy, with a significantly lower standard deviation. These differences can be attributed to differences in software handling, but they still lend credence to the overall reliability of the simulations, since each result lies within the standard deviation of the others.

Table 3.28: Monte Carlo Simulation Settings

| Parameter | Value | Units |
|---|---|---|
| Number of simulations | 2000 | – |
| Launch rail angle $\sigma$ | 2 | ° |
| Launch rail direction $\sigma$ | 2 | ° |
| Launch altitude $\sigma$ | 4 | ft |
| Launch latitude $\sigma$ | 0 | ° |
| Launch longitude $\sigma$ | 0 | ° |
| Wind speed $\sigma$ | 2 | mph |
| Wind direction $\sigma$ | 2 | ° |
| Temperature $\sigma$ | 4.00 | °F |
| Pressure $\sigma$ | 1.00 | inHg |
| Mass variation $\sigma$ | 0.5 | % |
| Initial velocity $\sigma$ | 0 | ft/s |
| Target Apogee | 4600 | ft |

Table 3.29: Monte Carlo Simulation Results

| Software | Mean Apogee Without Air Brakes Deployment | Standard Deviation | Mean Apogee With Air Brakes Deployment | Standard Deviation |
|---|---|---|---|---|
| OpenRocket | 4823 (ft) | 11.3 (ft) | 4563 (ft) | 2.3 (ft) |
| RocketPy | 4764 (ft) | 68.4 (ft) | 4588.4 (ft) | 7.1 (ft) |

Figure 3.62 shows a histogram of the simulations from OpenRocket without Air Brakes deploying, and Figure 3.63 shows the results with Air Brakes Deployment. Each histogram shows a near-normal distribution of the results with the aforementioned low standard deviation.

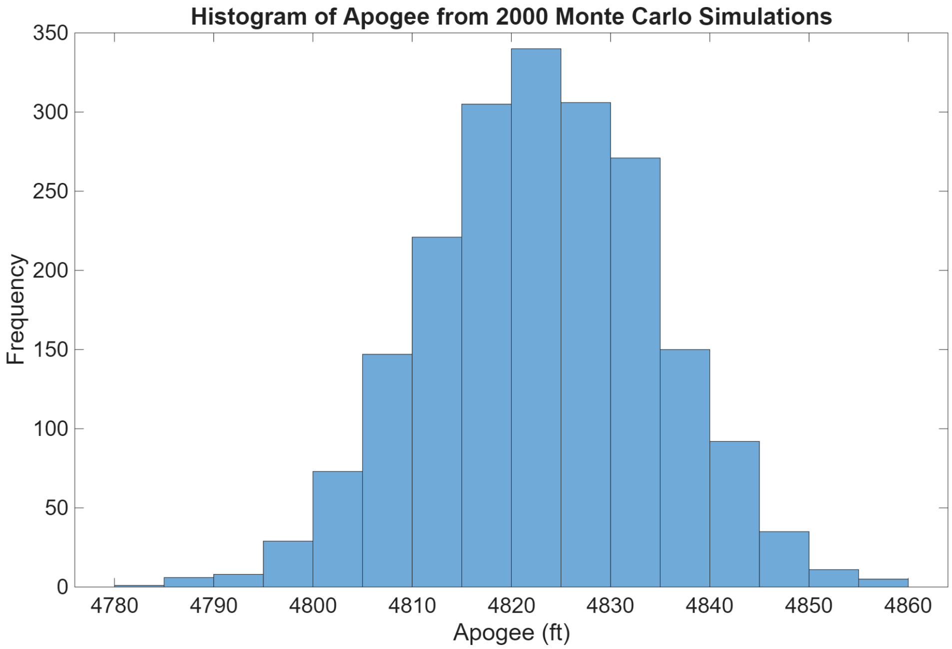


Figure 3.62: Histogram of 2000 Monte Carlo OpenRocket Simulations without Air Brakes Deployment in OpenRocket.

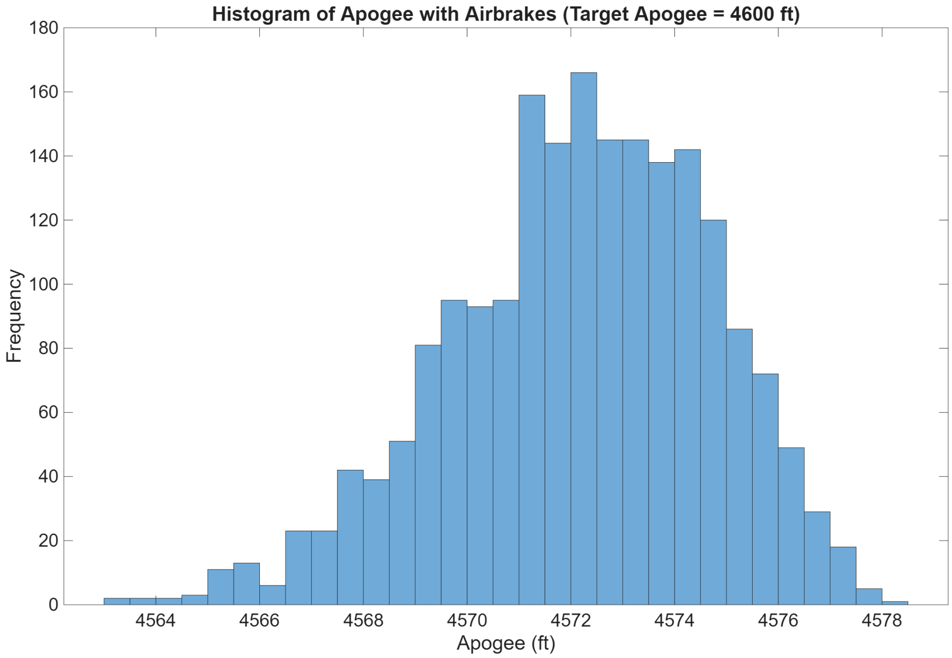


Figure 3.63: Histogram of 2000 Monte Carlo OpenRocket Simulations with Air Brakes Deployment in OpenRocket.

The results from the same parameters in RocketPy are presented in Figures 3.64 and 3.65 below.

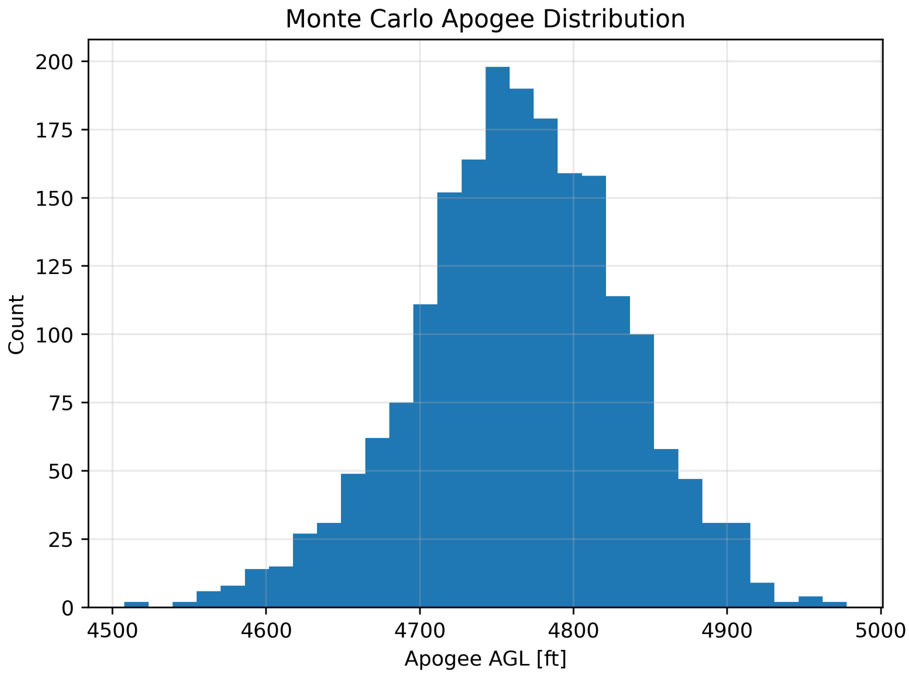


Figure 3.64: Histogram of 2000 Monte Carlo OpenRocket Simulations without Air Brakes Deployment in RocketPy.

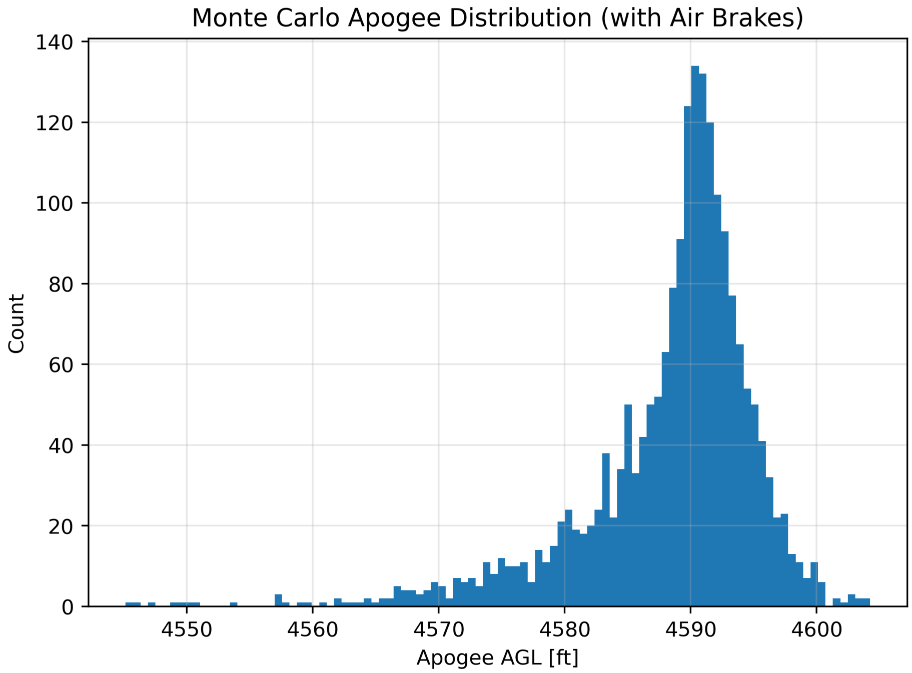


Figure 3.65: Histogram of 2000 Monte Carlo OpenRocket Simulations with Air Brakes Deployment in RocketPy.

Moreover, in Figure 3.66, the distribution of landing locations with Air Brakes deployment is shown. These measurements assume that the wind is blowing 90°straight east. Overall, the results align with the hand calculations for wind drift distance at an average wind speed of 10 (mph).

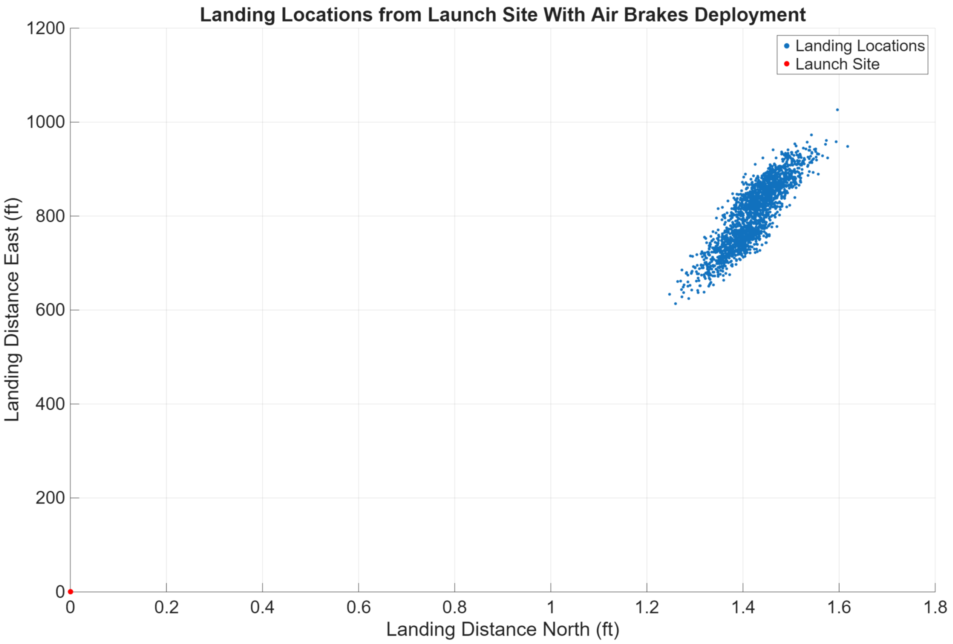


Figure 3.66: Landing locations from Monte Carlo Simulations with Air Brakes deployment.

### Static and Burnout CG

A major concern is maintaining the center of gravity forward of the Air Brake Fins' protuberance to meet the NASA requirement 2.13. As shown in Figure 3.67, the CG location is during the ascent phase. A dashed line in the figure indicates the location of the Air Brakes. Any Y value below that line is colored in green to signify the CG location is in front of the Air Brake Fins, and any Y value above that line is colored in red to show the opposite. A vertical black line signifies the time of motor burnout. Based on this figure, the static CG is at 64.629 (in) and the burnout CG is at 60.35 (in) measured from the nosecone. These values are far in front of the protuberance location at 84.5 (in) measured from the tip of the nosecone, well exceeding the requirement.

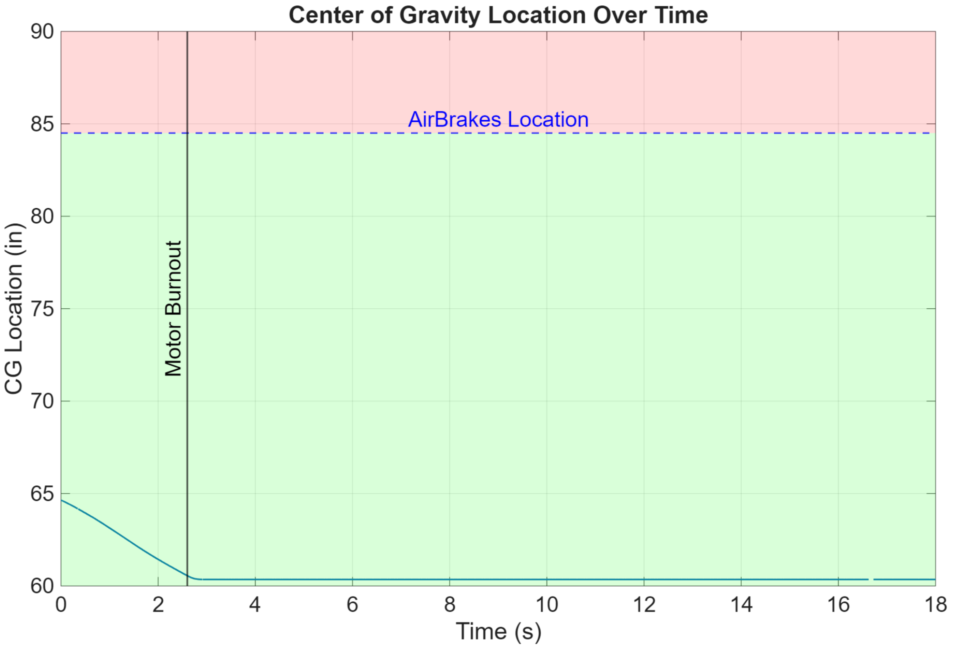


Figure 3.67: CG location during flight.

For further visualization, Figures 3.68 and 3.69 represent the static and burnout CG locations in OpenRocket. The figures include a green box that emphasizes the CG location. The red dot shows the CP location.

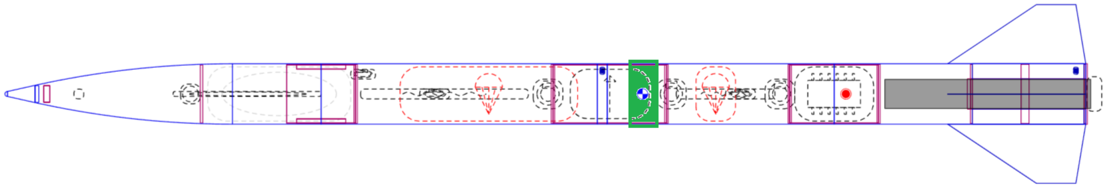


Figure 3.68: Static CG location.

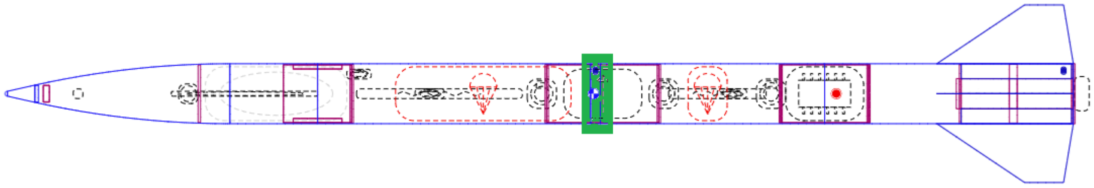


Figure 3.69: Burnout CG location.

### 3.6.7 Kinetic Energy

The predicted descent velocity of the vehicle was calculated using the following formula,

$$v_{desc} = \sqrt{\frac{2mg}{\rho A C_d}} \tag{28}$$

where $v_{desc}$ is the descent velocity, $m$ is the mass of the vehicle, $g$ is gravitational acceleration, $\rho$ is air density, $A$ is the projected area of the parachute, and $C_d$ is the drag coefficient of the parachute.

The selected drogue parachute is a 15 (in) elliptical parachute. This parachute has an estimated 1.5. Given that the dry mass of the launch vehicle is 35.35 (lb), the descent rate under the drogue parachute is calculated to be 129.66 (fps). The main parachute chosen for the vehicle is a 120 (in) toroidal parachute, which has a projected area of 76.12 (ft$^2$) and a $C_d$ of 2.2. This will result in a main descent rate of 13.33 (fps).

After obtaining the launch vehicle descent velocity, the kinetic energy of the heaviest section can be calculated using the following equation,

$$K = \frac{1}{2} m v_m^2 \tag{29}$$

where $K$ is the maximum kinetic energy, $m$ is the mass of the heaviest section, and $v_m$ is the descent velocity under the main parachute. Using a descent velocity of 13.33 (fps) and a mass of 16.05 (lb), the maximum kinetic energy of the launch vehicle is calculated to be 44.29 ft-lbf, satisfying NASA requirement 3.2.

Table 3.30: Kinetic energy for each section of the vehicle

| Drogue Descent | | | |
|---|---|---|---|
| **Section** | **Mass (lb)** | **Descent Velocity (fps)** | **Kinetic Energy (ft-lbf)** |
| Fin Can + Drogue Bay | 16.05 | 129.66 | 4189.9 |
| AV Bay + Main Bay + Nosecone | 17.40 | 129.66 | 4542.3 |
| **Main Descent** | | | |
| **Section** | **Mass (lb)** | **Velocity (fps)** | **Kinetic Energy (ft-lbf)** |
| Fin Can + Drogue Bay | 16.05 | 13.33 | 44.29 |
| AV Bay + Main Bay | 5.26 | 13.33 | 14.51 |
| Nosecone | 10.30 | 13.33 | 28.42 |

### 3.6.8 Expected Descent Time

The total descent time of the launch vehicle is calculated using Equation 30,

$$t_d = \frac{r_a - r_m}{v_d} + \frac{r_m}{v_m} \tag{30}$$

where $t_d$ is descent time, $r_a$ is the altitude of 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 the drogue deployment occurs at an apogee of 4600 (ft) and the main deployment occurs at 550 (ft), this results in a descent time of 72.49 (s), which satisfies NASA Requirement 3.11.

### 3.6.9 Expected Drift

Using the total descent time and wind speed, the drift distance of the launch vehicle can be calculated using Equation 31.

$$d_{drift} = v_w t_d \tag{31}$$

Table 3.31 presents the variation in drift distance of the launch vehicle with wind speeds ranging from 0 mph to 20 mph. The analysis assumes the vehicle reaches apogee directly above the launch pad and drifts at a constant rate with the wind. As these calculations are based on a worst-case scenario, specifically, constant wind conditions, the resulting values represent an upper bound on drift distance, satisfying NASA Requirement 3.10.

Table 3.31: Wind drift distance

| Wind Speed (mph) | Drift Distance (ft) |
|---|---|
| 0 | 0 |
| 5 | 531.62 |
| 10 | 1063.24 |
| 15 | 1594.86 |
| 20 | 2126.48 |

# 4 Payload Criteria

## 4.1 Payload Mission Statement and Success Criteria

The objective of the Habitat for Agricultural Utilization Study, or HAUS, is to secure the STEMnauts and to collect soil measurements. The HAUS must have an atmosphere-isolated compartment that retains the STEMnauts for the entirety of the flight. Additionally, the HAUS will collect and retain a 50 (mL) sample of soil within 15 minutes of landing. This soil will be tested for its pH level, electrical conductivity, and Nitrate-Nitrogen content.

The soil sample will be collected using an auger drill. To ensure this drill is pointed at the ground, a portion of the payload will deploy from the Launch Vehicle after landing and self-right using deploying legs. The soil collected by the auger will be deposited into a container within the payload that contains the soil sampler. The soil sensor will begin taking readings after a set time period and will record these readings using a Raspberry Pi.

Table 4.1: 2026 Payload Success Criteria

| Success Level | Payload Aspect | Safety Aspect |
|---|---|---|
| Complete Success | > 50 (mL) of soil is collected AND soil sensor data is retained. | No individuals are harmed during payload operations, and all risks are mitigated. |
| Partial Success | < 50 (mL) of soil is collected AND soil sensor data is retained. | No individuals are harmed during payload operations, but some risks are unmitigated. |
| Partial Failure | < 50 (mL) of soil is collected, but soil sensor data is not retained, OR > 50 (mL) of soil is collected, but no soil sensor data is retained | Individual(s) receive(s) minor harm by unmitigated risk in payload operations. |
| Total Failure | No soil is collected, and no soil sensor data is retained | Individual(s) receive(s) major harm by unmitigated risks in payload operations. |

## 4.2 Final Payload Design

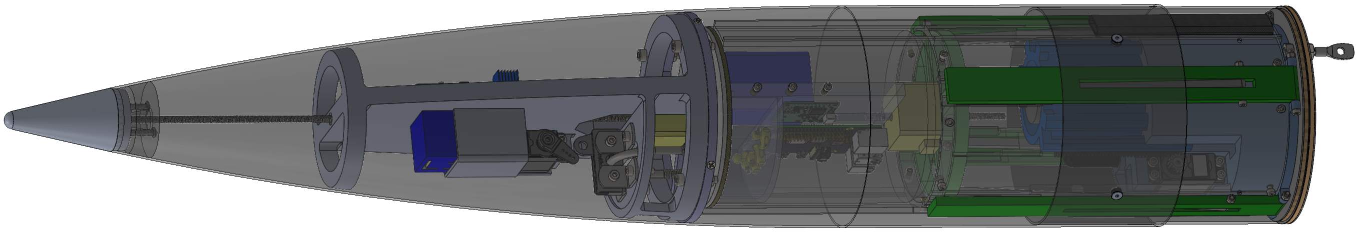


Figure 4.1: ZOMBIE and GrAVE payload mechanisms.

The final design chosen is a self-righting lander that is deployed from the Launch Vehicle's nosecone after landing. It will consist of two main systems: ZOMBIE and GrAVE. ZOMBIE, or Z-axis Orienting Mechatronic Botanical Investigative Extractor, is the lander that will perform the soil collection. GrAVE, or Ground Activated Vehicle Ejector, is the device that will deploy ZOMBIE from inside the nosecone. This combination of systems was chosen because it meets the needs for reliability and practicality. Both ZOMBIE and GrAVE will be able to be tested on the ground before launch, ensuring the systems can complete the given tasks.

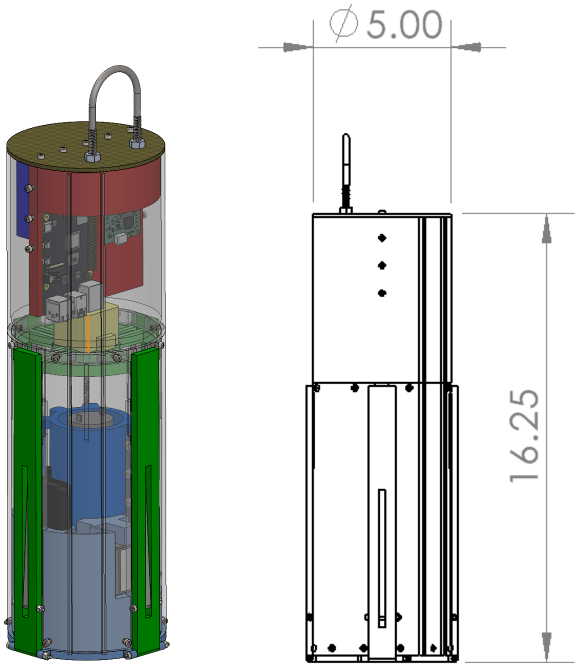


Figure 4.2: ZOMBIE in the retracted state.

ZOMBIE is a 3D printed 5 (in) diameter cylinder that stands 16.25 (in) tall, as shown in Figure 4.2. The dimensions were chosen to maximize the inside volume while still remaining inside the nosecone. Larger interior volume means less complexity for system integration. It will use four 3D printed deploying legs to self-right after deployment. Four legs were chosen to ensure that two legs are on the ground at all times during deployment. Three legs would have too much space between them, making self-righting difficult, and five legs would add unnecessary weight. Each leg is hinged at the base of the structure and connected via an aluminum linkage to a translating collar. The collar sits inside ZOMBIE and is attached to a lead screw motor that drives both elements during deployment. The lead screw itself is attached to ZOMBIE's cap and remains fixed during this process.

Once the legs are deployed and ZOMBIE is upright configuration as seen in Figure 4.3, it will begin soil collection. This will be accomplished with an auger that is rotated and extended into the soil simultaneously. The rotation is accomplished with a planetary gear motor, and the extension with a rack and pinion mechanism driven by a servo. Once fully extended, the auger will continue to rotate, driving dirt onto the auger blades. As the auger is retracted, the soil will be funneled into a collection chamber equipped with a soil sensor. As the soil falls, it will come into contact with the sensor's probes, ensuring good data collection. This system was chosen for its reliability and adaptability for soil collection. An auger will penetrate both soft and hard soil, allowing for collection in a variety of environments. By drilling downwards, the auger will also collect a predictable amount of soil reliably.

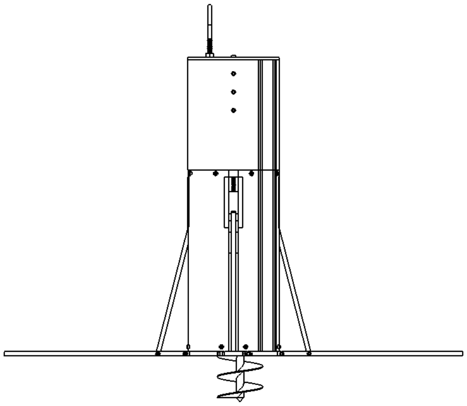


Figure 4.3: ZOMBIE in the deployed configuration.

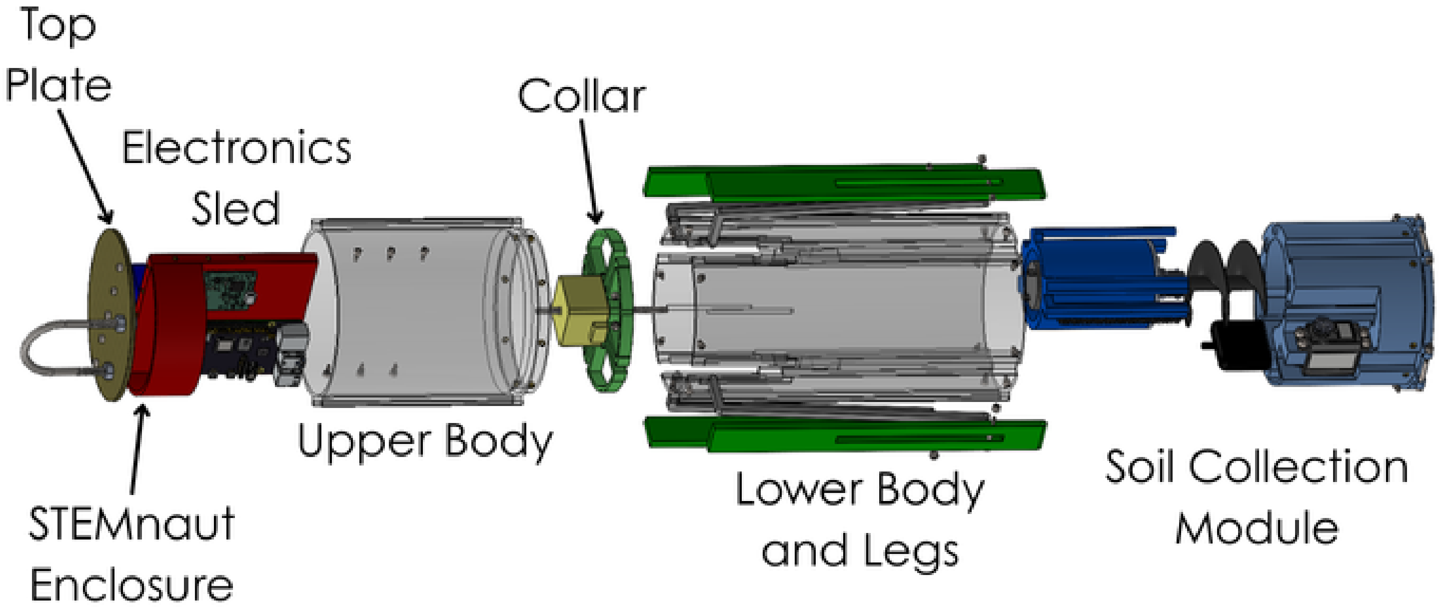


Figure 4.4: ZOMBIE structure exploded view.

ZOMBIE's structure, as seen in Figure 4.4, is made up of four distinct sections: the top plate and electronics sled, the upper body, the lower body, and the soil collection module. The top plate connects ZOMBIE to the retention system and houses the electronics sled, which is integrated with the STEMnaut atmosphere-isolated housing compartment. The main portion of ZOMBIE's structure comes from the body tubes. The lower tube contains tracks for the leg deployment collar and openings that allow the collar to connect to the leg linkages. The upper tube closes the strut openings and has mounting points for the top plate. ZOMBIE is closed at the bottom by the removable soil collection platform, which contains the drilling mechanism and soil chamber, and includes mounting points that attach to the bottom of the legs to allow them to fold out. A modular design was selected to allow for rapid prototyping and easy adjustment of internal components.

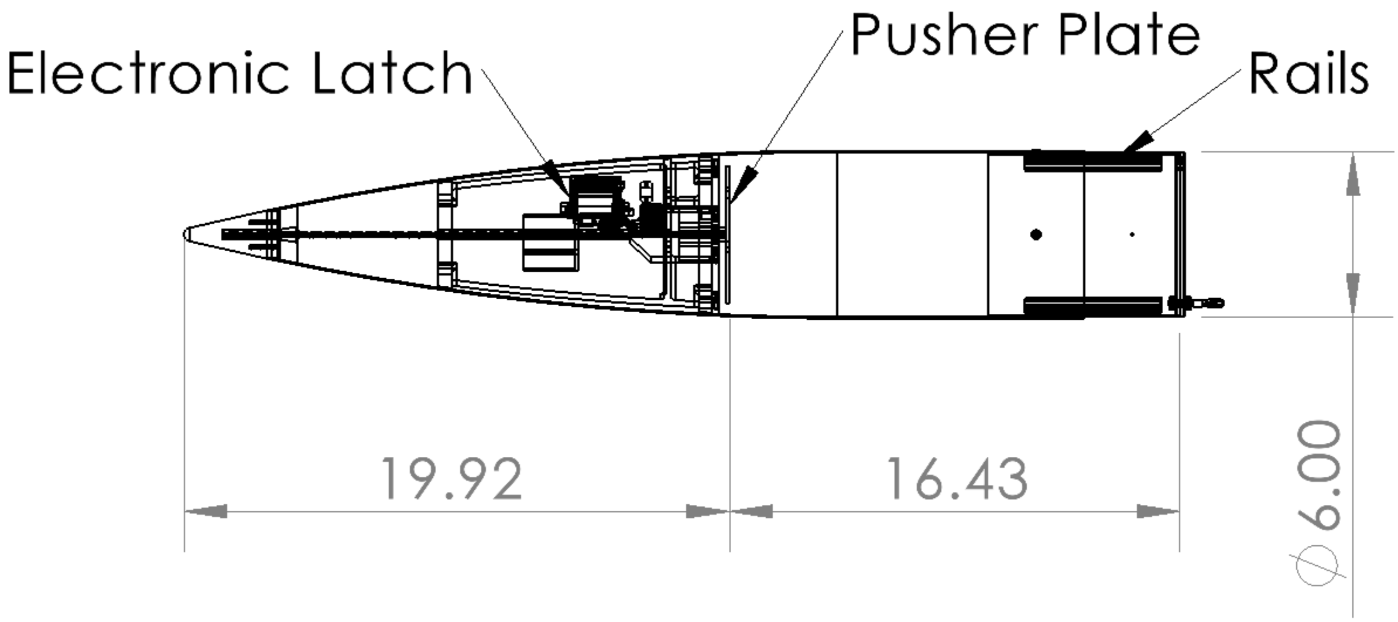


Figure 4.5: GrAVE dimensions while retracted.

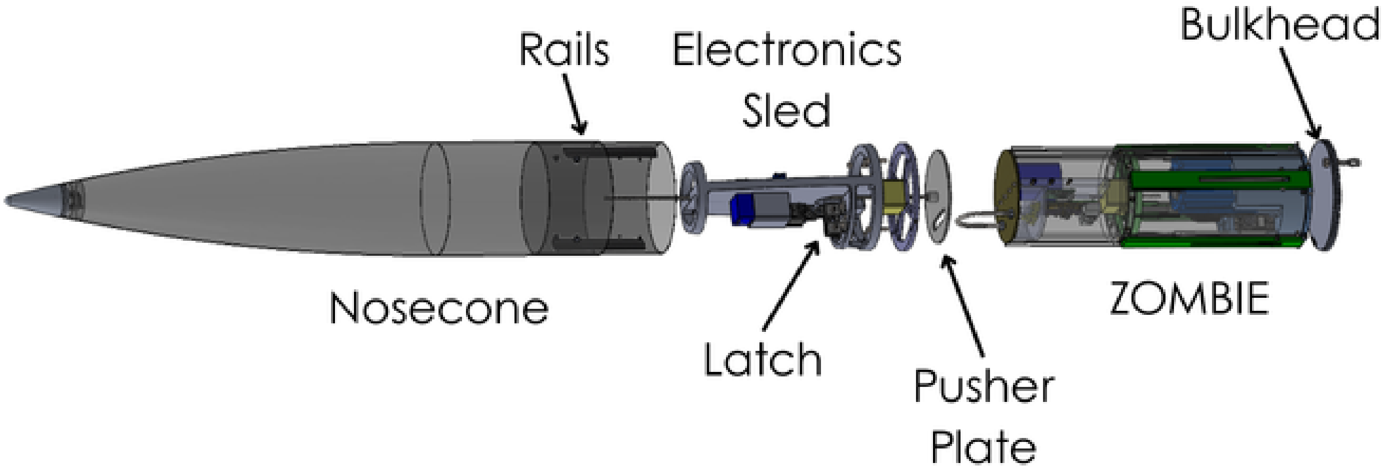


Figure 4.6: Exploded view of GrAVE.

GrAVE contains three mechanisms that work to constrain ZOMBIE during flight and facilitate an easy exit on landing. These mechanisms are illustrated in Figures 4.5 and 4.6. Carbon fiber rails provide the interface between ZOMBIE's outer structure and the nosecone. These prevent side-to-side translation of the payload during flight, while also minimizing friction during deployment. A lead screw with a pusher plate at the end is used to apply the force to deploy ZOMBIE. An electronic latch connects to ZOMBIE when the pusher plate is retracted, constraining ZOMBIE's movement along the long axis of the launch vehicle. A ground-deploying system was selected over an air-deploying one for a variety of reasons. The ground deploy option has more mechanical complexity but less operational complexity. Deploying with a parachute would necessitate the ability to receive signals while in the air, adding significant electrical complexity. Additionally, landing with a parachute brings a multitude of issues. Wind could catch the parachute after landing, knocking ZOMBIE over. A mechanism to reel in or cut off the parachute would add a huge amount of complexity and weight to ZOMBIE. Therefore, a mechanism within the nosecone was designed to provide reliability and ease of testing.

## 4.3 Payload Concept of Operations

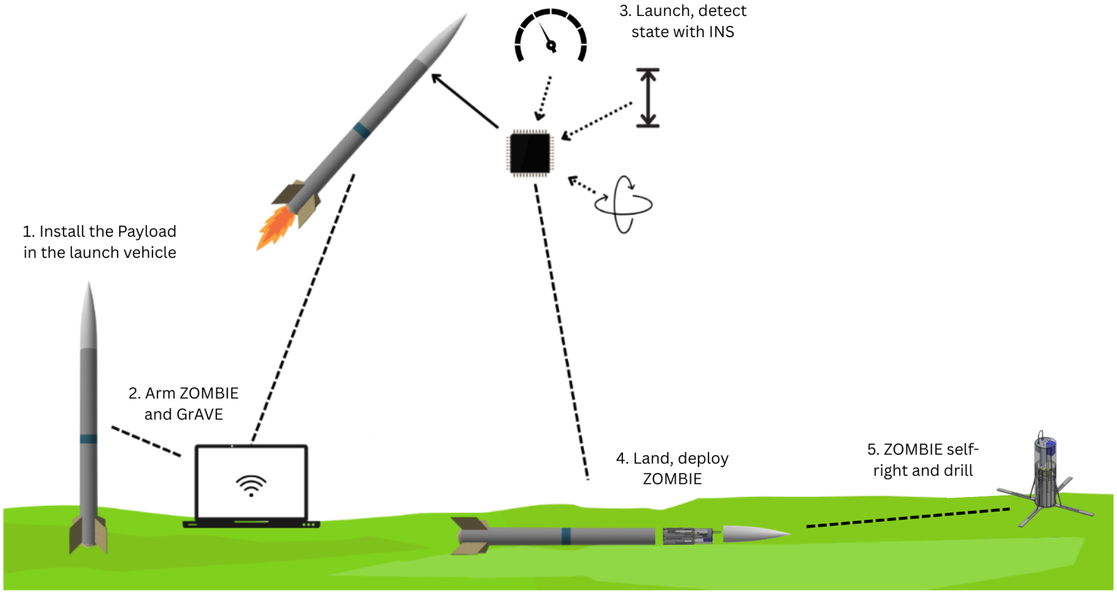


Figure 4.7: General concept of operations.

Before launch, GrAVE will be installed in the nosecone structure. A machined aluminum mounting structure will be placed 16.4 (in) from the aft end of the nosecone and screwed into the nosecone structure. A lead screw motor will be mounted to the back of this bulkhead, and an electronic latch will be mounted to the side. A pusher plate attached to a threaded rod will be inserted into the lead screw motor. The pusher plate will have a slot cut out for ZOMBIE's U-bolt so the electronic latch can securely connect to ZOMBIE while the system is retracted. Two carbon fiber rails will be installed further down the nosecone. They will run the length of the coupler section and be attached to the airframe with epoxy. During pre-launch preparation, ZOMBIE will be aligned with these rails and the pusher plate slot, then a command will be issued to retract the threaded rod. This will ensure ZOMBIE is in the correct orientation for launch.

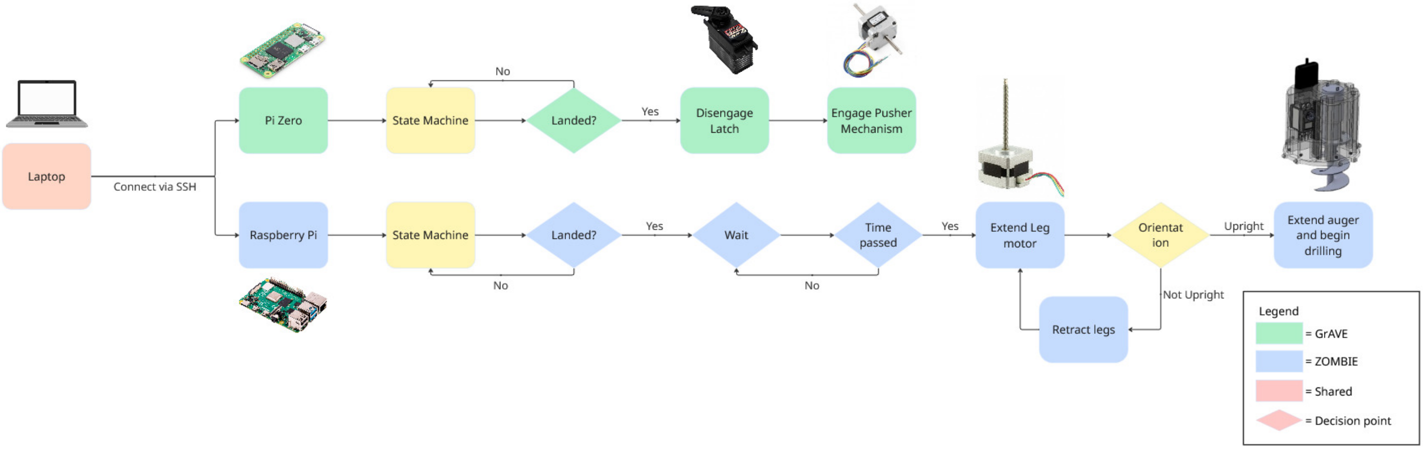


Figure 4.8: CONOPS flow diagram.

On the launch pad, GrAVE and ZOMBIE will be primed by removing pull-pin switches. This will connect the batteries to the rest of the electronics in the payload. Once the electronics are confirmed to be active, a team member will connect their laptop to the microcomputers via Secure Shell (SSH) protocol. The programs that run during flight will be activated and checked to ensure they are working properly. Once verified, the payload is ready for flight.

During the launch vehicle's flight, all the mechanisms in GrAVE will hold ZOMBIE in place. The rails will secure side to side translation and the electronic latch will prevent rotation and movement on the long axis of the launch vehicle. A removable bulkhead will be placed at the end of the nosecone, completely separating ZOMBIE and GrAVE from the main parachute bay. This blocks ZOMBIE from the harmful pressure and temperature spikes from ejection charges while also allowing free deployment on landing. The bulkhead detaches during the descent phase when it is pulled free by a previously slack length of shock cord pulled taut by the main parachute deployment.

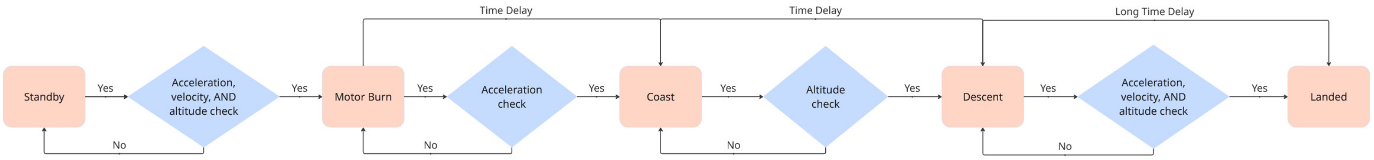


Figure 4.9: Finite state machine flow diagram.

Landing will be detected with an Inertial Navigation System (INS) and finite state machine program. The INS used is a SRAD sensor that combines pressure, temperature, gyroscopic, and acceleration sensors. Two such sensors will be used, one feeding into ZOMBIE's microcomputer and the other into GrAVE's. Both will be running variations of the same state machine code, which works as follows. When the electronics are activated on the launch pad, the state machine will default into the ”Prelaunch” state. The code will continually run checks to compare current altitude, velocity, and acceleration against predetermined values. For the transition from Prelaunch to the ”Motor Burn” state, velocity must be positive, acceleration must be greater than the force of gravity, and altitude must be greater than the starting altitude. The checked values will be tested and refined with previous launches. When the current value for all three exceeds their thresholds, the state will shift to Motor Burn. After Motor Burn, the next state is ”Coast.” This state occurs between motor burnout and apogee. The transition from Motor Burn to Coast will occur either when acceleration drops below a certain threshold or once a set amount of time has passed. The acceleration check will be used as the primary indicator, but the time check will be used as a backup in the event the acceleration check does not trigger. After the Coast phase comes ”Descent.” The transition will be triggered when altitude starts decreasing or, again, once a certain amount of time has passed. Finally, the transition from the Descent to ”Landed” states is the most important for Payload operations. The checks for this transition will be that current altitude is close to takeoff altitude, velocity is close to zero, and acceleration is close to one G. An additional time check will be instituted to guarantee the transition, and the time allotted will account for irregularities such as main parachute deployment at apogee or the launch vehicle's main parachute dragging the vehicle along the ground after landing.

Once landing is detected with all three checks or enough time has passed, GrAVE will extend and deploy ZOMBIE. First, the electronic latch secured to the top of ZOMBIE will unlatch. Then, the lead screw pushing mechanism will force ZOMBIE out of the nosecone. This will be facilitated by the rails connecting the two. After ZOMBIE is fully separate from the launch vehicle, it will begin its own deployment. ZOMBIE's lead screw motor will activate a set amount of time after landing is detected, giving time for GrAVE's deployment process. This motor will drive itself and a collar connected to all four legs down the threaded rod. Linear motion will be ensured with alignment tabs that keep the collar centered within ZOMBIE. As the collar extends, it will create a force on the struts which are attached to it. This force will be transmitted to the joint between the struts and legs, acting as a moment arm around the leg's hinged base. The moment will act between the legs and the body of ZOMBIE. The legs are braced against the ground, resulting in all rotation acting on the body. During deployment, two legs will always be in contact with the ground, ensuring stability. At maximum deployment, all four legs will be perpendicular to the body of ZOMBIE and parallel to the ground. This creates a wide, stable base to support ZOMBIE during its drilling operations.

Once upright, ZOMBIE will run an orientation check using the Inertial Navigation System before the drilling process can begin. The INS is programmed to output heading with respect to gravitational direction. This is achieved through sensor fusion of gyroscopic, magnetometric, and acceleration data. If ZOMBIE's orientation is too far from ”up,” the legs will retract and re-extend to provide a more upright position. This will be repeated until the conditions for being considered ”upright” are met.

After the orientation is confirmed, a bladed auger will extend and drill into the soil. These actions will be performed in tandem with a planetary motor for rotation and a rack and pinion for extension. This will allow the auger to cut into the soil with minimum resistance. Once the rack and pinion reaches maximum extension, it will pause, then retract. The planetary motor will continue to spin. This action will direct the soil with manufactured walls into a soil collection chamber. The soil sensor that collects the required readings will already be positioned in the chamber such that it will be covered by falling soil. This minimizes mechanical complexity and ensures reliable readings. The auger will extend and retract a set number of times to ensure enough soil is collected. New soil which has fallen into the drilled hole from the surrounding earth will be collected, forcing previously collected soil up the auger and into the collection chamber. This extra soil will compact the soil already in the chamber, increasing the reliability of soil measurements.

Soil measurements will be taken after the drilling ceases. A 7-in-1 soil sensor will be used that collects all three readings listed in NASA Requirement 4.1. ZOMBIE's Raspberry Pi microcomputer will pull the data from the soil sensor and combine it with the current time based on the onboard clock. The data will be saved to a micro SD card and will be presented in the PLAR.

## 4.4 Payload Subsystems

### 4.4.1 ZOMBIE

**Deploying Legs**

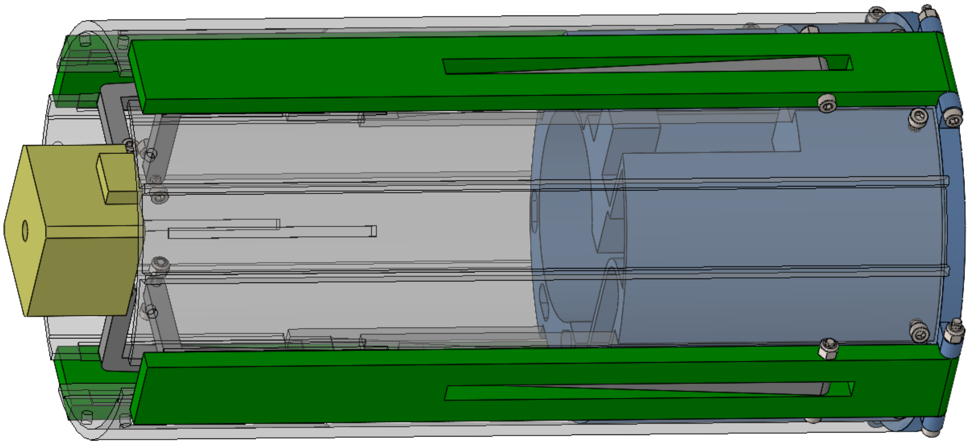


Figure 4.10: Leg deployment mechanism.

The ZOMBIE lander will use four legs to right itself, shown in green in Figure 4.10. The legs will all be identical 3D printed structures 1 (in) wide, 0.25 (in) thick, and 10 (in) long, as shown in Figure 4.11. They will use 100% infilled PLA filament to achieve the rigidity needed to support ZOMBIE.

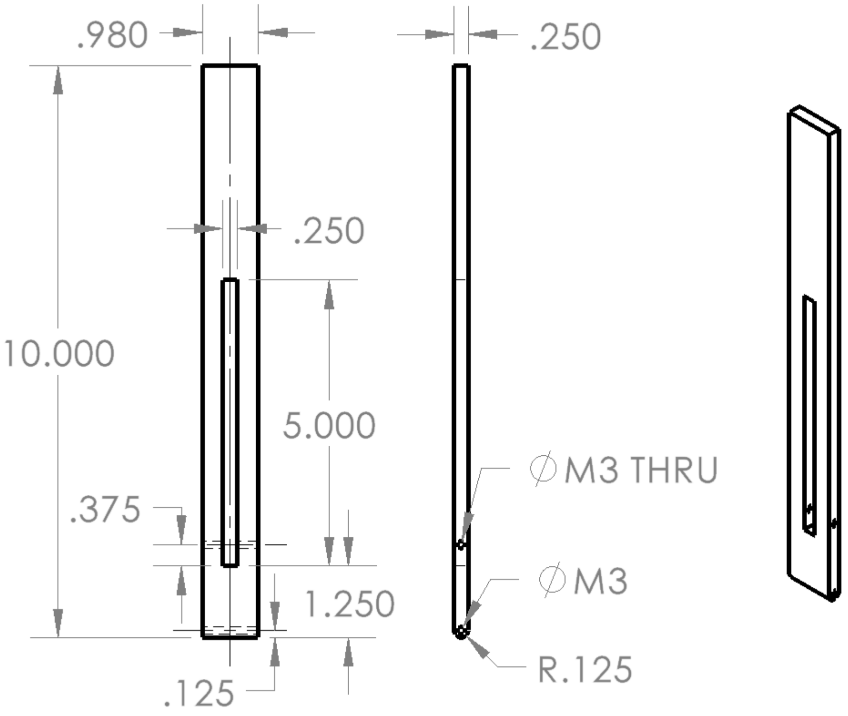
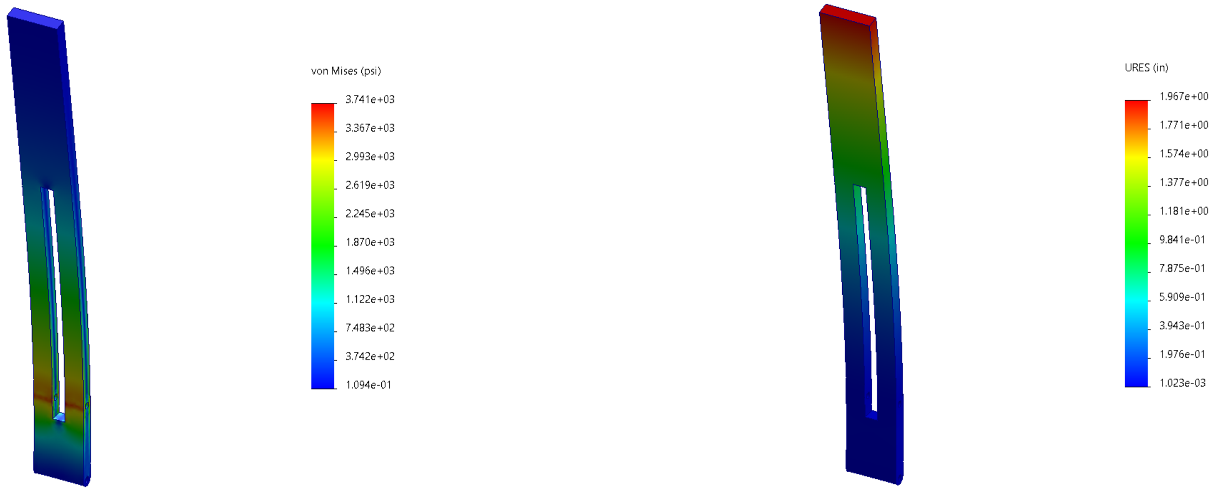


Figure 4.11: Deploying leg drawing (in).

To verify the legs will be able to withstand the forces present during the self-righting process, a static simulation was run using Solidworks. The leg was pinned but free to rotate at both of its mounting points, and a 40 (lbf) bearing load was applied laterally to the linkage mounting holes to simulate the maximum force that can be provided by the lead screw motor. A 7 (lbf) load was applied to the leg face opposing the bearing force to simulate the worst-case scenario where the entire weight of ZOMBIE is applied to one single leg during self-righting. The results of the analysis are shown in Figure 4.12. For a PLA leg of the designed geometry, the maximum equivalent stress under the applied loads is 3471 (psi), which is below the PLA filament's bending strength of 76 (MPa) or 11000 (psi)[2], meaning that though the legs will experience some bending, they will not break under the forces, thus validating the leg design.



(a) Leg equivalent stress plot.

(b) Leg displacement plot.

Figure 4.12: Landing leg static simulation results.

Each leg will be hinged at two locations: one at the base of ZOMBIE and another 1.625 (in) farther out to a 8 (in) aluminum linkage. Both hinges will be secured with M3 mounting screws and lock nuts. The linkages will connect the legs to the 3D printed collar inside ZOMBIE's main structure. Aluminum was chosen for the linkages because of the increased stiffness it provides compared to PLA, as the shape of the linkages means they experience high bending forces.

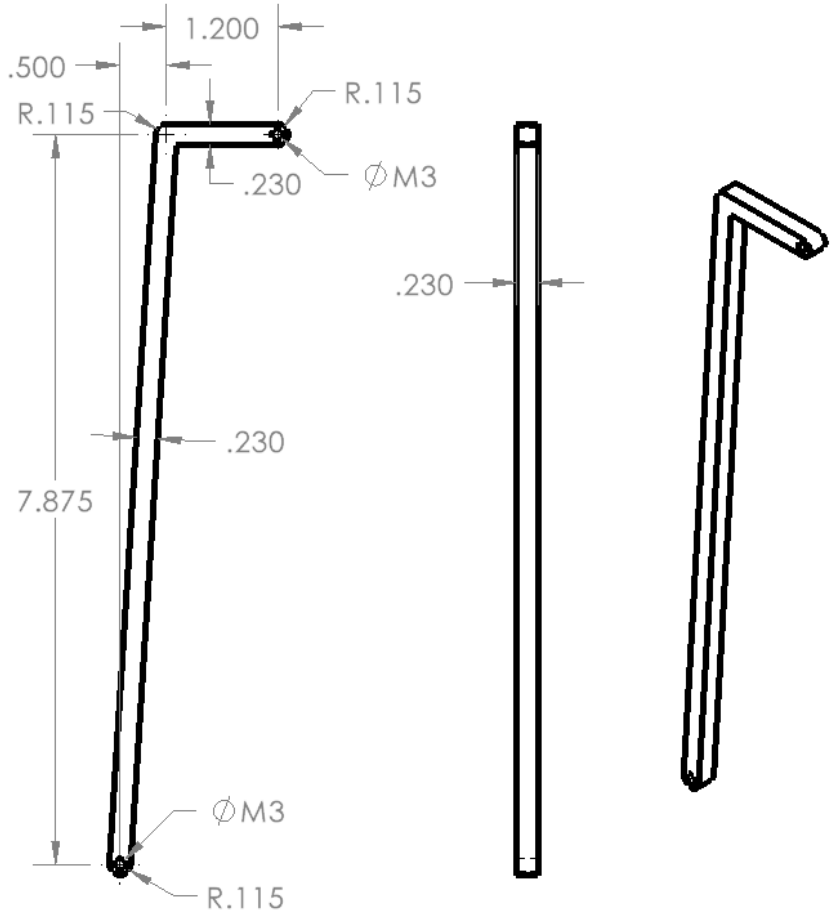


Figure 4.13: Linkage drawing (in).

The linkages depicted in Figure 4.13 connect to the collar with M3 hardware through slots in ZOMBIE's outer structure. The collar is held in place by rails included in the 3D printed outer body's design. These rails keep the collar in an orientation normal to ZOMBIE's long axis, and therefore prevent the collar from rotating out of alignment. A lead screw stepper motor is mounted with M3 hardware to the center of the collar. The lead screw runs through the motor and is fixed to an insert in the electronics sled. Since the lead screw is fixed, as the stepper motor actuates, the motor and collar assembly is forced downwards. This force is transmitted through the linkages and thus acts as an outward-pushing force on the legs, causing them to deploy outward and push against the ground, which in turn causes ZOMBIE to self-right.

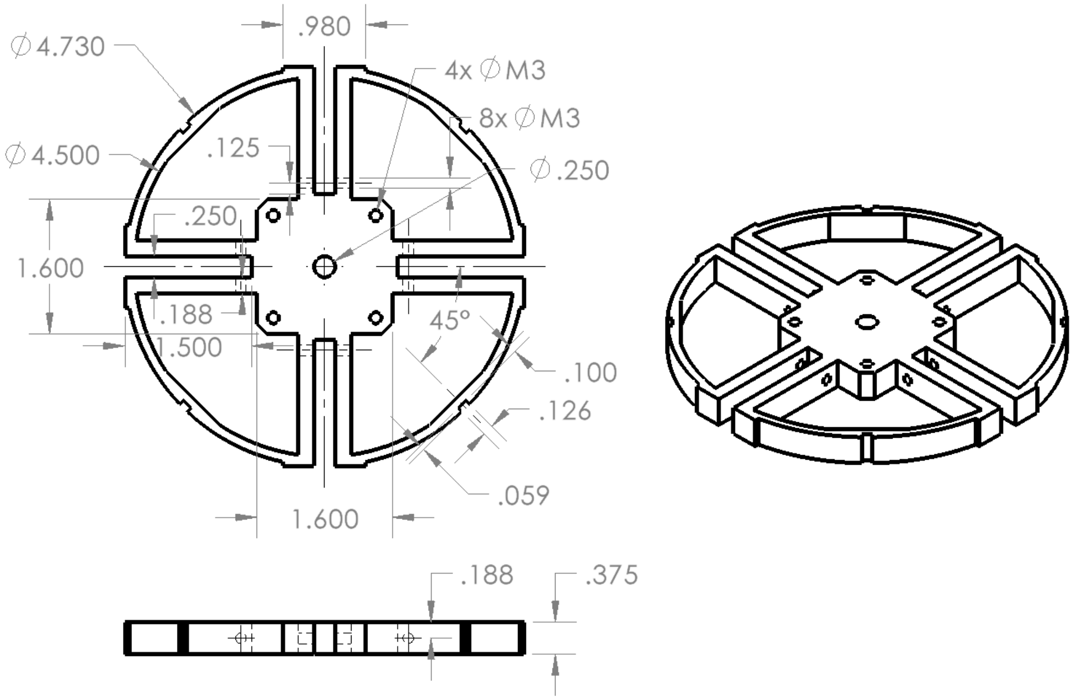


Figure 4.14: Collar drawing (in).

The connection point from the collar to the linkages lies close to the center of the collar to maximize the moment arm available for the lead screw motor's force to act upon to deploy the legs. A drawing of the collar is included in Figure 4.14. To accommodate for this connection location without sacrificing internal space, the linkages are an L shape geometry instead of linear. This achieves the same force transmission and torque as a linear linkage without requiring longer slots in the outer body for the linkages to pass through and interfering with the soil collection module and its components.

**Soil Collection Module**

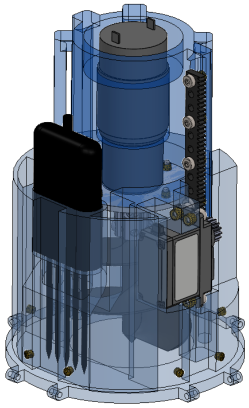


Figure 4.15: Soil collection module.

At the bottom of ZOMBIE's structure lies the module for soil collection and testing. This structure is shown in Figure 4.15 The main structure of this section consists of a single 3D printed part and houses the auger, motors, soil collection chamber, and soil sensor. The auger is attached by a shaft and coupler to a planetary gear motor that allows it to rotate, and the motor is encased by a 3D printed housing that includes rails that allow the auger-motor assembly to slide smoothly vertically. A servo drives a rack and pinion to allow the auger assembly to actuate to drill into the ground. As the auger brings soil up into ZOMBIE, the soil falls into the built-in collection chamber, which is equipped with a soil sensor to measure the soil qualities.

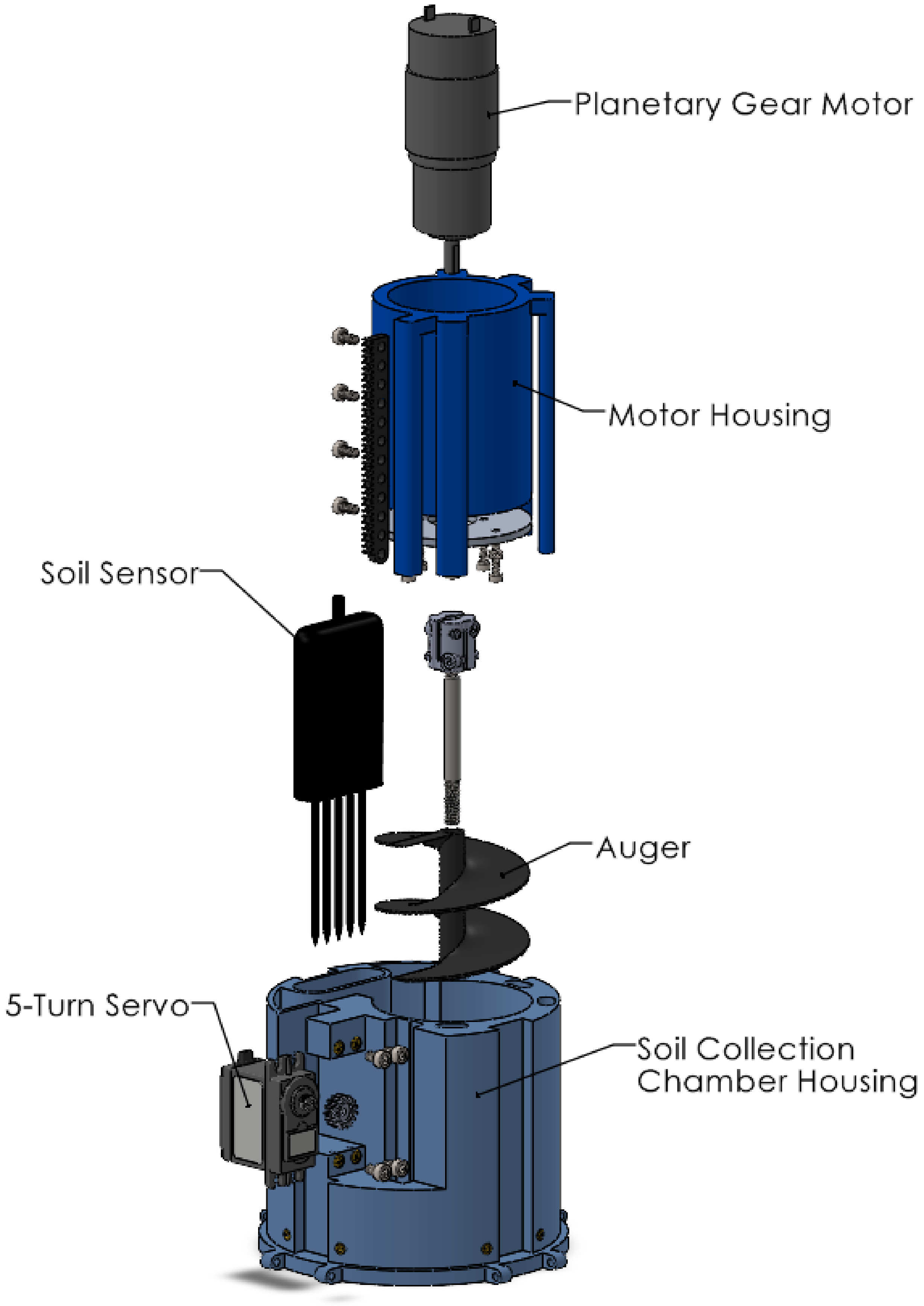


Figure 4.16: Soil collection module exploded view.

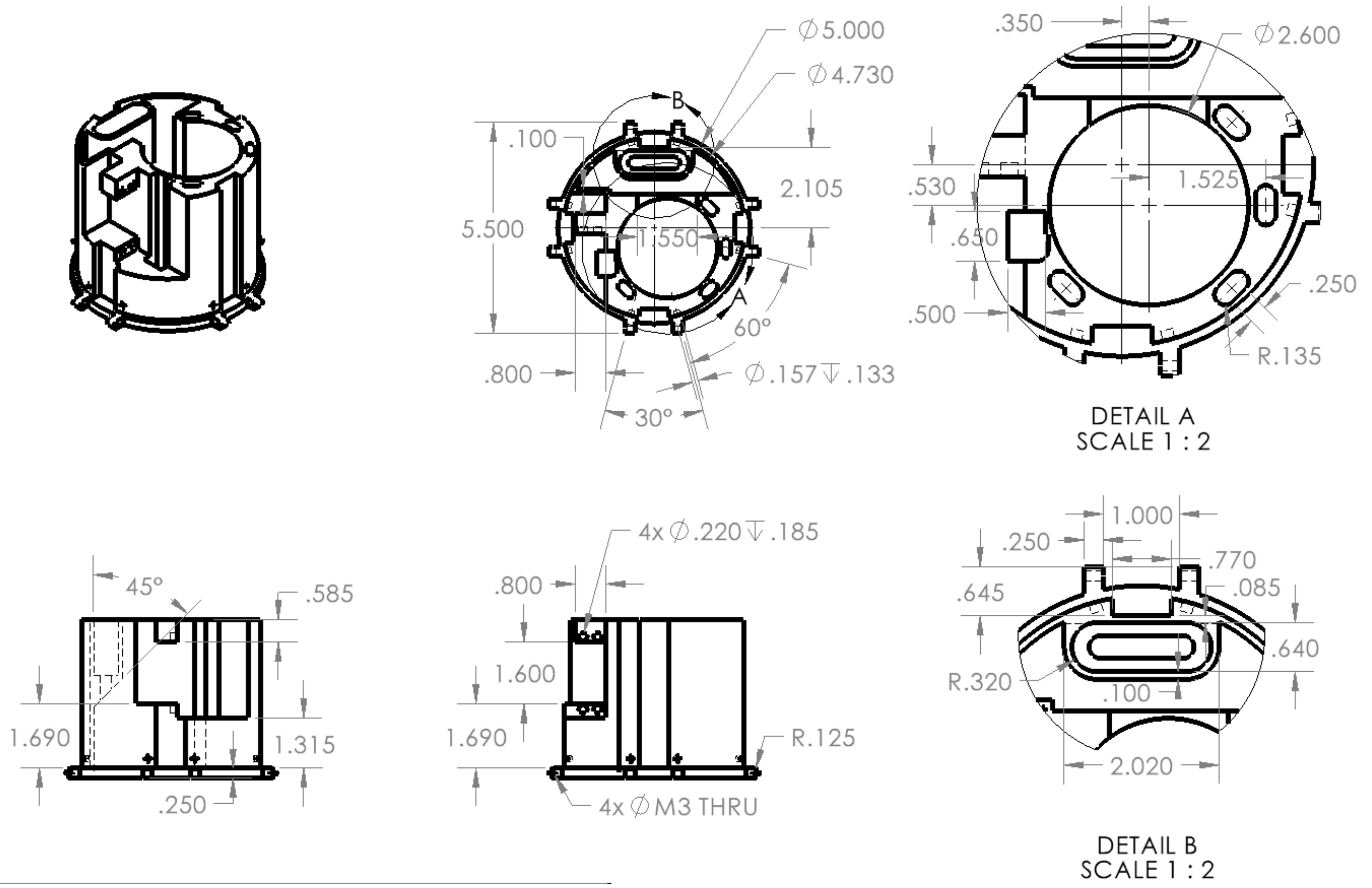
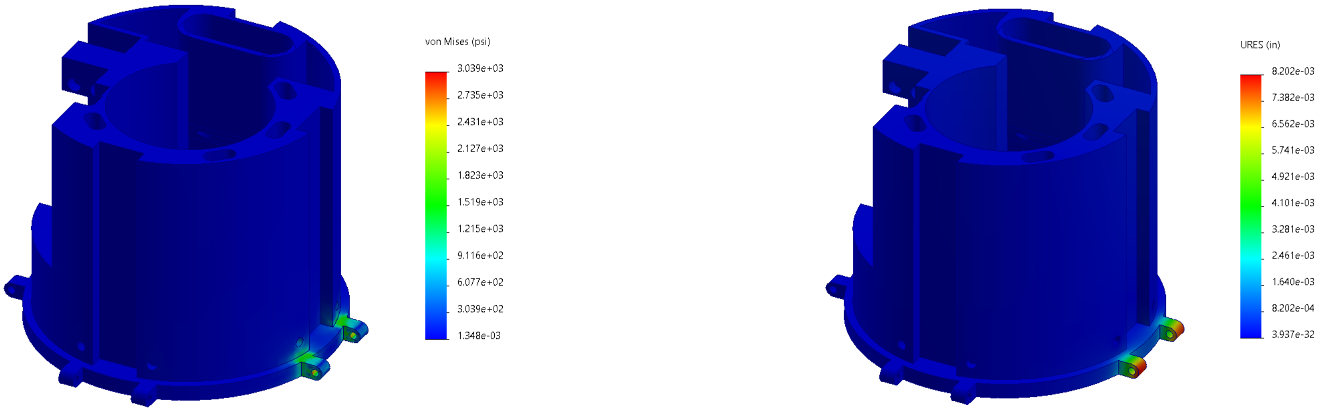


Figure 4.17: Soil housing drawing (in).

The main housing structure of the soil collection module is a single piece 3D printed from PLA filament for rapid iteration and ease of manufacturing. The dimensions are given in Figure 4.17. A 2.6 (in) diameter hole runs through the part to allow for the auger-motor assembly to slide through the housing. The structure also has a large cutout in its design for the soil collection chamber, and a sloped ramp that connects to the auger hole. The base of the chamber cutout has an area of 3.718 (in$^2$), and the bottom lip of the soil ramp is 1.265 (in) above the base. This gives a volume of 4.703 (in$^3$) or 77.07 (mL), therefore satisfying team derived requirement PD 2. The structure also includes cutouts and mounting points for the soil sensor, the rack and pinion servo, and the auger-motor assembly's rails. The base of the part has mounting points to attach the section to both the rest of the outer body structure and to the four deploying legs.



(a) Soil housing equivalent stress plot.

(b) Soil housing displacement plot.

Figure 4.18: Soil housing static simulation results.

A Solidworks static simulation was run for the soil housing to demonstrate that the bracket connecting the linkages to the housing would be sufficient to withstand the forces of ZOMBIE self-righting. The heat-set insert holes were fixed, and a downward bearing force of 40 (lbf) was applied to one set of mounting holes to simulate the maximum force from the lead screw motor acting on one single leg during deployment. The resulting stress and displacement plots are given in Figure 4.18. The maximum stress on the housing is 3039 (psi), which is less than the PLA filament's Z-axis tensile strength of 31 (MPa) or 4500 (psi)[2], which means that the housing's leg mounting brackets will withstand the forces from the leg deployment.

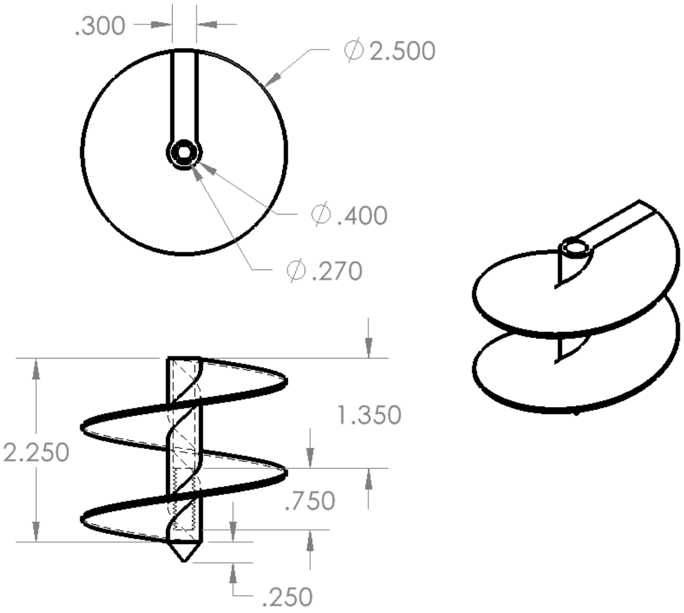


Figure 4.19: Auger drawing (in).

The auger, as seen in Figure 4.19, is a 2.5 (in) diameter, custom-designed 3D printed element that attaches to a 1/4"-20 partially threaded shaft. Using a 3D printed auger allows more customization over commercial off-the-shelf metal augers at the same performance and lower mass. Various designs have and will be tested, varying parameters such as auger diameter, blade pitch, and general geometry. The interior of the auger is threaded to hold securely to the threaded shaft, and as the auger will only rotate clockwise, the shaft will not be able to unscrew from the printed part.

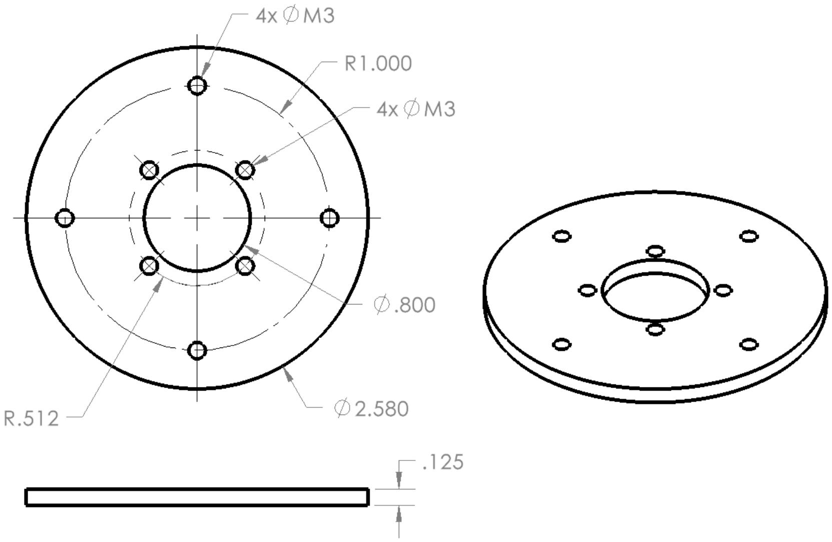


Figure 4.20: Motor mounting plate drawing (in).

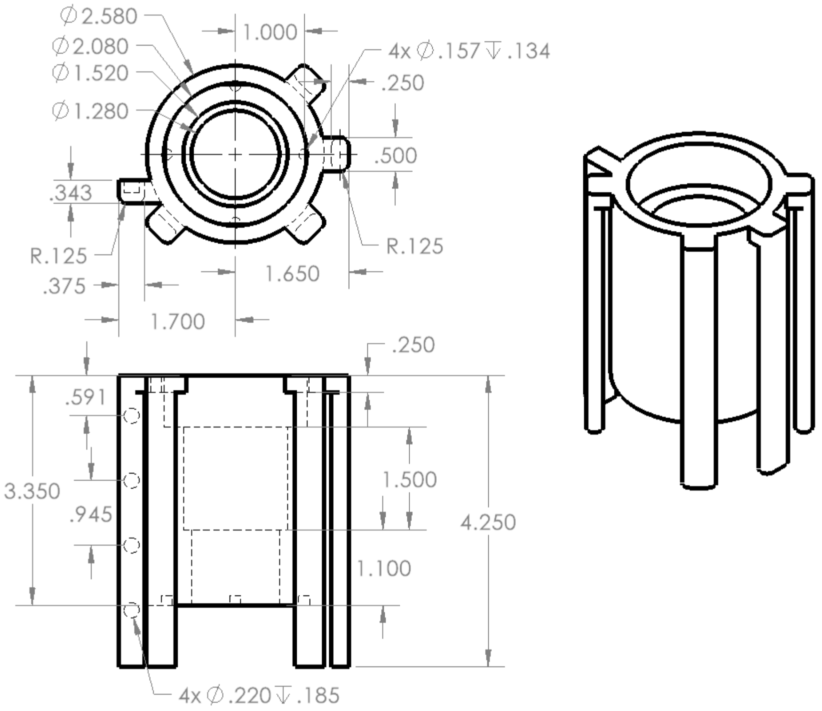


Figure 4.21: Motor housing drawing (in).

The threaded shaft is then connected to a planetary gear motor by a coupler. The motor is mounted to an aluminum plate (see Figure 4.20 which is itself connected to a 3D printed piece (see Figure 4.21) that fits the motor and has rails to both interface with the main housing part and mount the gear rack for the rack and pinion. A lubricant will be applied to the rails and their tracks to ensure the assembly translates smoothly up and down. This assembly fits snugly into the auger hole in the main housing and allows the auger to only rotate and translate along its long axis, and restricts motion in all other degrees of freedom.

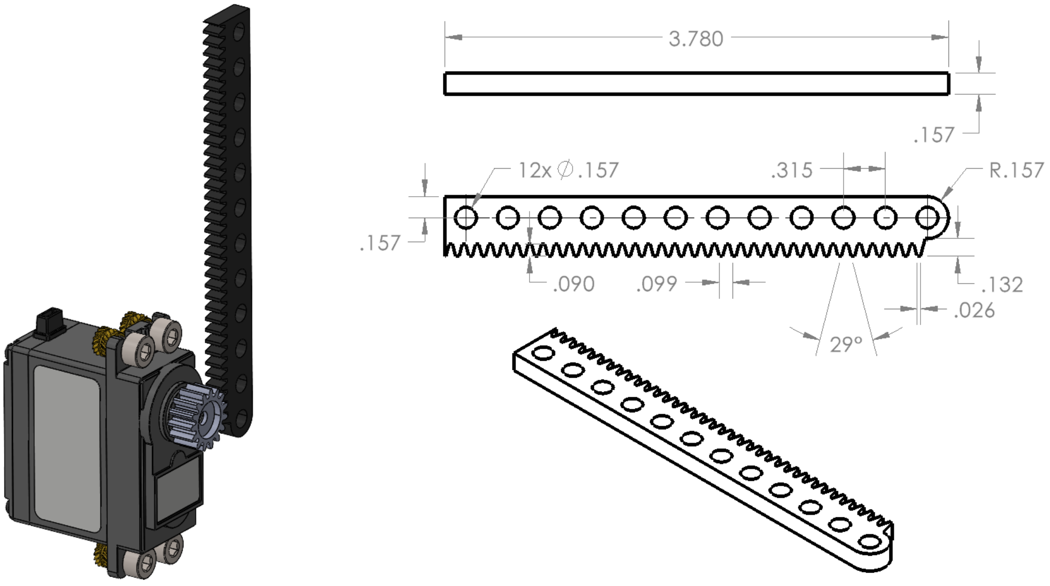


Figure 4.22: Rack and pinion assembly.

The auger-motor assembly's gear rack interfaces with a pinion gear attached to a 5-turn dual mode servo, which was chosen for high torque at low speeds and because the whole mechanism does not need to spin more than 800 degrees. The servo is mounted to its space in the main housing by M4 hardware and heat set inserts. This system is shown in Figure 4.22

**STEMnaut Housing and Electronics Sled**

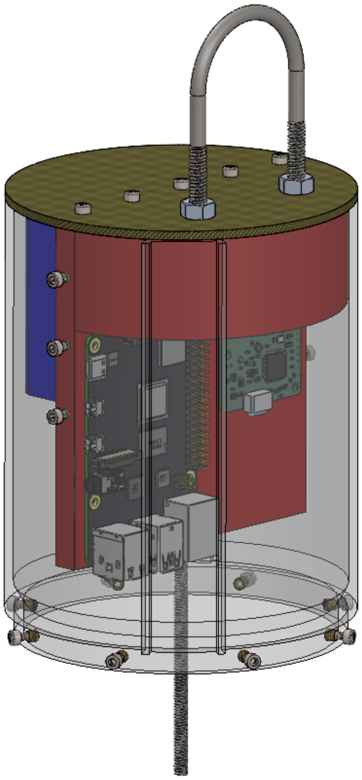


Figure 4.23: Top assembly.

ZOMBIE's top is a combined structural element, electronics sled, and STEMnaut enclosure. The structure is shown in Figure 4.23.

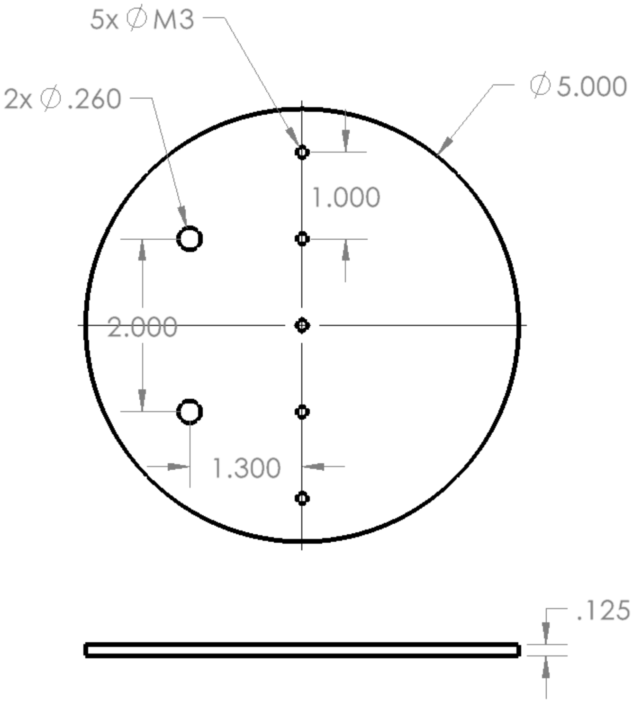


Figure 4.24: Top plate drawing (in).

The top part will be bulkhead made from 0.04 (in) thick S2 fiberglass face sheets on the opposing sides with a 0.125 (in) honeycomb Nomex core. Composites were chosen to meet the strength requirements imposed on the structure by launch and landing. The disk contains mounting points to connect to the rest of ZOMBIE with M3 hardware, a U-bolt to connect to GrAVE, and mounting points to connect the 3D printed STEMnaut/electronics sled. The positions of these holes are given in Figure 4.24

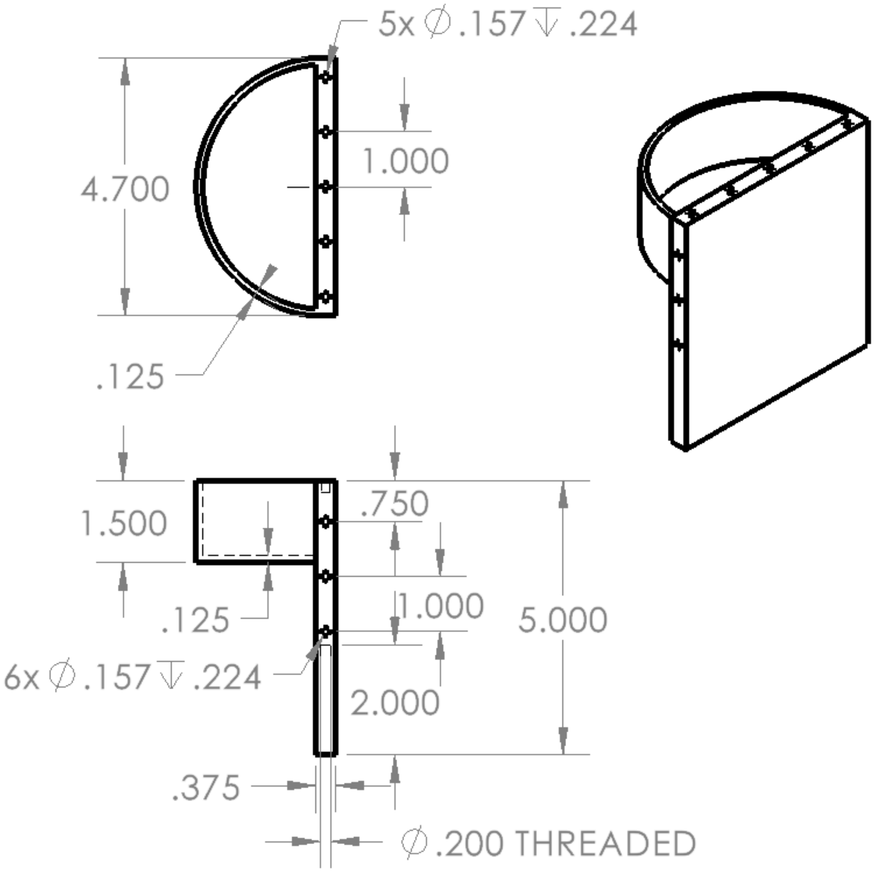


Figure 4.25: STEMnaut housing and electronics sled drawing (in).

The STEMnaut housing and electronics sled is a single 3D printed piece that attaches both to the top plate and to the upper body section to join them together. The dimensions are given in Figure 4.25. The electronics sled will consist of all the space not used by the STEMnaut enclosure. The Raspberry Pi and INS will be mounted under the enclosure, with the Li-Po battery, pull pin switches, and motor drivers mounted on the opposite side. At the bottom of the sled is the mounting point for a threaded rod. This will be the structural threaded rod used during ZOMBIE's leg deployment, described in Section 4.4.1. The M5 double-start threaded rod will be screwed into a manufactured hole in the sled.

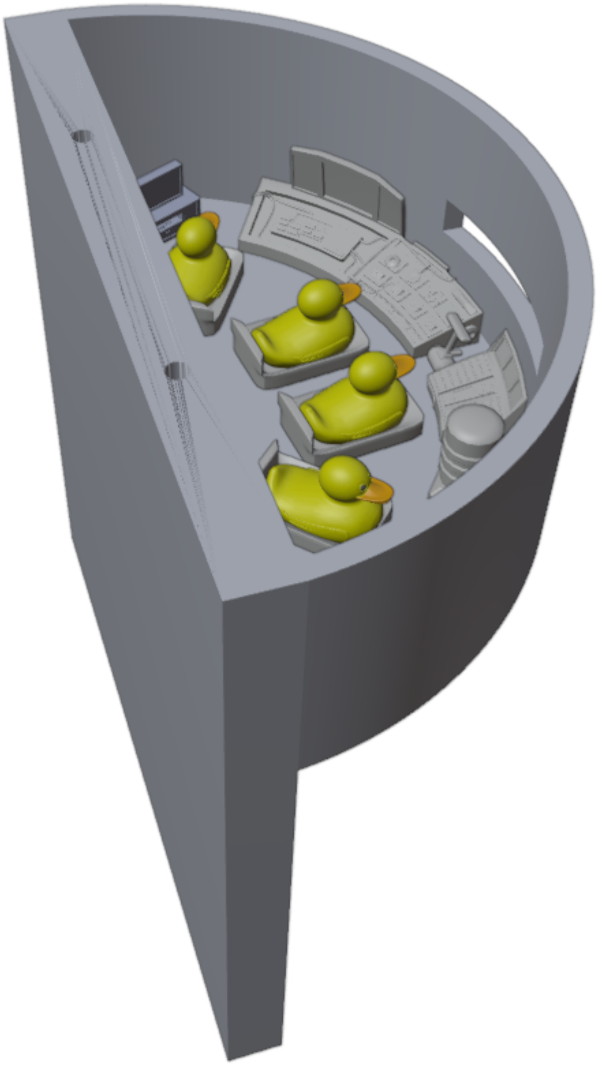


Figure 4.26: STEMnaut enclosure.

The STEMnaut enclosure will be a hollow half-cylinder which contains many fixtures to improve their quality of life. A rendering of the accommodations is shown in Figure 4.26. To ensure the STEMnauts have adequate stimulation and supplies for their voyage, a number of features have been added to their environment. Chairs, a water cooler, a TV, and a control panel will be 3D printed within the structure. A plastic window will also be installed facing out of the rocket to give the STEMnauts an entertaining view during their mission while still ensuring that they remain protected from the external atmosphere. The enclosure will be open on the top before it is mounted to the composite lid, allowing for easy placement of the STEMnauts. The STEMnauts will be secured to their chairs with Velcro to restrain them in flight but allow for easy removal after landing.

Figure 4.27: STEMnaut resin duck.

The team has chosen four resin ducks as the STEMnauts who will fly aboard ZOMBIE during the mission. Commander Joel will lead the crew, which includes pilot Ellie, engineer Shaun, and scientist Robert. Each STEMnaut measures approximately 0.6 (in) tall, 0.5 (in) wide, and 0.7 (in) long and weighs 0.0031 (lbm).

### Outer Body

ZOMBIE's outer body is composed of two 5 (in) diameter 3D printed sections joined together by M3 hardware. The body is split into two separate parts due to size limits of 3D printers available to the team; the split also allows for placement of the leg deployment collar inside the structure.

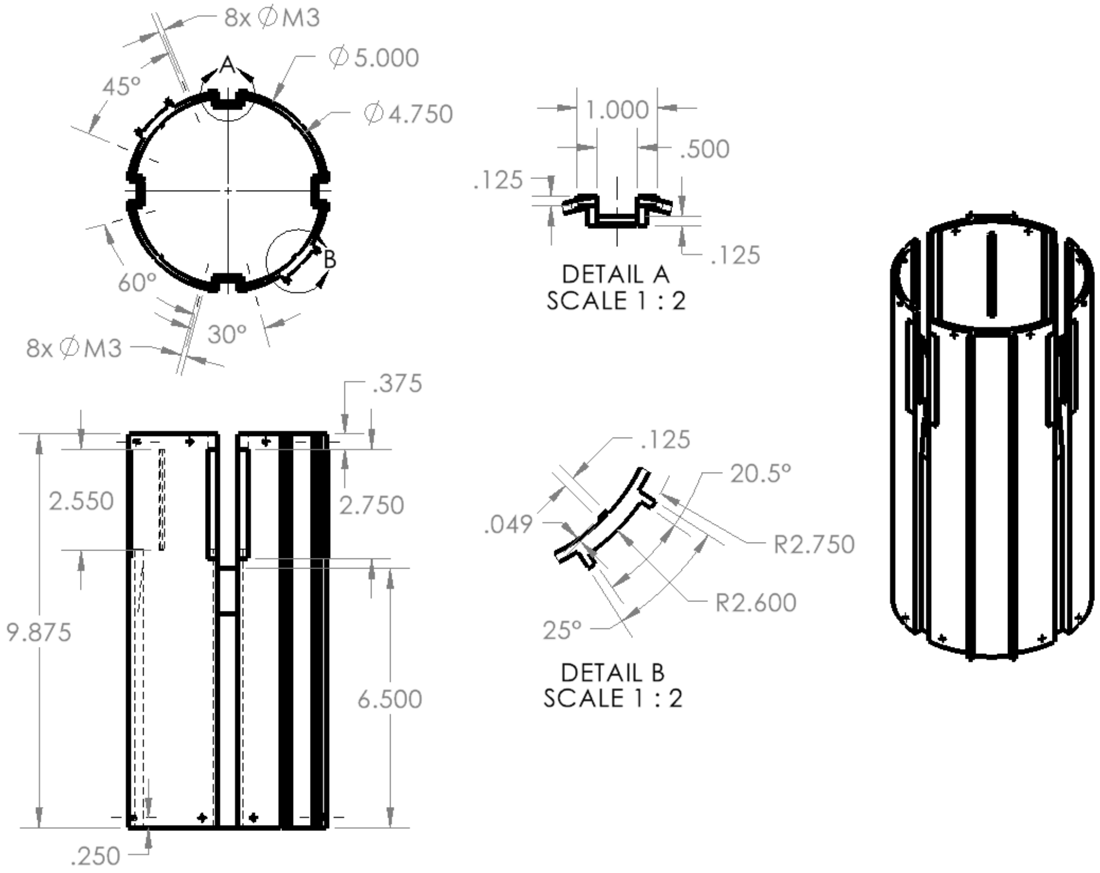


Figure 4.28: Lower body drawing (in).

The 9.875 (in) tall lower section seen in Figure 4.28 has four slots in the walls for the leg linkages, as well as four small rails integrated with the structure to support the collar during leg deployment to ensure the collar stays in its set orientation and does not rotate. It includes eight M3 holes around its bottom to attach to the soil collection module, and eight more M3 holes at the top to attach to the upper section.

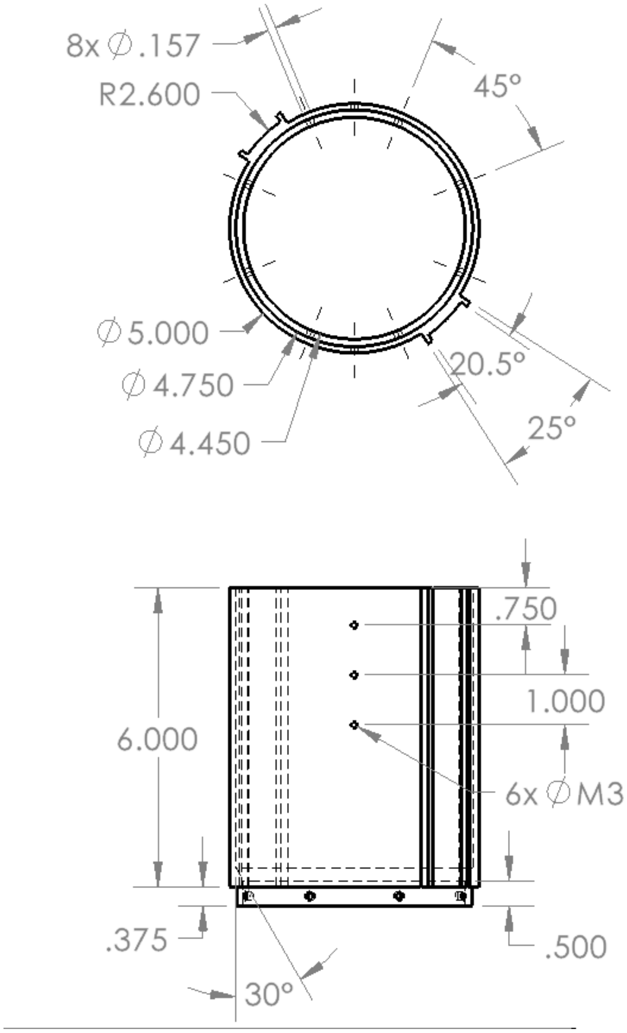


Figure 4.29: Upper body drawing (in).

The 6 (in) tall upper body section has a 0.375 (in) ring of slightly smaller diameter around its bottom that allows it to fit smoothly into the lower body section. This is shown in Figure 4.29. It also has six M3 holes on its outer face for connection to the STEMnaut housing and electronics sled, and eight holes around its bottom ring for mounting to the lower section.

### 4.4.2 GrAVE

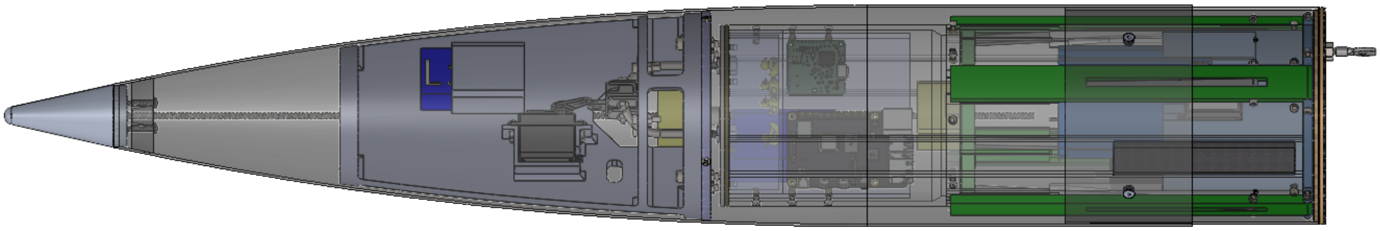


Figure 4.30: GrAVE with ZOMBIE inserted.

The Ground Activated Vehicle Ejector is the system that contains all mechanisms responsible for ejecting ZOMBIE. GrAVE remains completely within the nosecone after landing. All mechanisms are mounted to the nosecone in some fashion. These mechanisms include the rails, the lead screw pusher plate, and the electronic latch. There will be two carbon fiber rails that run the length of the coupler section manufactured in-house for this system. The rails are tubes approximately 1 (in) wide, 0.3 (in) thick and molded to mate directly with the curved interior of the nosecone. One rail will serve as a guide tube for the main recovery parachute shock cord. ZOMBIE will have matching fixtures to keep it aligned with the rails.

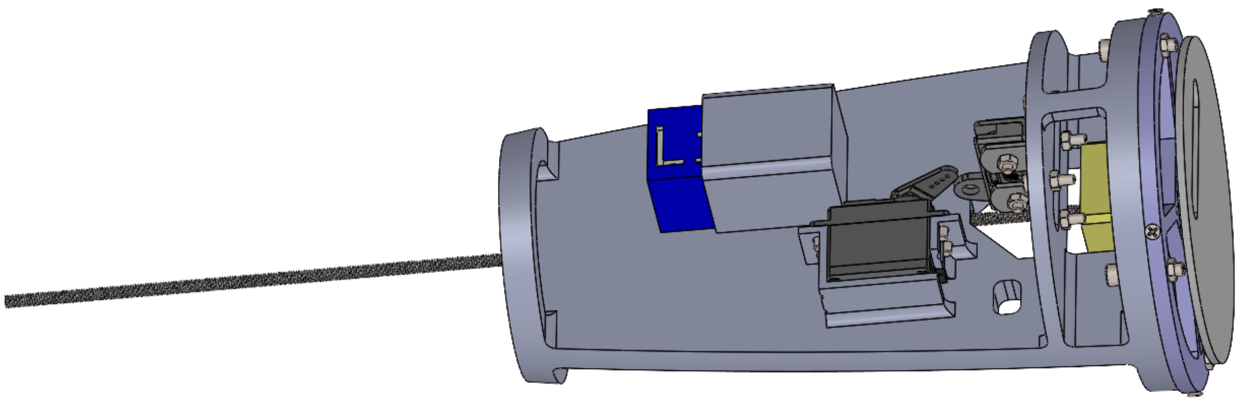


Figure 4.31: GrAVE sled with latch and pusher plate installed.

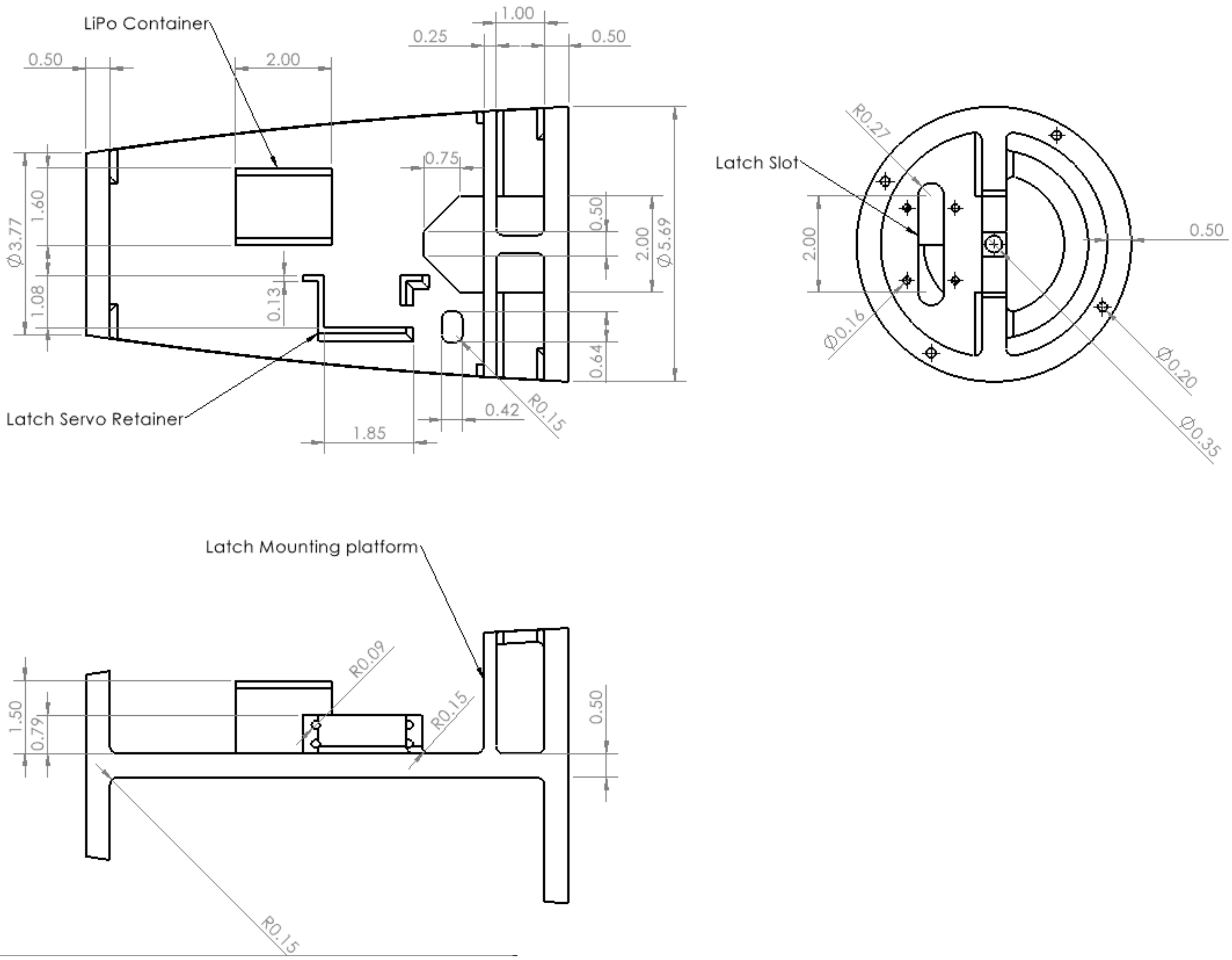


Figure 4.32: GrAVE sled drawing (in).

The lead screw pusher plate and electronic latch function in tandem to release and eject the payload after landing. Both mechanisms are attached to a Raspberry Pi Zero 2 W, chosen for its low cost and versatility. The mechanisms, Pi Zero, INS, and motor drivers are mounted to a 3D printed sled shown in Figure 4.31, attached to a bulkhead 16.4 (in) from the bottom of the nosecone. The INS will feed telemetry to the Pi Zero, which will have the same state machine as ZOMBIE loaded onto it. The sled itself consists of a flat portion between two disks. The disks and the sides of the plate are fitted to the inside of the nosecone's ogive shape. An additional platform is used on one side as a mounting point for the latch mechanism.

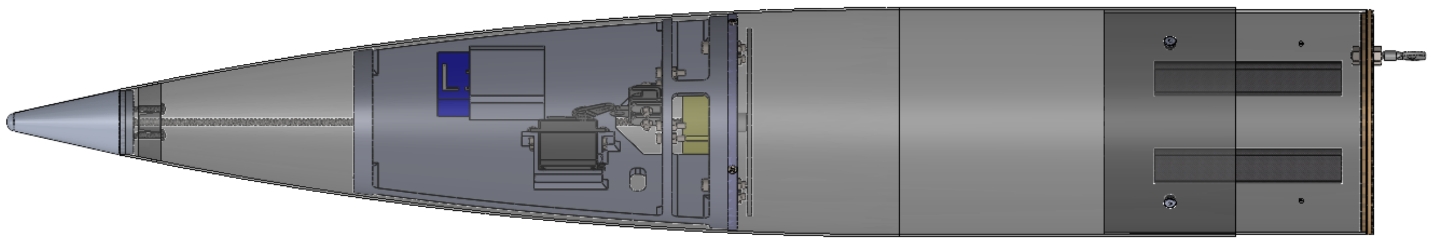


Figure 4.33: GrAVE retracted.

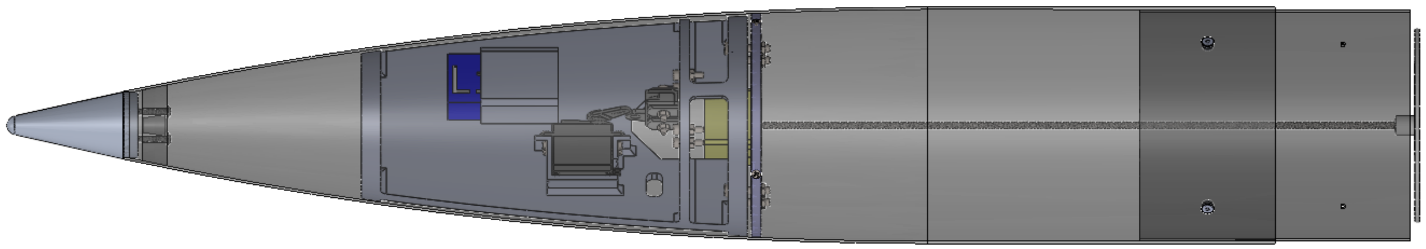


Figure 4.34: GrAVE extended.

When landing is detected, GrAVE will transition from the configuration shown in Figure 4.33 to that shown in Figure 4.34. The servo on the electronic latch will rotate to release the U-bolt on the top of ZOMBIE.

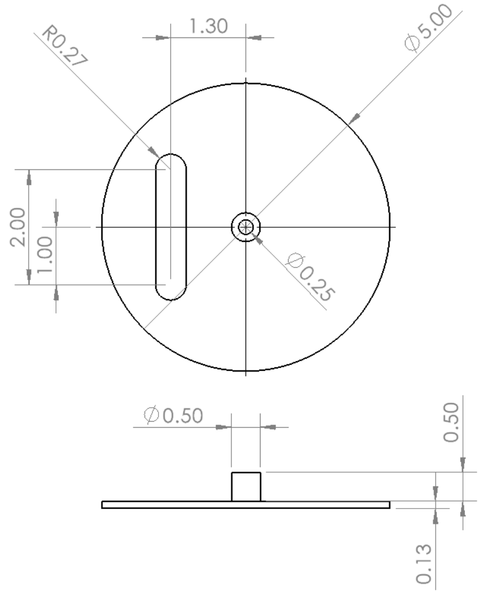
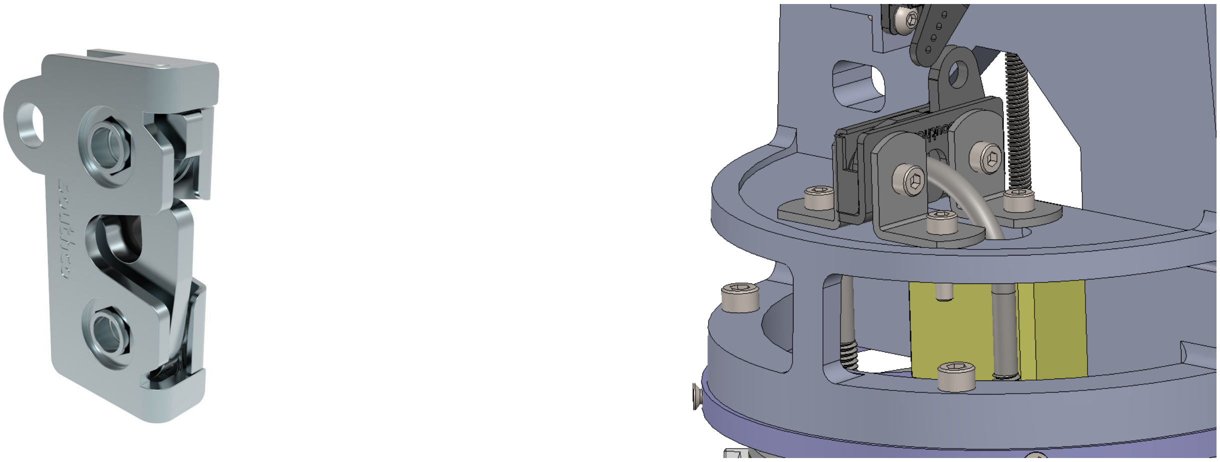


Figure 4.35: Pusher plate drawing (in).

While retracted, ZOMBIE's U-bolt will be slotted in a hole through the pusher plate, seen in Figure 4.35. This allows the pusher plate to maintain a large contact surface when pushing ZOMBIE out of the nosecone and to prevent rotation of either element. This pushing mechanism is driven by a lead screw motor mounted to the bulkhead. Unlike in ZOMBIE where the motor moves and the screw remains in place, GrAVE's lead screw motor remains in place and moves the screw. The larger application area from the pusher plate results in lower material strength needed on each side, in addition to creating a more balanced load distribution. Uneven loading could result in ZOMBIE getting caught in the rails, making deployment more difficult and possibly damaging the structure. The lead screw will be 18.4 (in) long, allowing it to extend well beyond ZOMBIE's height to ensure a full separation.

To ensure proper retention of ZOMBIE during flight, a mechanical rotary latch that interfaces with the U-bolt on ZOMBIE will be utilized.

The latch is made from zinc and will be mounted with L-brackets and M4 screws.



(a) SouthCo rotary latch.

(b) Latch interface with U-Bolt.

Figure 4.36: Demonstration of use of rotary latch in GrAVE.

The latch is capable of withstanding 2600 newtons of average force without failing. The latch is engaged by simply pressing the latch down. To disengage the latch a small arm must be pushed. For GrAVE a servo will rotate and a connected arm will disengage the latch after landing. The latch is raised from the base of GrAVE to allow space for the stepper motor driving the pusher plate.

## 4.5 Payload Electronics

### 4.5.1 ZOMBIE Electronic Design

**Flight Computer**

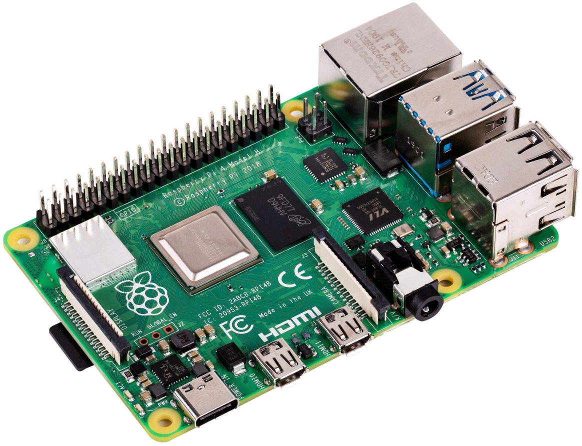


Figure 4.37: Raspberry Pi 4b microcomputer.

ZOMBIE requires that the computer chosen is able to handle active control of multiple motor systems while simultaneously processing and logging sensor data from multiple sources. The Raspberry Pi 4B was chosen primarily because of its high processing power and ability to handle multiple processes at once. It is shown here in Figure 4.37 Another important factor is the Pi's ability to run Python code. Python is the primary language with which the system logic is designed. The language is relatively simple to learn and extremely versatile with extensive library support for hardware integration. The Raspberry Pi is capable of WiFi communication with other devices with allows for wireless activation on the pad after power is connected.

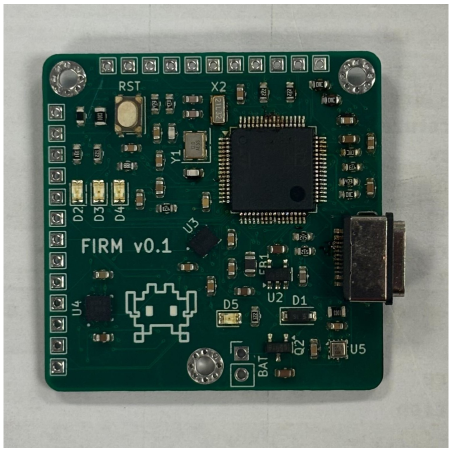


Figure 4.38: INS.

The Raspberry Pi will communicate with an onboard INS that will constantly supply inertial data to the system for logic control. A picture of this device is seen in Figure 4.38. This INS has three different sensors, a BMP581 pressure sensor, a MMC5983 magnetometer, and a ICM45686 6-axis inertial measurement unit (IMU).

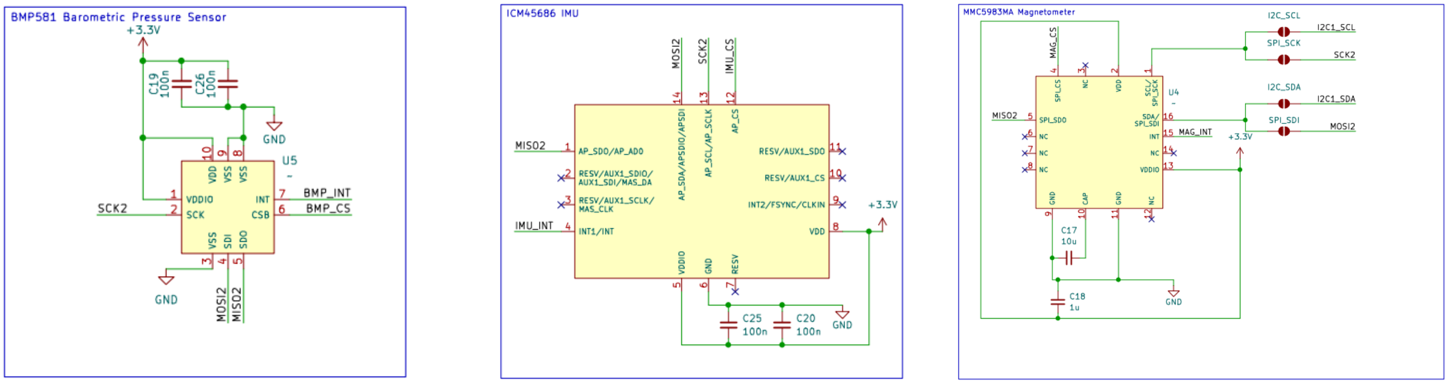


Figure 4.39: Electrical schematics of all INS sensors.

These sensors communicate with a STM32F405RGTx microcontroller. The controller is programmed in C and handles the data from the sensors and communication with other systems like the Raspberry Pi. The INS will be connected to the Raspberry Pi through a USB-A to USB-C chord and uses serial communication.

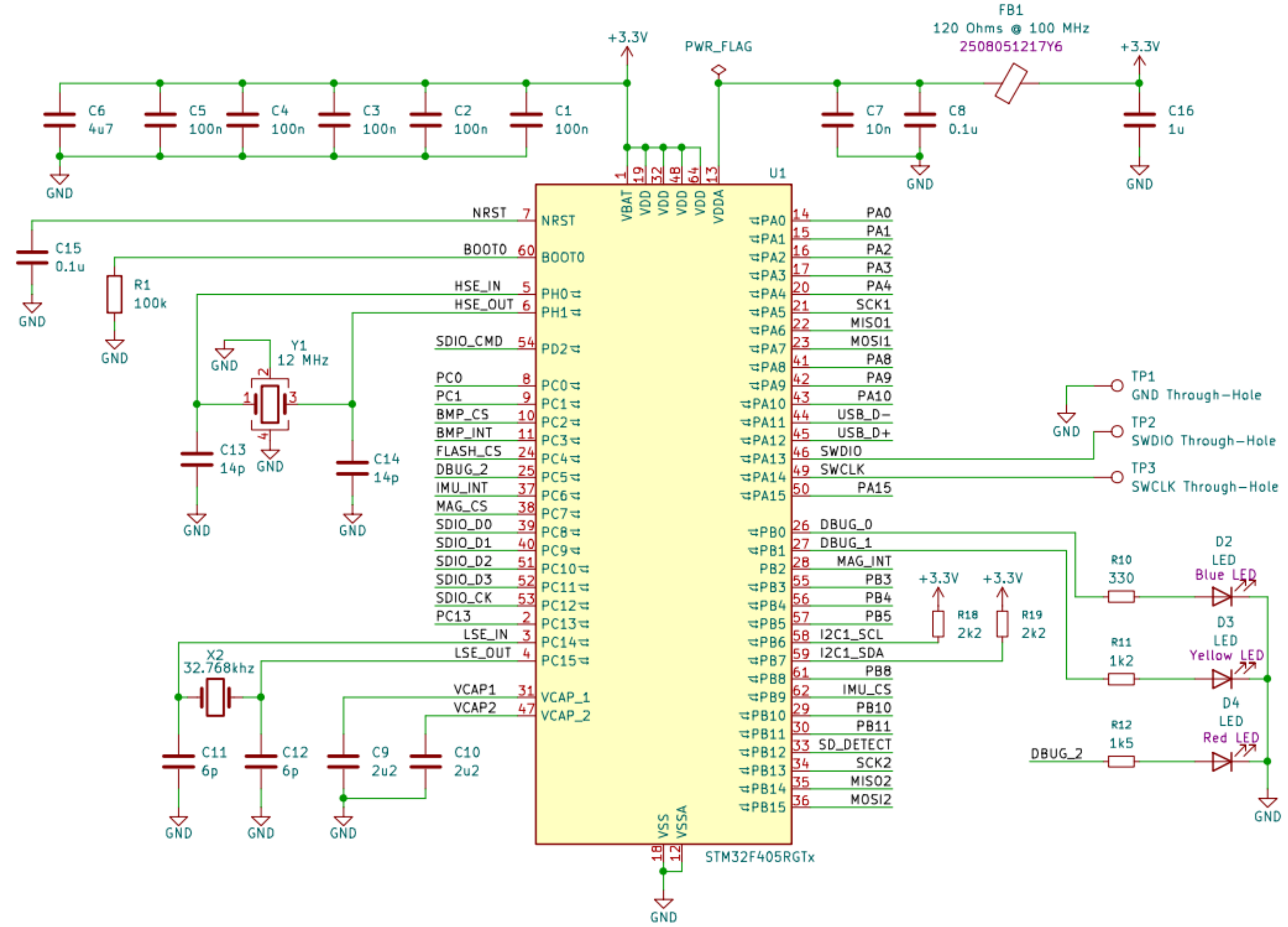


Figure 4.40: Electrical schematic of INS microcontroller.

**Soil Probe**

Figure 4.41: Soil sensor probe.

The soil probe used is a commercially sourced soil sensor that is capable of reading seven different measurements. It is shown above in Figure 4.41. It is capable of measuring the temperature, moisture content, pH, electrical conductivity, and the nitrogen, phosphorus, and potassium levels in the soil. The sensor uses 5 metal probes that insert into the soil sample for measurements.

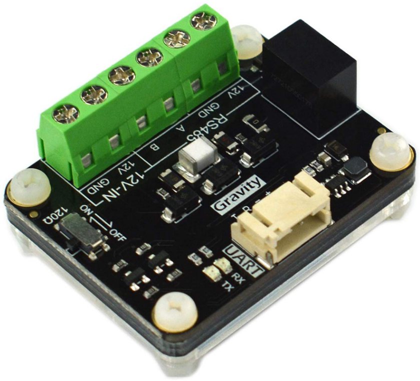


Figure 4.42: DFRobot signal adapter.

The sensor operates nominally at 12 volts of power. It communicates using the Modbus RTU communication protocol and uses the RS485 communication standard. This standard uses 2 wires, an A and a B wire, to create a voltage differential between the two. This differential is used for communicating signals. The Raspberry Pi is not able to communicate using RS485 so a converter will be utilized to translate to UART signal. The converter board used is a signal adapter module from DFRobot, as shown in Figure 4.42.

**Soil Collection System**

(a) Servo City planetary gear motor.

(b) Wasp R/C motor controller.

Figure 4.43: Electrical components driving the auger rotation.

The soil collection system is driven by a motor to control the rotation of the auger bit and a servo to actuate a rack and pinion system controlling the linear actuation of the drill. The DC motor chosen for this system is a Servo City planetary gear motor that is capable of spinning up to 313 RPM at 12 volts. It is seen in Figure 4.43a. The motor is driven by voltage, so a PWM controller will be used to control the direction and speed of the motor. The Robot Power Wasp R/C motor controller will be used to control the motor, shown in Figure 4.43b. The Wasp features a dual H-bridge design, which allows for multidirectional control and back voltage protection. The Wasp is also protected up to 30 amps and is completely independent from the Raspberry Pi. These built-in protections are important for protecting the overall system from unwanted voltage spikes and overcurrent. To protect from jamming and to satisfy team derived requirement PD 5 from Table 7.27, a current sensor will be used to detect current spikes in the circuit. When the current spikes, it is most likely due to high mechanical resistance resulting in stalling. The current sensor chosen is the INA 260 current sensor from Adafruit. The sensor will be programmed to detect spikes in current early so as to not damage the motor from stalls. This sensor will also allow for the system to take corrective action by reversing the motor to resolve the issue.

Figure 4.44: GoBilda 5-turn servo.

To control the linear motion of the drill system, a servo will be used that is connected to a rack and pinion system. The two most important design considerations when choosing a servo for this purpose was that the motor needed to travel a relatively large distance and also needed to deliver high force to force the drill into the ground. The servo chosen was the GoBilda 5-turn high torque servo, shown in Figure 4.44. This servo is capable of 1800 degrees of travel while still retaining position awareness and is capable of producing 350 (oz-in) of torque. With the designed half inch pinion, the servo would be able to deliver 43 lbs of force before stalling. This is well above what the system needs, as anything higher than the weight of ZOMBIE would lift the system up instead of drilling downwards. The servo is powered with 7.4 volts and receives a PWM signal from the Raspberry Pi for control.

### Leg Actuation System

The legs on ZOMBIE will be actuated by a stepper motor that uses a lead screw to act as a linear actuator. The motor is capable of high linear force due to the mechanical advantage achieved by rotating around the lead screw. The chosen motor is a NEMA 15 stepper motor linear actuator that is capable of 29 oz-in of torque at low speed.

(a) NEMA 15 stepper motor linear actuator.

(b) Adafruit TCM 2209 stepper motor driver.

Figure 4.45: Electrical components driving leg mechanism.

The stepper motor operates at 12V of power and will be controlled by the Raspberry Pi through the Adafruit TCM 2209 stepper motor driver. The driver receives 3.3 volts of power from the Pi and is controlled via a step and direction signal. The motor is powered by the 14.8V battery stepped down to 12V. The motor loses torque as the phase frequency increases, so the motor will be programmed to move slowly to maximize the power delivered to the collar and legs.

### Battery

NASA Requirement 2.2 states that the payload must be powered by batteries large enough to ensure the entire system can withstand 3 hours of idle time on the pad without losing functionality of any critical components. To satisfy this requirement, the power draws of all components in the ZOMBIE system were calculated and a battery was chosen from the results.

| Component | Watts | Expected Operating Time (hrs) | Voltage | Expected mAh |
|---|---|---|---|---|
| Planetary Gear Motor | 12 | 0.25 | 12 | 250 |
| Servo | 1,48 | 0.25 | 7.4 | 50 |
| INS | 0.429 | 3 | 3.3 | 390 |
| Stepper Motor | 4.8 | 0.25 | 12 | 100 |
| Raspberry Pi 4b | 5 | 3 | 5 | 3000 |
| Required Capacity (mAh) | | | | 3790 |
| Chosen Capacity (mAh) | | | | 4000 |

Table 4.2: Expected ZOMBIE battery draw.

Table 4.2 shows how much power draw is expected from all components assuming 3 hours idle on the pad. The minimum amount of capacity was 3790 mAh. The battery chosen is a 4000 mAh LiPo battery. 4000 mAh was chosen because it is the largest battery that can fit in the payload while having sufficient capacity to meet requirement 2.2.

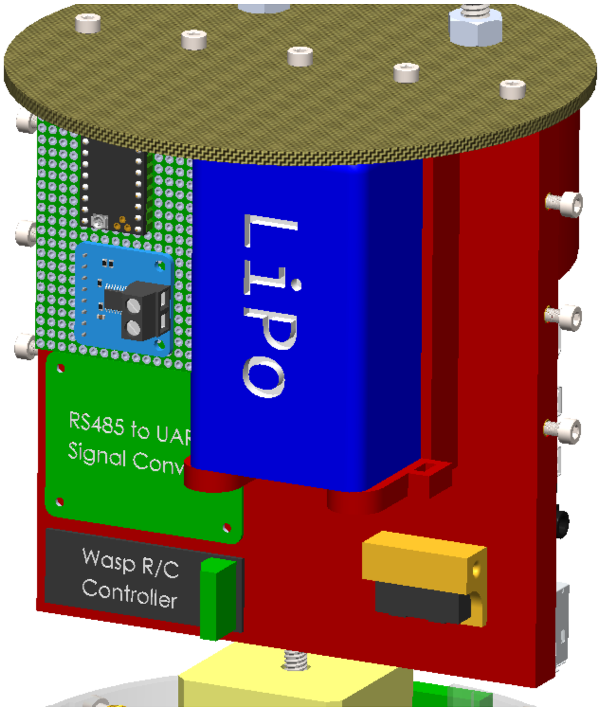


Figure 4.46: Battery placement on ZOMBIE.

The battery will be mounted on the electronics sled and be secured using Velcro and zipties. When mounted in the sled, the battery will be fully retained, satisfying NASA Requirement 2.19.

### ZOMBIE Full Schematic and Layout

Figure 4.47 shows the full electrical schematic of the ZOMBIE subsystem. A pull pin switch will be used to activate and deactivate the system while inside the rocket by fully disconnecting the battery from the system.

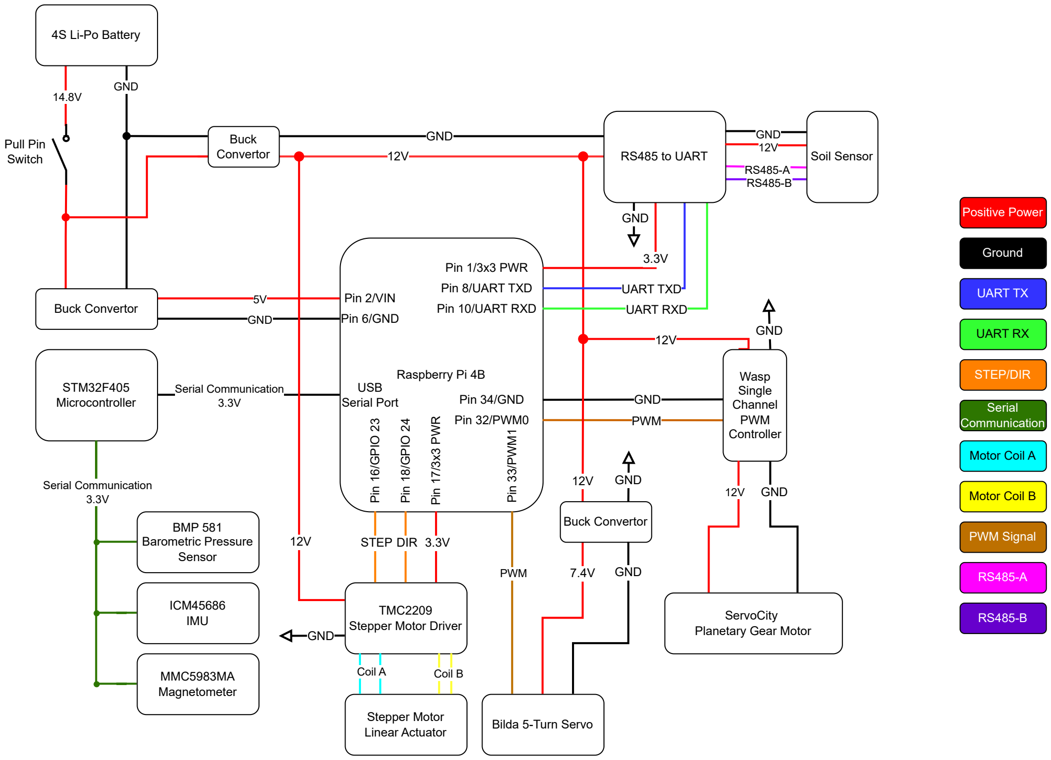


Figure 4.47: ZOMBIE electrical schematic.

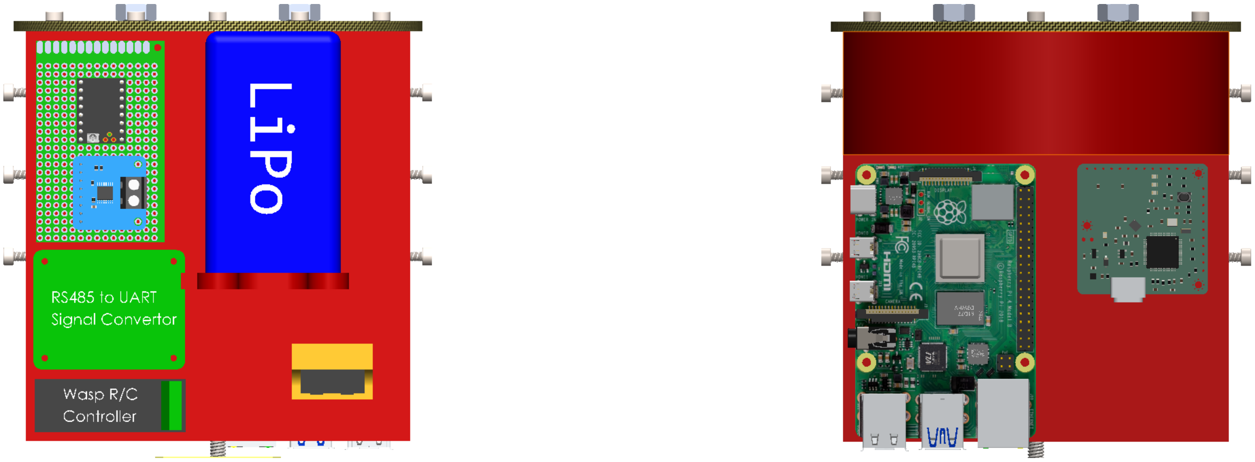


Figure 4.48: ZOMBIE electronic sled design.

Figure 4.48 shows the front and back of the designed electronics sled. The Rasberry Pi 4B and the INS system are on one side while the battery and all control boards are on the other. The control boards and sensors are all on one side to reduce the complexity of wiring. The current sensor and the stepper motor driver will be mounted on a protoboard to wire them together. The pull pin switch is also located on the side with the battery.

### 4.5.2 GrAVE Electronic System

**Flight Computer**

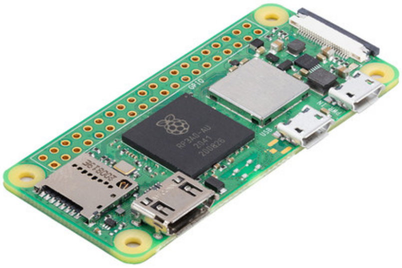


Figure 4.49: Raspberry Pi Zero 2W.

The flight computer that will be used in the GrAVE subsystem is the Raspberry Pi Zero. An Arduino Nano was previously planned to be used; however, the Raspberry Pi Zero offers higher processing power and is able to process and run Python code. Switching to the Pi Zero streamlines the programming process by making both flight computers able to run the same code for state logging. The Pi Zero also features a camera slot for recording video. To ensure that the Air Brakes system is operating nominally and to satisfy team derived requirement AF 2, a camera slot is necessary to record the Air Brakes system during flight. To determine flight state, an INS identical to the one used in ZOMBIE will collect inertial data in-flight.

**Airbrakes Camera**

To satisfy team derived requirement AF 2, a camera will be placed on the side of the nosecone to monitor the performance of the Air Brakes system. The camera is located on the extended straight section of the nosecone and points aft to record the Air Brakes in flight. The camera records data on the Raspberry Pi 4B and stores it on an SD card. The camera connects to the Pi Zero using a ribbon cable that slots into the Pi Zero. The ribbon cable will be taped to the inner wall of the nosecone to avoid any collisions with ZOMBIE.

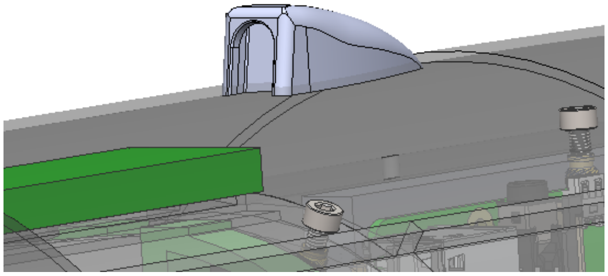


Figure 4.50: Camera mount for Air Brakes camera.

**Payload Retaining Latch**

ZOMBIE's deployment will be initiated by an electronically-controlled latch that retains it during flight and releases it after landing. The latch's release will be activated by a servo that has a lever arm attached to it. The servo chosen is an HS-7955TH servo. The servo runs on 7.4V of power and will be controlled by the onboard Raspberry Pi Zero.

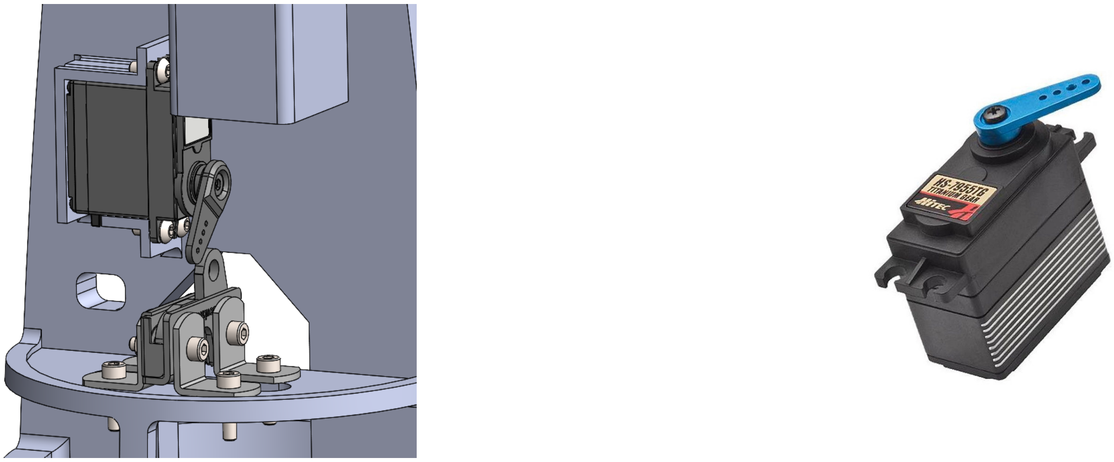


Figure 4.51: Servo controlling latch mechanism.

**ZOMBIE Ejection System**

GrAVE is designed to eject ZOMBIE by using a plate that can push ZOMBIE outside the rocket fully. This will be done using a lead screw stepper motor to push the plate along the length of the nosecone. The motor will rotate threads around a threaded rod. Both the rod and the motor cannot rotate so the rod is pushed forwards. The motor that will be used by the system is the same NEMA 15 stepper motor that is used in ZOMBIE for leg actuation. The motor is capable of 29 oz-in of torque at slow speeds. The motor will be controlled via the TCM 2209 stepper motor driver by the Raspberry Pi Zero.

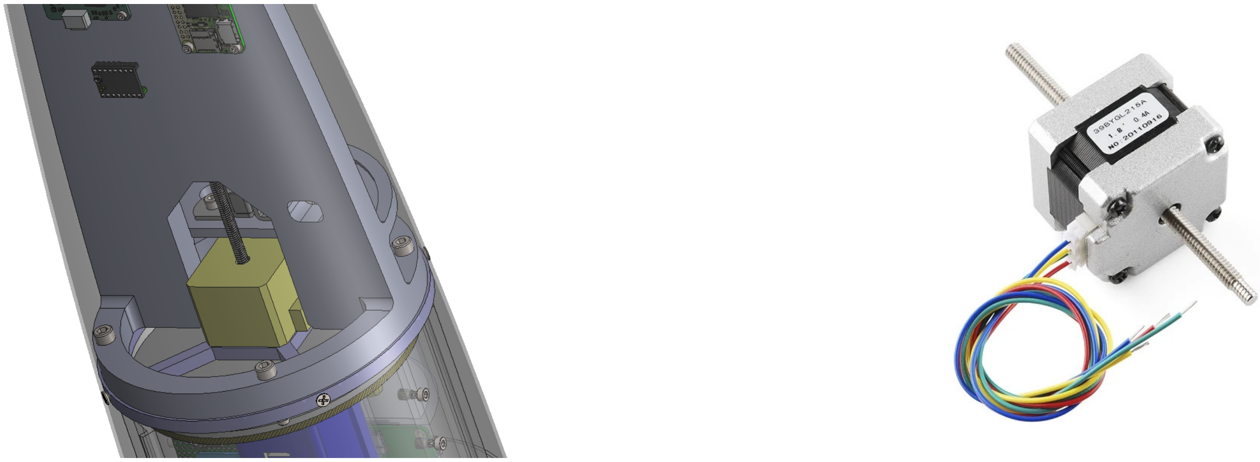


Figure 4.52: GrAVE stepper motor linear actuator.

**Battery**

As mentioned with ZOMBIE, the battery for the GrAVE system needs to be able to power all electronics for at least 3 hours to satisfy NASA Requirement 2.2.

| Component | Watts | Expected Operating Time (hrs) | Voltage | Expected mAh |
|---|---|---|---|---|
| Servo | 0.054 | 0.05 | 6 | 0.45 |
| INS | 0.429 | 3 | 3.3 | 390 |
| Stepper Motor | 5.26 | 0.05 | 12 | 22 |
| Raspberry Pi Zero | 1 | 3 | 5 | 600 |
| Required Capacity (mAh) | | | | 1012 |
| Chosen Capacity (mAh) | | | | 2200 |

Table 4.3: Expected GrAVE battery draw.

The chosen battery for the GrAVE system is a 2200 mAh 4S LiPo battery. This battery is a significant overshoot from the expected draw of 1012 mAh, with a factor of safety of 2.2. To power the motors in GrAVE, the battery was changed from a 2S to a 4S LiPo that is able to provide 14.8V of power. The reason this specific battery was chosen was because it is capable of satisfying NASA Requirement 2.2 and is readily available in the team's inventory. The battery will be mounted inside a 3D printed housing integrated into the electronics sled and will be retained using a zip tie.

### GrAVE Full Schematic and Layout

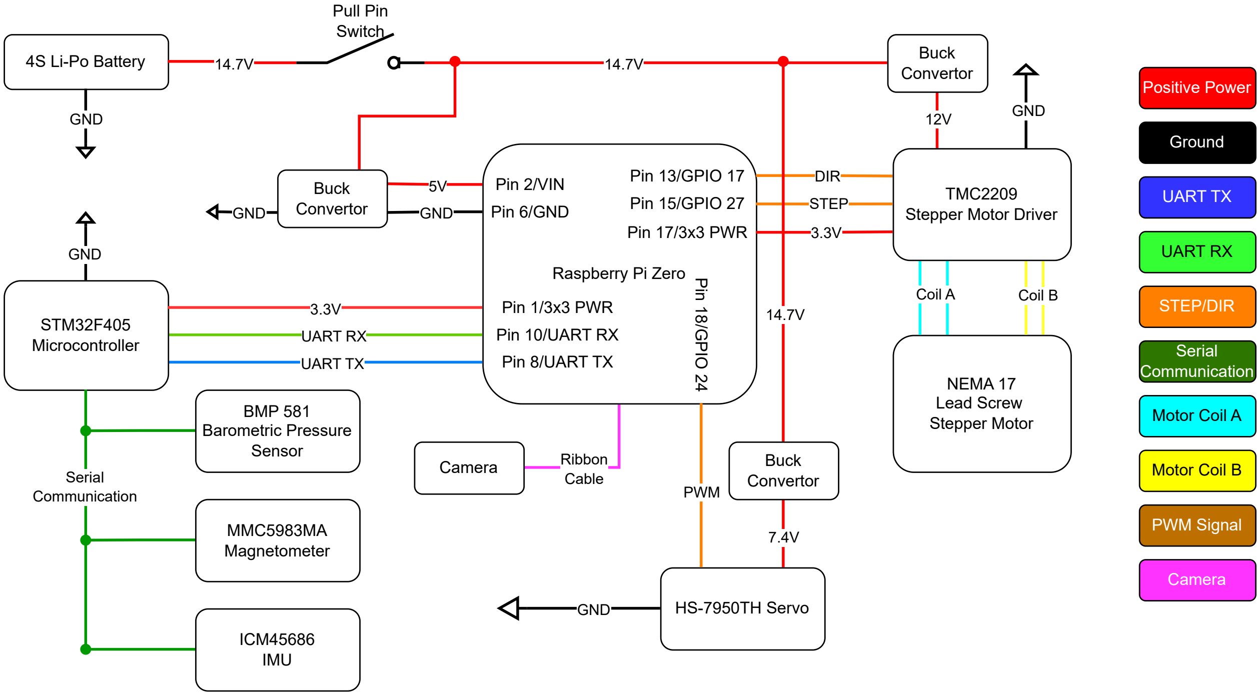


Figure 4.53: Grave Electronics

Figure 4.54: GrAVE electronic sled design.

Figure 4.53 shows the full electronic schematic of the GrAVE system. To power on and off the system while in the rocket, a pull pin switch will be utilized. This switch will be directly connected to the battery to ensure that no power is able to be transmitted when the pull pin is engaged.

The electronics sled is designed with the battery and servo on one side and the flight computer and stepper motor driver on the other. The layout is designed to reduce the complexity of the wiring and to keep the different subsystems separate. The stepper motor driver connects to the motor on the same side it is mounted. For the servo to connect to the Pi, a hole was placed near the servo so that it's cables can pass to the other side of the sled to connect to the Pi. Power cables will pass over the top of the sled to power the flight computer.

## 4.6 Payload Manufacturing Methods

### 4.6.1 Payload Structures

The structural components of the payload will be manufactured using three processes: 3D printing, waterjet cutting, and composite plate layups. 3D printing allows the payload components to have complex geometries that would otherwise be difficult to achieve using off-the-shelf components while also giving the ability to rapidly iterate designs. 3D printing also saves weight, as the density of 3D printing filament is much lower than that of metals. 3D printing will be used for most of the payload structures, including ZOMBIE's body, legs, deploying collar, sled, and soil collection module housing, as well as GrAVE's sled. PLA filament has been chosen as the desired material for printing because of its low cost, strength, and ease of printing.

Some parts of both ZOMBIE and GrAVE bear greater loads across smaller components, such as ZOMBIE's leg linkages and planetary gear motor mount and GrAVE's mount to attach it to the nosecone. These parts will be manufactured using a waterjet cutter to cut the desired geometries out of stock sheet aluminum. The waterjet is capable of accurately reproducing planar geometries of uniform thickness, which is adequate for all the parts listed above. Using aluminum instead of 3D printing for these components greatly reduces the size and therefore the weight required to bear the heightened loads exerted upon the components.

Metal hardware will be used to fasten the payload's components together. M3 and M4 screws will be used for all mounting holes except those through the nosecone into GrAVE's mount, where #6-32 screws identical to those used in the rest of the launch vehicle's structure will be threaded into tapped holes in the mount. Nylon-insert locknuts will secure the screws in place when the screws extend completely through two components, thus allowing a nut to be threaded onto the other end. In some cases, screws are not able to thread all the way through a 3D printed component. In places where this occurs, heat-set inserts will be set into the plastic part, giving increased security to hold the screw in place compared to simply threading the screw into the plastic.

ZOMBIE's top cap plate will be made using the same composite plate manufacturing method described in Section 3.3.2. Composites were chosen for this piece due to the high loads experienced by the plate, as it is the sole connection point between ZOMBIE's U-bolt that interfaces with GrAVE's latch and the electronics sled which connects it to the rest of ZOMBIE's structure. Aluminum was considered for this application; however, an aluminum plate of the size needed would have a mass of approximately 0.25 (lbm), whereas the composite plate is estimated to weigh only 0.0936 (lbm) as manufactured.

### 4.6.2 Payload Electronics

Most of the electronic components in both ZOMBIE and GrAVE will be mounted directly to the electronics sleds using nylon screws and heat-set inserts. Nylon hardware will be used because the material places less stress on the electronics when tightly mounted. On ZOMBIE, the breakout boards that do not have terminal blocks will be soldered onto a protoboard for ease of wiring. This includes the current sensor and the stepper motor driver. On the GrAVE electronics sled, however, the stepper motor driver will be directly mounted onto the electronics sled and wires will be directly soldered onto the board. Pull pin switches will be mounted to each electronics sled using metal M2 screws.

## 4.7 Payload Component Mass Breakdown

The following tables detail the masses of the components that make up the payload, distributed between both ZOMBIE and GrAVE. The total mass of the entire payload system is 8.3471 (lbm), satisfying team derived requirement PF 5.

| Component | Amount | Unit Mass (lbm) | Total Mass (lbm) |
|---|---|---|---|
| Auger | 1 | 0.0327 | 0.0327 |
| Partially threaded shaft | 1 | 0.0325 | 0.0325 |
| Clamping coupler | 1 | 0.0353 | 0.0353 |
| Aluminum motor mount | 1 | 0.0564 | 0.0564 |
| Motor housing and rail piece | 1 | 0.2325 | 0.2325 |
| Soil collection chamber housing | 1 | 0.4547 | 0.4547 |
| Soil sensor | 1 | 0.3000 | 0.3000 |
| Gear rack | 1 | 0.0102 | 0.0102 |
| Pinion gear | 1 | 0.0090 | 0.0090 |
| Signal converter | 1 | 0.0040 | 0.0040 |
| Raspberry Pi 4 | 1 | 0.1020 | 0.1020 |
| INS | 1 | 0.0895 | 0.0895 |
| Planetary gear motor | 1 | 0.7231 | 0.7231 |
| Lead screw threaded rod | 1 | 0.0289 | 0.0289 |
| Lead screw motor | 1 | 0.3630 | 0.3630 |
| Lead screw motor driver | 1 | 0.0040 | 0.0040 |
| Leg | 4 | 0.0950 | 0.3800 |
| Linkage | 4 | 0.0480 | 0.1920 |
| Collar | 1 | 0.0866 | 0.0866 |
| Lower outer body | 1 | 0.9787 | 0.9787 |
| Upper outer body | 1 | 0.6330 | 0.6330 |
| Top cap plate | 1 | 0.0936 | 0.0936 |
| STEMnaut electronics sled | 1 | 0.3200 | 0.3200 |
| STEMnaut resin duck | 4 | 0.0031 | 0.0124 |

| | | | |
|---|---|---|---|
| 4S LiPo | 1 | 0.6041 | 0.6041 |
| Buck converter | 1 | 0.0310 | 0.0310 |
| Rack and pinion servo | 1 | 0.1411 | 0.1411 |
| PWM controller | 1 | 0.0198 | 0.0198 |
| Current sensor | 1 | 0.0040 | 0.0040 |
| U-bolt | 1 | 0.0756 | 0.0756 |
| 1/4-20 nuts | 4 | 0.0027 | 0.0108 |
| Heat-set insert (M3, 3.4 mm) | 25 | 0.0005 | 0.0125 |
| Heat-set insert (M3, 5.7 mm) | 6 | 0.0008 | 0.0048 |
| Heat-set insert (M4, 4.7 mm) | 8 | 0.0012 | 0.0096 |
| Screw (M3, 6 mm) | 21 | 0.0016 | 0.0336 |
| Screw (M3, 8 mm) | 14 | 0.0018 | 0.0252 |
| Screw (M3, 20 mm) | 8 | 0.0029 | 0.0232 |
| Screw (M3, 30 mm) | 4 | 0.0043 | 0.0172 |
| Screw (M3, 45 mm) | 4 | 0.0062 | 0.0248 |
| Screw (M4, 6 mm) | 4 | 0.0032 | 0.0128 |
| Screw (M4, 8 mm, low-profile) | 4 | 0.0030 | 0.0120 |
| Lock nut (M3) | 12 | 0.0013 | 0.0156 |
| Total Mass | | | 6.2518 |

Table 4.4: ZOMBIE Component Masses and Quantities

| Component | Amount | Unit Mass (lbm) | Total Mass (lbm) |
|---|---|---|---|
| Sled | 1 | 0.5335 | 0.5335 |
| Servo (Latch) | 1 | 0.1430 | 0.1430 |
| Pi Zero | 1 | 0.0120 | 0.0120 |
| INS | 1 | 0.0895 | 0.0895 |
| Threaded Rods | 1 | 0.1343 | 0.1343 |
| Lead Screw Motor | 1 | 0.3630 | 0.3630 |
| Lead screw motor driver | 1 | 0.0040 | 0.0040 |
| 4S LiPo | 1 | 0.4725 | 0.4725 |
| Buck Converter | 1 | 0.0310 | 0.0310 |
| Mount | 1 | 0.2545 | 0.2545 |
| Pusher plate | 1 | 0.0661 | 0.0661 |
| Nut (M4) | 6 | 0.0002 | 0.0012 |
| Screw (M5, 25mm) | 4 | 0.0003 | 0.0012 |
| Bracket | 4 | 0.0028 | 0.0112 |
| Screw (M4, 16mm) | 4 | 0.0007 | 0.0028 |
| Screw (M4, 10mm) | 4 | 0.0004 | 0.0016 |
| Screw (M2.5, 5mm) | 4 | 0.0001 | 0.0004 |
| Screw (M5, 25mm) | 4 | 0.0016 | 0.0064 |
| Nut (M5) | 4 | 0.0002 | 0.0008 |
| Screw (M2, 5mm) | 3 | 0.0001 | 0.0003 |
| Screw (M4, 20mm) | 2 | 0.0008 | 0.0016 |
| Latch Assembly | 1 | 0.0130 | 0.0130 |
| Total Mass | | | 2.0953 |

Table 4.5: GrAVE Component Masses and Quantities

# 5 Air Brakes System

## 5.1 Air Brakes Objective

The Air Brakes system, hereafter referred to as Air Brakes, aims to reduce the maximum altitude reached by the launch vehicle. In its implementation, it is an active control system with four fins that deploy simultaneously, protruding into the freestream air during the launch vehicle's coast phase. This increases the reference area to which the rocket is subjected, thereby increasing the effects of pressure drag and consequently reducing the apogee.

## 5.2 Air Brakes Success Criteria

As shown in Table 5.1 below, the team derived success criteria for Air Brakes.

Table 5.1: Levels of Success and Criteria for Air Brakes

| Level of Success | Air Brakes Criteria |
|---|---|
| **Complete Success** | Apogee prediction algorithm generates a flight profile that allows the active control system to deploy and retract Air Brakes to reach an altitude within 4% of the target height when overshooting **AND** does not deploy when undershooting the target apogee. |
| **Partial Success** | Apogee prediction algorithm generates a flight profile that allows the active control system to deploy and retract Air Brakes to reach an altitude within 15% of the target altitude when overshooting **AND** does not deploy when undershooting the target apogee. |
| **Partial Failure** | The apogee prediction algorithm generates a flight profile that allows the control system to deploy and retract Air Brakes to reach an altitude within 25% of the target height **OR** deploy Air Brakes when undershooting the target apogee. |
| **Complete Failure** | Apogee prediction algorithm fails to generate a flight profile within the allotted time window **OR** the Air Brakes active control system fails to deploy Air Brakes **OR** the altitude reached exceeds 45% of the target altitude. |

## 5.3 Air Brakes Design

The finalized Air Brakes design will employ four fins that deploy simultaneously in an Iris configuration, driven by a central helical gear, to reduce friction within the system. There will be two pairs of adjacent fins, tall fins and short fins, which are rigidly attached to the central housing of the Air Brakes housing. Two aluminum rods pass through two cutouts that attach the Air Brake housing, servo retainer plate, O-ring seal, and upper electronics sled, and further attach to the top and bottom bulkheads for the Air Brakes coupler section. This section outlines the design, placement, and manufacturing of all components within the Air Brakes system. Finally, a camera will be mounted in the launch vehicle's nosecone to verify Air Brakes Deployment.

### 5.3.1 Mechanical Components and Design

The Air Brakes central structure is based on an Iris design with a planetary-gear layout to deploy four fins simultaneously. The gear design was chosen to be helical to reduce friction in the system and enable smooth deployment. Straight cut gears would not have been sufficient, as they would require more torque to deploy. This design decision meets the Team-Derived requirement AD 1. The central gear is directly screwed into the horn of the servo + encoder assembly. The servo is directly retained by a plate that restrains it and serves as a spacer between the air brake housing and the O-ring plate. These details are illustrated in Figure 5.2. Most of the electronics, including the Raspberry Pi 5, the Pi hat, and the battery, will be screwed directly onto the O-ring plate. The INS unit and screw switch for arming the entire system will sit on a plate above the Air Brakes cutouts, sealed to prevent airflow induced internal pressure spikes. This layout meets Team Derived Requirement AD 4. The mounting locations can be seen in Figures 5.1 and 5.2.

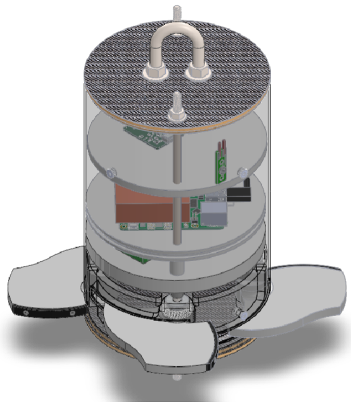


Figure 5.1: Air Brakes assembly fully deployed.

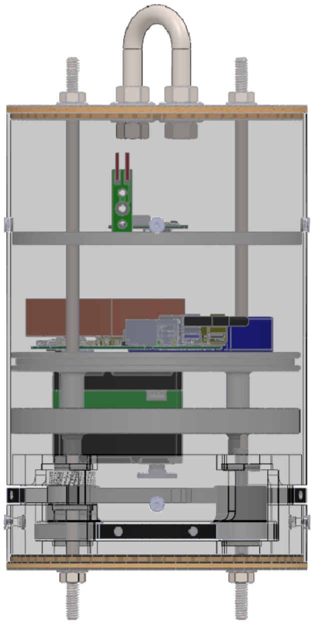


Figure 5.2: Air Brakes assembly fully retracted.

The central gear is in direct contact with four smaller helical gears, which sit on the top shaft of each fin. These small helical gears and the Air Brake fins are one piece, facilitating manufacturing. The overall gear ratio is 52:15, which ensures smooth operation. The contact point for a short fin and the central gear can be seen in Figure 5.5. The area of each fin is 8.249 ($in^2$) with an extender that is screwed into the end of the fin. The extender fills the lost fin area within the housing cutout, bringing the overall deployable area to 29.512 ($in^2$). This allows for greater control than initially predicted. The tall and short fin designs can be seen in Figures 5.3 and 5.4, respectively.

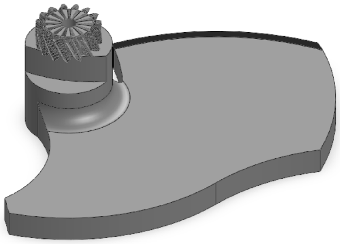


Figure 5.3: Air Brakes Tall Fin Design

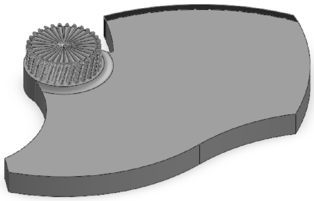


Figure 5.4: Air Brakes Short Fin Design

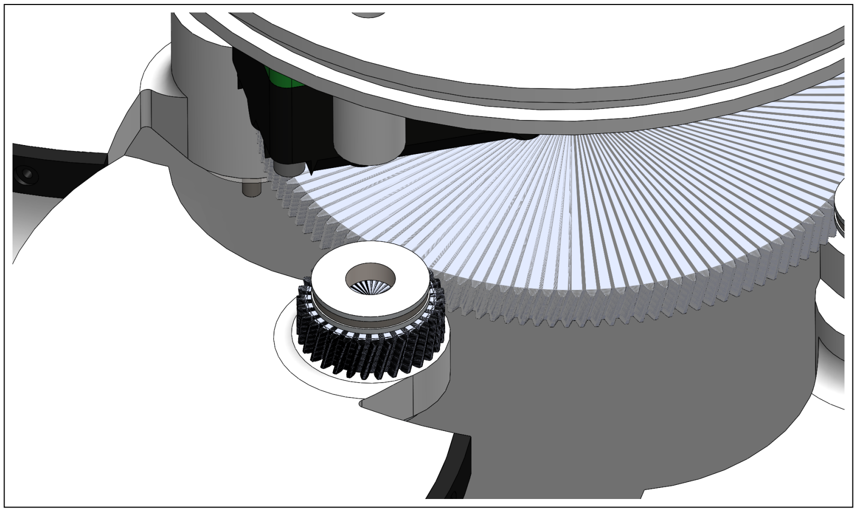


Figure 5.5: Central Helical Gear

At the top and bottom of each fin shaft, thrust bearing assemblies will be mounted to ensure smooth fin deployment during operation. An exploded view of the tall fin bearing assembly is shown in Figure 5.6. The main housing of the system has grooves cut into it to accommodate the thrust bearing assemblies. Moreover, the central housing has the short and tall fins staggered in height, with the pair of short fins parallel and 0.425 (in) forward of the tall fins. The entire assembly is mounted using two aluminum rods, which are secured with two nuts on either side of the forward and aft bulkheads. Both the tall and short fin pairs are designed with a factor of safety of 2 to account for the loads the fins will experience during the coast phase of flight. Testing will be conducted in January to verify compliance with Team Derived Requirement AD 3. Further details are provided in Section 7.3.5. Overall, the design allows Air Brakes to control drag only, ensuring compliance with Team Derived Requirement AF 1. Moreover, as shown in Figure 5.7, the deployed configuration is off-center of the fins to ensure that dirty airflow does not compromise performance. This design choice meets Team Derived Requirement AF 4.

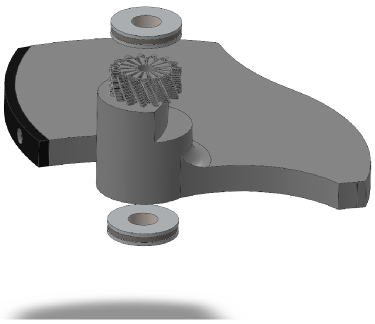


Figure 5.6: Tall Fin bearing assembly exploded view.

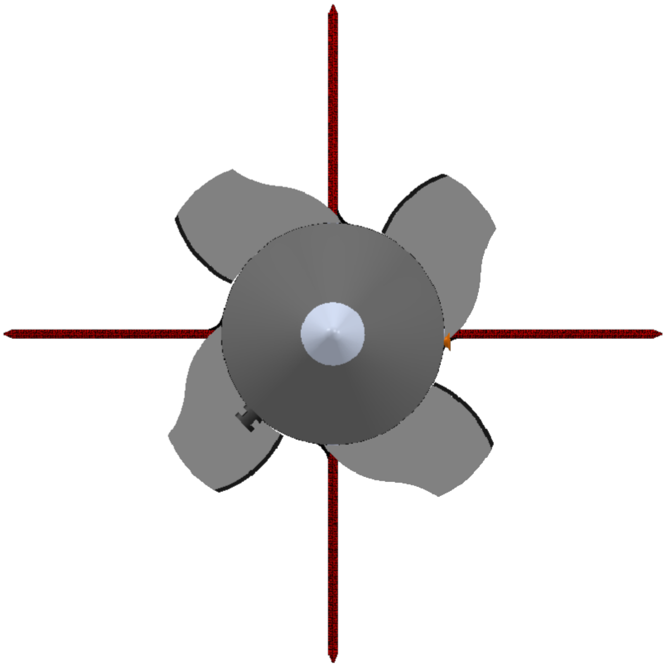


Figure 5.7: Air Brake fins orientation relative to vehicle fins

### 5.3.2 Electrical Components and Design

The central flight computer is the Raspberry Pi 5 shown in Figure 5.8. The Raspberry Pi 5 is a quad-core ARM-based processor with nearly twice the processing power of the Raspberry Pi 4. This processing unit provides sufficient compute power to process incoming INS system data, command the deployment of Air Brakes, and run the apogee prediction algorithm simultaneously. It also provides a ubiquitous amount of GPIO pins for sensor connections, power inputs, and data outputs. Moreover, the GPIO pins enable the Raspberry Pi 5 to be powered by a Li-Po battery rather than the standard USB-C connector on the board.

To actuate the gears, the Hiwonder HTD-85H is used as the central servo and encoder unit for the system, as shown in Figure 5.9. It allows for a working voltage between 9 and 14.8 (V) with a 5 (amp) stall current, a peak torque of 73.77 (lbf-in), and a max rotation angle of 240°. This allows the servo to communicate directly with the Raspberry Pi Hat via a PWM 14 (V) signal for power to actuate the central gear.

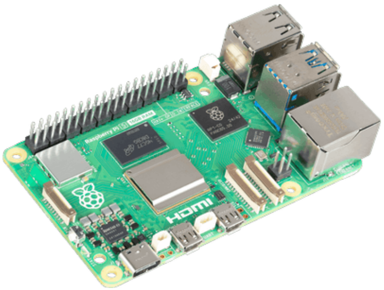


Figure 5.8: Raspberry Pi 5 Central Computer

Figure 5.9: Hiwonder HTD-85H Servo and Encoder

The main system for gathering data, such as orientation, barometric pressure, and inertia, is done via the same INS system that the Payload uses, outlined in Section 4.5.1. Shown in Figure 5.10 is a completed PCB design for the INS system. This will replace the Parker Lord IMU from the preliminary design. To power the entire system is one 4S 2200 (mAh) Li-Po battery, which grants a pad idle time of around 5 hours, which exceeds the NASA requirement 2.2 shown in Figure 5.11. This was chosen to simplify the overall design and ensure that the pad's ideal time occurs on launch day. Lastly, the entire system is equipped with a screw switch mounted on the side of the Air Brakes Coupler to provide ease of access without the space requirements of a pullpin switch. This further ensures compliance with Team Derived Requirement AS 3.

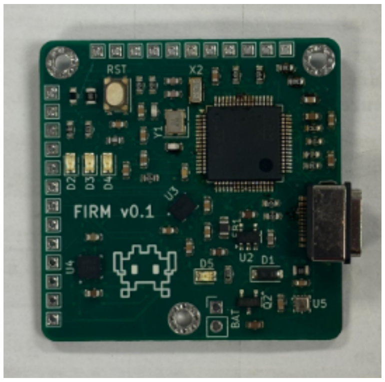


Figure 5.10: Inertial Navigation System PCB

Figure 5.11: Single 4S 2200 mAh Li-Po Battery

To provide power and control for various voltages and circuits to aid the Raspberry Pi 5, a custom PCB, a Raspberry Pi Hat, was designed. It details a versatile servo driver and power management system anchored by an AOZ6605PI-1 synchronous buck converter, designed to deliver a variable output voltage (selectable between 7V and 14.2V) via a bank of jumper-configured feedback resistors. The design integrates robust monitoring and control features, including 2 INA219 I2C current sensors for precise load measurement on both the Raspberry Pi and the servo, and an N-channel MOSFET configured for low-side switching to toggle servo power via the Pi's GPIO. The remainder of the layout features a secondary 5 (V) regulator that provides stable power to the Pi, a reverse-polarity detector and protector, a resettable polyfuse for the servo, and 3 debug LEDs to indicate various power modes. The final wiring diagrams can be seen from Figures 5.12 and 5.13

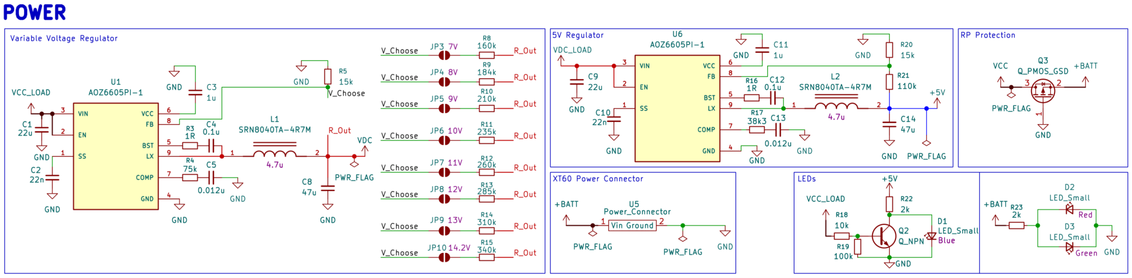


Figure 5.12: Raspberry Pi Hat power circuit diagram.

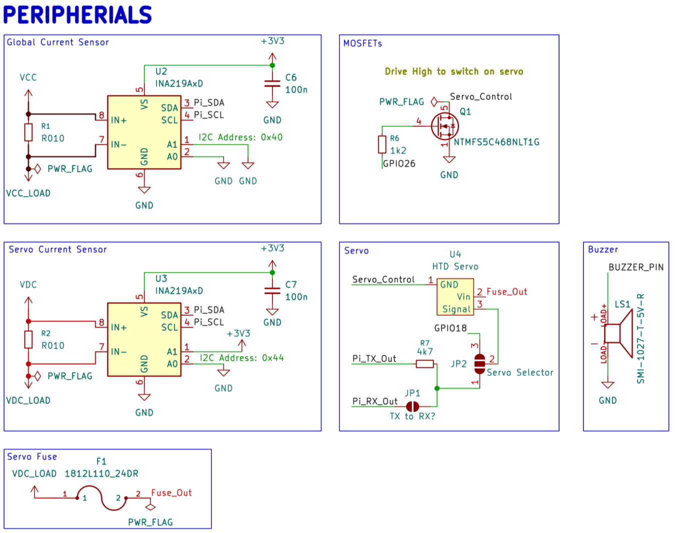


Figure 5.13: Raspberry Pi Hat peripherals circuit diagram.

The Raspberry Pi Hat will connect to all GPIO pins on the Raspberry Pi 5 as shown in Figure 5.14 below.

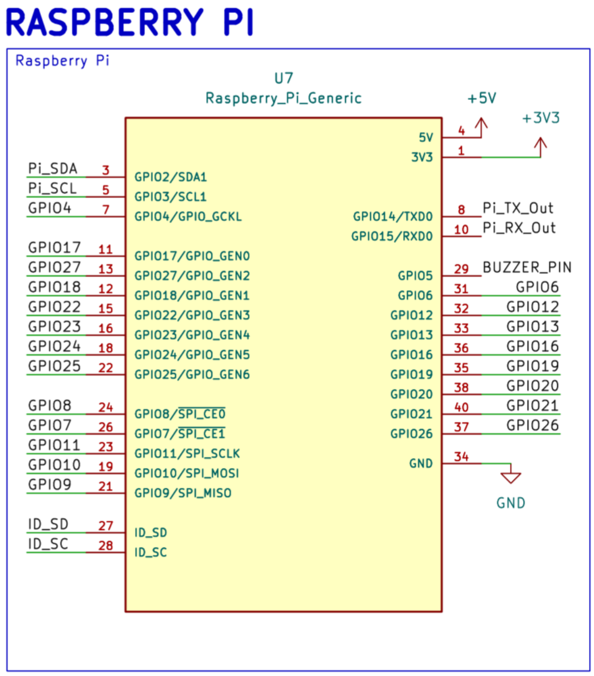


Figure 5.14: Raspberry Pi 5 GPIO diagram for Pi Hat interface.

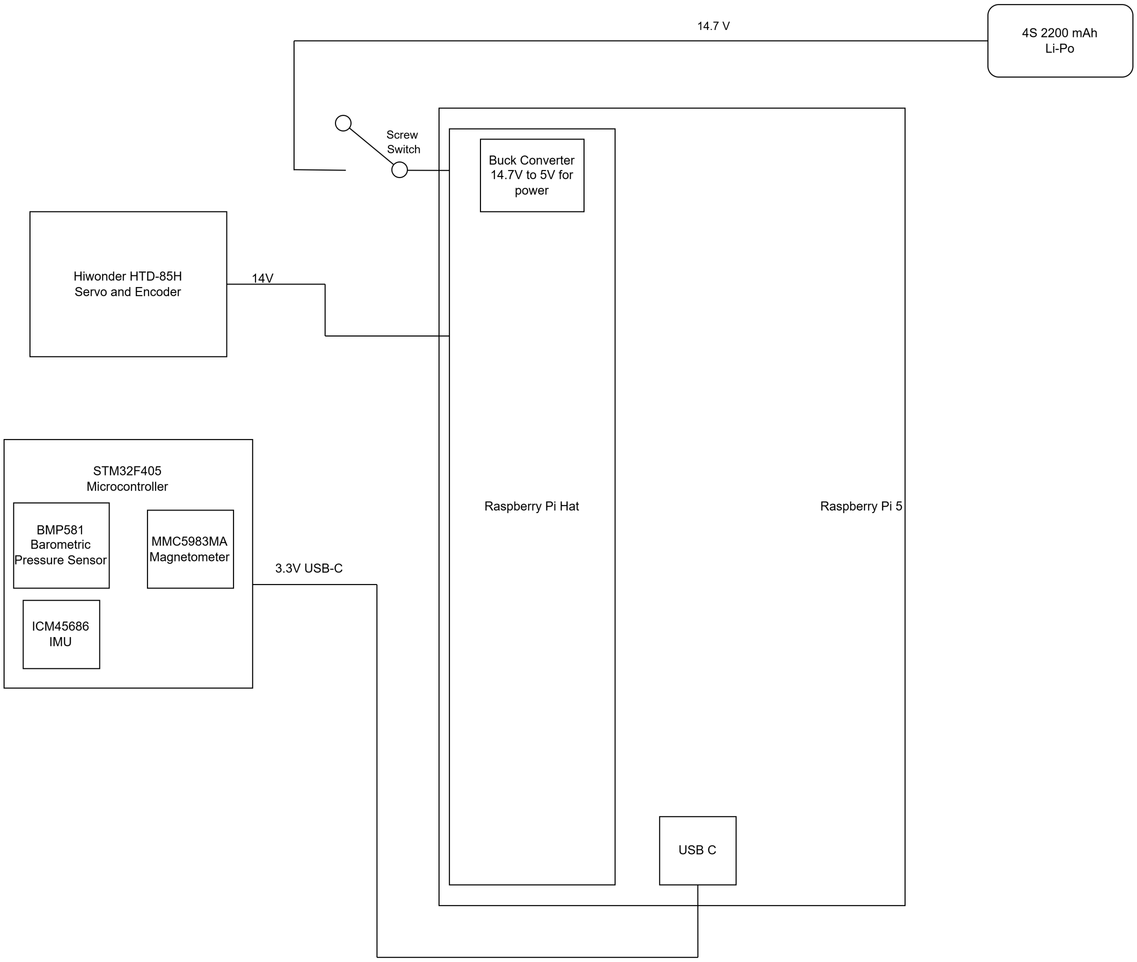


Figure 5.15: Air Brakes System wiring diagram

### 5.3.3 Manufacturing Methods and Assembly

As stated in the preliminary design, all major components, such as the assembly housing, Air Brake fins, gears, and similar components, will be primarily 3D-printed. 3D printing enables the production of low-cost, rapid, and reliable parts via additive manufacturing. The material of choice is PETG due to its high rigidity. Many types of PLA offer the same speed and ease of use in manufacturing, but do not achieve the desired yield stresses. All other components, such as threaded rods, nuts, and screws, are made of aluminum to provide high stress resistance for repeated use and to reduce the overall system weight. Other components, such as hardware, threaded rods, and some electronic parts, are COTS. Finally, both the INS system and the Raspberry Pi Hat are designed in-house and ordered to spec for the final PCB.

## 5.4 Software and Control Scheme

### 5.4.1 Control Scheme

The chosen scheme for the Air Brakes is bang-bang control. This allows the Air Brakes to be either fully deployed or fully retracted, facilitating ease of programming and design. A traditional PID approach is not realistic here because it requires many launches to tune effectively, and the resulting constants hold only for a single flight configuration, which does not meet our time and budget constraints. A bang-bang controller is simpler to implement while still delivering comparable performance, and any remaining gap can be closed with an accurate apogee prediction algorithm (Section 5.4.3), which also satisfies team requirement AD 2. The control algorithm block diagram can be seen below in Figure 5.16.

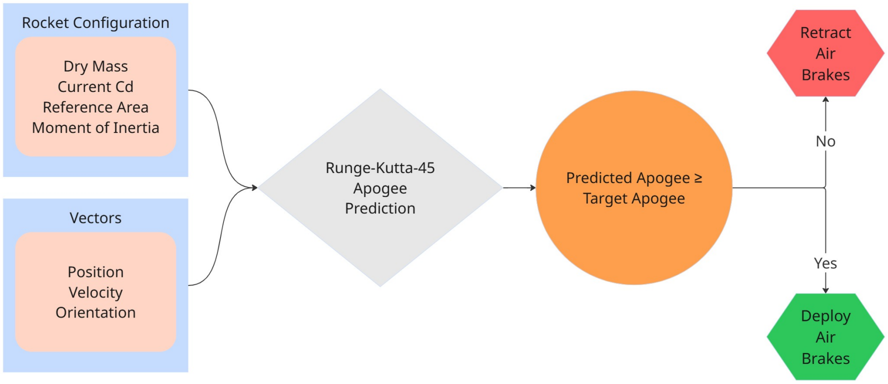


Figure 5.16: Bang-Bang Control algorithm overview

### 5.4.2 States for Software

The core software is written in Python and uses a finite-state machine to track the flight stages. This ensures that the Air Brakes fins extend only during the coast phase and meet the team-derived requirement AD 2. To prevent system failure, the codebase implements numerous checks to ensure that each stage, also known as a state, is followed. Each state detected by the Air Brakes is described in its respective section below. Shown in figure 5.17 is an overview of the system's states with checks for how the transition is handled between states.

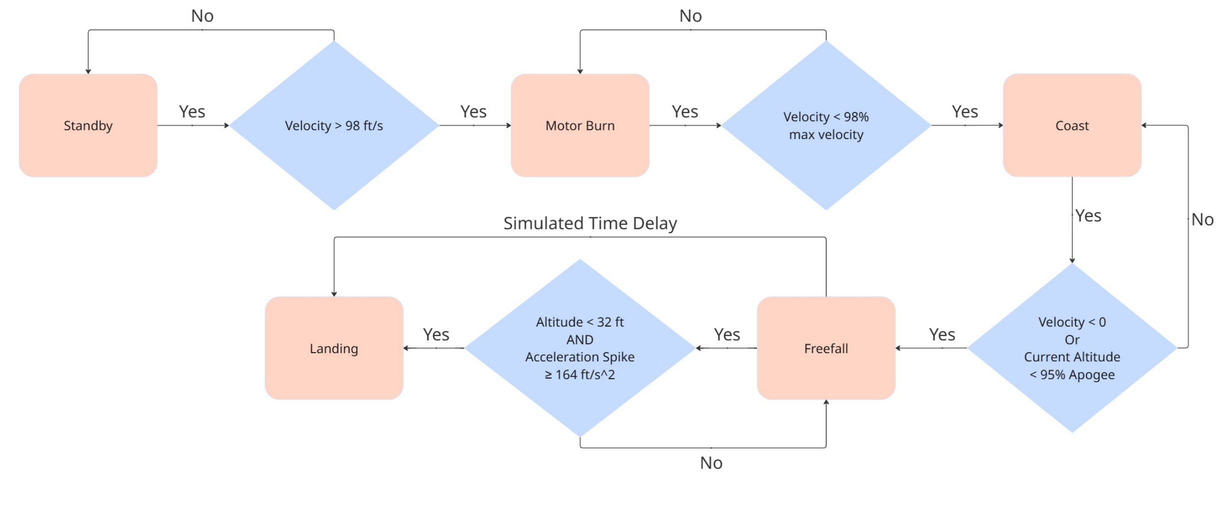


Figure 5.17: Air Brakes State Machine Overview

**Standby State**

The software boots up in the standby state. This zeros out critical measurements such as pressure, altitude, and acceleration. A rolling buffer window is employed to discard redundant and unnecessary data while the vehicle idles on the launch rail. It also allows for only 6 seconds before motor ignition is recorded. This state persists until the appropriate checks pass for the transition to Motor Burn. This also satisfies the team-derived requirement AS 2, since the Standby State will be the default unless any of the criteria below are met to trigger a state transition.

#### Motor Burn State

The system transitions to Motor Burn when the rocket's speed exceeds 98 $\frac{ft}{s}$. This is also triggered if the IMU measures an altitude above 32.81 ft. The data in this state are unreliable due to noise produced by motor burning. This data is logged, and conditions are monitored until Coast begins. This satisfies team derived requirement AF 2.

#### Coast State

The transition from Coast to Motor Burn occurs when the flight computer determines that the current velocity is less than the motor's maximum velocity. This logic holds because the maximum velocity occurs only while the motor is burning, producing the maximum thrust the launch vehicle will experience. Coast can also be manually set in software as a time delay after motor burnout, since the burn time is known before launch. During this state, the software will take 1-2 seconds to gather data for the apogee prediction algorithm to predict the rocket's apogee. As Coast continues, the apogee prediction will be updated at 500 Hz. Moreover, this state runs the control algorithm to deploy the Air Brakes if the predicted altitude exceeds the target apogee and to retract the fins if the predicted altitude falls below the target apogee.

#### Free Fall State

Once the rocket reaches its maximum altitude, the system checks whether the current altitude has decreased by 5% of the apogee altitude or whether the current velocity is negative. If the criteria are met, the state commands the Air Brakes' fins to retract fully.

#### Landing State

Lastly, the Landing State begins when the measured altitude is less than 32 (ft) and an acceleration spike exceeds 164 ($\frac{ft}{s^2}$). The flight computer issues another 10-second buffer window to log all final data and ensure that all vehicle motion has ceased. The program will then be shut down to prevent excessive power consumption, and all flight data will be saved for post-analysis.

### 5.4.3 Apogee Prediction

The apogee prediction software was rewritten from the preliminary design to extract better analysis and prediction during flight. Instead of using a curve fit based on acceleration data, the software now uses the Runge-Kutta 4 method to discretize nonlinear differential equations. In this implementation, the state vector $y$ represents the flight state being propagated. At the same time, $f(t, y)$ is the nonlinear dynamics model that returns $\dot{y}$ from forces such as gravity and aerodynamic drag. The intermediate terms $k_1$ through $k_4$ correspond to derivative estimates at the start of the step, two midpoint predictions, and the end of the step, which allows the integrator to capture curvature in the trajectory within a single time step. The update equation then advances the state using the weighted combination $\frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)$, producing a fourth-order accurate propagation for a chosen step size $h$. This approach improves robustness relative to a curve-fit method because it directly enforces the governing equations of motion and provides consistent time-marching behavior during rapid changes in drag and acceleration near burnout and apogee. The equations utilized are shown in Equations 32 through 37

$$k_1 = f(t_n, y_n) \tag{32}$$

$$k_2 = f\left(t_n + \frac{h}{2}, y_n + h\frac{k_1}{2}\right) \tag{33}$$

$$k_3 = f\left(t_n + \frac{h}{2}, y_n + h\frac{k_2}{2}\right) \tag{34}$$

$$k_4 = f(t_n + h, y_n + hk_3) \tag{35}$$

$$y_{n+1} = y_n + \frac{h}{6}\Big(k_1 + 2k_2 + 2k_3 + k_4\Big) \tag{36}$$

$$t_{n+1} = t_n + h \tag{37}$$

Using the aforementioned equations, along with mimicked sensor states, the apogee prediction was directly implemented in RocketPy for testing, and a mimicked version was implemented in OpenRocket. Shown below in Figure 5.18 is the Subscale flight data overlaid with its trajectory from RocketPy and the predicted Apogee during the coast phase. The target Apogee was set to 1600 (ft) to ensure Air Brakes deployment during flight. The predicted apogee came to 0.12% of the simulated trajectory within 5 seconds after motor burnout. The apogee prediction remains consistent via the simulation but the prediction was thrown off due to the irregularities explained earlier in Section 3.4

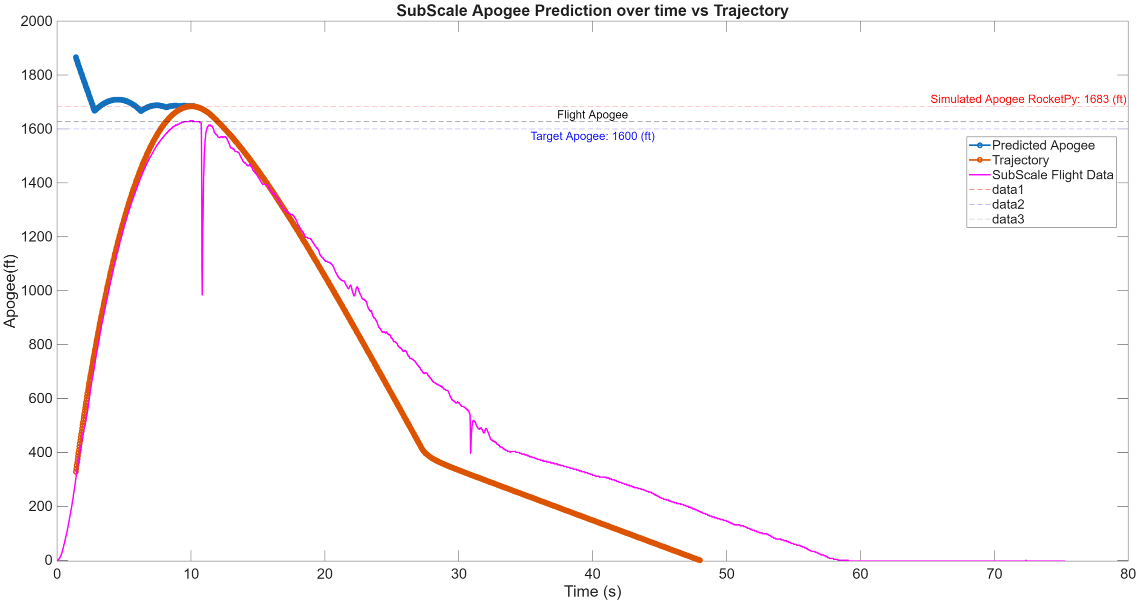


Figure 5.18: Runge-Kutta-4 predictions for simulated and actual Subscale flight

Moreover, the same prediction algorithm was run on the Fullscale launch vehicle, and the apogee prediction was 0.21% off the set target apogee in a similar amount of time to the subscale vehicle. This is depicted in Figure 5.19. The apogee for the simulation was only 0.19% off of the target Apogee.

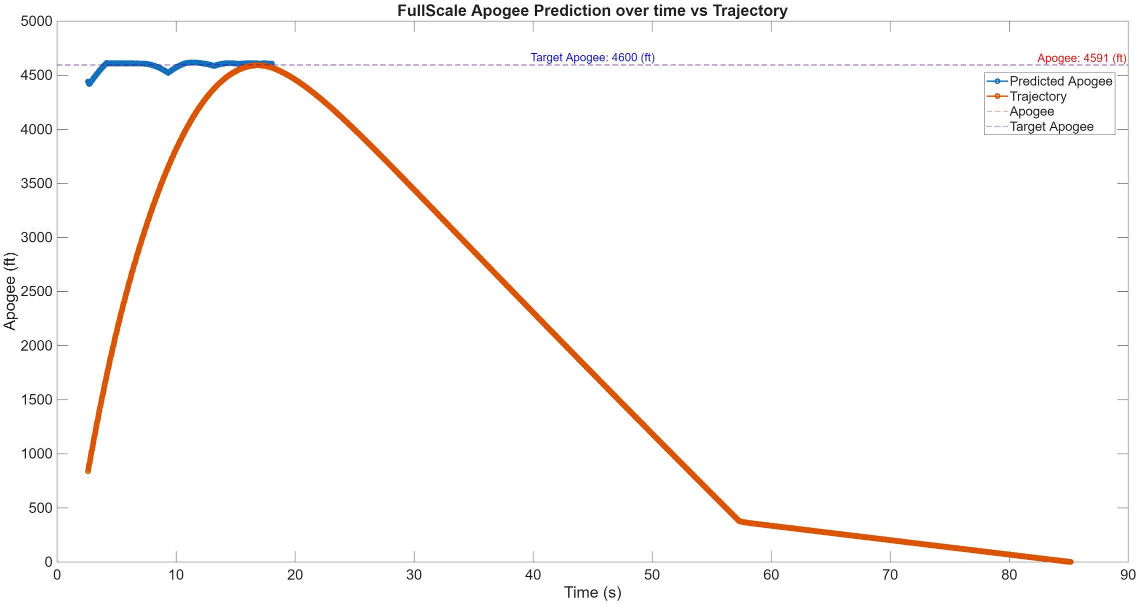


Figure 5.19: Runge-Kutta-4 Prediction for Fullscale flight

## 5.5 Assembly and Component Masses

Table 5.2: Air Brakes System Component Weights

| Component | Weight (oz) |
|---|---|
| Raspberry Pi 5 | 1.647 |
| Additional Wires | 0.112 |
| INS | 1.310 |
| Battery | 8.113 |
| Screw Switch | 0.080 |
| Aluminum Threaded Rods | 5.390 |
| Thrust Bearing Assemblies | 0.848 |
| Housing | 5.664 |
| Retainer | 7.834 |
| O-Ring Plate | 6.460 |
| Tall Fin Pair | 4.748 |
| Short Fin Pair | 3.852 |
| Servo + Encoder | 5.397 |
| Central Gear | 4.982 |
|  | + |
| Total Weight | 56.437 |

# 6 Safety

## 6.1 Final Assembly Checklist

In order to safely and efficiently assemble the launch vehicle before a launch, a pre-flight checklist is followed. Below is the Teams' preliminary Full-scale Vehicle checklist, including assembly guides for all of the components of the rocket. This checklist is based off of the subscale checklist used in the November 1st subscale launch. Required at each step of the checklist are the Team Lead and the Safety Officer. For the Motor Assembly section of the checklist, the teams technical mentor is required to be in attendance. There are also other members named for each checklist item, these are the subteam leads who oversee the subteam that checklist item pertains to. Each of these required members must sign their name in box to the right of their printed name to document their presence. The Safety Officer must also sign boxes to the right of individual checklist items that state the safety officer must approve.Checklist steps with hazardous material present are marked with red highlight, while checklist steps that require PPE are marked with yellow highlight.

# *Fullscale Rocket - To Be Named*

# Launch Day Checklist

**This checklist completed by: ___________________________**

**On: __ / __ / __**

## Checklist Legend

PPE Required - The highlighted steps indicates that PPE is required for the subsequent steps.

**Explosives/Energetics - DANGER!**

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

***Begin Launch Day Checklist***

# 1. ENERGETICS INSTALLATION FORWARD BULKHEAD

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Lauren Wilkie | |
| **Personnel 2** | | |
| **Personnel 3** | | |

**Required Materials**

| Item | Quantity | Location | Check |
|---|---|---|---|
| Safety glasses | / | Safety Glasses Toolbox | |
| Nitrile gloves | / | Versa-Stack Bottom | |
| Hodgdon Black Powder (with spoon) | 1 | Blast Containment Box | |
| FWD Bulkhead | 1 | Avionics Box | |
| Funnel | 1 | Blast Containment Box | |
| E-match | 2 | E-Match containers | |
| Biodegradable Insulation | 1 | Trash Bag | |
| Measuring cup | 1 | Blast Containment Box | |
| Scale | 1 | Versa-Stack Top | |
| Blue tape | 1 | Versa-Stack Top/Bottom | |
| Wire cutters | 1 | Launch Day Toolbox | |
| Mini screwdriver | 1 | Launch Day toolbox | |
| E tape | 1 | Versa-Stack Bottom | |
| Copy paper | 1 | Versa-Stack Bottom | |
| Plumbers putty | 1 | Versa-Stack Bottom | |
| Blast Containment Box | 1 | / | |

**Procedure**

| Number | Task | Completion |
|---|---|---|
| | **Forward Bulkhead** | |
| 1.1 | Safety officer confirms all participating members are wearing safety glasses and nitrile gloves | **Safety Officer Confirmation:** |
| 1.2 | Place one small plastic resealable container onto the scale. Zero the scale. | |
| 1.3 | Carefully measure out 2.75g of black powder for the main primary charge using a spoon | |
| 1.4 | Reseal the container | |
| 1.5 | Label the top of the container with blue tape labeled “MP” | |
| 1.6 | Place another small plastic resealable container onto the scale. Zero the scale. | |
| 1.7 | Carefully measure out 3.66g of black powder using a spoon for the main backup charge. | |
| 1.8 | Label the top of the container with blue tape labeled “MB” | |
| 1.9 | Place the bottom of the funnel into the Black blast cap on the forward bulkhead | |
| 1.10 | Pour the container marked “MP” into the black blast cap. When finished, lightly tap the funnel to ensure all black powder has been emptied. | |
| 1.11 | Bend the e-match so the head is perpendicular to the rest of the wire and place it in the blast cap so it lies on top of the black powder. | |
| 1.12 | Bend the e-match over the side of the blast cape, and tape it to the side of the blast cap so it does not move. | |
| 1.13 | Fill the empty space in the blast cap with biodegradable insulation; do not pack it in, just fill the space. | |
| 1.14 | Put 3 layers of blue tape over the top of the blast cap tightly so that the layers overlap in different orientations. | |
| 1.15 | Wrap a layer of blue tape around the base of the blast cap to secure the 3 layers of tape. | |
| 1.16 | Place a piece of copy paper on the table, and do a shake test of the blast cap over the copy paper | |
| 1.17 | If black powder falls out, remove the blue tape and reseal.<br>**Improper sealing of the cap could result in a failure for the Black Powder to ignite, which could lead to a lack of separation and the launch vehicle landing ballistically.** | **Safety Officer Confirmation:** |
| 1.18 | Place the bottom of the funnel into the white blast cap on the forward bulkhead | |
| 1.19 | Pour the container marked “MB” into the white blast cap. When finished, lightly tap the funnel to ensure all black powder has been emptied. | |
| 1.20 | Bend the e-match so the head is perpendicular to the rest of the wire and place it in the blast cap so it lays on top of the black powder. | |
| 1.21 | Bend the e-match over the side of the blast cape, and tape it to the side of the blast cap so it does not move | |
| 1.22 | Fill the empty space in the blast cap with biodegradable insulation; do not pack it in, just fill the space | |
| 1.23 | Put 3 layers of blue tape over the top of the blast cap tightly so that the layers overlap in different orientations | |
| 1.24 | Wrap a layer of blue tape around the base of the blast cap to secure the 3 layers of tape | |
| 1.25 | Place a piece of copy paper on the table, and do a shake test of the blast cap over the copy paper | |
| 1.26 | If black powder falls out, remove the blue tape and reseal.<br>**Improper sealing of the cap could result in a failure for the Black Powder to ignite, which could lead to a lack of separation and the launch vehicle landing ballistically.** | **Safety Officer Confirmation:** |
| 1.27 | Cut the e-matches to size so that they have length to run to the WAGOs. | |
| 1.28 | Strip the e-matches half an inch | |
| 1.29 | Twist them together and tape them with electrical tape. Failure to do so could result in the Black Powder charges igniting without input. | |
| 1.30 | Ensure all holes in the bulkhead are sealed with plumbers' putty | |
| 1.31 | Place into an anti-static bag, and then store in the blast containment box. | |

# 2. ENERGETICS INSTALLATION AFT BULKHEAD

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Lauren Wilkie | |
| **Personnel 2** | | |
| **Personnel 3** | | |

| Required Materials | | | |
|---|---|---|---|
| Item | Quantity | Location | Check |
| Safety glasses | / | Safety Glasses Toolbox | |
| Nitrile gloves | / | Versa-Stack Bottom | |
| Hodgdon Black Powder (with spoon) | 1 | Blast Containment Box | |
| AFT Bulkhead | 1 | Avionics Box | |
| Funnel | 1 | Blast Containment Box | |
| E-match | 2 | E-Match containers | |
| Biodegradable Insulation | 1 | Trash Bag | |
| Measuring cup | 1 | Blast Containment Box | |
| Scale | 1 | Versa-Stack Top | |
| Blue tape | 1 | Versa-Stack Top/Bottom | |
| Wire cutters | 1 | Launch Day Toolbox | |
| Mini screwdriver | 1 | Launch Day toolbox | |
| E tape | 1 | Versa-Stack Bottom | |
| Copy paper | 1 | Versa-Stack Bottom | |
| Plumbers putty | 1 | Versa-Stack Bottom | |
| Blast Containment Box | 1 | / | |

| Procedure | | |
|---|---|---|
| Number | Task | Completion |
| | Forward Bulkhead | |
| 2.1 | Confirm all participating members are wearing safety glasses and nitrile gloves. | **Safety Officer Confirmation:** |
| 2.2 | Place one small plastic resealable container onto the scale. Zero the scale. | |
| 2.3 | Carefully measure out 2.92 g of black powder for the drogue primary charge using a spoon | |
| 2.4 | Reseal the container | |
| 2.5 | Label the top of the container with blue tape labeled "DP" | |
| 2.6 | Place another small plastic resealable container onto the scale. Zero the scale. | |
| 2.7 | Carefully measure out 3.89 g of black powder using a spoon for the Drogue backup charge. | |
| 2.8 | Label the top of the container with blue tape labeled "DB" | |
| 2.9 | Place the bottom of the funnel into the black blast cap on the forward bulkhead . | |
| 2.10 | Pour the container marked "DP" into the black blast cap. When finished, lightly tap the funnel to ensure all black powder has been emptied. | |
| 2.11 | Bend the e-match so the head is perpendicular to the rest of the wire and place it in the blast cap so it lays on top of the black powder. | |
| 2.12 | Bend the e-match over the side of the blast cape, and tape it to the side of the blast cap so it does not move | |
| 2.13 | Fill the empty space in the blast cap with insulation; do not pack it in, just fill the space | |
| 2.14 | Put 3 layers of blue tape over the top of the blast cap tightly so that the layers overlap in different orientations | |
| 2.15 | Wrap a layer of blue tape around the base of the blast cap to secure the 3 layers of tape | |
| 2.16 | Place a piece of copy paper on the table, and do a shake test of the blast cap over the copy paper | |
| 2.17 | If black powder falls out, remove the blue tape and reseal. **Improper sealing of the cap could result in a failure for the Black Powder to ignite, which could lead to a lack of separation and the launch vehicle landing ballistically.** | **Safety Officer Confirmation:** |
| 2.18 | Place the bottom of the funnel into the white blast cap on the forward bulkhead | |
| 2.19 | Pour the container marked "DB" into the white blast cap. When finished, lightly tap the funnel to ensure all black powder has been emptied. | |
| 2.20 | Bend the e-match so the head is perpendicular to the rest of the wire and place it in the blast cap so it lays on top of the black powder. | |
| 2.21 | Bend the e-match over the side of the blast cape, and tape it to the side of the blast cap so it does not move | |
| 2.22 | Fill the empty space in the blast cap with insulation; do not pack it in, just fill the space | |
| 2.23 | Put 3 layers of blue tape over the top of the blast cap tightly so that the layers overlap in different orientations | |
| 2.24 | Wrap a layer of blue tape around the base of the blast cap to secure the 3 layers of tape | |
| 2.25 | Place a piece of copy paper on the table, and do a shake test of the blast cap over the copy paper | |
| 2.26 | If black powder falls out, remove the blue tape and reseal. **Improper sealing of the cap could result in a failure for the Black Powder to ignite, which could lead to a lack of separation and the launch vehicle landing ballistically.** | **Safety Officer Confirmation:** |
| 2.27 | Cut the e-matches to size so that they have length to run to the WAGOs. | |
| 2.28 | Strip the e-matches half an inch | |
| 2.29 | Twist them together, and tape them with electrical tape<br>**Failure to do so could result in the Black Powder charges igniting without input.** | |
| 2.30 | Ensure all holes in the bulkhead are sealed with plumbers' putty | |
| 2.31 | Place into an anti-static bag, and then store in the blast containment box. | |

# 3. AVIONICS BAY ASSEMBLY

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Lauren Wilkie | |
| **Personnel 2** | | |
| **Personnel 3** | | |

| Required Materials | | | |
|---|---|---|---|
| Item | Quantity | Location | Check |
| Safety glasses | / | Safety Glasses Toolbox | |
| FWD bulkhead | 1 | Anti-static bag | |
| AFT bulkhead | 1 | Anti-static bag | |
| Avionics Sled | 1 | Avionics Bucket | |
| Av Bay Coupler | 1 | / | |
| Easy-Mini | 1 | Sled | |
| Fluctus | 1 | Sled | |
| 1s 500 mA battery | 1 | LiPo bag | |
| 2s 800 mA battery | 1 | LiPo bag | |
| Double pull pin switch | 1 | Sled | |
| Multimeter | 1 | Versa-Stack Bottom | |
| ¼ 20 Nuts | 8 | Versa Stack Top | |
| Pull pin | 1 | Launch Day Toolbox | |

| Procedure | | |
|---|---|---|
| Number | Task | Completion |
| 3.1 | Verify that the Fluctus ignitor wires are connected to the three-way WAGO. | |
| 3.2 | Verify that piro wire 1, piro wire 2, and common positive wires are tight in the fluctus terminals and WAGO terminals by a pull test. | |
| 3.3 | Verify that the main and drogue wires are snug in the easy mini terminal. | |
| 3.4 | Verify that the switch wires for the Easy Mini are snug within their terminal blocks. | |
| 3.5 | Verify that the easymini switch wires and the fluctus switch wires are snugly connected to the pull pin switch | |
| 3.6 | Check the battery voltage of the 1s battery, write this number down<br>If the voltage is not at least 3.7, replace.<br>**Failure to replace the battery could result in recovery events not occurring, such as the launch vehicle not separating. This could result in the launch vehicle coming in ballistic.** | **Record Voltage:** |
| 3.7 | Check the battery voltage of the 2s battery, write this number down<br>If the voltage is not at least 7.4, replace.<br>**Failure to replace the battery could result in recovery events not occurring, such as the launch vehicle not separating. This could result in the launch vehicle coming in ballistic.** | **Record Voltage:** |
| 3.8 | Using the multimeter, confirm continuity of:<br>• Fluctus: Power, main, and drogue wires<br>• Easymini: Power, main, and drogue wires<br>• Pull pin switch | |
| 3.9 | Connect the fluctus battery connecter | |
| 3.10 | Connect the battery cable directly to the EasyMini | |
| 3.11 | Verify the Fluctus and easymini are working | |
| 3.12 | Put in the recovery pull pin into the hole marked "rp". | |
| 3.13 | Ensure all members on the checklist are wearing safety glasses | **Safety Officer Check:** |
| 3.14 | Take the AFT bulkhead out of the anti-static bag and connect the primary wires (blue and black wires) to the black WAGO connector. Perform a tug test. | |

| | | |
|---|---|---|
| | **Primary and backup wires not being completely connected could lead to a lack of separation, and the launch vehicle coming in ballistic.** | |
| 3.15 | Connect the backup wires (red and black wires) to the white WAGO. Perform tug tests. | |
| 3.16 | Place the aft bulkhead on the threaded rods on the av bay coupler, hand-tighten with 2 nuts | |
| 3.17 | Remove the pull pin switch. | |
| 3.18 | Slide into the AV bay coupler, using alignment marks within the switch band | |
| 3.19 | Place the pull pin into the hole marked “rp”. | |
| 3.20 | Secure the pull pin to the launch vehicle with blue tape, so that the tape wraps fully around the circumference of the launch vehicle. | |
| 3.21 | Verify the fluctus and easymini are turned off | |
| 3.22 | Get the FWD bulkhead from its anti-static bag and connect the blue and black wires to the black WAGO. Perform a tug test.<br>**Primary and backup wires not being completely connected could lead to a lack of separation, and the launch vehicle coming in ballistic.** | |
| 3.23 | On the forward bulkhead, connect the red and black wires to the white WAGO. Perform a tug test. | |
| 3.24 | Slide the forward coupler into the AV bay, put all nuts on, and hand-tighten. | |
| 3.25 | Use a wrench to tighten all nuts. Safety Officer confirms nuts are secure. | **Safety Officer Check:** |
| 3.26 | Place the whole assembly into an anti-static bag | |

# 4. Air Brakes/Fin Can

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Aditya Chadha | |
| **Personnel 2** | | |
| **Personnel 3** | | |

| Required Materials | | | |
|---|---|---|---|
| **Item** | **Quantity** | **Location** | **Check** |
| Fin can | 1 | / | |
| Firm Module | 1 | Air Brakes Bucket | |
| White Lithium Grease | 1 | Versa-Stack Bottom/Top | |
| Air Brakes Coupler | 1 | / | |
| Plumbers Putty | 1 | Versa-Stack Bottom | |
| Electronics Sled | 1 | Air Brakes Bucket | |
| 2s 2200 mA LiPo battery | 1 | LiPo Bag | |
| USB extender | 1 | Air Brakes Bucket | |
| Flathead ¼ in screws | 4 | Versa-Stack Top | |
| Multiway Screwdriver | 1 | Versa-Stack bottom | |
| Air Brakes Fin Module | 1 | Air Brakes Bucket | |
| O-Ring | 1 | Air Brakes Bucket | |
| Multimeter | 1 | Launch Day Toolbox | |
| ¼ inch 20 nut | 4 | Versa Stack Bottom | |
| Sealing clamp: White | 1 | Air Brakes Bucket | |
| Sealing clamp: Black | 1 | Air Brakes Bucket | |
| Laptop | 1 | Aerodynamics Lead | |
| Fin extenders | 4 | Air Brakes Bucket | |

| Procedure | | |
|---|---|---|
| **Number** | **Task** | **Completion** |
| 4.1 | Ensure proper placement of the O-ring bulkhead with alignment marks | |
| 4.2 | Ensure the two spacers between the servo sled and the fin housing are flush with both housings | |
| 4.3 | Place the fin module in the Air Brakes coupler, ensuring the indent is aligned with the servo. | |
| 4.4 | Route the encoder and servo wires through the hole in the O-ring bulkhead when inserting. Ensure the wires are not on top of the servo. | |
| 4.5 | Ensure the screw switch is in the off position. | **Safety Officer Confirm:** |
| 4.6 | Align the threaded rods with the holes in the o-ring bulkhead and push the air brake module in until the air brakes are lined up with the fin slots. | |
| 4.7 | Firmly grasp the coupler, and push the threaded rods enough so that you can put the avionics sled onto the other side. | |
| 4.8 | Route encoder and servo wires out of the top of the coupler | |
| 4.9 | Take the white sealing clamp and place into the divet on the Air Brakes sled on the side closest to the center of the coupler. The sealing clamp should be positioned within the divet so that the lip is touching the bottom of the divet. | |
| 4.10 | Take the black sealing clamp and place into the divet on the Air Brakes sled on the side closest to the outer edge of the coupler. The sealing clamp should be positioned within the divet so that the lip is touching the lip of the white sealing clamp. | |
| 4.11 | Coat cracks and holes where wires are going through in plumbers' putty. Seal cracks around and within the sealing clamps with plumbers' putty. | |
| 4.12 | Coat the bottom threaded rod holes with plumbers putty | |
| 4.13 | Check LiPo battery voltage, ensure it is over 14.8 V. Write the battery voltage down.<br>If the voltage is not at least 14.8, replace.<br>**Failure to replace the battery could result in recovery events not occurring, such as the launch vehicle not separating. This could result in the launch vehicle coming in ballistic.** | **Record Battery Voltage:** |
| 4.14 | Firmly grasp the coupler and align the screw switch with the screw switch hole | |
| 4.15 | Route the servo cable through the bottom hole in the electronics bay, and slide the cable all the way through | |
| 4.16 | Seat the sled onto the threaded rods | |
| 4.17 | Plug in the encoder wire | |
| 4.18 | Plug in the servo wire; brown to black, yellow to white | |
| 4.19 | Slide the sled into the coupler, ensuring that no wires get pinched on the way in. Ensure that you can see the screw switch through the screw switch hole. | |
| 4.20 | Apply pressure across the top of the sled to spread the plumbers' putty | |
| 4.21 | Ensure IMU USB is plugged in | |
| 4.22 | Ensure the INS is plugged in | |
| 4.23 | Plug in the LiPo battery | |
| 4.24 | Cable management within the module | |
| 4.25 | Place the forward bulkhead onto the threaded rods | |
| 4.26 | Screw nuts onto the threaded rods, ensuring the nuts make contact with the bulkhead. Hand-tighten screws. | |
| 4.27 | Place AFT bulkhead on the bottom of the coupler, and tighten the nuts onto the threaded rods. | |
| 4.28 | Wrench down all nuts. Do not overtighten, as they are steel nuts on aluminum threaded rods. | |
| 4.29 | Line up the screw holes near the air brakes to the screw holes on the coupler. Ensure the flathead ¼ in screws fit | |
| 4.30 | Lube the AV bay coupler between the fins and the top of the alignment arrows | |
| 4.31 | Place the coupler into the fin can using the alignment marks. Ensure the fin slots line up with the fins | |
| 4.32 | Loosely hand-tighten all flathead screws to ensure alignment | |
| 4.33 | Screw down all flathead screws, ensuring that there is little to no resistance | |
| 4.34 | Test the Air Brakes servo | |
| 4.35 | Make a hotspot on the laptop with the following information<br>Name: HPRC<br>Password: tacholycos<br>Band: 2.4 GHz<br>Turn the hotspot on after it has been made | |
| 4.36 | Screw on the screw switch | |
| 4.37 | Run command: ssh pi@dirtypi | |
| 4.38 | Once you ssh into the pi, the password is raspberry | |
| 4.39 | Run command: cd AirbrakesV2 | |
| 4.40 | Run command: uv run scripts/run_servo_and_encoder_tui.py to extend and contract the finds | |
| 4.41 | Run command: uv run scripts/run_firm.py to ensure the INS is sending data properly | |
| 4.42 | Screw off the screw switch. Failure to do so could result in the LiPo battery draining completely. In this case, the Air Brakes would fail to deploy, causing the Apogee to be much higher than predicted. | |

# 5. Motor Assembly

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Jim Livingston (Mentor) | |
| **Personnel 2** | | |
| **Personnel 3** | | |

| Required Materials | | | |
|---|---|---|---|
| **Item** | **Quantity** | **Location** | **Check** |
| Nitrile Gloves | / | Versa-Stack Bottom | |
| Motor Reload Kit | 1 | Blast Containment Box | |
| Motor Assembly Instructions | 1 | Launch Lead Binder | |
| Motor Casing | 1 | Motor Box | |
| Motor Liner | 1 | Motor Box | |
| Super Lube | 1 | Versa-Stack Top | |
| Wire Strippers | 1 | Launch Day Toolbox | |
| Blue Tape | 1 | Versa-Stack Top/Bottom | |
| Blast Containment Box | 1 | Ground | |
| Anti-Static Bag | 1 | Blast Containment Box | |

| Procedure | | |
|---|---|---|
| **Number** | **Task** | **Completion** |
| 5.1 | Gather all materials and go to the L3 mentor, Jim Livington, to begin motor assembly. The L3 mentor must lead the assembly and be present for the entire duration. | |
| 5.2 | Safety officer to confirm all members on the checklist are wearing safety glasses | **Safety Officer Confirm:** |
| 5.3 | Safety officer to confirm that all members constructing the motor are wearing nitrile gloves. | **Safety Officer Confirm** |
| 5.4 | Examine each propellant grain for any defects or voids. | |
| 5.5 | Lightly lube the motor casing threads. | |
| 5.6 | Apply a light coat of super lube to the manufacturer's specified O-rings. | |
| 5.7 | Insert the smoke grain into the insulator tube with a spacer. Ensure it is fully snug. | |
| 5.8 | Take one end of the smoke grain and lightly grease it with lube. | |
| 5.9 | Have the greased side of the smoke grain face the insulator tube. Insert and ensure it is fully seated within the tube. | |
| 5.10 | Install the O-ring onto the forward disk seal. | |
| 5.11 | Insert the forward seal disk and its O-ring into one end of the motor liner. Ensure it is fully seated. | |
| 5.12 | Load the three propellant grains into the motor liner. | |
| 5.13 | Insert the motor liner into the motor casing. Ensure the liner is centered within the casing as it is being placed inside. | |
| 5.14 | Place the forward O-ring into the forward end of the motor casing, ensuring it is flush against the forward seal disk assembly. | |
| 5.15 | Attach the forward closure and smoke grain assembly to the forward end of the motor casing. Only tighten by hand. | |
| 5.16 | Install the AFT nozzle onto the AFT end of the motor casing | |
| 5.17 | Place the AFT O-ring on the AFT nozzle. Ensure it is flush. | |
| 5.18 | Put the AFT closure on the AFT O-ring. | |
| 5.19 | Thread the AFT closure assembly onto the rear of the motor casing and tighten by hand. | |
| 5.20 | Install the nozzle cap/ | |
| 5.21 | Prepare the motor ignitor according to the motor reload kit guide. | |
| 5.22 | Route the igniter lead along the side of the motor casing | |
| 5.23 | Secure it in place with blue tape. | |
| 5.24 | Separate the tow ignitor wire leads. | |
| 5.25 | Strip insulation from the end of the igniter wires. | |
| 5.26 | Re-coil the ignitor wires. | |
| 5.27 | Secure the ignitor with blue tape to the side of the motor casing. | |
| 5.28 | Return to the launch setup table with the motor. Place in an anti-static bag. | |
| 5.29 | Have a team member hold the motor in a shaded area, while wearing nitrile gloves and safety glasses, until the checklist step 7.3. | |

# 6. ELECTRONICS ASSEMBLY

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Ben Radspinner | |
| **Personnel 2** | Aditya Chadha | |
| **Personnel 3** | | |

| Required Materials | | | |
|---|---|---|---|
| **Item** | **Number** | **Location** | **Check** |
| Computer | 1 | Aerodynamics Lead | |
| Avionics Bay | 1 | Blast Containment Box | |
| Electrical tape | 1 | Versa-stack bottom | |
| Scissors | 1 | Toolbox middle | |
| Payload/Nosecone | 1 | Ground | |
| Air brakes/AFT assembly | 1 | Ground | |
| Screwdriver | 1 | Launch day toolbox middle | |
| Camera | 1 | Team Member's Phone | |
| M3 Screws | 27 | Versa-Stack Bottom | |
| Locknuts | 8 | Versa-Stack Bottom | |

| Procedure | | |
|---|---|---|
| **Number** | **Task** | **Completion** |
| | **PAYLOAD** | |
| 6.1 | Confirm all electronics are on the ZOMBIE sled. | |
| 6.2 | Attach the legs of ZOMBIE to the inner collar assembly with 4 M3 screws and locknuts. | |
| 6.3 | Slide the soil collection module into the aft end of the lower outer body. Attach with 8 M3 screws. | |
| 6.4 | Slide the collar into the forward end of the lower body so that the tips of the legs are aligned with the aft end of the soil body housing. Align the legs so that they are directly between two extruded holes. | |
| 6.5 | Connect the legs of ZOMBIE to the soil housing attachment points using 4 M3 screws and 4 locknuts. | |
| 6.6 | Route the 4 sets of wires through the collar so that they are on the same side as the Pi. | |
| 6.7 | Place the upper body of ZOMBIE onto the lower body of ZOMBIE, ensuring that the two forward rails are aligned with the two aft rails. Double-check this placement with the alignment mark that is located on the outer body. | |
| 6.8 | Secure the stemnauts. | |
| 6.9 | Secure the ZOMBIE LiPo battery to the sled by attaching it to velcro on the electronic sled wall and threading a zip tie around the top of the battery and through the two slots on either side. Ensure it is snug. | |
| 6.10 | Connect the 4 sets of connectors to their respective wired connectors. Each connector is labeled with a number 1-4. For example, connect the "1" connector from the upper body to the "1" connector from the ZOMBIE sled. | |
| 6.11 | Place the ZOMBIE pull pin into the hole marked "zp". Ensure it is fully seated. | |
| 6.12 | Plug in the LiPo battery | |
| 6.13 | Check the Voltage of the ZOMBIE LiPo battery. Record the Voltage.<br>If the voltage is not at least 14.8, replace.<br>Failure to replace the battery could result in the legs of ZOMBIE not deploying, and the payload functionality failing. | **Record Battery Voltage:** |
| 6.14 | Attach the bulkhead to the sled using 5 M3 screws. | |
| 6.15 | Take the ZOMBIE pull pin out | |
| 6.16 | Slide the bullhead sled assembly into the forward end of the ZOMBIE upper body. Ensure the attachment screw holes on the bulkhead sled assembly and the forward end of ZOMBIE are aligned using the alignment marks. | |
| 6.17 | Stand ZOMBIE up and unfold the legs so that they are fully horizontal. | |
| 6.18 | Make a hotspot on the laptop with the following information<br>Name: HPRC<br>Password: tacholycos<br>Band: 2.4 GHz<br>Take note of the IP address of the Raspberry Pi after it connects | |
| 6.19 | Run command in vs code: ssh pi@Zombie | |
| 6.20 | Once you ssh into the pi, the password is raspberry | |
| 6.21 | Pull up the ZOMBIE script | |

| | | |
|---|---|---|
| **6.22** | Run the script to raise the lead screw motor so that the legs are fully retracted. | |
| **6.23** | Attach the upper body housing to the sled using 6 M3 screws. | |
| **6.24** | Put the ZOMBIE pull pin back into the hole marked “zp”. Ensure it is fully seated. | |
| **6.25** | Slot battery into housing on GrAVE electronics sled. Secure by wrapping zip tie around the housing. | |
| **6.26** | Insert GrAVE Pull Pin into the pull pin hole. | |
| **6.27** | Plug in the LiPo Battery. | |
| **6.28** | Check the Voltage of the ZOMBIE LiPo battery. Record the Voltage.<br>If the voltage is not at least 14.8, replace. Failure to replace could result in ZOMBIE not being ejected, and the payload functionality failing. | **Record Voltage:** |
| **6.29** | Take GrAVE pull pin out. | |
| **6.30** | Ensure a team member is holding onto the aft end of the pusher plate of GrAVE to ensure that it does not rotate. Ensure the team member is not restricting the lateral movement of the plate. | |
| **6.31** | Make a hotspot on the laptop with the following information<br>Name: HPRC<br>Password: tacholycos<br>Band: 2.4 GHz<br>Take note of the IP address of the Raspberry Pi after it connects | |
| **6.32** | Run command in VS Code: ssh pi@Grave | |
| **6.33** | Once you ssh into the pi, the password is raspberry | |
| **6.34** | Locate the GrAVE script | |
| **6.35** | Run the script to retract the pusher plate. | |
| **6.36** | Route the ribbon cable around the pusher plate so that it is aft of the sled. | |
| **6.37** | Slide the sled into the nosecone using the alignment mark. Ensure it is pushed all the way forward so that the outer body of the sled is flush with the inside of the nosecone. | |
| **6.38** | Screw 4 countersunk screws into the nosecone to secure the GrAVE sled. | |
| **6.39** | Place the GrAVE pull pin back into the hole marked “gp”. Ensure it is fully seated. | |
| **6.40** | Insert the camera into the camera housing | |
| **6.41** | Tape the ribbon cable so that the entire length is flush and secure against the inner wall. | |
| **6.42** | Take the ZOMBIE pull pin out. | |
| **6.43** | Slide ZOMBIE into the nosecone so that it is aligned with the rails and the U-bolt is aligned with the cutout in the pusher plate. Latch should engage with U-Bolt so that it is secure. | |
| **6.44** | Put the ZOMBIE pull pin back into the hole marked “zp”. Ensure it is fully seated. | |
| **6.45** | Slide the aft nosecone bulkhead into the aft end of the nosecone so that it is seated. Check alignment marks to verify fit. | |
| **6.46** | Remove the pull pins in the holes marked “gp” and “zp”. | |
| **6.47** | Run command: cd firm | |
| **6.48** | Run command: uv run run_firm_test.py and ensure data is being received from FIRM. | |
| **6.49** | Run command: uv run run_magnetometer_cal.py | |
| **6.50** | Spin the nosecone for three minutes | |
| **6.51** | Take a picture of the calibration results | |
| **6.52** | Re-insert the pull pins into the holes marked “zp” and “gp” ensuring that they are both fully seated. | |
| | **AIR BRAKES** | |
| **6.53** | Screw on the screw switch | |
| **6.54** | Run command: ssh pi@dirtypi | |
| **6.55** | Once you ssh into the pi, the password is raspberry | |
| **6.56** | Run command: cd AirbrakesV2 | |
| **6.57** | Run command:  uv run scripts/run_servo_and_encoder_tui.py to extend and contract the finds | |
| **6.58** | Run command: uv run scripts/run_firm.py to ensure INS is sending data properly | |
| **6.59** | Run command: uv run run_magnetometer_cal.py | |
| **6.60** | Spin the Fincan for three minutes | |
| **6.61** | Take a picture of the calibration results | |
| **6.62** | Screw off the screw switch | |

# 7. DROGUE RECOVERY ASSEMBLY

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Lauren Wilkie | |
| **Personnel 2** | | |
| **Personnel 3** | | |

| Required Materials | | | |
|---|---|---|---|
| **Item** | **Quantity** | **Location** | **Check** |
| Gloves | / | Versa-stack bottom | |
| Safety Glasses | / | Safety Glasses toolbox | |
| Motor | 1 | Blast Containment box | |
| AV Bay Assembly | 1 | Blast Containment box | |
| Softlink #1,2,3 | 3 | Versa-stack top | |
| Drogue Parachute (folded) | 1 | Versa-stack top | |
| Drogue nomex | 1 | Versa-stack top | |
| Drogue shock cord | 1 | Versa-stack top | |
| Insulation | 1 | Versa-stack bottom | |
| Countersunk screws | 4 | Versa-stack top | |
| Shear pins | 2 | Versa-stack top | |
| Blue tape | 1 | Versa-stack top/bottom | |
| Screwdriver | 1 | Launch day toolbox middle | |
| Lithium grease | 1 | Versa-stack bottom | |
| Motor retention ring | 1 | AFT assembly | |
| #632 screws | 4 | AFT assembly | |
| Small Black Wire | 2 | Versa-stack top | |
| Small White Wire | 2 | Versa-stack top | |

| Procedure | | |
|---|---|---|
| **Number** | **Task** | **Completion** |
| **7.1** | Accordion fold the shock cord between loops 1-2 and 2-3. | |
| **7.2** | Take the drogue shock cord and connect loop 1 to the air brakes bay U-bolt with soft link 1. Wrap the soft link 3 times before tightening. Ensure when looping over the stopper that you pull the neck of the loop so it cinches down. Safety Officer confirms loops are secure. | **Safety Officer Confirm:** |
| **7.3** | Fold the drogue parachute per the Fruity Chutes folding recommendations | |
| **7.4** | Wrap Nomex around the drogue parachute like a burrito, ensuring the entirety of the parachute is covered. If it is not protected from black powder charges, the parachute could be damaged and may come down at an unsafe velocity. | |
| **7.5** | Connect the drogue shock cord loop 2 to the drogue parachute and drogue Nomex using soft link 2.  Wrap the soft link 3 times before tightening. Ensure when looping over the stopper that you pull the neck of the loop so it cinches down. Safety Officer confirms loops are secure. | **Safety Officer Confirm:** |
| **7.6** | Take the parachute and shock cord, and push in through the aft end of the drogue bay | |
| **7.7** | Slide the drogue bay onto the air brakes bay coupler using the alignment marks | |
| **7.8** | Once it is aligned, verify that you can see the holes for the screws | |
| **7.9** | Screw 4 countersunk screws into the holes | |
| **7.10** | Safety Officer to ensure all members have safety glasses on | **Safety Officer Confirm:** |
| **7.11** | Retrieve the Avionics bay | |
| **7.12** | Open both connectors of the white WAGO block on the AFT bulkhead, and place each end of a small white wire into a connector. Verify continuity | |
| **7.13** | Open both connectors of the black WAGO block on the AFT bulkhead, and place each end of a small black wire into a connector. Verify continuity | |
| **7.14** | Open both connectors of the white WAGO block on the forward bulkhead, and place each end of a small white wire into a connector. Verify continuity | |
| **7.15** | Open both connectors of the black WAGO block on the forward bulkhead, and place each end of a small black wire into a connector. Verify continuity | |
| **7.16** | On the Aft bulkhead, take the e-tape off of the e-match wires, and put the e-match wires from the white blast cap into the white WAGO. Place a piece of e-tape over the holes in the WAGO block. | |
| **7.17** | On the Aft bulkhead, put the e-match wires from the black blast cap into the black WAGO. Place a piece of e-tape over the holes in the WAGO block. | |
| **7.18** | On the forward bulkhead, take the e-tape off the e-match wires, and put the e-match wires from the white blast cap into the white WAGO. Place a piece of e-tape over the holes in the WAGO block. | |
| **7.19** | On the forward bulkhead, put the e-match wires from the black blast cap into the black WAGO. Place a piece of e-tape over the holes in the WAGO block. | |
| **7.20** | Ensure the WAGO blocks on the aft and forward end have e-tape covering the top holes of the connector. | |
| **7.21** | Connect the drogue shock cord loop 3 to the aft av bay U-bolt with soft link 3. Wrap the soft link 3 times before tightening. Ensure when looping over the | **Safety Officer Confirm:** |

| | | |
|---|---|---|
| | stopper that you pull the neck of the loop so it cinches down. Safety Officer confirms loops are secure. | |
| 7.22 | Take insulation and put one inch worth into the drogue bay on top of the parachute | |
| 7.23 | Put a healthy rim of lithium grease aft of the shear pin holes, all the way around. | |
| 7.24 | Take the AV bay coupler, along the aft side of the AV bay switch band, and put a rim of grease | |
| 7.25 | Slide the AV bay into the drogue bay using the alignment marks | |
| 7.26 | Place 2 shear pins in holes across from each other. | |
| 7.27 | Place one long piece of blue tape along the entire circumference of the launch vehicle, covering both shear pins | |
| 7.28 | Confirm 1 rubber band on the Lead's wrist | |
| 7.29 | Unscrew the motor retention plate | |
| 7.30 | Remove the motor from the anti-static bag. | |
| 7.31 | Inspect to ensure no ejection charges are present. | **Safety Officer Confirm:** |
| 7.32 | Insert the motor into the motor mount tube | |
| 7.33 | Screw in motor retention system. Confirm it is snug.<br>Failure to do this could result in the motor not being secure within the launch vehicle and lead to an unplanned motor ejection. | |

# 8. MAIN BAY RECOVERY ASSEMBLY

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Lauren Wilkie | |
| **Personnel 2** | | |

| Required Materials | | | |
|---|---|---|---|
| **Item** | **Number** | **Location** | **Check** |
| Gloves | / | Versa-stack bottom | |
| Safety glasses | / | Safety glasses toolbox | |
| Main shock Cord | 1 | Versa-stack top | |
| Main Parachute | 1 | Versa-stack top | |
| Deployment Bag | 1 | Versa-stack top | |
| Main Nomex | 1 | Versa-stack top | |
| Shear pins | 2 | Versa-stack top | |
| Lithium Grease | 1 | Versa-stack bottom | |
| AFT assembly | 1 | / | |
| Countersunk screws | 4 | Versa-stack top | |
| Soft links 4 and 5 | 2 | Versa-stack top | |
| Insulation | 1 | Versa-stack bottom | |

| Procedure | | |
|---|---|---|
| **Number** | **Task** | **Completion** |
| 8.1 | Safety officer to ensure all members are wearing safety glasses | **Safety Officer Confirm:** |
| 8.2 | Verify the nosecone shock cord loop 8 is connected to the nosecone carbon fiber tube by pulling the main shock cord through the bulkhead | |
| 8.3 | Fold the main parachute per the Fruity Chutes folding recommendations. Ensure a member holds onto the bundle to ensure it does not unfold. | |
| 8.4 | Place the main parachute in the deployment bag per the Fruity Chutes deployment bag folding recommendations. Connect the deployment bag to loop 5 of the AV Bay shock cord. | |
| 8.5 | Place the bulkhead shock cord loop 7, the main parachute bridle, the AV Bay shock cord loop 6, and the nose cone shock cord loop 8. | |
| 8.6 | Connect all four loops using a soft link. Wrap the soft link 3 times before tightening. Ensure when looping over the stopper that you pull the neck of the loop so it cinches down. Safety lead confirms loops are secure and that there are three soft link passes through all four loops. | **Safety Officer Confirm:** |
| 8.7 | Slide the main parachute, which is inside the deployment bag, and the main shock cord into the forward end of the main bay so that loop 4 is facing aft. | |
| 8.8 | Connect the shock cord loop 4 to the forward AV bay U-bolt using soft link 4. Wrap the soft link 3 times before tightening. Ensure when looping over the stopper that you pull the neck of the loop so it cinches down. Safety lead confirms loops are secure. | **Safety Officer Confirm:** |
| 8.9 | Slide the nosecone coupler into the forward end of the main bay, using the alignment marks | |
| 8.10 | Place two shear pins on opposite sides of the airframe. Put a piece of blue tape fully around the rocket, covering both shear pins. | |
| 8.11 | Put insulation into the aft end of the main bay, about 1 inch worth. Ensure they are forward of the screw holes. | |
| 8.12 | Put a healthy rim of lithium grease forward of the screw holes within the tube | |
| 8.13 | Put a rim of lithium grease just forward of the switchband on the AV bay | |
| 8.14 | Slide the main bay and nosecone onto the forward end of the AV bay using the alignment marks | |
| 8.15 | Place the 4 countersunk screws into the holes, and tighten | |
| 8.16 | Put blue tape around the forward adjoining section of the switchband. | |

# 9. FINAL MEASUREMENTS

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Donald Gemmel | |
| **Personnel 2** | | |
| **Personnel 3** | | |

| Required Materials | | | |
|---|---|---|---|
| **Item** | **Quantity** | **Location** | **Check** |
| Rope | 1 | Launch day toolbox top | |
| Fish scale | 1 | Launch day toolbox top | |
| Blue tape | 1 | Versa-stack | |
| Sharpie | 1 | Launch day toolbox middle | |
| Calculator | 1 | Phone | |
| Launch vehicle | 1 | Ground | |
| Launch Vehicle Stands | 2 | Ground | |
| Tape measurer | 1 | Launch day toolbox top | |

| Procedure | | |
|---|---|---|
| **Number** | **Task** | **Completion** |
| 9.1 | Safety Officer confirms all members are wearing safety glasses | **Safety Officer Confirm:** |
| 9.2 | Place the launch vehicle on the launch vehicle stands | |
| 9.3 | Wrap the rope around the center of the launch vehicle and gently hold it up using the fish scale. The rope should be carefully moved with someone holding the launch vehicle gently until the center of gravity is found. Have the person holding the launch vehicle gently remove their hands to ensure balance. | |
| 9.4 | Place a small piece of blue tape at the location of the rope | |
| 9.5 | Record the weight of the launch vehicle from the fish scale readout. | |
| 9.6 | Remove the rope and fish scale. Label the CG found using the rope with Sharpie on the placed blue tape. Replace the blue tape if necessary, ensuring it stays at the same location. | |
| 9.7 | Measure the distance between the CG tape and the tip of the nose cone. Ensure the tape measure does not bend along the nosecone. Write down the location of the center of gravity. | **Record CG Location:** |

| | | |
|---|---|---|
| 9.8 | Mark the center of pressure using blue tape labeled “CP” with Black Sharpie<br>CP should be 63.125 | |
| 9.9 | Calculate the stability margin using the formula<br>$S = \frac{(CP-CG)}{D}$<br>Record the stability margin | **Record Stability Margin:** |
| 9.10 | Load the field recovery box with the items required for the launch field checklist | |
| 9.11 | Team lead confirms that there are 5 rubber bands around the wrist | **Team Lead Confirm:** |
| 9.12 | Proceed to the RSO desk | |

# 10. LAUNCH PAD

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Lauren Wilkie | |
| **Personnel 2** | Mason Meyer | |

**Required Materials**

| Item | Quantity | Location | Check |
|---|---|---|---|
| Nitrile Gloves | 1 | Versa-stack bottom | |
| Heavy Duty Gloves | 2 | Recovery toolbox | |
| Fire extinguisher | 1 | Recovery toolbox | |
| Safety Glasses | / | Safety glasses toolbox | |
| Motor Ignitor | 1 | Recovery toolbox | |
| Air Brakes Laptop | 1 | Aerodynamics Lead | |
| Recovery Laptop | 1 | Recovery Lead | |
| Wire snips | 1 | Launch day toolbox middle | |
| Wire strippers | 1 | Launch day toolbox middle | |
| Blue tape | 1 | Versa-stack | |
| Vaseline | 1 | Versa-stack bottom | |
| Payload Laptop | 1 | Payload Lead | |
| Recovery box | 1 | Recovery Box | |
| Electrical Tape | 1 | Launch day toolbox middle | |

**Procedure**

| Number | Task | Completion |
|---|---|---|
| 10.1 | Fill out and submit the flight card for review.<br>Name: North Carolina State University (Jim Livingston) | |
| 10.2 | Gather team personnel for a picture | |
| 10.3 | The safety officer confirms that all checklist members have safety glasses | **Safety Officer Confirm:** |
| 10.4 | Proceed to the launch pad with RSO permission | |
| 10.5 | Confirm the blast deflector is mounted below the launch rail | |
| 10.6 | Align the rail buttons with the forward slots in the launch rail, then carefully slide the launch vehicle onto the launch rail | |
| 10.7 | Confirm the launch vehicle slides smoothly along the rail.<br>- If necessary, remove the launch vehicle and apply lube to the launch vehicle to ensure no resistance | |
| 10.8 | Upright the launch rail and ensure the locking mechanism is deployed | |
| 10.9 | Angle the launch rail to no less than 5 degrees from the vertical, away from spectators. Confirm the locking mechanism is working. | |
| 10.10 | Take a team picture | |
| 10.11 | Confirm all individuals on the checklist are wearing safety glasses | **Safety Officer Confirm:** |
| | **Payload** | |
| 10.12 | Remove both the ZOMBIE pull pin and the GrAVE pull pin. Place in the launch recovery toolbox. | |
| 10.13 | Make a hotspot on the laptop with the following information<br>Name: HPRC<br>Password: tacholycos<br>Band: 2.4 GHz<br>Take note of the IP address of the Raspberry Pi after it connects | |
| 10.14 | Run command in vs code: ssh pi@zombie | |
| 10.15 | Run command in vs code: ssh pi@grave | |
| 10.16 | Once you ssh into the two Raspberry Pis, the password is raspberry | |
| 10.17 | Remove both the ZOMBIE pull pin and the GrAVE pull pin. Place in the launch recovery toolbox. | |
| 10.18 | Make a hotspot on the laptop with the following information<br>Name: HPRC<br>Password: tacholycos<br>Band: 2.4 GHz<br>Take note of the IP address of the Raspberry Pi after it connects | |
| 10.19 | Run command in vs code: ssh pi@zombie | |
| 10.20 | Run command in vs code: ssh pi@grave | |
| 10.21 | Once you ssh into the two Raspberry Pis, the password is raspberry | |
| 10.22 | Access fullscaleFlight.py | |
| 10.23 | Run script | |
| 10.24 | Disconnect from Raspberry Pi | |
| | **Air Brakes** | |
| 10.25 | Turn on the air brakes; screw the screw switch in | |
| 10.26 | Create a mobile hotspot with name: HPRC, password: tacholycos, band: 2.4 GHz<br>Wait for the pi to connect to the hotspot; it will beep when it connects; (note IP address), and then, run: ssh pi@[Pi IP Address]<br>Connect via tmux, run: tmux new -s airbrakes | |
| 10.27 | Navigate to the AirbrakesV2 directory (if not already in it) run: cd AirbrakesV2/<br>Now run: uv run real<br>You should now see a display of what the air brakes code is doing | |
| 10.28 | Continue to monitor the display before launch, making sure it stays in **StandbyState**.<br>If the display reports an invalid field from the IMU, restart the pi by running: `sudo reboot`<br>Then repeat steps 8.17-8.19.<br>Once the rocket is about to launch, detach from the session by pressing **Ctrl + b**, then **d**<br>*Note: even if you don’t detach and it simply loses connection due to being out of range, everything will still run fine* | |
| | **Recovery** | |
| 10.29 | Pull the pull pin out halfway to power the EasyMini, and ensure the team member’s head is at least 12 inches away from the location of the electronics. | |
| 10.30 | Listen for the EasyMini beeps. Dit Dit Dit | **Safety Officer Confirm:** |
| 10.31 | Pull out the pull pin fully to power the fluctus. Put the pull pin in the recovery box. Ensure the team member is at least 12 inches away from the location of the electronics. | |
| 10.32 | Turn on the ground station and connect it to the FCC (Fluctus control center) | |
| 10.33 | Do a ping pong test to ensure connection with Fluctus | |
| 10.34 | Read the configuration on the Fluctus software and ensure it is the correct configuration. Ensure it is not going directly into flight mode | |
| 10.35 | Arm the fluctus manually | |
| 10.36 | Insert the ignitor fully into the motor. | |
| 10.37 | Tape the ignitor into place at the bottom of the launch vehicle. | |

| | | |
|---|---|---|
| 10.38 | Confirm that the launch pad power is turned off. | |
| 10.39 | Connect the ignitor wires to the launch pad power. | |
| 10.40 | Confirm launch pad continuity. | **Safety Officer Confirm:** |
| 10.41 | All personnel navigate to a safe location behind the launch table. | |
| 10.42 | Pass the primary checklist and field recovery toolbox to the Safety Officer. | |
| 10.43 | Inform the RSO that the team is ready for launch. | |
| 10.44 | Launch! | |

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# 11. FIELD RECOVERY

| Required Personnel | | Confirmation |
|---|---|---|
| **Lead** | Elizabeth Bruner | |
| **Safety Officer** | Aidan McCloskey | |
| **Personnel 1** | Lauren Wilkie | |
| **Personnel 2** | Emily Cates | |
| **Personnel 3** | | |

| Required Materials | | | |
|---|---|---|---|
| **Item** | **Quantity** | **Location** | **Check** |
| Nitrile Gloves | / | Versa-stack bottom | |
| Safety Glasses | / | Safety glasses toolbox | |
| Heavy Duty Gloves | 2 | Recovery toolbox | |
| Fire extinguisher | 1 | Recovery toolbox | |
| Fluctus connecting laptop/phone | 1 | Recovery Lead | |
| Recovery Pull Pin | 1 | Recovery toolbox | |
| Nosecone Pull Pin | 1 | Recovery toolbox | |
| Screwdriver | 1 | Launch day toolbox middle | |
| Rubber bands | 4 | Versa-stack bottom | |
| Wire snips | 1 | Launch day toolbox middle | |
| Blue tape | 1 | Versa-stack | |
| Wire strippers | 1 | Launch day toolbox middle | |
| Adjustable wrench | 1 | Launch day toolbox middle | |
| Launch Vehicle (Assembled) | 1 | On the Field | |

| Procedure | | |
|---|---|---|
| **Number** | **Task** | **Completion** |
| 11.1 | The QR code from the fluctus will read out a location on Google Maps. Begin to follow this location. | |
| 11.2 | Confirm that all personnel are wearing safety glasses | |
| 11.3 | Confirm that all personnel handling the rocket are wearing nitrile gloves | |
| 11.4 | Disarm the fluctus once you reach the vicinity of the rocket | |
| 11.5 | Approach the launch vehicle | |
| 11.6 | Take pictures of the launch vehicle in its landed orientation. Take pictures of each section up close. Make sure to document the forward and aft ends of each section. High quality pictures. | |
| 11.7 | If the parachute is open and dragging the rocket, only approach from the billowed side. Pull down the parachute from the aft end, ensuring not to pull on the shroud lines or shock cord. | |

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| | | |
|---|---|---|
| 11.8 | Secure the main parachute and drogue parachute with rubber bands. | |
| 11.9 | Put the recovery pull pins back in if possible | |
| 11.10 | Put the payload pull pin back in | |
| 11.11 | Screw the screwswitch | |
| 11.12 | Equip heavy-duty gloves before handling any section of the body tube. | |
| 11.13 | Carefully pick up the forward end of the AV bulkhead just enough to inspect the forward AV bulkhead for unblown black powder charges. | |
| 11.14 | Inspect the AFT AV bulkhead for unblown black powder charges. If any un-blown charges are found, see APPENDIX B for instructions on how to properly dispose of them. | |
| 11.15 | Inspect the FWD AV bulkhead for unblown black powder charges. If any un-blown charges are found, see APPENDIX B for instructions on how to properly dispose of them. | |
| 11.16 | Visually and auditorily inspect ZOMBIE to ensure it is not operating. | |
| 11.17 | Ensure that ZOMBIE stays upright during the entire recovery process. Only pick up ZOMBIE by the forward U-bolt. | |
| 11.18 | Place both the ZOMBIE and the GrAVE pull pin back into the holes marked, respectively, "zp" and "gp". Ensure both are properly seated. | |
| 11.19 | Collect each launch vehicle section and return to the launch site. | |
| 11.20 | Take pictures of any damage to the launch vehicle. | |
| 11.21 | Inspect for and collect non-biodegradable waste from the landing site. | |

# APPENDIX A – EASYMINI BEEP SHEET

EasyMini

| 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 main igniter. |
| Both | dit dit dit | Continuity detected on both igniters. |

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.

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# APPENDIX B - EMERGENCY PROCEDURES

### PREMATURE BLACK POWDER IGNITION

- ALL PERSONS CLEAR THE AREA
- CLEAR FLAMMABLE OBJECTS FROM THE AREA
- USE FIRE EXTINGUISHER TO EXTINGUISH ANY REMAINING FIRE

*If Persons are Injured:*

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

### LAUNCH RAIL COLLAPSE AT LAUNCH

- TAKE COVER IF NECESSARY
- CLEAR THE AREA IN DIRECTION OF NOSE CONE TIP
- LISTEN TO RSO INSTRUCTIONS

*If Persons are Injured:*

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

*Once Hazard is Clear:*

- FOLLOW FIELD RECOVERY CHECKLIST

### CATASTROPHE AT TAKE OFF

- LISTEN TO RSO INSTRUCTIONS
- ALL PERSONS CLEAR THE AREA
- DO NOT APPROACH UNTIL CONDITIONS AT THE LAUNCH PAD ARE CLEAR

*If Persons are Injured:*

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

### BALLISTIC DESCENT

- LISTEN TO RSO INSTRUCTIONS
- DETERMINE LOCATION OF BALLISTIC DESCENT
- ALL PERSONS MOVE AWAY FROM DESCENT PATH
- MAINTAIN VISUAL CONTACT WITH LAUNCH VEHICLE

*If Persons are Injured:*

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

### UNBLOWN CHARGES

- ENSURE THERE IS NO POWER GOING TO THE ALTIMETERS (PULL PIN SWITCH, ETC)
- USING WIRE CUTTERS, CUT THE E-MATCH WIRES GOING TO THE CHARGE. DO NOT REMOVE BLUE TAPE
- PROCEED TO LAUNCH PREFECT FOR INSTRUCTIONS ON HOW TO DISPOSE OF CHARGE

*If Persons are Injured:*

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

### FAILED MOTOR IGNITION

- LISTEN TO RSO INSTRUCTIONS
- WAIT UNTIL RSO APPROVED APPROACH
- EXPECT POSSIBLE MOTOR IGNITION
- APPROACH LAUNCH PAD WITH PPE
- INSPECT IGNITOR AND WIRING
- CONSULT RSO FOR FURTHER ACTION

### NO IGNITOR CONTINUITY

- LISTEN TO RSO INSTRUCTIONS
- DESIGNATED PERSONNEL APPROACH THE LAUNCH PAD WITH PPE
- CHECK IF ALLIGATOR CLIPS ARE PROPERLY ATTACHED TO IGNITOR AND ENSURE BOX IS WIRED TO CORRECT LAUNCH PAD

*If No Continuity Persists:*

- SEEK RSO DIRECTION
- CHANGE LAUNCH PAD

### BLACK POWDER SPILL

- ALL NON-DESIGNATED PERSONS CLEAR THE AREA
- EQUIP PPE FOR HANDLING BLACK POWDER
- ACQUIRE FUNNEL AND EMPTY PLASTIC CONTAINER
- BRUSH/FUNNEL AS MUCH OF THE SPILLED BLACK POWDER AS POSSIBLE INTO THE CONTAINER USING GLOVED HANDS
- DISPOSE OF REMAINING BLACK POWDER
- USE WET WIPES TO CLEAN REMAINING BLACK POWDER

### MISSING REQUIRED TOOL

- ASK TEAM MEMBERS FOR PERSONAL TOOLS
- ASK OTHER LAUNCH PATRONS
- ACQUIRE NEW TOOL FROM HARDWARE STORE IF POSSIBLE

*If Unable to Resolve:*

- ABORT LAUNCH PROCEDURE
- FIRST REMOVE ANY ENERGETICS FROM LAUNCH VEHICLE
- PACKAGE ENERGETICS IN STATIC BAGS
- PLACE BAGS IN LOCKED ENERGETICS BOX OR FLAME CABINET
- DISASSEMBLE REMAINDER OF VEHICLE

### RAPID WEATHER CHANGE AT LAUNCH

- LISTEN TO RSO INSTRUCTIONS
- REMOVE VEHICLE FROM LAUNCH RAIL
- REMOVE ANY ENERGETICS FROM LAUNCH VEHICLE
- PACKAGE UNUSED ENERGETICS IN STATIC BAGS
- PLACE BAGS IN LOCKED ENERGETICS BOX OR FLAME CABINET
- DISASSEMBLE REMAINDER OF VEHICLE

### PARACHUTE UNFOLDS DURING ASSEMBLY

- DISCONNECT PARACHUTE FROM QUICK LINK
- REFOLD PARACHUTE
- REATTACH PARACHUTE TO QUICK LINK
- GRASP PARACHUTE FOR FURTHER ASSEMBLY
- RESUME RECOVERY ASSEMBLY CHECKLIST AT NOMEX INSTALLATION CHECKLIST ITEM

### HARDWARE DAMAGE POST-LANDING

- REPLACE HARDWARE FOR FUTURE LAUNCHES
- NASA REQUIRES RE-FLIGHT ON NEW HARDWARE
- NASA REQUIRES RE-FLIGHT IF DATA LOST

## 6.2 Safety Documentation

Likelihood-Severity (LS) matrices were used to assess hazard risk and mitigation effectiveness. Each identified hazard was evaluated in terms of likelihood of occurrence and severity of consequence prior to and following mitigation efforts. Hazard rankings were assigned using the severity scale defined in Table 6.1 and the likelihood scale defined in Table 6.2, with severity levels ranging from Level 1 (lowest) to Level 4 (highest) and likelihood levels ranging from Level A (least probable) to Level D (most probable).

Hazards were categorized as personnel, design, or environmental and assigned unique identifiers. The LS matrices document the hazard description, causal conditions, and potential effects, along with pre-mitigation and post-mitigation likelihood–severity rankings as defined in Tables 6.1 and 6.2. Mitigation measures were classified as Prevention (P), Detection (D), and Mitigation (M), and post-mitigation rankings reflect the effectiveness of implemented controls. The Results column points to the location where the mitigation efforts can be verified.

In addition to LS matrices, Fault Tree Analysis (FTA) were constructed shown in Section 6.6. FTAs were developed for the major subsystems, including Structures, Recovery, Payload and Air Brakes. FTAs identify root causes that lead to failures within each subssytem, and providing a visual aid that LS matrices tend to lack. Together, FTA and LS matrices provide a comprehensive view of subsystem and system-level risk and mitigation effectiveness.

Table 6.1: Level of Severity Key

| **Level of Severity** | **Mission** | **Launch Vehicle** | **Personnel** | **Environment** |
|---|---|---|---|---|
| (1) Negligible Harm | Negligible impact on mission objectives | Negligible damage | Personnel unaffected | No damage |
| (2) Minor Harm | Minor, reversible impact on mission objectives | Minor reversible damage | Minor injuries, can be treated with basic first aid | Minor reversible damage |
| (3) Moderate Harm | Partial loss or delay of mission objectives | Major reversible damage or minor irreversible damage | Moderate injuries requiring intensive first aid or professional medical care | Major reversible damage or minor irreversible damage |
| (4) Major Harm | Mission failure or critical compromise of objectives | Major irreparable damage or complete destruction | Urgent lifesaving medical care necessary | Major irreversible damage |

Table 6.2: FMEA Likelihood Key

| Likelihood of Occurrence | | | |
|---|---|---|---|
| A<br>Very Unlikely | B<br>Unlikely | C<br>Likely | D<br>Very Likely |
| 0–15%<br>Occurrence | 16–25%<br>Occurrence | 26–50%<br>Occurrence | 51–100%<br>Occurrence |

Tables 6.3, 6.4, 6.5, 6.6, 6.7, and 6.8 show how mitigation efforts effect the LS of the Personnel, Design, and Environmental Hazards.

Table 6.3: Personnel Risks Assessment Before Mitigation

| | | Level of Severity | | | |
|---|---|---|---|---|---|
| | | 1 Low Risk | 2 Medium Risk | 3 High Risk | 4 Severe Risk |
| Likelihood of Occurrence | A Very Unlikely | 0.0% (0) | 0.0% (0) | 3.33% (2) | 0.0% (0) |
| | B Unlikely | 0.0% (0) | 6.67% (4) | 5.0% (3) | 6.67% (4) |
| | C Likely | 0.0% (0) | 15.0% (9) | 33.33% (20) | 5.0% (3) |
| | D Very Likely | 0.0% (0) | 13.33% (8) | 11.67% (7) | 0.0% (0) |

Table 6.4: Personnel Risks Assessment After Mitigation

| | | Level of Severity | | | |
|---|---|---|---|---|---|
| | | 1 Low Risk | 2 Medium Risk | 3 High Risk | 4 Severe Risk |
| Likelihood of Occurrence | A Very Unlikely | 41.67% (23) | 23.33% (14) | 1.67% (1) | 5.0% (3) |
| | B Unlikely | 13.33% (8) | 13.33% (8) | 0.0% (0) | 0.0% (0) |
| | C Likely | 1.67% (1) | 0.0% (0) | 0.0% (0) | 0.0% (0) |
| | D Very Likely | 0.0% (0) | 0.0% (0) | 0.0% (0) | 0.0% (0) |

Table 6.5: Design Risks Assessment Before Mitigation

| | | Level of Severity | | | |
|---|---|---|---|---|---|
| | | 1 Low Risk | 2 Medium Risk | 3 High Risk | 4 Severe Risk |
| Likelihood of Occurrence | A Very Unlikely | 0.0% (0) | 0.0% (0) | 1.32% (1) | 9.21% (7) |
| | B Unlikely | 0.0% (0) | 2.63% (2) | 9.21% (7) | 32.89% (25) |
| | C Likely | 0.0% (0) | 5.24% (4) | 11.84% (9) | 25% (19) |
| | D Very Likely | 0.0% (0) | 1.32% (1) | 1.32% (1) | 0.0% (0) |

Table 6.6: Design Risks Assessment After Mitigation

| | | Level of Severity | | | |
|---|---|---|---|---|---|
| | | 1 Low Risk | 2 Medium Risk | 3 High Risk | 4 Severe Risk |
| Likelihood of Occurrence | A Very Unlikely | 47.37% (36) | 31.58% (24) | 1.32% (1) | 5.24% (4) |
| | B Unlikely | 6.58% (5) | 5.24% (4) | 2.63% (2) | 0.0% (0) |
| | C Likely | 0.0% (0) | 0.0% (0) | 0.0% (0) | 0.0% (0) |
| | D Very Likely | 0.0% (0) | 0.0% (0) | 0.0% (0) | 0.0% (0) |

Table 6.7: Environmental Risks Assessment Before Mitigation

| | | Level of Severity | | | |
|---|---|---|---|---|---|
| | | 1 Low Risk | 2 Medium Risk | 3 High Risk | 4 Severe Risk |
| Likelihood of Occurrence | A Very Unlikely | 0.0% (0) | 0.0% (0) | 11.11% (2) | 5.56% (1) |
| | B Unlikely | 0.0% (0) | 5.56% (1) | 11.11% (2) | 11.11% (2) |
| | C Likely | 0.0% (0) | 11.11% (2) | 16.67% (3) | 11.11% (2) |
| | D Very Likely | 0.0% (0) | 11.11% (2) | 5.56% (1) | 0.0% (0) |

Table 6.8: Environmental Risks Assessment After Mitigation

| | | Level of Severity | | | |
|---|---|---|---|---|---|
| | | 1 Low Risk | 2 Medium Risk | 3 High Risk | 4 Severe Risk |
| Likelihood of Occurrence | A Very Unlikely | 44.44% (8) | 5.56% (1) | 11.11% (2) | 0.0% (0) |
| | B Unlikely | 22.22% (4) | 16.67% (3) | 0.0% (0) | 0.0% (0) |
| | C Likely | 0.0% (0) | 0.0% (0) | 0.0% (0) | 0.0% (0) |
| | D Very Likely | 0.0% (0) | 0.0% (0) | 0.0% (0) | 0.0% (0) |

## 6.3 Personnel Hazard Analysis

Table 6.9: Personnel Hazards

| ID | Hazard | Cause | Effect | LS Pre | Mitigation Factors | LS Post | Results |
|---|---|---|---|---|---|---|---|
| Hazards Encountered in Rocketry Lab | | | | | | | |
| PHZ.1 | Exposure to APCP | Handling solid rocket motor propellant without appropriate protective gloves | skin irritation or eye irritation. | 2C | **P:** Require use of appropriate protective gloves.<br>**D:** Supervisor/mentor present during motor assembly.<br>**M:** Wash exposed skin with cold water. | 1B | Section 6.1 includes motor assembly instructions (See Section 5). Safety Handbook [11] describes APCP handling. |
| PHZ.2 | Spontaneous motor ignition | Presence of heat sources, open flames, or electrical discharge in proximity to motor assembly | **(1)** Severe thermal burns to personnel<br>**(2)** Potential ignition of surrounding materials leading to fire<br>**(3)** Risk of ear and eye injury | 4C | **P:** Conduct motor assembly away from heat sources and electronics.<br>**D:** Lead inspects assembly area for potential ignition sources.<br>**M:** Keep fire extinguisher and burn first aid kits nearby. Store motors in flame cabinet, anti-static bags, or explosion box when not in use. | 4A | Section 6.1 includes motor assembly instructions (See Section 5). |
| PHZ.3 | Exposure to Black Powder | **(1)** Improper handling of black powder during loading or disposal<br>**(2)** Failure to use appropriate protective gloves | **(1)** Harmful if ingested<br>**(2)** Serious eye irritation<br>**(3)** Skin or respiratory tract irritation from direct contact or inhalation of dust | 2D | **P:** Require gloves and safety glasses.<br>**D:** Safety leads supervises all black powder handling and packing.<br>**M:** Wash exposed skin with cold water. | 1A | Black powder charge packing described in Section 6.1. Proper handling is described in HPRC Safety Handbook [11]. |
| PHZ.4 | Premature ignition of black powder | **(1)** Accumulation or discharge of static electricity near black powder handling areas<br>**(2)** Presence of unintended electrical current or live wiring in proximity to pyrotechnic materials | **(1)** Thermal burns to personnel from rapid ignition<br>**(2)** Eye injury from flash or particulates<br>**(3)** Increased risk of localized fire or ignition of nearby materials | 4C | **P:** Ground personnel before handling; keep ejection charge packing away from electronics and heat sources. Wear Gloves and Safety glasses.<br>**D:** Monitor voltages and continuity during charge packing.<br>**M:** Keep fire extinguisher ready; ensure flammable materials are clear of packing area. | 2A | Black powder charge packing described in Section 6.1. Proper handling is described in HPRC Safety Handbook [11]. |
| PHZ.5 | Prolonged Exposure to Acetone, Isopropyl Alcohol, or Spray Paint Fumes | **(1)** Inadequate ventilation in work areas<br>**(2)** Failure to wear appropriate respiratory protection | **(1)** Headaches, dizziness, or nausea<br>**(2)** Respiratory irritation or distress<br>**(3)** Potential long-term health effects from repeated inhalation of volatile organic compounds | 3D | **P:** Work in well-ventilated areas, wear respirators, and limit exposure time.<br>**D:** Detect abnormal or strong unfamiliar odors.<br>**M:** Move to fresh air after exposure; take breaks if symptoms occur. | 1A | Vaporous chemical handling is described in HPRC Safety Handbook [11]. |
| PHZ.6 | Exposure to Colloidal Silica Particles | **(1)** Mixing or handling colloidal silica without appropriate respiratory protection<br>**(2)** Failure to wear protective gloves and safety eyewear | **(1)** Coughing and respiratory tract irritation due to inhalation<br>**(2)** Skin irritation from direct contact with material<br>**(3)** Eye irritation or discomfort from airborne particles | 3C | **P:** Wear gloves, safety glasses, and appropriate respirator.<br>**D:** Stay aware of nearby operations, wear a mask if colloidal silica is in use.<br>**M:** Wash exposed skin and eyes with water; clean affected area thoroughly. | 2A | Colloidal Silica Particle guidelines located in HPRC Safety Handbook [11]. SDS Sheets located in Reference [13]. |

Table 6.9: Personnel Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre | Mitigation Factors | LS Post | Results |
|---|---|---|---|---|---|---|---|
| PHZ.7 | Epoxy contact with skin | While working with epoxy (composites, fillets, etc.):<br>**(1)** Insufficient PPE<br>**(2)** Improper training | **(1)** Acute skin irritation<br>**(2)** Allergic reaction developed due to repeated exposure<br>**(3)** Possibility of chemical burns if allowed to cure on skin | 2D | **P:** Wear gloves while handling epoxy.<br>**D:** Understand resin curing times to identify optimal working viscosity.<br>**M:** Wash exposed skin with cold water. | 1C | Proper Epoxy handling located in HPRC Safety Handbook [11]. |
| PHZ.8 | Skin Contact with Sharp Composite Edges | **(1)** Handling composite parts without appropriate protective gloves<br>**(2)** Lack of awareness of sharp edges on fabricated components | **(1)** Lacerations or puncture wounds from sharp edges<br>**(2)** Splinters embedded in skin<br>**(3)** Risk of secondary infection if wounds are not properly treated | 2C | **P:** Ensure composites are sealed and edges are smooth; wear gloves during fabrication.<br>**D:** Inspect each composite component before handling.<br>**M:** Remove splinters with tweezers; apply antibiotic ointment as needed. | 1A | Proper composite handling described in HPRC Safety Handbook [11]. |
| PHZ.9 | Entanglement with Rotating Power Tools (Drill Press, Miter Saw, etc.) | **(1)** Presence of loose clothing, long hair, or jewelry near moving parts<br>**(2)** Inadequate adherence to machine safety or guards | **(1)** Lacerations<br>**(2)** Dismemberment<br>**(3)** Crushing injuries to extremities | 3D | **P:** Tie back hair, remove jewelry, and wear fitted clothing.<br>**D:** Lead observes operation for unsafe behavior.<br>**M:** Use emergency stop buttons; keep first aid nearby. | 2A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.10 | Kickback or Excessive Friction During Cutting or Drilling | **(1)** Improper clamping or securing of workpiece<br>**(2)** Use of dull or inappropriate cutting tools<br>**(3)** Incorrect feed rates or rotational speeds | **(1)** Impact injuries to hands, arms, or other body parts<br>**(2)** Lacerations or contusions from sudden tool or material movement<br>**(3)** Risk of eye injury from ejected debris or tool fragments | 3D | **P:** Secure workpiece, use sharp tools, and correct feed/speed rates.<br>**D:** Ensure guards are properly installed and functional.<br>**M:** Use emergency stop buttons; keep first aid nearby. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.11 | Contact with Moving Blades or Sanding Belts | **(1)** Operator inattention or distraction while using equipment<br>**(2)** Bypassing or removing machine guards | **(1)** Severe cuts, abrasions, or lacerations<br>**(2)** Risk of partial or complete dismemberment of fingers | 3D | **P:** Wear safety glasses, train personnel, and never bypass guards.<br>**D:** Ensure guards are in place before use.<br>**M:** Use emergency stops; keep first aid nearby. | 2A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.12 | Ejected Debris or Chips | **(1)** Improper feed techniques during cutting, drilling, or grinding operations<br>**(2)** Inadequate use of machine guards or personal protective equipment | **(1)** Lacerations, or punctures<br>**(2)** Facial injuries | 3C | **P:** Feed material slowly; use guards and safety glasses.<br>**D:** Inspect material to ensure smooth cutting operation.<br>**M:** Use emergency stops; keep first aid nearby. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.13 | Dust Inhalation from Sanding or Sawing | **(1)** Inadequate ventilation in work area<br>**(2)** Failure to use appropriate respiratory protection | Respiratory irritation, coughing, or shortness of breath | 2C | **P:** Use respiratory protection and ensure adequate ventilation.<br>**D:** Inspect workspace for dust accumulation; clean as needed.<br>**M:** Move to fresh air after exposure. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.14 | Electrical Shock While Using Power Tools | **(1)** Damaged or frayed power cords connected to tools<br>**(2)** Exposure to live electrical components due to improper handling | **(1)** Electrical shock or burns to personnel<br>**(2)** Arc flash or flash burns from sudden electrical discharge<br>**(3)** risk of fire | 3A | **P:** Inspect power cords before use.<br>**D:** Stop operation immediately if broken wires are observed.<br>**M:** Disconnect power; use insulated tools. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |

Table 6.9: Personnel Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre | Mitigation Factors | LS Post | Results |
|---|---|---|---|---|---|---|---|
| PHZ.15 | Noise Exposure While Using Power Tools | **(1)** Prolonged operation of high-noise tools without appropriate hearing protection<br>**(2)** Lack of awareness or enforcement of occupational noise safety standards | **(1)** Temporary or permanent hearing loss<br>**(2)** Tinnitus (ringing or buzzing in the ears) | 2C | **P:** Use earplugs during prolonged tool operation.<br>**D:** Inspect equipment if it sounds unusually loud or damaged.<br>**M:** Take breaks during extended use of loud tools. | 2A | Proper PPE usage described in HPRC Safety Handbook [11]. |
| PHZ.16 | Loss of Control of Handheld Power Tools | **(1)** Improper grip or handling technique during operation<br>**(2)** Tool kickback due to binding, improper feed rate, or incorrect use | **(1)** Injuries to hands, wrists, or arms, including lacerations or fractures<br>**(2)** Facial injuries from sudden tool movement or flying debris | 3D | **P:** Train users on grip and handling techniques; wear PPE as appropriate.<br>**D:** Stop use if abnormal vibration occurs and inspect tool for damage.<br>**M:** Keep first aid kit nearby. | 1B | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.17 | Contact with Heat Gun Nozzle or Hot Air | **(1)** Improper handling or use of the heat gun<br>**(2)** Operator inattention or distraction near the heated nozzle or airflow | **(1)** Thermal burns to skin or underlying tissue<br>**(2)** Ignition of flammable materials in the surrounding area | 2D | **P:** Train on proper handling; clear area of flammable materials.<br>**D:** Monitor heat gun temperature.<br>**M:** Provide burn aid supplies. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.18 | Tripping Over Loose Cords | **(1)** Electrical or extension cords placed across walkways or in crowded workspaces<br>**(2)** Inadequate cable management or failure to secure cords | **(1)** Trips and falls resulting in bruises, sprains, or fractures<br>**(2)** Potential secondary injuries from falling onto equipment or tools | 2D | **P:** Route cables overhead rather than across walkways.<br>**D:** Inspect work area for cables before starting work.<br>**M:** Reroute or secure cords as needed. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.19 | High-Speed Dremel Bit Contact with Skin | **(1)** Operator inattention or distraction during use<br>**(2)** Loss of grip or improper handling technique<br>**(3)** Inadequate personal protective equipment | Cuts, punctures, or lacerations to the skin | 3D | **P:** Train proper tool handling and bit selection.<br>**D:** Monitor RPM during use.<br>**M:** Stop tool immediately and apply first aid. | 2B | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.20 | Fragmentation of Dremel Bits | **(1)** Exceeding the recommended rotational speed (RPM)<br>**(2)** Applying excessive force or pressure during operation<br>**(3)** Using bits outside of their intended material or application | **(1)** Cuts or lacerations from flying fragments<br>**(2)** Eye injuries from high-velocity debris | 3D | **P:** Train proper usage and speed limits. Always wear safety glasses during operation.<br>**D:**inspect bit for damage before use<br>**M:** Check that a Dremel bit isn’t cracked before use. | 2A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.21 | Contact with Soldering Iron Tip | **(1)** Accidental contact with the hot tip during use<br>**(2)** Improper placement or storage of the soldering iron while hot<br>**(3)** Inattention or distraction during soldering operations | Burns | 3D | **P:** Use proper stands; keep workspace uncluttered.<br>**D:** Monitor soldering tip temperature.<br>**M:** Keep burn relief supplies nearby. | 2A | Proper Electronics usage described in HPRC Safety Handbook [11]. |
| PHZ.22 | Electrical Shock or Arc Flash from Lab Power Supplies | **(1)** Improper wiring or exposed electrical connections<br>**(2)** Incorrect use of power supplies or failure to follow safe operating procedures | **(1)** Electrical shock or burns to personnel<br>**(2)** Arc flash causing thermal injuries or damage to nearby equipment<br>**(3)** Increased risk of fire from electrical faults | 3C | **P:** Follow correct wiring procedures; use insulated equipment.<br>**D:** Inspect voltage and current values during operation.<br>**M:** Keep burn first aid available. | 2B | Proper Electronics usage described in HPRC Safety Handbook [11]. |

Table 6.9: Personnel Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre | Mitigation Factors | LS Post | Results |
|---|---|---|---|---|---|---|---|
| PHZ.23 | Overcharging LiPo Batteries | **(1)** Incorrect charger settings or use of an incompatible charger<br>**(2)** Negligence or inattention during the charging process | **(1)** Battery venting or thermal runaway<br>**(2)** Fire or explosion risk | 3D | **P:** Follow manufacturer's instructions and charger compatibility.<br>**D:** Monitor charge progress; listen for completion indicators.<br>**M:** Place failed batteries in sand bucket for containment. | 1B | Proper Electronics usage described in HPRC Safety Handbook [11]. |
| PHZ.24 | Punctured or Damaged LiPo Batteries | **(1)** Improper handling, storage, or transportation of batteries<br>**(2)** Incorrect charging procedures or use of damaged cells | **(1)** Fire or thermal runaway<br>**(2)** Explosion risk from rapid gas release or combustion<br>**(3)** Severe burns or other injuries to personnel | 3D | **P:** Protect batteries from sharp objects during handling and storage.<br>**D:** Inspect all batteries for damage before use.<br>**M:** Treat burns; bury compromised batteries in sand bucket. | 1A | Proper Electronics usage described in HPRC Safety Handbook [11]. |
| PHZ.25 | Burns from 3D Printer | **(1)** Accidental contact with heated components such as the nozzle, or heated bed<br>**(2)** Inattention or improper handling during printer operation or maintenance | Minor burns to skin | 2D | **P:** Keep hands away from heated components; provide user training.<br>**D:** Monitor nozzle and bed temperature.<br>**M:** Apply burn first aid. | 1A | Proper Electronics usage described in HPRC Safety Handbook [11]. |
| PHZ.26 | Dust Exposure from Sanding or Cutting Composite Components | **(1)** Dry sanding or cutting without proper dust extraction<br>**(2)** Failure to use appropriate personal protective equipment (PPE), such as respirators, gloves, or safety goggles | **(1)** Respiratory irritation or long-term respiratory issues from inhalation of fine particles<br>**(2)** Skin irritation due to contact with composite dust<br>**(3)** Eye injuries from airborne particles | 3D | **P:** Use proper PPE including respirators, safety glasses, and gloves.<br>**D:** Inspect and clean work area for composite dust accumulation.<br>**M:** Wash exposed skin with cold water and move to fresh air. | 2A | Proper composite handling described in HPRC Safety Handbook [11]. |
| PHZ.27 | Exposure to Flammable Mold Release Agents | **(1)** Handling without appropriate gloves or protective clothing<br>**(2)** Inhalation of dust or particles from solid material<br>**(3)** Improper storage near heat or ignition sources | **(1)** Eye, skin, nose, or throat irritation<br>**(2)** Fire or explosion hazard due to flammable vapors<br>**(3)** Ingestion may be fatal if swallowed and enters airways<br>(4) Potential long-term health effects from repeated exposure, including carcinogenic risk | 3D | **P:** Use gloves and respirators; store securely away from ignition sources.<br>**D:** Monitor storage conditions.<br>**M:** Wash exposed skin with cold water and move to fresh air. | 2A | Proper mold release procedure is described in HPRC Safety Handbook [11]. SDS sheets for mold release agents located in Reference [13]. |
| PHZ.28 | Transportation/storage of Heavy Objects | **(1)** Improper lifting technique or manual handling<br>**(2)** Unsecured storage or placement of heavy objects | **(1)** Crush injuries or fractures to hands, feet, or other body parts<br>**(2)** Risk of damage to equipment or work surfaces | 3C | **P:** Use proper lifting techniques; avoid overexertion.<br>**D:** Leads verify lifting safety; avoid lifting objects beyond comfort level.<br>**M:** Provide first aid for crush injuries. | 2A | HPRC Safety Handbook [11] |
| PHZ.29 | Unintentional Igniter or Ematch Activation | **(1)** Static electricity discharge or stray electrical currents<br>**(2)** Mishandling of igniters or e-matches during preparation or transport | **(1)** Burns<br>**(2)** Fire or ignition of surrounding materials | 2B | **P:** Use anti-static bags, safety glasses, and grounding procedures.<br>**D:** Inspect igniters and wiring for damage.<br>**M:** Keep fire extinguisher and burn first aid supplies nearby. | 1A | Black powder charge packing described in Section 6.1. Proper handling is described in HPRC Safety Handbook [11]. |

Table 6.9: Personnel Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre | Mitigation Factors | LS Post | Results |
|---|---|---|---|---|---|---|---|
| PHZ.30 | Skin Pierced by Sharp Object | **(1)** Improper training or lack of familiarity with equipment<br>**(2)** Failure to use appropriate personal protective equipment | **(1)** Cuts, punctures, or lacerations to the skin<br>**(2)** Bleeding or potential for secondary infection if wounds are not treated | 2C | **P:** Provide training on equipment use; utilize guards and PPE.<br>**D:** Inspect components for sharp edges before handling.<br>**M:** Treat wounds with first aid and antibiotic ointment. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.31 | Injuries from Improper Hammer or Mallet Use | **(1)** Improper swinging technique or loss of control during use<br>**(2)** Striking incorrect surfaces or materials<br>**(3)** Slippage of the tool due to inadequate grip or worn handle | Fractures, bruising or blunt force injuries from impact | 3C | **P:** Train proper striking technique; strike surfaces head-on.<br>**D:** Inspect workpiece; ensure flat contact surfaces.<br>**M:** Keep first aid nearby. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.32 | Contact with File During Operation | **(1)** Slipping or loss of control while using the file<br>**(2)** Improper technique or incorrect application of force | Bruising, abrasions, or cuts to the skin | 2D | **P:** Use proper technique and secure workpiece.<br>**D:** Inspect material and re-secure as needed.<br>**M:** Apply first aid for cuts or abrasions. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.33 | Contact with Sharp Blades | **(1)** Improper cutting techniques or mishandling of blades<br>**(2)** Missing or bypassed safety guards<br>**(3)** Inattention or distraction during operation | **(1)** Cuts, lacerations, or puncture wounds to the skin<br>**(2)** Bleeding and potential secondary infection if wounds are not properly treated | 3D | **P:** Use proper cutting techniques; never bypass safety guards; keep hands clear.<br>**D:** Maintain awareness of blade position at all times.<br>**M:** Apply bandages and antibiotic ointment as needed. | 2A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.34 | Pinching of Appendages or Skin in Clamping | Careless or improper use of clamps or compression equipment | **(1)** Bruising, abrasions, or cuts to hands, fingers, or other body parts<br>**(2)** Potential secondary injuries from sudden release or movement of clamped objects<br>**(3)** Risk of crushed tissue or joint injury in severe cases | 2D | **P:** Require use of appropriate protective gloves.<br>**D:** Supervisor/mentor present during motor assembly.<br>**M:** Wash exposed skin with cold water. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.35 | Hot Glue Contact with Skin | **(1)** Accidental contact with the hot glue gun tip or molten adhesive<br>**(2)** Improper handling or inattention during application | Burns to skin | 2D | **P:** Keep hands clear of glue gun tip and molten adhesive.<br>**D:** Keep power disconnected when not in use.<br>**M:** Wash skin and apply burn first aid. | 1B | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.36 | Skin Contact with Sandpaper During Hand Sanding | **(1)** Improper handling or technique while sanding by hand<br>**(2)** Inattention or lack of control over sanding motion | Abrasions, scratches, or minor cuts to the skin | 2D | **P:** Secure material and use controlled motion.<br>**D:** Inspect sandpaper and replace when worn.<br>**M:** Wash exposed skin and apply bandages or ointment. | 1A | Proper tool usage described in HPRC Safety Handbook [11], |
| PHZ.37 | Exposure to High-Pressure Compressed Air | **(1)** Direct contact with compressed air hose or nozzle<br>**(2)** Improper use or handling of compressed air equipment<br>**(3)** Pointing nozzle toward the body or others during operation | **(1)** Eye injuries from debris propelled by compressed air<br>**(2)** Skin injuries, including bruising<br>**(3)** Hearing damage from high-pressure air discharge | 3D | **P:** Never direct nozzle at people; wear PPE including ear protection.<br>**D:** Monitor shutoff valves and ensure they function properly.<br>**M:** Apply first aid for injuries as needed. | 1B | Proper tool usage described in HPRC Safety Handbook [11], |
| Hazards Encountered on Launch Field | | | | | | | |

Table 6.9: Personnel Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre | Mitigation Factors | LS Post | Results |
|---|---|---|---|---|---|---|---|
| PHZ.38 | Contact with Black Powder (Unblown Charges) | **(1)** Failure to properly detonate black powder charges<br>**(2)** Improper handling without gloves or other protective equipment<br>**(3)** Inattention during recovery | skin irritation | 2D | **P:** Require use of gloves and safety glasses during recovery.<br>**D:** Inspect for unblown charges; check for charge leaks.<br>**M:** Wash exposed skin with cold water, neutralize black powder with water, and provide first aid for irritation. | 1A | Black powder contact described in Section 6.1 (See Appendix B). |
| PHZ.39 | Launch Vehicle Components Entering Ballistic Trajectory | **(1)** Failure of any launch vehicle stage or component to separate properly<br>**(2)** Parachute or recovery system failure<br>**(3)** Components becoming detached from the launch vehicle during flight | **(1)** Impact injuries, including fractures or blunt force trauma<br>**(2)** Potential fatality from high-velocity impacts | 4C | **P:** Instruct personnel on proper procedures during ballistic descent of any launch vehicle.<br>**D:** Listen to the launch coordinator and maintain visual contact with launched vehicles.<br>**M:** Maintain a safe distance from recovery areas and contact EMS if an impact occurs. | 4A | Emergency Procedures described in Section 6.1 (See Appendix B). |
| PHZ.40 | Airborne Shrapnel | **(1)** Motor overpressure or casing rupture<br>**(2)** Improper handling or assembly of motor components | **(1)** Eye injuries, cuts, or bruising from high-velocity fragments<br>**(2)** Potential fatality from severe impacts | 4D | **P:** Verify motor assembly per manufacturer’s recommendations; maintain safe distances from the launch pad.<br>**D:** Lead inspects motor assembly; follow launch coordinator instructions during launches.<br>**M:** Provide PPE for personnel near the launch pad; contact EMS if a serious injury occurs. | 4A | Emergency Procedures described in Section 6.1 (See Appendix B). |
| PHZ.41 | Smoke from Motors | **(1)** Ignition of propellant producing smoke or particulate matter<br>**(2)** Incomplete combustion of motor fuel<br>**(3)** Wind direction carrying smoke toward personal or work areas | **(1)** Respiratory irritation or difficulty breathing<br>**(2)** Eye irritation from smoke or airborne particles<br>**(3)** Reduced visibility | 2D | **P:** Launch from safe distances and monitor wind direction.<br>**D:** Observe smoke dispersion; monitor personnel for irritation.<br>**M:** Move personnel upwind, rinse eyes with clean water, and provide respiratory protection if needed. | 1A | Emergency Procedures described in Section 6.1 (See Appendix B). |
| PHZ.42 | Loud noises | **(1)** Rocket ignition, pyrotechnic events<br>**(2)** Lack of use of appropriate hearing protection | **(1)** Temporary or permanent hearing damage<br>**(2)** Tinnitus | 2D | **P:** Train members to remain alert during all launches, not just team launches.<br>**D:** Alert members when launches are occurring, especially if the launch coordinator is out of earshot.<br>**M:** Move affected personnel away from loud areas (e.g., into vehicles) and provide first aid as needed. | 1B | Emergency Procedures described in Section 6.1 (See Appendix B). Proper PPE is described in HPRC Safety Handbook [11]. |
| PHZ.43 | Motor Ignition During Assembly | **(1)** Accidental activation of the motor due to static electricity, stray currents, or mishandling<br>**(2)** Improper assembly procedures or failure to follow safety protocols<br>**(3)** Presence of ignition sources near the motor during assembly | **(1)** Burns or lacerations to personnel<br>**(2)** Fire or ignition of surrounding materials | 4C | **P:** Follow anti-static protocols; keep ignition sources away from the assembly area.<br>**D:** Lead supervises all motor assembly operations and checks for static or spark risks.<br>**M:** Keep fire extinguishing equipment nearby; administer burn first aid if needed. | 1A | Emergency Procedures described in Section 6.1 (See Appendix B). |

Table 6.9: Personnel Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre | Mitigation Factors | LS Post | Results |
|---|---|---|---|---|---|---|---|
| PHZ.44 | Falling from Elevated Positions (e.g., Ladders) | **(1)** Use of ladders or elevated platforms to arm devices or perform tasks<br>**(2)** Improper ladder setup, unstable footing, or overreaching | Bruises, sprains, or fractures | 3D | **P:** Ensure proper ladder technique is followed and stable footing maintained.<br>**D:** Inspect ladder legs for security before use.<br>**M:** Provide first aid for bruises and minor injuries; seek medical attention if needed. | 1B | Emergency Procedures described in Section 6.1 (See Appendix B). |
| Hazards Encountered at STEM Engagement Event | | | | | | | |
| PHZ.45 | Launch Vehicle Falling | **(1)** Inadequate supporting or anchoring of the launch vehicle<br>**(2)** Horseplay or unsafe behavior around launch vehicles | Impact injuries to personnel from falling rockets | 2C | **P:** Use stable launch vehicle stands; prohibit horseplay; secure stands before presentations.<br>**D:** Inspect stands before use; do not use damaged or broken stands.<br>**M:** Catch any falling launch vehicles if possible; provide first aid for any injuries. | 2A | Outreach Safety procedures described in HPRC Safety Handbook [11]. |
| PHZ.46 | Unintended Ignition of Estes Motor | **(1)** Damaged or faulty motor<br>**(2)** Improper handling or accidental activation during preparation<br>**(3)** Presence of ignition sources near the motor | **(1)** Severe burns to personnel<br>**(2)** Fire or ignition of surrounding materials<br>**(3)** Eye and ear injuries | 3C | **P:** Follow manufacturer instructions; keep ignition sources away during assembly; inspect motors for potential defects.<br>**D:** Ensure children remain at a safe distance; perform visual and continuity checks before connecting ignitors.<br>**M:** Use fire extinguishers; report incidents to supervisors; provide burn first aid if needed. | 1A | Outreach Safety procedures described in HPRC Safety Handbook [11]. |
| PHZ.47 | Estes or Bottle Rocket Striking Personnel | **(1)** Incorrect launch angle or trajectory<br>**(2)** Improper stabilization of the rocket on the launch pad<br>**(3)** Launching too close to personnel or crowded areas | Impact injuries, including bruises, fractures, or blunt trauma | 3C | **P:** Maintain safe distances; provide stable launch equipment; enforce clear launch zones.<br>**D:** Confirm launch pad alignment away from personnel; provide proper countdowns to prepare personnel.<br>**M:** Provide medical aid for impact injuries; report incidents to supervisors. | 2B | Outreach Safety procedures described in HPRC Safety Handbook [11]. |
| PHZ.48 | Smoke from Estes Motors | **(1)** Ignition of motor propellant producing smoke or particulate matter<br>**(2)** Incomplete combustion of motor fuel<br>**(3)** Wind carrying smoke toward personal or work areas | **(1)** Respiratory irritation or difficulty breathing<br>**(2)** Eye irritation from smoke or airborne particles<br>**(3)** Reduced visibility | 2D | **P:** Position personnel upwind; maintain safe distances.<br>**D:** Observe smoke direction; monitor personnel for irritation.<br>**M:** Move personnel upwind; relocate to fresh air and allow lungs to recover. | 1A | Outreach Safety procedures described in HPRC Safety Handbook [11]. |
| PHZ.49 | Rocket (bottle, estes, straw) Becomes Stuck in Trees or Vegetation | **(1)** Wind direction or gusts carrying rocket toward trees or vegetation<br>**(2)** Launching too close to treelines or improperly aimed trajectory | **(1)** Damage to trees or vegetation<br>**(2)** Environmental pollution from rocket materials left in nature | 2B | **P:** Launch away from treelines and tall vegetation.<br>**D:** Track rocket trajectory carefully.<br>**M:** Carefully retrieve the rocket without damaging the environment; prevent children from attempting retrieval. | 1A | Outreach Safety procedures described in HPRC Safety Handbook [11]. |

Table 6.9: Personnel Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre | Mitigation Factors | LS Post | Results |
|---|---|---|---|---|---|---|---|
| Hazards to Project Schedule | | | | | | | |
| PHZ.50 | Vehicle Lead Becomes Unavailable | Unforeseen personal circumstances, illness, or scheduling conflicts | **(1)** Potential delays in vehicle structure, recovery system, or air brake system tasks<br>**(2)** Risk of cascading schedule impacts on payload integration or launch readiness<br>**(3)** Increased workload for remaining team members, potentially affecting quality or safety | 3C | **P:** Cross-train team members; prepare design and schedule plans early; maintain updated documentation of manufacturing or analysis methods.<br>**D:** Provide progress updates; keep leadership aware of individual workloads.<br>**M:** Redistribute responsibilities among trained members; adjust timelines; seek mentor support if needed. | 2B | Team lead responsibilities are described in Section 1.4 of Proposal [5]. |
| PHZ.51 | Payload Lead Becomes Unavailable | Unforeseen personal circumstances, illness, or scheduling conflicts | **(1)** Incomplete or delayed payload design and development<br>**(2)** Potential schedule impacts on vehicle integration and testing<br>**(3)** Increased risk of errors or oversights due to redistributed workload among remaining team members | 3C | **P:** Cross-train team members; prepare design and schedule plans early; maintain updated documentation of manufacturing or analysis methods.<br>**D:** Provide progress updates; keep leadership aware of individual workloads.<br>**M:** Redistribute responsibilities among trained members; adjust timelines; seek mentor support if needed. | 2B | Team lead responsibilities are described in Section 1.4 of Proposal [5]. |
| PHZ.52 | Team Lead or Integration Personnel Becomes Unavailable | Unforeseen personal circumstances, illness, or scheduling conflicts | **(1)** Reduced communication and coordination across subsystems<br>**(2)** Poor overall project coordination, potentially causing schedule delays or design conflicts<br>**(3)** Increased risk of errors or misalignment between vehicle, payload, and recovery systems | 3C | **P:** Develop leadership plans; cross-train other leads on integration practices; maintain clear communication.<br>**D:** Track leadership responsiveness and schedules; document responsibilities.<br>**M:** Appoint interim leadership personnel; re-evaluate timelines and responsibilities. | 2B | Team lead responsibilities are described in Section 1.4 of Proposal [5]. |
| PHZ.53 | Key Officer (Safety, Treasurer, Outreach) Becomes Unavailable | Unforeseen personal circumstances, illness, or scheduling conflicts | **(1)** Decrease in project funding management, oversight, or allocation<br>**(2)** Potential lapses in safety protocols or risk management<br>**(3)** Reduced effectiveness of community outreach and engagement activities | 3C | **P:** Train deputies; document safety, financial procedures, and outreach templates.<br>**D:** Keep updates on officer progress; monitor workloads.<br>**M:** Redistribute work; elect new officers if needed; adjust timelines. | 2B | See Club Constitution [14]. |
| PHZ.54 | Insufficient Team Member Overlap (No Redundancy) | **(1)** Lack of cross-training among team members for critical systems<br>**(2)** Dependence on single individuals for specific tasks | **(1)** Important tasks delayed if a team member is unavailable<br>**(2)** Potential loss of quality or errors in project deliverables<br>**(3)** Increased workload and stress on remaining team members, possibly affecting safety and performance | 4C | **P:** Cross-train members across subsystems; maintain proper documentation; create a shared knowledge culture.<br>**D:** Identify single points of failure.<br>**M:** Redistribute work; adjust deadlines if needed. | 2B | N/A |

Table 6.9: Personnel Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre | Mitigation Factors | LS Post | Results |
|---|---|---|---|---|---|---|---|
| PHZ.55 | Member Fatigue or Burnout | **(1)** Large workload without sufficient breaks or rest periods<br>**(2)** Lack of recognition or support for team contributions<br>**(3)** Extended periods of high stress or repetitive tasks | **(1)** Reduced quality or accuracy of project work<br>**(2)** Loss of key team members due to disengagement or withdrawal | 3C | **P:** Enforce reasonable workloads; allow rest periods; recognize contributions; share heavy responsibilities.<br>**D:** Observe performance declines or absenteeism; provide space for honest feedback.<br>**M:** Encourage rest; provide morale support; adjust workloads. | 1A | Refer members to NC State mental health resources Appendix [10]. |
| PHZ.56 | Elevated Stress or Anxiety | **(1)** High schedule pressure or tight deadlines<br>**(2)** Unclear expectations or poorly defined responsibilities<br>**(3)** Lack of support or communication within the team | **(1)** Reduced quality or accuracy of project work<br>**(2)** Decision-making errors or poor judgment | 3D | **P:** Set clear expectations; ensure workloads are balanced; establish achievable milestones.<br>**D:** Observe signs of stress or reduced performance.<br>**M:** Provide a supportive environment; offer breaks; redistribute tasks; recognize efforts. | 1B | Refer members to NC State mental health resources Appendix [10]. |
| PHZ.57 | Team Conflict or Poor Interpersonal Dynamics | **(1)** Miscommunication or unclear expectations among team members<br>**(2)** Lack of conflict resolution or mediation mechanisms<br>**(3)** Differences in work styles or priorities without structured collaboration | **(1)** Lower productivity and efficiency<br>**(2)** Reluctance to collaborate, share information, or assist peers | 3B | **P:** Set behavior expectations; establish outlets for conflict resolution.<br>**D:** Track interpersonal issues that could escalate.<br>**M:** Facilitate mediation; remain neutral; treat all sides with respect; refocus on shared goals. | 1A | Refer members to NC State mental health resources Appendix [10]. |
| PHZ.58 | Emotional Exhaustion Following Failure | **(1)** Setbacks or project failures without structured debriefing or reflection<br>**(2)** Lack of emotional support | **(1)** Drop in team morale and motivation<br>**(2)** Emergence of blame culture or interpersonal tension | 3B | **P:** Establish post-launch debriefing.<br>**D:** Monitor morale after setbacks; observe engagement.<br>**M:** Provide morale support; reassure team members of priorities. | 2A | Refer members to NC State mental health resources Appendix [10]. |
| PHZ.59 | Mental Health Degradation | **(1)** Unawareness of available mental health resources<br>**(2)** Stigma or reluctance to seek support<br>**(3)** Lack of proactive outreach | **(1)** Increased stress, anxiety, or emotional fatigue<br>**(2)** Decline in performance, productivity, or quality of work | 4B | **P:** Promote awareness of campus mental health resources; encourage work-life balance.<br>**D:** Observe signs of stress, fatigue, or withdrawal.<br>**M:** Offer check-ins; guide those seeking help to resources; adjust expectations. | 2A | Refer members to NC State mental health resources Appendix [10]. |
| PHZ.60 | Leadership Insensitivity to Team Members' Wellbeing | **(1)** Emphasis on deliverables over personnel needs<br>**(2)** Dismissive or unresponsive attitudes toward team concerns | **(1)** Loss of trust and respect for leadership<br>**(2)** Decreased team cohesion and stability | 3A | **P:** Create an open dialogue; emphasize people over deadlines.<br>**D:** Monitor for dismissive attitudes from leaders; listen to observations from team members.<br>**M:** Coach insensitive leaders; recognize team member contributions. | 1A | Refer members to NC State mental health resources Appendix [10]. |

## 6.4 Design Hazards Analysis

Table 6.10: Design Hazards

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| Launch Vehicle Hazards | | | | | | | |
| Propulsion System Hazards | | | | | | | |
| DHZ.1 | Overpressure Explosion | **(1)** Incorrect assembly of RMS hardware<br>**(2)** Missing or improperly installed forward seal disc<br>**(3)** Failure to follow proper assembly or inspection procedures | **(1)** Catastrophic motor failure<br>**(2)** Severe damage to the vehicle structure | 4D | **P:** Follow manufacturer instructions for motor assembly.<br>**D:** Ensure mentor and qualified member are present during assembly; inspect and confirm O-rings, seal discs, and all closures are properly installed.<br>**M:** Maintain fire suppression methods; maintain safe distances until RSO gives approval to approach the launch vehicle. | 4A | Section 6.1 includes motor assembly instructions (See Section 5). Emergency Procedures described in Section 6.1 (See Appendix B). |
| DHZ.2 | Igniter Failure | **(1)** Damaged, defective, or incorrect type of initiator<br>**(2)** Improper handling or storage of igniters | Failure of the motor or rocket to launch as intended | 3D | **P:** Properly store igniters; handle with clean hands.<br>**D:** Check for continuity before arming; inspect for visible physical defects.<br>**M:** Replace igniter and use backups until ignition success is achieved. | 1A | See 6.1 (Section 10) for proper ignitor installation. |
| DHZ.3 | Propellant Contamination | Improper storage or handling (exposure to moisture, oils, or foreign particulates) | **(1)** Unpredictable burn behavior<br>**(2)** Reduced motor performance and reliability<br>**(3)** Increased risk of motor overpressure, casing rupture, or catastrophic failure | 4A | **P:** Store propellant in manufacturer container until use; inspect all O-rings for wear or deformation.<br>**D:** Verify propellant looks unaltered; no discoloration or noticeable wear.<br>**M:** Safely dispose of contaminated grains; use backup motors as needed. | 1A | Safety Handbook [11] describes APCP handling and storage. SDS Sheets for APCP Motors is located in Reference [13]. |
| DHZ.4 | Unintended Ignition | Presence of heat sources, open flames, or electrical discharge in proximity to motor assembly | **(1)** Severe thermal burns to personnel<br>**(2)** Potential ignition of surrounding materials leading to fire<br>**(3)** Risk of ear and eye injury | 4D | **P:** Assemble motors away from ignition sources.<br>**D:** Inspect work area and confirm no ignition sources are nearby.<br>**M:** Evacuate area; fight fire using water instead of CO2. | 4A | Section 6.1 includes motor assembly instructions (See Section 5). Emergency Procedures described in Section 6.1 (See Appendix B). |
| DHZ.5 | Motor Retention Failure | **(1)** Motor retention system breaks due to material fatigue or damage<br>**(2)** Improper installation or attachment of the retention system | **(1)** Motor falls out of the launch vehicle after burnout<br>**(2)** Potential impact injuries to personnel or property from falling motor | 4B | **P:** Verify motor retention system during launch checklists.<br>**D:** Visually inspect retention hardware; replace damaged components; inspect after launch.<br>**M:** Maintain safe distances; monitor location of motor; retrieve after RSO deems safe. | 2A | Motor retention is described in Section 3.2.8. Motor retention assembly is described in Section 6.1. |
| Structural Hazards | | | | | | | |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.6 | Composite Components Fail Under Loading | **(1)** Miscalculated composite layup or structural design errors<br>**(2)** Use of defective or improperly cured composite materials<br>**(3)** Inadequate quality control during fabrication or assembly | **(1)** Launch vehicle structural damage or partial failure<br>**(2)** Reduced reusability of vehicle components | 4C | **P:** Perform multiple calculations to verify correct expected loading.<br>**D:** Conduct mechanical testing on test pieces to verify material can withstand expected loading.<br>**M:** Reinforce or replace failed components; recalculate and review fabrication process for improvements. | 2A | Section 3.2.9 describes analysis for composite components. Material testing is described in Section 7.2.7 and 7.2.10. |
| DHZ.7 | Fin Flutter | **(1)** Aerodynamic forces interacting with structural vibrations of fins<br>**(2)** Insufficient stiffness or improper fin attachment | **(1)** Fin failure or detachment during flight<br>**(2)** Loss of vehicle stability and control | 4B | **P:** Design fins to withstand flutter; use stiff materials expected to handle loading.<br>**D:** Inspect fin bonds to ensure structural integrity.<br>**M:** Recover debris, recalculate flutter analysis assumptions, and redesign as needed. | 1A | Section 3.2.9 describes analysis for composite components. Material testing is described in Section 7.2.7 and 7.2.10. |
| DHZ.8 | Fin Fracture | Heavy landing impacts or rough recovery | **(1)** Launch vehicle becomes aerodynamically unstable<br>**(2)** Vehicle may be unable to fly or maintain controlled flight | 4C | **P:** Reinforce fin roots to airframe; limit descent rate using parachutes; use impact-resistant materials.<br>**D:** Inspect post-flight vehicle for fractures, cracks, or delamination.<br>**M:** Replace damaged fins and add reinforcement. | 1A | Section 3.2.9 describes analysis for composite components. Fin Can drop testing is described in Section 7.2.8. |
| DHZ.9 | Fin Layup Delamination | **(1)** Insufficient or improper composite layups during fabrication<br>**(2)** Inadequate bonding or curing of layers<br>**(3)** Lack of inspection or quality control during assembly | Poor local stiffness of fins, leading to structural weakness | 4C | **P:** Follow layup procedures; ensure full wetting of fibers; use vacuum bagging.<br>**D:** Inspect for visible delaminations; remanufacture if found.<br>**M:** Repair negligible delaminations; replace fins if needed. | 2A | Section 3.2.9 describes analysis for composite components. Reference [3] describes composite Manufacturing standards. |
| DHZ.10 | Composite Fiber Misalignment | Insufficient or incorrect layup placement during composite fabrication | **(1)** Reduced load-carrying capacity of composite components<br>**(2)** Unexpected bending, shear failure, or structural deformation under load | 3C | **P:** Follow fiber orientation procedures; verify alignment with multiple members.<br>**D:** Inspect each layer before laminating to ensure correct fiber orientation.<br>**M:** Repurpose misaligned parts. | 1A | Section 3.2.9 describes analysis for composite components. Reference [3] describes composite Manufacturing standards. |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.11 | Bulkhead Cracking | **(1)** Excessive stress concentration during parachute deployment<br>**(2)** Use of insufficiently reinforced or damaged bulkhead materials | **(1)** Parachutes may disconnect from the launch vehicle<br>**(2)** Portions of the vehicle may enter uncontrolled ballistic trajectories | 4C | **P:** Analyze loads expected from parachute deployment and motor thrust; use stiff bulkhead materials.<br>**D:** Monitor bulkheads before and after launch; note any deformities.<br>**M:** Replace damaged bulkheads; refine fabrication and reinforce attachment points. | 2A | Section 3.2.9 describes analysis for composite components. Section 7.2.6 describes tensile testing for bulkheads. Reference [3] describes composite Manufacturing standards. |
| DHZ.12 | Bulkheads Burn | **(1)** Incorrect black powder packing or overloading<br>**(2)** Improper assembly or failure to follow safe procedures | **(1)** Damage to bulkheads, compromising structural integrity<br>**(2)** Broken seals potentially damaging avionics or internal components | 4B | **P:** Do not overuse black powder for separation; insulate bulkheads; use flame-resistant materials.<br>**D:** Visual inspection after launch and ejection testing to verify burn marks.<br>**M:** Replace damaged bulkheads. | 2A | Ejection testing is described in Section 7.2.5. |
| DHZ.13 | Improper Bulkhead Stepping | Incorrect layup technique or measurement errors during fabrication | **(1)** Bulkheads too large, undersized, or misaligned within the airframe<br>**(2)** Difficulty during assembly or poor fitment between sections | 3C | **P:** Verify bulkhead dimensions; use precise measuring tools and templates.<br>**D:** Dry fit before bonding.<br>**M:** Sand or trim oversize bulkheads; re-fabricate undersized ones; re-purpose old bulkheads. | 2A | Dry Run located in 7.5. Ejection testing is described in Section 7.2.5. |
| DHZ.14 | Bulkhead Not Properly Sealed | **(1)** Unsecured or improperly installed Waygo terminals, U-bolts, or pass-through fittings<br>**(2)** Inadequate sealing materials | **(1)** Black powder gases or residue entering the avionics bay during ejection events<br>**(2)** Potential damage or contamination of altimeters and sensitive electronics<br>**(3)** Loss of flight data or deployment control reliability<br>**(4)** Reduced reusability of avionics and risk of mission failure | 4B | **P:** Apply sealant as needed; test during ejection.<br>**D:** Inspect for soot or residue post-flight and post-ejection testing.<br>**M:** Clean avionics bay; replace damaged electronics; reseal bulkhead and retest ejection. | 2B | Dry Run located in 7.5. Ejection testing is described in Section 7.2.5. |
| DHZ.15 | Airframe Delamination | **(1)** Insufficient resin wetting or uneven resin distribution during layup<br>**(2)** Poor compaction | **(1)** Localized loss of stiffness and structural integrity<br>**(2)** Increased susceptibility to cracking or buckling under aerodynamic or landing loads | 4C | **P:** Maintain tight rolling and proper wetting techniques.<br>**D:** Inspect for visible delaminations.<br>**M:** Replace sections as needed. | 2A | Section 3.2.9 describes analysis for composite components. Reference [3] describes composite Manufacturing standards. |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.16 | Resin-Rich or Resin-Poor Regions in Composites | **(1)** Incorrect resin-to-fiber ratio during layup or infusion<br>**(2)** Inconsistent resin distribution caused by poor mixing, application, or vacuum bagging technique | **(1)** Formation of weak spots prone to cracking or delamination under load<br>**(2)** Reduced structural performance and uneven stress distribution | 4C | **P:** Weigh resin and fiber prior to layups; verify proper fiber-to-resin ratio.<br>**D:** Inspect for over- or under-saturated regions.<br>**M:** Repair negligible defects; remake composites if necessary. | 1A | Section 3.2.9 describes analysis for composite components. Reference [3] describes composite Manufacturing standards. |
| DHZ.17 | Incomplete Curing of Composite Materials | **(1)** Incorrect curing temperature or insufficient curing duration<br>**(2)** Improper epoxy-to-hardener ratio during mixing | **(1)** Compromised structural integrity and reduced mechanical strength<br>**(2)** Increased risk of delamination, soft spots, or deformations | 4C | **P:** Follow manufacturer instructions for ratios and curing temperatures.<br>**D:** Inspect composites for tackiness or soft spots.<br>**M:** Re-fabricate incompletely cured components. | 1A | Section 3.2.9 describes analysis for composite components. Reference [3] describes composite Manufacturing standards. |
| DHZ.18 | Airframe Zippering | Excessive snatch force from rapid parachute deployment or taut shock cords | **(1)** Longitudinal splitting of the airframe at separation points<br>**(2)** Structural damage preventing vehicle reusability | 4C | **P:** Verify shock cord selection follows RD 6 guidelines.<br>**D:** Inspect airframe post-flight for tearing.<br>**M:** Re-fabricate damaged sections; recalculate for proper loading. | 2A | Section 3.2.9 describes analysis for composite components. Reference [3] describes composite Manufacturing standards. |
| Air Brakes System Hazards | | | | | | | |
| DHZ.19 | Asymmetric Air Brakes Deployment | Improper air brakes assembly or actuator misalignment | **(1)** Induced asymmetric aerodynamic moments causing vehicle instability<br>**(2)** Unpredictable flight trajectory and potential deviation from safe flight path | 4A | **P:** Verify that air brakes deploy mechanically and simultaneously on all sides.<br>**D:** Inspect assembly for asymmetries prior to flight.<br>**M:** Reassemble the fin system; sand components for proper fit or reprint fins if necessary. | 1A | Air Brakes deployment testing described in Section 7.3.5. Section 6.1 describes Air Brakes assembly. |
| DHZ.20 | Air Brakes Fail to Deploy or Retract | **(1)** Improperly sized fin slots<br>**(2)** Excessive friction in air brakes gears | Launch vehicle fails to reach intended target apogee | 4C | **P:** Ensure slot tolerances meet design specifications; verify fins move freely with minimal friction.<br>**D:** Perform bench tests with the airframe to confirm deployment and retraction.<br>**M:** File or adjust fin slots until air brake fins deploy and retract smoothly. | 1B | Air Brakes deployment testing described in Section 7.3.5. Section 6.1 describes Air Brakes assembly. |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.21 | Air Brakes Prediction Algorithm Incorrect | Software errors or logic flaws in apogee prediction algorithm | **(1)** Air brakes deploy at the wrong time, too early or too late<br>**(2)** Launch vehicle fails to reach intended target apogee | 4B | **P:** Validate apogee prediction algorithm through simulations and test flights.<br>**D:** Log and review flight data from test launches to verify algorithm accuracy.<br>**M:** Reevaluate and correct algorithm errors as identified. | 4A | Air Brakes effectiveness testing is described in Section 7.3.6. Additional test flight is scheduled in Section 7.5. |
| DHZ.22 | Inaccurate Barometric Pressure Sensor Data | Air brakes flight computer not properly sealed | **(1)** Air brakes fins may retract prematurely or fail to deploy correctly<br>**(2)** Launch vehicle fails to reach intended target apogee | 4B | **P:** Ensure the flight computer is properly sealed to prevent pressure data corruption.<br>**D:** Test sealing integrity using vacuum or pressure testing.<br>**M:** Analyze flight data; redesign sealing methods if pressure inconsistencies are detected. | 2A | Air Brakes effectiveness testing is described in Section 7.3.6. Additional test flight is scheduled in Section 7.5. |
| Aerodynamics/Stability Hazards | | | | | | | |
| DHZ.23 | Launch Vehicle Over-Stability | Inaccurate mass distribution or miscalculated center of gravity during simulation | **(1)** Weathercocking during ascent<br>**(2)** Increased drift distance from intended landing zone | 2B | **P:** Maintain a documented mass list and update stability analyses as component masses change.<br>**D:** Monitor and record how the vehicle's mass properties evolve during integration.<br>**M:** Add ballast to the aft section of the launch vehicle until the stability margin is within the acceptable range. | 1A | Section 6.1 includes measuring Stability before launch. Tables 3.2.10, 5.2, and 4.7 describe current mass estimates. Ballast calculations are described in 3.6.4. |
| DHZ.24 | Launch Vehicle Under-Stability | Inaccurate mass distribution or miscalculated center of gravity during simulation | Oscillation, coning, or tumbling of the vehicle during ascent | 4B | **P:** Maintain a documented mass list and update stability analyses as component masses change.<br>**D:** Monitor and record how the vehicle's mass properties evolve during integration.<br>**M:** Add ballast to the forward section of the launch vehicle until the stability margin meets design requirements. | 2A | Section 6.1 includes measuring Stability before launch.Tables 3.2.10, 5.2, and 4.7 describe current mass estimates. Ballast calculations are described in 3.6.4. |
| DHZ.25 | Assembled Launch Vehicle Exceeds Anticipated Mass | Underestimation of payload or vehicle component mass during design | Launch vehicle fails to reach target apogee, falling below NASA-specified range | 3C | **P:** Maintain a detailed bill of materials with updated component masses throughout development.<br>**D:** Weigh every component within each subsystem to confirm accuracy against design models.<br>**M:** Reduce unnecessary weight where possible; if not feasible, redesign components to meet mass constraints. | 2B | Section 6.1 includes measuring Stability before launch.Tables 3.2.10, 5.2, and 4.7 describe current mass estimates. Ballast calculations are described in 3.6.4. |
| Recovery System Hazards | | | | | | | |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.26 | Parachute Fails to Deploy | **(1)** Improper packing technique<br>**(2)** Insufficient black powder charge to separate the launch vehicle | Launch vehicle enters ballistic descent | 4D | **P:** Train members on proper parachute packing; use dual altimeters for redundancy.<br>**D:** Check for continuity on deployment charges; lead inspects parachutes for correct packing.<br>**M:** Maintain visual tracking during descent; do not recover until cleared by the RSO. | 4A | Proper Packing is described in Reference [7]. Parachute packing is located in Section 6.1. |
| DHZ.27 | Main Parachute Deploys Early | **(1)** Altimeter failure or incorrect pressure readings<br>**(2)** Pressure buildup causing premature separation<br>**(3)** Improper avionics bay assembly | **(1)** Extended descent time<br>**(2)** Increasing drift distance | 3C | **P:** Ground test altimeters; ensure pressure ports are properly vented.<br>**D:** Verify arming sequence in altimeter programming.<br>**M:** Review flight data; retest or replace altimeters as needed. | 3A | Proper Packing is described in Reference [7]. Parachute packing is located in Section 6.1. |
| DHZ.28 | Main Parachute Deploys Late | Altimeter failure | **(1)** Launch vehicle descends with excessive kinetic energy<br>**(2)** Failure to meet NASA requirement 3.1.2 | 4C | **P:** Ground test altimeters; ensure pressure port holes are properly vented; confirm shear pins are correctly installed.<br>**D:** Verify arming sequence in altimeter programming.<br>**M:** Inspect and replace damaged altimeters; relaunch at backup opportunity. | 2A | Altimeter testing is described in Section 7.2.2. Altimeter programming is required by RS 5. Section 6.1 (Section 3) includes altimeter continuity checks. |
| DHZ.29 | Motor Ejection Deploys | Improper motor assembly | **(1)** Damage to air brakes system<br>**(2)** Premature separation of vehicle sections<br>**(3)** Failure to meet NASA requirement 3.1.3 | 4B | **P:** During motor assembly, ensure motor ejection charges are not installed.<br>**D:** Lead inspects motor assembly and verifies absence of ejection charges.<br>**M:** Internal bulkhead design prevents black powder intrusion into the air brakes module. | 1A | Section 6.1 includes motor assembly instructions (See Section 5). |
| DHZ.30 | Launch Vehicle Sections Collide During Ascent | Insufficient shock cord spacing | Damage to vehicle sections | 3B | **P:** calculate shock cord lengths with accordance to RD 6, verify proper routing and recovery attachments<br>**D:** Visually inspect assembled vehicle and confirm adequate separation distances between sections.<br>**M:** Inspect sections for damage post-flight; replace if necessary; recalculate shock cord lengths. | 1A | Shock cord calculations is described in Section 3.5.2. Shock cord must allow a minimum of 8 (ft) between sections by RD 6. |
| DHZ.31 | Insufficient Black Powder in Charge Wells | **(1)** Miscalculated black powder amounts<br>**(2)** Lack of ejection testing | **(1)** Vehicle sections fail to separate<br>**(2)** Launch vehicle enters ballistic descent | 4B | **P:** Calculate ejection charges with an appropriate factor of safety.<br>**D:** Conduct ground ejection tests to confirm full separation of all recovery components.<br>**M:** Fly redundant ejection charges with a factor of safety of at least 1.5. | 1A | Black Powder charges are calculated in Section 3.5.4. Ejection testing is described in Section 7.2.5. |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.32 | Black Powder Fails to Ignite | Overpressurization of charge well causing cap to separate before all black powder ignites | Launch vehicle enters ballistic descent | 4C | **P:** Secure tape firmly around charge wells to ensure full pressurization before ignition.<br>**D:** Test continuity of ematches; use reliable, high-tack tape rather than electrical tape.<br>**M:** Fly redundant ejection charges with a factor of safety of at least 1.5. | 1A | Black Powder charges are calculated in Section 3.5.4. Ejection testing is described in Section 7.2.5. |
| DHZ.33 | In-House Made Parachutes Fail to Deploy | Improper manufacturing technique | **(1)** Launch vehicle descends too quickly<br>**(2)** Excessive forces may cause main parachute failure | 4B | **P:** Follow validated stitching patterns and proven canopy designs.<br>**D:** Load test seems to confirm expected tensile strength.<br>**M:** Inspect any damaged parachutes and refabricate using improved methods. | 1B | Parachute testing is described in Section 7.2.4. Parachute manufacturing methods is described in Section 3.5.2. |
| DHZ.34 | Shroud Lines Break or Snap | Snatch force exceeds line strength | **(1)** Parachute failure<br>**(2)** Launch vehicle enters ballistic descent | 4B | **P:** Select line materials with verified tensile strength exceeding expected loads.<br>**D:** Static-load test parachutes; ensure even load distribution among lines.<br>**M:** Reinforce attachment points and redesign using stronger materials. | 1A | Parachute testing is described in Section 7.2.4. Parachute manufacturing methods is described in Section 3.5.2. |
| DHZ.35 | Parachute Deploys Inside-Out | Improper packing technique | **(1)** Launch vehicle descends faster than intended<br>**(2)** Failure to meet kinetic energy requirements | 4C | **P:** Follow standard packing procedures from a trusted vendor or documented method.<br>**D:** Conduct ground deployment tests prior to flight.<br>**M:** Review and retrain on proper packing procedures. | 3B | Proper Packing is described in Reference [7]. |
| Electrical/Avionics Hazards | | | | | | | |
| DHZ.36 | Altimeters Fail to Send Proper Current to Igniters | **(1)** Continuity loss in wiring<br>**(2)** Unexpected resistance in wiring | **(1)** Launch vehicle fails to separate<br>**(2)** Vehicle enters ballistic descent | 4A | **P:** Perform preflight continuity tests; use altimeters from trusted manufacturers.<br>**D:** Test altimeters in simulated flight environments.<br>**M:** Use dual altimeters to provide redundancy. | 2A | Altimeter testing is described in Section 7.2.2. Proper voltage for altimeter batteries is verified in Section 6.1 (Section 3). |
| DHZ.37 | Batteries Depleted at Launch | Improper charging procedure or failure to charge batteries | **(1)** Electronic systems fail, including altimeters and deployment circuits<br>**(2)** Launch vehicle enters ballistic descent<br>**(3)** Air brakes system fails to reduce apogee to target | 4C | **P:** Establish night-before charging checklists; replace batteries after manufacturer-recommended usage limits; pack backup batteries.<br>**D:** Measure battery voltage prior to launch vehicle integration.<br>**M:** Use dual altimeters to ensure system redundancy. | 1A | Proper voltage for altimeter batteries is verified in Section 6.1 (Section 3). |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.38 | Electromagnetic Interference | **(1)** Nearby transmitting devices<br>**(2)** Poor cable shielding or routing | false triggers, inaccurate telemetry, missing deployment commands. | 4B | **P:** Route signal and power cables separately; apply conductive shielding to deployment electronics.<br>**D:** Inspect avionics bay for proper shielding and cable routing prior to flight.<br>**M:** Use dual altimeters to ensure redundant deployment logic. | 1A | AV Bay design is described in 3.5.3. AV Bay assembly is described in Section 6.1 (Section 3). |
| DHZ.39 | Connector misalignment | improper seating or connector manufacturing | **(1)** False triggers or missed deployment commands<br>**(2)** Inaccurate telemetry or sensor readings | 3C | **P:** Train team members on proper connector assembly and handling.<br>**D:** Check continuity and resistance across connectors before integration.<br>**M:** Use dual altimeters for redundant deployment confirmation. | 2A | AV Bay design is described in 3.5.3. AV Bay assembly is described in Section 6.1 (Section 3). |
| Payload Hazards | | | | | | | |
| Structural Hazards | | | | | | | |
| DHZ.40 | Lander Loses Balance After Self-Righting | Uneven mass distribution | **(1)** Lander tips over<br>**(2)** Inability to collect soil samples | 3C | **P:** Conduct center-of-gravity analysis and balance testing during design.<br>**D:** Perform physical balance tests post-assembly; verify self-righting dynamics through ground tests.<br>**M:** Design leg geometry to self-stabilize under minor imbalance conditions. | 2B | Self-righting mechanisms are described in Section 4.3. Self-righting testing is described in Section 7.3.1. |
| DHZ.41 | Payload Body Fracture | **(1)** 3D-printed enclosure delaminates under load<br>**(2)** Poor print quality or insufficient infill | Loss of structural integrity | 4B | **P:** Use high-quality 3D printing processes and stiff filament materials.<br>**D:** Inspect prints for delamination, voids, or under-extrusion.<br>**M:** Replace damaged sections with reinforced or redesigned components. | 1A | Payload material is described in Section 4.2. |
| DHZ.42 | Leg or Leg Hinges Shearing | **(1)** Improper aluminum thickness or weak material choice<br>**(2)** Unanticipated loading at hinges during landing | **(1)** Loss of one or more legs<br>**(2)** Failure of the lander to upright after landing | 4C | **P:** Select hinge materials and thicknesses based on calculated landing loads.<br>**D:** Validate material performance via drop tests.<br>**M:** Replace damaged hinges; reinforce hinge joints as needed. | 3B | Payload material is described in Section 4.2. Payload testing is described in Section 7.3. |
| DHZ.43 | Collar Jams | **(1)** Debris intrusion in hinge or collar mechanism<br>**(2)** Lack of lubrication or poor tolerance control | Legs fail to deploy fully | 3B | **P:** Maintain clean hinge and collar assemblies; implement dust control during integration.<br>**D:** Manually cycle the mechanism before integration; verify smooth deployment during test runs.<br>**M:** Redesign mechanism with integrated dust guards. | 2A | Payload testing is described in Section 7.3. Payload assembly is described in 6.1. |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.44 | Auger bit breaks | **(1)** Torsional overloading during soil collection<br>**(2)** Use of insufficiently reinforced material or incorrect speed | **(1)** Incomplete soil collection<br>**(2)** Potential damage to the motor or drive system | 4B | **P:** Use torque-limited motors to prevent overload.<br>**D:** Perform pre-flight torque checks and inspect materials for cracks or wear.<br>**M:** Reinspect motor components; redesign or strengthen auger bit as required. | 2A | PD 5 prevents auger from over-torquing. Payload assembly is described in 6.1. |
| DHZ.45 | Latch Doesn't Open | Servo malfunction or electrical failure | **(1)** Lander trapped in the nose cone<br>**(2)** Inability to deploy legs or collect soil | 4B | **P:** Validate servo operation during integration.<br>**D:** Conduct deployment tests under simulated flight conditions.<br>**M:** Inspect failure points; re-fly at backup launch after correction. | 1A | Payload deployment testing is described in Section 7.3.3. |
| DHZ.46 | Lead Screw Binding | **(1)** Misalignment of components<br>**(2)** Insufficient lubrication of threads | Lander fails to eject | 4B | **P:** Ensure precise alignment during assembly; apply thread lubricant.<br>**D:** Cycle mechanism during ground tests to confirm smooth travel.<br>**M:** Inspect lead screw for binding; redesign or replace screw if necessary. | 2A | Payload deployment testing is described in Section 7.3.3. Payload assembly is described in 6.1. |
| DHZ.47 | Soil Enclosure Cracking | Hard impact with the ground during landing | Insufficient soil collected | 3C | **P:** Use high-quality 3D prints with stiff filament material.<br>**D:** Inspect prints for delamination, voids, or under-extrusion.<br>**M:** Replace broken enclosures with improved designs or stronger materials. | 1A | Payload material is described in Section 4.2. Payload testing is described in Section 7.3. |
| DHZ.48 | Guide Rails Become Disconnected | **(1)** Improper adhesion or mechanical fasteners failing<br>**(2)** Poor alignment during assembly | Lander does not eject smoothly | 4A | **P:** Ensure proper epoxy bonding via surface preparation.<br>**D:** Perform visual inspection pre-launch and vibration/pull testing.<br>**M:** Reinforce guide rail joints; redesign using mechanical fasteners. | 1A | Nosecone manufacturing is described in Section 3.3.3. Payload Deployment testing is described in Section 7.3.3. |
| DHZ.49 | 3D Prints Warping | Overheating during payload operations | **(1)** Warped structural elements<br>**(2)** Compromised alignment or mounting of payload components<br>**(3)** Reduced structural integrity and potential payload malfunction | 4B | **P:** Select heat-resistant filament rated for expected temperatures.<br>**D:** Inspect geometry post-fabrication.<br>**M:** Replace warped parts; redesign with thermal management or cooling considerations. | 1B | Payload material is described in Section 4.2. Payload testing is described in Section 7.3. |
| Electronics Hazards | | | | | | | |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.50 | Flight state misidentified | **(1)** Sensor miscalibration<br>**(2)** Incorrect threshold logic in software | **(1)** Premature deployment<br>**(2)** Incorrect sequencing of payload operations | 4B | **P:** Calibrate all sensors before integration; verify calibration against known reference conditions.<br>**D:** Log sensor inputs during ground testing and flight to validate threshold logic and state detection.<br>**M:** Review and correct flight-state logic following post-flight data analysis; revalidate through bench tests. | 2A | Payload software is described in Section 4.3. |
| DHZ.51 | Communication errors between sensor and Pi | Incompatible communication protocols between the Modbus and Raspberry Pi | Inability for the payload to collect or transmit soil data | 4B | **P:** Verify Modbus–Raspberry Pi compatibility during design phase; use standardized communication libraries.<br>**D:** Conduct communication handshake tests during integration to confirm reliable data transmission.<br>**M:** Buffer data locally for later retrieval. | 2A | Payload software is described in Section 4.3. Payload testing is described in Section 7.3. |
| DHZ.52 | Loss of power | **(1)** Loose connector<br>**(2)** Improper power distribution<br>**(3)** Faulty solder joints | Payload unable to collect data, drive motors, or perform drilling operation | 4B | **P:** Inspect all connections and solder joints; use proper wire gauge for components.<br>**D:** Use a multimeter to test battery output and verify continuity across all power lines before integration.<br>**M:** Re-inspect and repair any failed connections; prepare system for reflight once power reliability is verified. | 1A | Section 6.1 describes Payload assembly including continuity checks (Section 6). |
| Contamination Hazards | | | | | | | |
| DHZ.53 | Soot on Sensors | Improper sealing from ejection charges | **(1)** False measurements<br>**(2)** Electronic failures | 3C | **P:** Ensure payload electronics and sensors are properly sealed from ejection gases.<br>**D:** Inspect sensors after ejection charge testing for any soot or residue accumulation.<br>**M:** Clean sensors post-flight, inspect for damage, and replace compromised components; redesign sealing method if recurring contamination occurs. | 2A | Section 6.1 describes Payload assembly. |
| DHZ.54 | Soot on moving parts (gears, lead screw, rack and pinion, etc.) | Improper sealing from ejection charges | **(1)** Mechanical jamming<br>**(2)** Payload unable to drill, self-right, or deploy | 2C | **P:** Design mechanical assemblies with seals or enclosures to prevent soot intrusion into moving parts.<br>**D:** Inspect mechanisms post-flight and document areas showing soot or residue buildup.<br>**M:** Disassemble and clean contaminated components; apply lubricant or protective coating as necessary. | 1A | Section 3.2.3describes sealing from ejection charges. Section 6.1 describes Payload assembly. |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.55 | Soil sensor probes contaminated | Residual dust or dirt from prior testing | Soil sensor misreading, inaccurate data collection | 3B | **P:** Thoroughly clean soil probes between tests to remove all dust or debris.<br>**D:** Inspect probes during pre-flight checklist to ensure no residue or damage from prior use.<br>**M:** Wipe probes after each flight and store in protective containers to prevent future contamination. | 2A | Section 6.1 describes Payload assembly (Section 6). |
| Integration Hazards | | | | | | | |
| Payload Integration Hazards | | | | | | | |
| DHZ.56 | Payload Fails to Sit on Racks | **(1)** Improper payload dimensions<br>**(2)** Debris or foreign objects in rack tracks | Lander fails to eject smoothly | 3B | **P:** Verify payload dimensions and tolerances; apply lubricant to rack tracks if necessary.<br>**D:** Perform dry-fit tests of payload on racks; if misalignment is observed, redesign for proper fit.<br>**M:** Remove payload and clean tracks, ensuring all debris is cleared before reassembly. | 1A | Dry run is scheduled in 7.5. Payload deployment testing is described in Section 7.3.3. |
| DHZ.57 | Pusher Plate Deforms Under Loads | **(1)** Insufficient stiffness or inadequate material thickness<br>**(2)** Excessive ejection forces | Lander ejects improperly or at an angle | 3B | **P:** Fabricate pusher plate from sufficiently stiff material with appropriate thickness.<br>**D:** Measure plate deflection during ground testing to ensure deformation remains within tolerance.<br>**M:** Reinforce plate or redesign using a stiffer material if deformation exceeds limits. | 2A | Payload material is described in Section 4.2. Payload testing is described in Section 7.3. |
| DHZ.58 | Payload Shifting Center of Gravity | Unanticipated payload mass gain | Altered vehicle stability | 2D | **P:** Maintain a payload mass log, updating entries as fabrication progresses.<br>**D:** Re-measure the center of gravity during final assembly and integration.<br>**M:** Update simulations and add ballast to the aft end of the launch vehicle as necessary to rebalance stability. | 1A | Payload Mass estimates is described in Table 4.7. Ballast calculations are described in 3.6.4. |
| DHZ.59 | Parachute Re-Inflates Upon Landing | Wind gusts | **(1)** Payload dragged across the ground if still connected to nose cone<br>**(2)** Damage to payload housing or legs | 3D | **P:** Program the state machine to detect landing and deactivate systems that may allow parachute drag.<br>**D:** Conduct ground tests to verify state machine behavior under simulated drag conditions.<br>**M:** Inspect payload post-flight for drag-related damage and reinforce vulnerable components if needed. | 2A | Payload deployment testing is described in Section 7.3.3. Payload software is described in Section 4.3. |
| Recovery Integration Hazards | | | | | | | |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.60 | Parachute Does Not Fit Into Airframe/Fin Can | **(1)** Miscommunication of dimensions between Structures and Recovery subteams<br>**(2)** Failure to perform a full test fit prior to launch | **(1)** Launch vehicle cannot accommodate recovery system<br>**(2)** Flight must be canceled due to lack of recovery capability | 4A | **P:** Maintain clear communication between Structures and Recovery subteams regarding airframe dimensions and packed parachute sizes.<br>**D:** Confirm fit via dry fit testing of parachute in airframe.<br>**M:** Repack parachutes, ensuring they properly fit within the airframe before launch. | 1A | Dry run is scheduled in Section 7.5. Recovery assembly is described in Section 6.1 (Sections 7 and 8). |
| DHZ.61 | Ejection Gasses Escape the Airframe | Improper or incomplete seal around avionics bay sections | **(1)** Failure to separate airframe sections<br>**(2)** Launch vehicle descends ballistically | 4C | **P:** Ensure proper sealing during assembly and verify with ejection testing.<br>**D:** Perform ejection tests and inspect for gas leaks; apply appropriate sealant or lubricant as needed.<br>**M:** Fly redundant ejection charges with a factor of safety of 1.5 to ensure separation. | 1A | Proper sealing is described in Section 6.1 (Sections 7 and 8). |
| DHZ.62 | Main and Drogue Parachutes Installed in Wrong Sections | Miscommunication of forward/aft bay configuration | **(1)** Main parachute deploys at apogee<br>**(2)** Increased descent time and drift distance | 3A | **P:** Clearly label main and drogue parachutes and their respective airframe sections.<br>**D:** Perform dry runs to verify proper placement before flight.<br>**M:** Reassess and update checklist procedures to ensure parachutes are installed in the correct sections. | 1A | Dry run is scheduled in Section 7.5. Recovery assembly is described in Section 6.1 (Sections 7 and 8). |
| Structural Integration Hazards | | | | | | | |
| DHZ.63 | Arming Hole in Switchband Does Not Align with Pull Pin | **(1)** Incorrect bulkhead or avionics sled design that does not ensure proper fit or tolerance stack-up<br>**(2)** Inadequate assembly procedures or failure to verify alignment during installation | Failure to reliably prevent charges from becoming armed (unintended arming) or to arm when required | 4C | **P:** Use alignment jigs during fabrication, add alignment marks, properly sand parts for fit.<br>**D:** Visually confirm alignment and fitment during dry fit; perform dry fit before launch.<br>**M:** Disassemble launch vehicle if misaligned, realign bulkheads, fabricate new bulkheads or repurpose existing ones if necessary. | 1A | Airframe manufacturing is described in Section 3.3.1. AV Bay assembly is described in Section 6.1. |
| DHZ.64 | Incorrect Nosecone Dimensions After Composite Construction | **(1)** Improper layup technique or inaccurate mold geometry<br>**(2)** Excessive material buildup or uneven resin application | **(1)** Reduced internal payload volume or interference with payload fitment<br>**(2)** Potential misalignment with couplers or airframe sections | 4C | **P:** Verify mold geometry before composite layup.<br>**D:** Perform dri fit of nosecone with payload assembly.<br>**M:** Sand or trim components to meet tolerances; remake components if necessary with tighter control. | 2B | Nosecone manufacturing is described in Section 3.3.3. Nosecone assembly is described in Section 6.1. |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.65 | Recovery Attachments Break Off Bulkheads | **(1)** Miscommunication of expected snatch forces<br>**(2)** Improperly mounted attachment points | **(1)** Airframe sections completely separate<br>**(2)** Launch vehicle descends ballistically | 4B | **P:** Clearly communicate snatch force calculations between Recovery and Structures leads.<br>**D:** Conduct strength tests on bulkheads to verify they meet expected snatch forces.<br>**M:** Reinforce or replace damaged attachment points with stronger designs. | 2A | AV Bay tensile testing is described in Section 7.2.6. Snatch force calculations are described in Section 3.5.2. |
| DHZ.66 | Air Brake Fin Slots Incorrectly Placed | Miscommunication of placement dimensions between Structures and Aerodynamics subteams | **(1)** Air brakes unable to deploy<br>**(2)** Air brakes system deploys over fins | 4C | **P:** Maintain accurate CAD models of launch vehicle and air brakes to ensure correct integration.<br>**D:** Verify placement using jigs when cutting air brake fin slots.<br>**M:** File fin slots to fit if minor misalignment; remake fin can and recut slots if misalignment is significant. | 1A | Dry Run is described in Section 7.5. Air Brakes deployment testing is described in Section 7.3.5. |
| Air Brakes Integration Hazards | | | | | | | |
| DHZ.67 | Center of Pressure Shifts Toward Air Brakes | Deployment of air brake fins alters aerodynamic profile | Vehicle's stability margin changes during flight | 2D | **P:** Design air brakes such that shifts in the center of pressure do not negatively impact stability.<br>**D:** Confirm placement of air brakes on the launch vehicle to ensure CP shifts remain within safe limits.<br>**M:** Add ballast to the forward or aft section as needed to restore ideal stability. | 1A | Air Brakes effect on stability is described in Section 3.6.6. |
| Launch Hazards | | | | | | | |
| Launch Support Equipment Hazards | | | | | | | |
| DHZ.68 | Rail buttons are either too large or too small | Incorrectly sized launch rail guides | Launch vehicle unable to launch | 4A | **P:** Verify rail dimensions against launch field's rail buttons and NASA-provided launch rails.<br>**D:** Measure rail buttons to confirm they meet required dimensions.<br>**M:** Use a testrail piece to ensure proper alignment and smooth sliding. | 1A | Rail buttons are described in Section 3.3.6. |
| DHZ.69 | Launch vehicle not assembled in time | Unprepared or slow assembly process | Launch vehicle unable to launch | 4B | **P:** Establish a detailed timeline and perform a dry run before launch day to ensure efficient assembly.<br>**D:** Track assembly progress during weekly meetings.<br>**M:** Maintain spare personnel for critical tasks; reschedule to backup launch if assembly cannot be completed on time. | 1B | Section 6.1 describes detailed launch vehicle assembly. Dry run is scheduled before launch day, in Section 7.5. |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.70 | Launch vehicle does not slide onto launch rails, or slides with excessive friction | Launch rails have too much friction or are filled with debris/dirt | Launch vehicle fails to exit rail properly, potential failure to meet NASA Requirement 2.14 | 4A | **P:** Inspect rail guides and remove debris before inserting the launch vehicle.<br>**D:** Perform a test fit on a test piece of rail.<br>**M:** Lubricate launch rail to ensure smooth rail exit. | 1A | Section 6.1 describes launch vehicle integration with launch rail (Section 10). |
| DHZ.71 | Tent falls over or flies away | High winds at launch field | **(1)** Injury to personnel<br>**(2)** Damage to equipment<br>**(3)** Obstruction of launch area | 2C | **P:** Secure tent with stakes.<br>**D:** Observe wind conditions and monitor tent stability.<br>**M:** Remove tent and proceed with checklist without it if necessary. | 1B | Packing checklist is located in Reference [15]. |
| DHZ.72 | Launch system fails to ignite motor ignitor | Ignition equipment failure, power loss, or electrical shorting | Launch vehicle unable to launch | 3B | **P:** Test continuity at the launch pad.<br>**D:** Check continuity and resistance in ignition system before launch.<br>**M:** Keep backup ignitor ready; consult launch coordinator if primary and backup ignitors fail. | 1A | Section 6.1 describes continuity checks for ignitors, as well as backup ignitors (Section 10). |
| Launch Operation Hazards | | | | | | | |
| DHZ.73 | Team Members Are Unable to Be Reached | Low or no phone signal at launch field | **(1)** Delayed response during launch operations<br>**(2)** Potentially missed safety checks or critical coordination | 2B | **P:** Utilize club-owned handheld radios.<br>**D:** Perform communication checks at the beginning of launch day; verify all pertinent team members can be reached.<br>**M:** Update all launch personnel on procedures so that the launch can still occur if radios fail. | 1A | Packing checklist is located in Reference [15]. |
| DHZ.74 | Personnel Are Disruptive Around Assembly of Launch Vehicle | **(1)** New team members not properly trained on launch day procedures<br>**(2)** Lack of clear roles or supervision | **(1)** Delays in launch vehicle assembly<br>**(2)** Potential launch cancellation<br>**(3)** Increased risk of assembly errors or safety incidents | 2C | **P:** Train all attendees on launch procedures; define roles, responsibilities, and behavior expectations.<br>**D:** Monitor behavior during assembly.<br>**M:** Temporarily remove disruptive personnel from assembly tasks and redistribute responsibilities if needed. | 1B | Launch Day safety briefing is located in Reference [1]. |
| DHZ.75 | Electronics Assembly Takes Longer Than Anticipated | **(1)** Complex wiring and unclear instructions<br>**(2)** Inexperienced personnel performing assembly | **(1)** Delayed launch schedule<br>**(2)** Rushed assembly increasing likelihood of missing safety checks | 3C | **P:** Provide clear assembly instructions.<br>**D:** Track dry-run assembly times to ensure they are within reasonable limits.<br>**M:** Prioritize critical connections; delay non-critical tasks as necessary. | 2A | Section 6.1 describes detailed launch vehicle assembly. Dry run is scheduled before launch day, in Section 7.5. |

Table 6.10: Design Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| DHZ.76 | Launch Vehicle Parts Left at Lab | **(1)** Improper packing or transport<br>**(2)** Miscommunication between subteams<br>**(3)** Last-minute changes | **(1)** Missing critical components at launch site<br>**(2)** Delays in assembly or incomplete vehicle integration<br>**(3)** Potential launch cancellation | 4A | **P:** Implement a detailed pre-launch checklist.<br>**D:** Verify all components are packed the night before launch.<br>**M:** Arrange rapid transport of missing components if possible; otherwise, reschedule to a backup launch date. | 1A | Packing checklist is located in Reference [15]. |

## 6.5 Environmental Hazards Analysis

Table 6.11: Environmental Hazards

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| Hazards to the Environment from Personnel | | | | | | | |
| EHZ.1 | Leftover Epoxy Improperly Disposed Of | Absence of proper disposal containers or protocols | Environmental contamination and potential harm to soil and water | 2B | **P:** Train personnel on proper disposal techniques per manufacturer's instructions.<br>**D:** Provide labeled waste containers.<br>**M:** Collect leftover epoxy in waste containers and dispose of it when full. | 1A | Proper disposal is described in Reference [17]. |
| EHZ.2 | Litter Left on Launch Field | Improper cleanup, failure to collect personal or team waste | **(1)** Environmental contamination<br>**(2)** Negative public perception of rocketry activities<br>**(3)** Potential loss of launch site access | 3B | **P:** Provide trash bags for all personnel attending launch.<br>**D:** Inspect work area after launch to ensure no trash is left behind.<br>**M:** Collect and dispose of waste properly; recycle when possible. | 1A | Section 6.1 describes litter left on field cleaning procedures (Section 11). |
| EHZ.3 | Paint, Solvent, or Adhesive Spills | Improper storage or accidental spills during preparation/manufacturing | Soil pollution, potential harm to local plant or animal life | 2C | **P:** Store chemicals in sealed containers.<br>**D:** Inspect work area for spills and monitor for leaks.<br>**M:** Contain and clean spills promptly. | 2A | Painting schedule is described in Section 7.5. |
| EHZ.4 | Battery Fluid Leakage | Damaged or punctured LiPo or alkaline cells after use | Chemical contamination of soil, risk to wildlife, and potential injury to personnel | 3B | **P:** Inspect batteries before use and handle with care.<br>**D:** Check batteries before and after use; replace and properly dispose of any degraded batteries.<br>**M:** Neutralize spilled fluids with appropriate absorbents; safely collect and dispose of old or damaged batteries. | 1A | Battery handling is described in HPRC Safety Handbook [11]. |
| EHZ.5 | E-match Wires and Tape Left on Ground | Failure to collect debris after recovery separations | **(1)** Litter accumulation<br>**(2)** Potential ingestion hazard for wildlife<br>**(3)** Negative public perception | 3C | **P:** Assign personnel via checklist to clean e-match wires and tape after launch.<br>**D:** Visually inspect launch pad and recovery site for debris.<br>**M:** Collect all tape and loose wires and dispose of properly. | 2B | Section 6.1 describes litter left on field cleaning procedures (Section 11). |
| Hazards to the Environment From Launch Vehicle | | | | | | | |

Table 6.11: Environmental Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| EHZ.6 | Recovery Insulation Contaminating the Environment | Ejection charges separating the launch vehicle, causing insulation to spill | Pollution of the launch site and surrounding areas; negative perception by landowners or authorities | 3D | **P:** Purchase cellulose-based insulation that is biodegradable.<br>**D:** Confirm that insulation is biodegradable.<br>**M:** Ensure insulation is biodegradable when packing parachutes into airframe bays. | 1A | Section 6.1 describes litter left on field cleaning procedures and usage of biodegradable insulation (Section 11). |
| EHZ.7 | Fire on Launch Field | **(1)** Motor ignition<br>**(2)** Improperly mounted blast deflector<br>**(3)** Ejection charge discharge on the field | **(1)** Damage to equipment<br>**(2)** Risk of injury to personnel<br>**(3)** Potential spread of fire to surrounding vegetation or structures | 4B | **P:** Ensure blast deflector is properly aligned.<br>**D:** Watch for sparks after motor ignition.<br>**M:** Deploy fire extinguishers if fire starts. | 2B | Emergency Procedures described in Section 6.1 (See Appendix B). |
| EHZ.8 | Composite Material Contamination on Launch Field | Damaged composite components left after assembly or recovery | **(1)** Environmental contamination<br>**(2)** Exposure risk to personnel<br>**(3)** Potential loss of launch site access | 3A | **P:** Provide trash bags for debris.<br>**D:** Inspect assembly and recovery areas and confirm no leftover composite material.<br>**M:** Dispose of trash properly and recycle when possible. | 1A | Section 6.1 describes litter left on field cleaning procedures (Section 11). |
| EHZ.9 | Launch vehicle damage to environment | Launch vehicle enters ballistic descent | **(1)** Environmental contamination **(2)** Harm to wildlife | 3A | **P:** Design and test launch vehicle recovery system such that it prevents ballistic descent.<br>**D:** Implement checks into recovery system assembly to ensure proper implementation of recovery system.<br>**M:** Remove launch vehicle from environment, rehabilitate landing area. | 1A | Section 6.1 describes litter left on field cleaning procedures (Section 11). |
| Hazards from the Environment to Personnel | | | | | | | |
| EHZ.10 | Heat Stroke | **(1)** Prolonged work in high-temperature environments<br>**(2)** Inadequate hydration during physical activity<br>**(3)** High levels of physical exertion without appropriate rest or cooling measures | **(1)** Confusion, disorientation, or cognitive impairment<br>**(2)** Nausea, weakness, or fainting<br>**(3)** Loss of consciousness or heat-related illness | 3C | **P:** Bring water to launch fields; enforce hydration.<br>**D:** Monitor team members for dizziness, nausea, confusion, or fatigue.<br>**M:** Move affected personnel to cool areas, shade, or air-conditioned vehicles; contact EMS if needed. | 1A | Launch Day safety briefing is located in Reference [1]. |
| EHZ.11 | Mud or Standing Water on Field | Recent rain or poor field drainage | **(1)** Personnel slipping and potential injuries<br>**(2)** Vehicle damage or instability on launch rails | 2D | **P:** Train recovery personnel to dress appropriately (pants, boots, etc.).<br>**D:** Inspect field conditions on launch day; note soft or unstable terrain.<br>**M:** Limit personnel on launch pad to reduce slips or falls. | 1B | Launch Day safety briefing is located in Reference [1]. |

Table 6.11: Environmental Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| EHZ.12 | Dehydration | **(1)** Inadequate water intake during work or activity<br>**(2)** Prolonged exposure to sunlight or high temperatures<br>**(3)** High levels of physical exertion without adequate hydration | **(1)** Dizziness, fatigue, or lightheadedness<br>**(2)** Fainting or heat-related illness<br>**(3)** Potential secondary injuries from falls | 3C | **P:** Encourage water breaks, provide water bottles, monitor outdoor temperatures.<br>**D:** Observe personnel for fatigue, dizziness, or reduced performance.<br>**M:** Move affected personnel to shade or air-conditioned vehicle; provide water. | 1B | Launch Day safety briefing is located in Reference [1]. |
| EHZ.13 | Loss of Footing | **(1)** Uneven terrain, loose gravel, or wet/slippery surfaces<br>**(2)** Inadequate attention to footing or environmental conditions<br>**(3)** Improper footwear for the terrain | **(1)** Scrapes, bruises, or abrasions<br>**(2)** Sprains or fractures | 2D | **P:** Train team to be aware of terrain; no running or unsafe paths.<br>**D:** Identify dangerous terrain and alert personnel.<br>**M:** First aid carried by safety officer during recovery. | 1B | Launch Day safety briefing is located in Reference [1]. |
| EHZ.14 | Exposure to Sun/UV Radiation | **(1)** Lack of protective clothing, hats, or sunglasses<br>**(2)** Failure to apply sunscreen or take regular shade breaks<br>**(3)** Prolonged outdoor activity during peak sunlight hours | **(1)** Sunburn or acute skin irritation<br>**(2)** Increased risk of skin cancer with repeated or prolonged exposure | 2D | **P:** Provide sunscreen and shaded assembly areas; remind team to reapply.<br>**D:** Before launch, note the UV index expected at the launch field.<br>**M:** Provide aloe vera to ease sunburn discomfort. | 1B | Launch Day safety briefing is located in Reference [1]. |
| EHZ.15 | Allergic Reactions | Exposure to plants, chemicals, or other environmental allergens | **(1)** Skin reactions such as rash or hives<br>**(2)** Respiratory distress, sneezing, or difficulty breathing<br>**(3)** Severe reactions, including anaphylaxis | 4B | **P:** Avoid known allergens; provide gloves if needed.<br>**D:** Observe skin and respiratory reactions.<br>**M:** Administer epipen if needed; call EMS for severe reactions. | 2B | Launch Day safety briefing is located in Reference [1]. |
| EHZ.16 | Insect or Bug Bites | **(1)** Extended exposure outdoors during launch activities<br>**(2)** Lack of protective clothing or insect repellant | **(1)** Localized itching, rash, or swelling<br>**(2)** Allergic reactions, potentially severe, including anaphylaxis | 4C | **P:** Use bug spray; wear long sleeves and pants.<br>**D:** Inspect team members for bites if irritation arises; monitor for swelling/rash.<br>**M:** Apply anti-itch ointment; use epipen for allergic reactions if necessary. | 1B | Launch Day safety briefing is located in Reference [1]. |
| Hazards from the Environment to Launch Vehicle | | | | | | | |
| EHZ.17 | Launch Vehicle Lands in a Tree | Premature main parachute ejection causing excessive drift distance | **(1)** Potential damage to trees<br>**(2)** Risk to personnel retrieving vehicle<br>**(3)** Possible launch site environmental impact | 4A | **P:** With RSO approval, angle launch rails away from treeline.<br>**D:** Monitor launch trajectory with recovery GPS.<br>**M:** Safely remove launch vehicle from tree if possible; consult launch officials if not. | 3A | Launch Day safety briefing is located in Reference [1]. |
| EHZ.18 | High Winds at Launch Site | **(1)** Sudden weather changes<br>**(2)** Failure to check or account for forecast prior to launch | **(1)** Launch vehicle trajectory deviation<br>**(2)** Potential launch delay or cancellation | 4C | **P:** Check weather forecasts before launch.<br>**D:** Monitor on-field wind conditions.<br>**M:** Delay launch to backup if winds remain too high. | 3A | Launch Day safety briefing is located in Reference [1]. |

Table 6.11: Environmental Hazards (continued)

| ID | Hazard | Cause | Effect | LS Pre-Mitigat | Mitigation Factors | LS Post-Mitigat | Results |
|---|---|---|---|---|---|---|---|
| EHZ.19 | Hypothermia | **(1)** Prolonged exposure to cold, wet, or windy conditions<br>**(2)** Inadequate or improper protective clothing<br>**(3)** Insufficient rest, shelter, or warming measures | **(1)** Shivering, loss of coordination, and slurred speech<br>**(2)** Confusion or cognitive impairment<br>**(3)** Can lead to unconsciousness or life-threatening conditions | 3C | **P:** Instruct members to bring proper clothing.<br>**D:** Monitor for shivering, slurred speech, or disorientation.<br>**M:** Provide blankets, move to warm shelter, contact EMS if needed. | 1A | Launch Day safety briefing is located in Reference [1]. |

## 6.6 Fault Tree Analysis

### 6.6.1 Vehicle Fault Tree Analysis

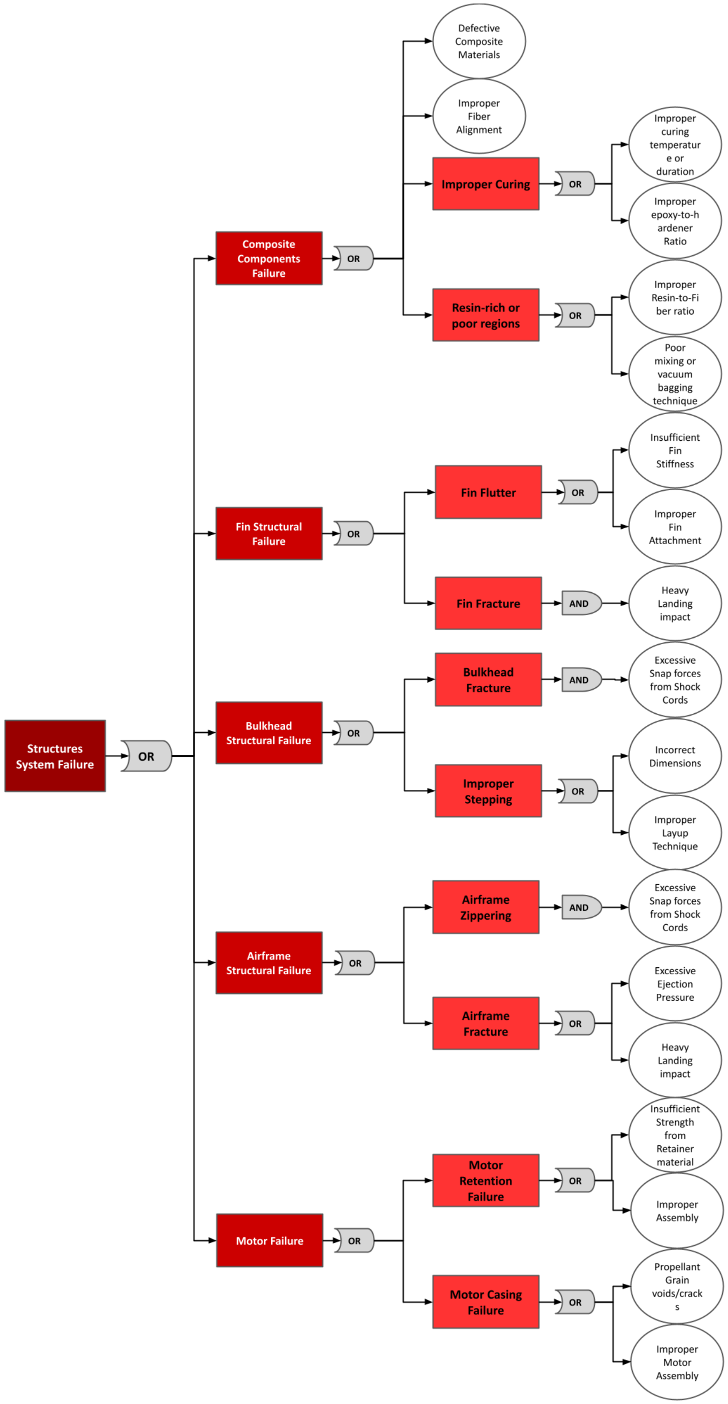


Figure 6.1: Structural Faulty Tree Analysis

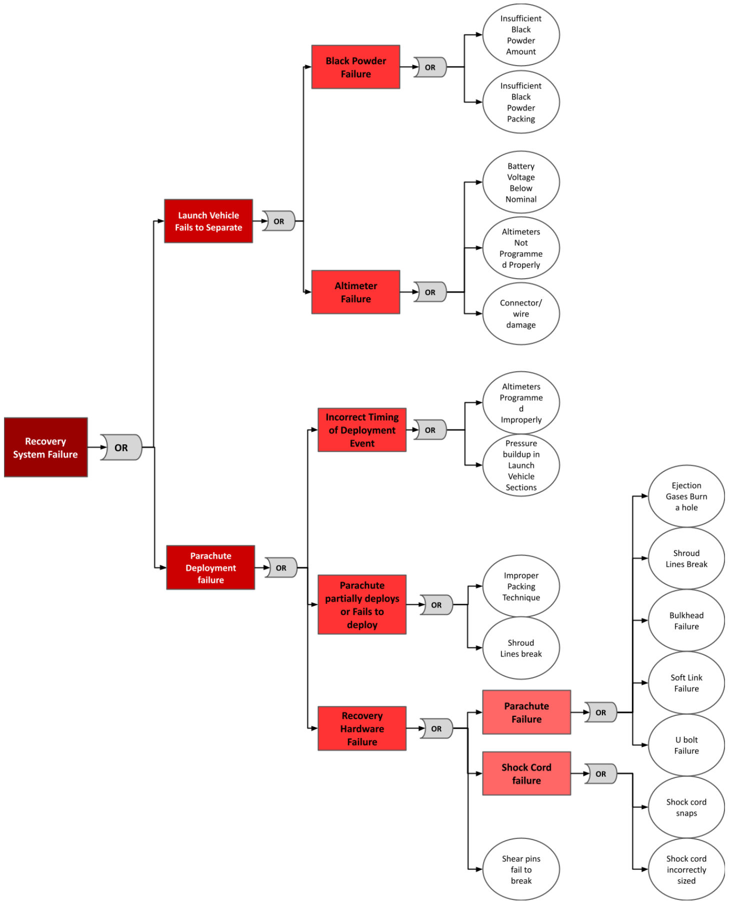


Figure 6.2: Recovery Subsystem Faulty Tree Analysis

### 6.6.2 Payload Fault Tree Analysis

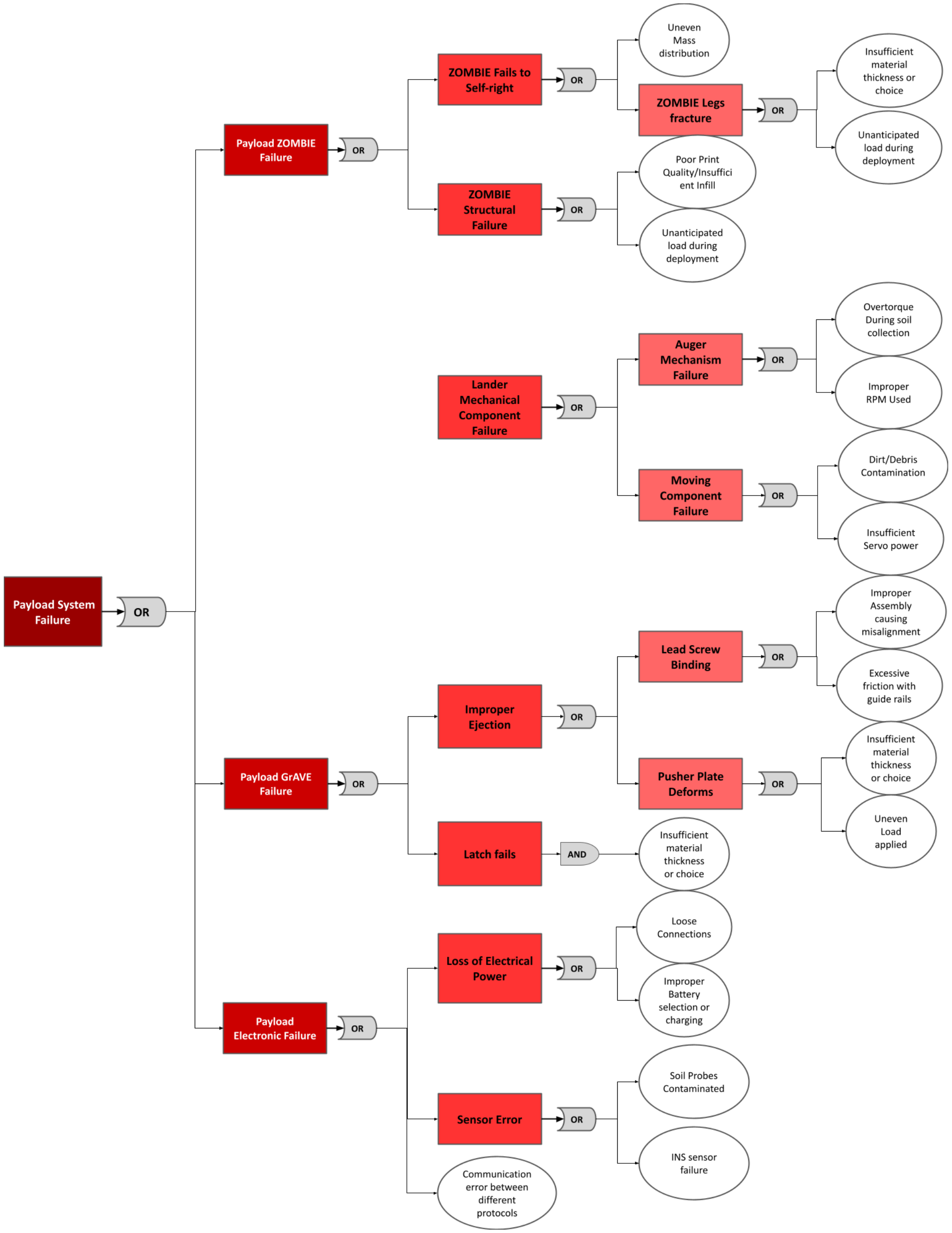


Figure 6.3: Payload Faulty Tree Analysis

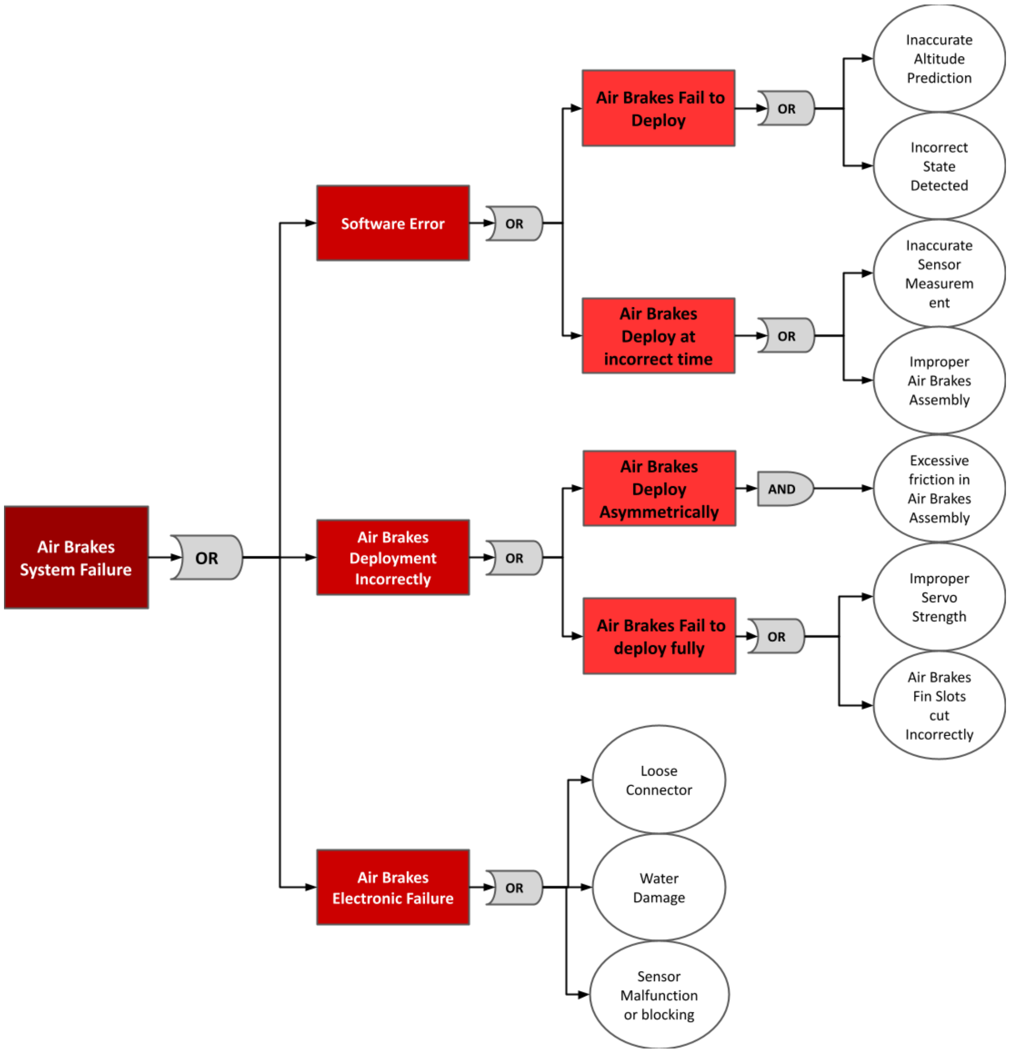


Figure 6.4: Air Brakes Faulty Tree Analysis

# 7 Project Plan

## 7.1 Testing Overview

Table 7.1: NASA Student Launch 2026 Test Plan

| Test Name | Date Planned | Requirement/Hazard | Verification |
|---|---|---|---|
| **Vehicle Test Suite** | | | |
| Subscale Ejection Test | Oct 20th, 2025 | RS 3, DHZ 12,13,14,31,32 | Verified |
| Altimeter Test | Feb 9th, 2026 | DHZ 28, 36 | Not Verified |
| GPS Test | Feb 9th, 2026 | NASA 3.12, RF 3 | Not Verified |
| Parachute Drop Test | Feb 2nd, 2026 | RF 7 DHZ 33,34 | Not Verified |
| Fullscale Ejection Test | Feb 16th, 2026 | RS 3, DHZ 12,13,14,31,32 | Not Verified |
| AV Bay Tensile Test | Feb 8th, 2026 | LVD 3, DHZ 11, 65 | Not Verified |
| Fincan Tube Compressive Test | Jan 30th, 2026 | LVD 2, DHZ 6,7 | Not Verified |
| Fincan Drop Test | Feb 8th, 2026 | LVD 1, LVE 4, DHZ 8 | Not Verified |
| MOI Test | Feb 14th, 2026 | | ˜ Not Verified |
| Three Point Bend Test | Jan 30th, 2026 | DHZ 6,7 | Not Verified |
| **Payload Test Suite** | | | |
| ZOMBIE Self-Righting Test | Jan 17th, 2026 | PF 3, PE 2, DHZ 40 | In Progress |
| ZOMBIE Drilling Test | Jan 24th, 2026 | PD 5, PE 1 | Not Verified |
| GrAVE Deployment Test | Feb 7th, 2026 | PF 2, PD 3, DHZ 45,46,48,56,59 | Not Verified |
| Ground Simulation of Payload Hardware | Feb 14th, 2026 | PF 2, PF 3, PD 3, PD 4, PD 5 | Not Verified |
| Air Brakes Deployment Test | Feb 16th, 2026 | AD 1,3, DHZ 19,20,66 | Not Verified |
| Air Brakes Effectiveness Flight Test (VDF) | Feb 24th, 2026 | AD 1,4, DHZ 21,22 | Not Verified |

## 7.2 Vehicle Testing Suite

### 7.2.1 Subscale Ejection Test

Subscale ejection testing was conducted to validate that black powder charge masses were adequate to achieve launch vehicle separation for parachute deployment. This testing served to confirm the accuracy of the analytical calculations. Completion of this test satisfies NASA Requirement 3.1 and team-derived requirement RS 3. The test was successfully performed on October 28, 2025, and the associated success criteria are summarized in Table 7.2.

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

**Required Facilities, Equipment, Tools, and Software**

- HPRC lab
- Assembled launch vehicle
- Safety glasses
- Nitrile gloves
- Fireproof gloves
- Foam pads
- SteadyBlue ground station
- Laptop with Fluctus Control Center software

**Methodology**

1. Assemble the subscale vehicle into launch configuration, ensuring the following modifications have been made:
   (a) Only the primary altimeter is connected to its respective battery, the secondary altimeter will not be used in ejection testing.
   (b) Only the primary charge wells are filled with black powder.
2. Verify that the pull-pin is properly installed in the AV bay.

3. The launch vehicle is positioned horizontally on foam pads outdoors, with both the forward and aft ends located a minimum of 3 (ft) from any walls or nearby obstructions.
4. Any walls located directly ahead of or behind the vehicle are shielded with an additional foam pad.
5. A designated team member wearing safety glasses approaches the launch vehicle and removes the pull-pin.
6. The team member then returns to a safe distance from the vehicle.
7. Confirmation is made that all team members are wearing safety glasses, no individuals are positioned directly in front of or behind the launch vehicle, and all personnel remain at least 20 (ft) from the sides of the vehicle.
8. The SteadyBlue ground station is verified to be transmitting properly, and the Fluctus is confirmed to be connected to the Fluctus Control Center software.
9. A designated team member initiates an audible countdown beginning at five.
10. At the end of the countdown, Igniter 1 is manually armed and fired using the Fluctus Control Center.
11. The designated team member and safety officer then approach the vehicle and, using fire-resistant gloves, verify adequate separation between vehicle sections. The safety officer empties the contents of each section and extinguishes any remaining sparks.
12. Steps 7-11 are repeated on the forward end of the vehicle to simulate main parachute deployment.

**Results**

Ejection testing produced complete separation of the launch vehicle for both drogue and main parachute deployment events. The results confirmed that the black powder charge sizes were adequate to shear the retention pins and initiate reliable parachute deployment during descent. Both drogue and main ejection tests were successful, and the corresponding black powder masses were documented for implementation in the Subscale Demonstration Flight.

### 7.2.2 Altimeter Test

Altimeter testing is performed to confirm that the secondary altimeter installed in the launch vehicle is functioning correctly and properly configured prior to flight. A simulated flight is used to verify that the drogue and main deployment outputs are initiated at their designated altitudes. This verification is required to ensure reliable recovery system performance on launch day. Successful test criteria are summarized in Table 7.3.

Table 7.3: Altimeter testing 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 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 pressure
- Visual indication method
- Testing repetition

**Required Facilities, Equipment, Tools, and Software**

- Altus Metrum EasyMini
- 1S 500 (mAh) LiPo battery
- Laptop with AltosUI
- Vacuum chamber
- LED altimeter testing board

**Methodology**

1. Program the secondary altimeter using the AltosUI software.
2. Connect the secondary altimeter to the altimeter testing board, with the red light signifying drogue and yellow light signifying main.
3. Connect the 1S 500 (mAh) LiPo battery to the altimeter.
4. Place the altimeter, battery, and testing board in the vacuum chamber.
5. Place the lid on the vacuum chamber.
6. Place a cell phone on the Plexiglass lid of the chamber and record a video of the test.
7. Slowly decrease the pressure in the chamber to the minimum pressure.
8. Verify that the red LED lit up shortly after the pressure reached a minimum.
9. Slowly increase the pressure in the chamber to atmospheric conditions.
10. Verify that the yellow LED lights up as pressure in the chamber increases.
11. Remove the altimeter, battery and testing board from the chamber and connect the altimeter to a laptop.
12. View the flight profile using AltosUI, verify the altimeter functioned as programmed.

**Expected Results**

As the chamber pressure is reduced to the minimum level, the red LED on the altimeter test board is expected to illuminate, signifying initiation of the drogue deployment event. When pressure is subsequently increased within the chamber, the yellow LED should activate, indicating proper main parachute deployment. The recorded flight data is expected to show the drogue output firing one second after the detected apogee event and the main output firing at an altitude of 500 (ft). In the event of faulty altimeter behavior, the issue will be investigated and the device retested. If proper functionality cannot be verified, the altimeter will be replaced with another device of the same model.

### 7.2.3 GPS Test

The GPS test is designed to assess the Full-scale GPS tracker's transmission capability, battery endurance, and locational accuracy. The unit must reliably transmit precise coordinates during launch operations in accordance with NASA Requirement 3.12 and maintain functionality for a minimum of three hours, as specified by NASA Requirement 2.2.

Table 7.4: GPS testing success criteria.

| Success Criteria | Status |
|---|---|
| GPS receiver maintains a consistent and reliable connection with the Fluctus GPS transmitter within a radius of 1.5 miles | Not Verified |
| Fluctus 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 Fluctus as the distance increases | Not Verified |

**Controllable Variables**

- Test location and environmental factors
- Maximum distance between transmitter and receiver
- Test repetition

**Required Facilities, Equipment, Tools, and Software**

- Silicdyne Fluctus
- SteadyBlue ground station
- Two team members
- Stopwatch
- Phone
- Laptop with Fluctus Control Center Software

**Methodology**

1. Ensure full battery life for GPS transmitter and receiver.
2. Power on Fluctus and ground station and start a stopwatch to record battery life.
3. Ensure the transmitter is powered on for the duration of the test.
4. Connect the ground station to the Fluctus via Fluctus Control Center.
5. One team member holds the ground station and laptop and stays in place outside.
6. The second team member holds the Fluctus and will move to a known secondary location a set distance away from the starting point.
7. At the secondary location, the Fluctus holder will use their mobile device to find the approximate distance from the ground station holder and record their latitude and longitude coordinates.
8. The ground station holder will record the coordinates displayed in the Fluctus Control Center.
9. Repeat steps 5-8 for 3-7 repetitions while the receiver holder remains in the same location.
10. Fluctus holder returns to the starting location.
11. At the starting location, the Fluctus holder and ground station holder compare coordinates recorded by both the Fluctus and ground station.
12. Accuracy is evaluated and any discrepancies are noted.
13. Turn off the ground station.
14. Verify that the Fluctus is on after completing the range test.
15. Allow the battery life to run out on the device and stop the stopwatch once the first battery dies.
16. Record the total time of the battery life.

**Expected Results**

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

### 7.2.4 Parachute Drop Test

The parachute drop test will verify the aerodynamic and structural integrity of the team's custom drogue parachute. One of the goal's of this test is to calculate a consistent drag coefficient for the parachute, an important characteristic that heavily impacts the recovery system's performance. Success criteria for this test are displayed in Table 7.5.

Table 7.5: Parachute drop test success criteria.

| Success Criteria | Status |
|---|---|
| Parachute demonstrates consistent and reliable inflation within an acceptable time frame | Not Verified |
| Shroud lines do not become entangled at any point | Not Verified |
| No damage to the canopy | Not Verified |
| No damage to the shroud lines | Not Verified |
| Steady descent is observed | Not Verified |

**Controllable Variables**

- Drop height
- Mass attached to parachute
- Test location

**Required Facilities, Equipment, Tools, and Software**

- Custom 15 (in) elliptical parachute
- Known mass
- Soft link
- Stopwatch/timer
- Phone
- Tape measure

**Methodology**

1. Record the mass of the object being attached to the parachute.
2. Use the soft link to secure the mass to the parachute shroud lines.
3. Take the parachute with mass attached, stopwatch, phone, and tape measure to a parking deck.
4. One team member takes the parachute to the top level. Another team member measures the distance from the ground to a visual marker on the parking deck. This height will be used to calculate the parachute's velocity during steady descent.
5. Ensure a video of the drop test is taken in 60 frames per second.
6. The team member will drop the parachute from the top of the parking deck.
7. Steps 4-6 are repeated 5-10 times.
8. From the recorded videos of each drop, the drop time is extracted. Using the drop time, known height, known mass, and parachute canopy area, the drag coefficient is calculated for each drop test.
9. Deviations in the data will be noted and the test will be repeated for irregular data.
10. Any damage to the parachute will be evaluated and repaired as needed.

**Expected Results**

The parachute is expected to inflate within a timely manner and descend steadily to the ground. No entanglement of the shroud lines or damage to the parachute is expected. A successful test will provide consistent drag coefficient calculations.

### 7.2.5 Full-scale Ejection Test

**Controllable Variables**

- Ejection charge size
- Test location

**Required Facilities, Equipment, Tools, and Software**

- HPRC lab
- Assembled launch vehicle
- Safety glasses
- Nitrile gloves
- Fireproof gloves
- Foam pads
- SteadyBlue ground station
- Laptop with Fluctus Control Center software

**Methodology**

1. Assemble the subscale vehicle into launch configuration, ensuring the following modifications have been made:
   (a) Only the primary altimeter is connected to its respective battery, the secondary altimeter will not be used in ejection testing.
   (b) Only the primary charge wells are filled with black powder.
2. Verify that the pull-pin is properly installed in the AV bay.
3. The launch vehicle is positioned horizontally on foam pads outdoors, with both the forward and aft ends located a minimum of 3 (ft) from any walls or nearby obstructions.
4. Any walls located directly ahead of or behind the vehicle are shielded with an additional foam pad.
5. A designated team member wearing safety glasses approaches the launch vehicle and removes the pull-pin.
6. The team member then returns to a safe distance from the vehicle.
7. Confirmation is made that all team members are wearing safety glasses, no individuals are positioned directly in front of or behind the launch vehicle, and all personnel remain at least 20 (ft) from the sides of the vehicle.
8. The SteadyBlue ground station is verified to be transmitting properly, and the Fluctus is confirmed to be connected to the Fluctus Control Center software.
9. A designated team member initiates an audible countdown beginning at five.
10. At the end of the countdown, Igniter 1 is manually armed and fired using the Fluctus Control Center.
11. The designated team member and safety officer then approach the vehicle and, using fire-resistant gloves, verify adequate separation between vehicle sections. The safety officer empties the contents of each section and extinguishes any remaining sparks.
12. Steps 7-11 are repeated on the forward end of the vehicle to simulate main parachute deployment.

**Expected Results**

Ejection testing will produce complete separation of the launch vehicle for both drogue and main parachute deployment events. The results will confirm that the black powder charge sizes are adequate to shear the retention pins and initiate reliable parachute deployment during descent. If drogue and main ejection tests are successful, the corresponding black powder masses will be documented for use in Full-scale launches. If the the ejection charge is unable to separate the vehicle, testing will be repeated with an additional 0.2 (g) added to the original charge. This process will be repeated until successful separation is achieved.

### 7.2.6 AV Bay Tensile Test

The AV Bay tensile test will subject the structural components of the avionics bay (AV Bay) assembly to tensile loading using a universal testing machine. This test will verify that the assembly is capable of withstanding the maximum calculated shock force from the recovery system during flight with an appropriate factor of safety. The maximum expected tensile load on the AV Bay during flight is 414 lbf; therefore, the assembly will be tested to a minimum load of 621 lbf, corresponding to a factor of safety of 1.5. Since the AV Bay bulkheads are used to attach the main parachute and the drogue parachute to the remainder of the launch vehicle, this test ensures that the recovery system will not compromise mission success. Success requirements are presented in Table 7.8

Table 7.6: AV Bay tensile test success criteria.

| Success Criteria | Status |
|---|---|
| AV Bay assembly sustains a minimum tensile load of 621 lbf | Not Verified |
| AV Bay assembly maintains a minimum factor of safety of 1.5 relative to the 414 lbf flight load | Not Verified |

**Controllable Variables**

- Configuration and alignment of AV Bay structural components
- Loading rate and procedure
- Testing equipment calibration
- Margin of safety
- Post-test inspection criteria
- Bulkhead material and layup
- Bulkhead thickness

**Required Facilities, Equipment, Tools, and Software**

- Universal tensile testing machine (MAE Structural Mechanics Lab)
- 2 × 3/8 in. stainless steel U-bolts with mounting plates
- 2 × stainless steel quick links
- 4 × 1/4 in. stainless steel threaded rods
- Fiberglass composite bulkheads, 0.32 in. thickness
- Stainless steel hex nuts and washers
- Safety glasses
- Camera

**Methodology**

1. Attach one stainless steel quick link to each U-bolt on either end of the AV Bay bulkhead assembly.
2. Secure each quick link into opposing jaws of the universal tensile testing machine.
3. Apply a small preload to place the AV Bay assembly in slight tension.
4. Begin video recording of the test.
5. Increase the tensile load in 10 lbf increments, briefly pausing after each increment to visually inspect the test article and listen for audible signs of failure.
6. If any component fails prior to reaching 621 lbf, immediately stop testing, document the failure, and revise the design before retesting.
7. Continue increasing the load until at least 621 lbf is achieved.
8. Remove the test assembly from the machine and visually inspect all components for damage or permanent deformation.

**Expected Results** The AV Bay assembly is expected to sustain a tensile load of at least 621 lbf without structural failure. Finite element analysis of the AV Bay structure and prior testing of similar recovery attachment designs indicate that the assembly will meet or exceed the required factor of safety. If a failure were to occur, it is expected to originate in the fiberglass composite bulkheads or threaded rod interfaces, in which case the design would be revised and the test repeated.

### 7.2.7 Fin Can Tube Compressive Testing

The validation test assesses the compressive strength of the fin can tube under axial and bending loads from motor thrust, aerodynamic drag, and fin-induced moments. The fiberglass composite tube, made from multiple layers of cloth with epoxy, includes machined and drilled features for fin attachment that act as stress concentrators. It has an inner diameter of approximately 6.00 (in) and a wall thickness of 0.06 (in). Testing on an Instron machine will apply axial compression at 0.05 (in/min) to a target stress of 5000 (psi), providing a factor of safety of 3.2, Table 7.10. Previous tests on similar tubes showed ultimate compressive strengths around 16,500 (psi), with failure through radial deformation.

Table 7.7: Fin can tube compressive test success criteria.

| Success Criteria | Status |
|---|---|
| Fin can tube sustains a 5000 psi compressive loading | Not Verified |

**Controllable Variables**

- Configuration and alignment of airframe tube
- Loading rate and procedure
- Testing equipment calibration
- Margin of safety
- Post-test inspection criteria
- airframe material and layup
- airframe thickness

**Required Facilities, Equipment, Tools, and Software**

- Universal testing machine (Instron, MAE Structural Mechanics Lab)
- Fiberglass fin can tube
- Flat compression plates
- Safety glasses
- Camera

**Methodology**

1. Measure the inner and outer diameters and wall thickness of the fin can tube at multiple axial and circumferential locations for accurate stress calculations.
2. Assemble the Instron testing machine with flat compression plates to provide a rigid and uniform load interface with the tube.
3. Calculate the axial load required to achieve a compressive stress of 5000 psi based on the measured cross-sectional area of the fin can tube.
4. Begin video recording prior to the start of loading to capture audible and visible signs of material failure.
5. Initiate compressive loading at a displacement rate of 0.01 in/min.
6. Monitor the tube throughout the test for audible cracking or visible deformation.
7. Temporarily pause the test if audible cracking is detected and attempt to visually locate the source of the damage.
8. Document any visible cracking or deformation with photographs if it occurs prior to reaching the 5000 psi load.
9. Continue loading until the applied stress reaches or exceeds 5000 psi.
10. Terminate the test once the target load is achieved.
11. Stop recording after the tube is fully unloaded and inspect the tube for any delayed damage or audible cracking.

**Expected Results**

The fin can tube is expected to sustain a compressive stress of 5000 psi without permanent deformation, buckling, or structural failure. The tube is expected to respond elastically throughout the duration of the test. Minor audible cracking may occur near regions of geometric discontinuity or stress concentration, such as drilled holes, fin slots, or air brake slots; however, no visible damage is anticipated at the target load level.

### 7.2.8 Fin Can Drop Test

The fin can's impact testing will simulate the landing energy transferred to the vehicle. The fin can will be tested alone with a weight fixed to simulate the maximum 75 ft-lbs impact energy that the launch vehicle could experience. Success requirements are presented in Table 7.8

Table 7.8: Fin can test success criteria.

| Success Criteria | Status |
|---|---|
| Fin can assembly is not damaged | Not Verified |
| Fin molded fairings do not delaminate upon landing from the impact | Not Verified |

**Controllable Variables**

- Configuration and alignment fin can assembly
- Height of drop
- Weight added to fin can assembly
- Margin of safety
- Post-test inspection criteria

**Required Facilities, Equipment, Tools, and Software**

- 1515 Aluminum rail with mounting structure
- Assembled fin can
- Additional weight fixed to the motor casing threaded rod
- Safety glasses
- 20 (ft) 1/8 (in) Kevlar shock cord
- Camera

**Methodology**

1. Affix the desired weights to the fin can through the motor casing's forward closure with 3/8 (in) threaded rod mounting points.
2. Secure the weights with 3/8 (in) washers and nuts
3. Measure the mass of the assembled test article.
4. Determine the height to generate 75 ft-lbs of kinetic energy via an impact with the measured mass of the assembly.
5. Tie a length of cord to lift the test article assembly up a fixed rail to the desired height over dirt.
6. Ensure all observers are safely distanced from the test article drop location.
7. Begin recording.
8. Drop the test article by releasing the cord until the test article impacts the ground.
9. Stop recording and visually inspect for any damage on the fin.

**Expected Results** The fin can is expected to withstand the impact energy without damaging or deforming the components. The molded fin fairings are expected to be driven into the ground by the beveled edges. Any break would be expected at the fin fairings, which can be cut off and remolded if necessary. Redesign would include a more blunted leading edge design with more surface area for bonding to the fin structure.

### 7.2.9 Moment of Inertia (MOI) Test

The moment of inertia (MOI) test will experimentally determine the longitudinal MOI of the launch vehicle using a swing-based test stand and onboard measurements. This test verifies that the MOI values used in OpenRocket and RocketPy are representative of the actual vehicle, thereby directly affecting trajectory prediction, resistance to wind-induced attitude changes, and air-brake control authority. The test will use the Air Brakes INS system to record oscillation data for a sufficient duration, after which MATLAB will be used to filter out noise and extract the oscillation period for the MOI calculation. Success requirements are presented in Table 7.9.

Table 7.9: Moment of inertia (MOI) test success criteria.

| Success Criteria | Status |
|---|---|
| Measured longitudinal MOI is within 20% of the simulated MOI value | Not Verified |
| Individual swing test results remain within 10 lb·m$^2$ of each other | Not Verified |

**Controllable Variables**

- Length of support ropes (target $>$ 2.5 ft to reduce sensitivity and error)
- Rope separation distance and symmetry about the vehicle centerline
- Structural stiffness and alignment of the swing frame and support beam
- Launch vehicle configuration (dry mass vs. wet mass, installed subsystems, payload state)
- Location of the INS system relative to the vehicle CG
- Initial angular displacement and release method
- Test duration (target $>$ 5 s) and sampling rate
- Sensor calibration, time synchronization, and mounting rigidity
- Number of trials and acceptance criteria for data quality
- MATLAB filtering and period-extraction settings

**Required Facilities, Equipment, Tools, and Software**

- MOI swing test stand
- Fully assembled launch vehicle in the test configuration of interest
- Air Brakes avionics for data collection
- Raspberry Pi and data logging software
- Laptop for data download and test monitoring
- USB extension cable to prevent cable interference with oscillation
- Screws/zip ties/fixtures to rigidly mount the avionics to the vehicle
- Measuring tape
- MATLAB for signal processing and oscillation period determination

**Methodology**

1. Construct the MOI swing test stand and verify that the structure can safely support the launch vehicle weight.
2. Measure and set the rope lengths (target $>$ 2.5 ft) and ensure both ropes are equal length and evenly spaced.
3. Mount the Air Brakes INS system rigidly near the launch vehicle center of gravity.
4. Connect the avionics to the Raspberry Pi and verify data logging to storage. Connect the Raspberry Pi to a laptop if needed.
5. Apply a small initial angular displacement about the vehicle's longitudinal axis and release the vehicle without imparting additional push.
6. Record oscillation data until the motion decays to rest. The test time should be greater than 5 seconds.
7. Repeat the test for a minimum of five trials, remounting and rechecking the setup as needed to ensure consistent data quality.
8. Import the recorded data into MATLAB and filter noise.
9. Determine the oscillation period from the processed data and compute the longitudinal MOI using the swing relationship.
10. Compare the measured MOI against simulated values and document the percent difference and run-to-run scatter.

**Expected Results**

The measured longitudinal MOI is expected to closely resemble the MOI values produced by OpenRocket for the same vehicle configuration. If the experimental MOI differs beyond the success criteria, the simulation inputs will be updated with the measured inertia, and the trajectory predictions will be re-evaluated to quantify the impact on apogee prediction and control behavior.

### 7.2.10 Three-Point Bending Test

The validation test assesses the mechanical properties of the fin and bulkhead materials under shear and moment loading anticipated from the recovery shock loading. The three-point bending tests will use double-thick plates with two honeycomb Nomex cores mimicking the sizing and layup sequence of the avionics bay and air brakes bay bulkheads. The dimensions will approximate 6.00 (in) long and 1.50 (in) wide. The plates will be tested until failure to determine the maximum stress that the manufactured materials can withstand the predicted forces. Testing on an Instron machine will apply axial compression at 0.05 (in/min). Similar tests were completed for the PDR milestone; the provided tests here expand on those previously completed with the as-manufactured layups.

Table 7.10: Three-point bending test success criteria.

| Success Criteria | Status |
|---|---|
| Samples maintain a minimum 10000 psi loading | Not Verified |

**Controllable Variables**

- Configuration and alignment of rectangle plates
- Loading rate and procedure
- Testing equipment calibration
- Post-test inspection criteria
- plate material and layup
- plate thickness

**Required Facilities, Equipment, Tools, and Software**

- Universal testing machine (Instron, MAE Structural Mechanics Lab)
- Rectangular samples
- 3D printed fixture for experiments
- Safety glasses
- Camera

**Methodology**

1. Measure the width, length, and thickness of the rectangular plate to verify stress cross-section.
2. Assemble the Instron testing machine with the 3D printed fixture.
3. Calculate the axial load required to achieve a compressive stress of 10000 psi based on the measured cross-sectional area of the rectangular plate.
4. Begin video recording prior to the start of loading to capture audible and visible signs of material failure.
5. Initiate compressive loading at a displacement rate of 0.01 in/min.
6. Monitor the plate throughout the test for audible cracking or visible deformation.
7. Temporarily pause the test if audible cracking is detected and attempt to visually locate the source of the damage.
8. Document any visible cracking or deformation with photographs if it occurs prior to reaching the 10000 psi load.
9. Continue loading until the applied stress reaches or exceeds 10000 psi.
10. Terminate the test once the plate reaches the ultimate loading.
11. Stop recording after the plate is fully unloaded and inspect the tube for any delayed damage or audible cracking.

**Expected Results**

The plates are expected to sustain a compressive stress of 10000 psi without permanent deformation or structural failure. An elastic response is expected throughout the duration of the test. Minor audible cracking is anticipated at the center of the loading. The core is anticipated to shear first in failure due to the sandwich composite construction.

## 7.3 Payload Testing Suite

### 7.3.1 ZOMBIE Self-Righting Test

The ZOMBIE self-righting test will experimentally prove that the mechanism to right ZOMBIE functions as intended. ZOMBIE, or the Z-axis Orienting Mechatronic Botanical Investigative Extractor, is the lander which will separate from the launch vehicle after landing and collect a soil sample. ZOMBIE contains a mechanism which will allow transition from a horizontal to vertical state using a deployable leg system. A collar in ZOMBIE's body will be extended using a lead screw motor. This collar connects to linkages which will cause hinged legs to fold out, lifting the main portion of ZOMBIE into the desired position.

Table 7.11: ZOMBIE self-righting test success criteria.

| Success Criteria | Status |
|---|---|
| ZOMBIE transitions from a horizontal to vertical orientation | In Progress |

**Control Variables**

- ZOMBIE mass
- Motor torque applied
- Surface on which self-righting is completed

**Required Facilities, Equipment, Tools, and Software**

- Lower body
- Upper body
- Top plate
- Soil container
- Leg mechanisms
- Electronics
- Laptop, WiFi, and required software
- A location with soil similar to that at the launch field in Huntsville, Alabama

**Methodology**

1. Write code that activates the lead screw motor for a set time/distance when called
2. Assemble ZOMBIE as close to final configuration as possible
3. If ZOMBIE's mass is significantly less than the final expected value, add a mass simulator
4. Place the assembled ZOMBIE on a surface with similar consistency to a tilled field
5. Upload the test code and initialize

6. Run the code

**Expected Results** The code will cause the lead screw motor to actuate, driving itself down along the threaded rod attached to ZOMBIE's structure. As the lead screw motor translate, it will force attached struts down as well. These struts are connected to legs hinged at the base of ZOMBIE. The downward movement of the struts will become a rotational moment around the hinge, forcing the legs to extend. Two of the legs will remain in contact with the ground while ZOMBIE's body rises from a horizontal to vertical orientation. The code should stop when the legs are fully extended.

### 7.3.2 ZOMBIE Drilling Test

The ZOMBIE drilling test will verify that the ZOMBIE lander can extract and test soil as required by NASA requirement 4.1 and 4.2. The test will start with ZOMBIE in the legs deployed configuration. This allows for a test of only the drilling mechanism. The drill will extend and rotate, allowing it to dig into the soil. The auger will then retract and deposit the soil into an internal collection chamber. This process will be carried out a set number of times to collect the required amount of soil. Once collection is done, the soil will be tested for Nitrate-Nitrogen content, electrical conductivity, and pH. These results will be timestamped and stored, just as they will be at the competition launch.

Table 7.12: ZOMBIE drilling test success criteria.

| Success Criteria | Status |
|---|---|
| 75 (ml) of soil collected | Not Verified |
| Nitrogen, EC, and pH measurements collected and timestamped | Not Verified |

**Control Variables**

- Location
- ZOMBIE mass
- Auger design used
- Motors and drill deployment system used
- Soil collection chamber volume
- Soil sensor function

**Required Facilities, Equipment, Tools, and Software**

- A location with soil similar to the launch field in Huntsville, Alabama
- ZOMBIE structure
- Soil collection assembly
- 3D printed auger
- Planetary gear motor
- Rack and pinion system
- Soil sensor
- Electronics
- Laptop, WiFi, and required code

**Methodology**

1. Write a code that simultaneously activates the rack and pinion servo and the planetary gear motor
2. When the servo is at maximum extension, reverse its direction while keeping the planetary gear motor spinning
3. Repeat this process for as many repetitions as it takes to fill the soil collection chamber
4. Finalize the code by writing a section that collects the required soil sensor measurements, timestamps them, and stores them
5. Construct ZOMBIE in a configuration as close to launch configuration as possible. Add mass simulators as needed
6. Place ZOMBIE on soil that is similar to that at the competition launch field
7. Upload, initialize, and run the code
8. When the code has finished, download the soil sensor data and measure the amount of soil collected

**Expected Results** Upon activation, the auger should extend into the soil and rotate. These motions in tandem should allow it to smoothly cut into the soil. The auger will break up the soil through which it drills. This soil will become stuck to the blades of the auger. At maximum extension, the auger will begin to retract. The soil on the auger blades will be pushed against a series of walls and ramps which direct it into the soil collection chamber. This process will occur as many times as are required to fill the chamber. When the chamber is full and the drilling has ceased, the soil sensor will take the required measurements. These measurements will be saved to an SD card along with the time at which they were collected. When removed, the soil collection chamber will contain at least 75 (mL) of soil.

### 7.3.3 GrAVE Deployment Test

The GrAVE deployment test will demonstrate that the ejection system is sufficient to disconnect ZOMBIE from the nosecone. GrAVE, or the Ground Activated Vehicle Ejector, is the system that will separate ZOMBIE from the nosecone after landing. It consists of three mechanisms: rails mounted to the inside of the nosecone, a lead screw pusher plate, and an electronic latch. These systems will all be used to facilitate an easy ejection of ZOMBIE.

Table 7.13: GrAVE deployment test success criteria.

| Success Criteria | Status |
|---|---|
| ZOMBIE separates fully from the nosecone | Not Verified |

**Control Variables**

- Motor speeds
- Deployment orientation
- ZOMBIE mass

**Required Facilities, Equipment, Tools, and Software**

- ZOMBIE, or the ZOMBIE body with mass simulators
- Nosecone with rails installed
- GrAVE electronics sled with lead screw motor and electronic latch
- Pusher plate attached to threaded rod
- Laptop, WiFi, and required code

**Methodology**

1. Write a code that disengages the electronic latch and then fully extends the pusher plate
2. Assemble ZOMBIE to as close as it can get to competition configuration
3. Install the GrAVE electronics/motor sled
4. Place the pusher plate in the lead screw motor and activate the retraction command
5. Place ZOMBIE in the nosecone in the correct orientation
6. Ensure ZOMBIE’s U-bolt attaches to the electronic latch
7. Upload, initialize, and run the code on GrAVE
8. Ensure no damage occurs to ZOMBIE or GrAVE during the ejection process

**Expected Results** During assembly, the electronics and motors will all fit snugly inside the nosecone. The pusher plate will be retracted in the right orientation by a pre-installed program. ZOMBIE will slot into the rails inside the nosecone and the U-bolt will attach to the latch through the hole in the pusher plate. When the code is run, the electronic latch will release the U-bolt and expel ZOMBIE smoothly. At the end of the deployment process, ZOMBIE will fall off the rails and out of the nosecone.

### 7.3.4 Ground Simulation of Payload Hardware

Before the payload is launched, it should be confirmed that ZOMBIE and GrAVE can work in tandem. A ground test is to be conducted where landing detection is artificially triggered. Following this, ZOMBIE will rise from the GrAVE and deploy. This systems-level test will ensure that all components work together properly and that the payload challenge can be completed. This whole test should take less than 15 minutes to meet NASA Requirement 4.1.1.

Table 7.14: Payload ground test success criteria.

| Success Criteria | Status |
|---|---|
| GrAVE recognizes the landing detection signal and ejects ZOMBIE | Not Verified |
| ZOMBIE self-rights | Not Verified |
| Auger deploys and collects soil | Not Verified |
| Soil sensor data is collected and timestamped | Not Verified |

**Control Variables**

- Payload physical configuration
- Deployment signal response
- GrAVE actions
- ZOMBIE actions
- Deployment location

**Required Facilities, Equipment, Tools, and Software**

- Laptop, WiFi, and required software
- Nosecone with pre-installed rails
- GrAVE electronics
- Latch system
- Pusher plate system
- ZOMBIE electronics

- ZOMBIE body
- Self-righting leg system
- Soil collection system
- Outdoor location with soil similar to the launch field in Huntsville, Alabama

**Methodology**

1. Write a Python script for GrAVE that can call the output of the state machine function and activate the ejection mechanisms
2. Write a Python script for ZOMBIE that can self-right the system, drill, and record soil data after landing is detected.
3. Collect all hardware components
4. Assemble the ZOMBIE lander
5. Install the GrAVE mechanism into the nosecone
6. Insert ZOMBIE into the nosecone and connect to GrAVE
7. Place the entire nosecone assembly on a patch of soil similar to the competition location
8. Send a signal to the motor that activates the lead screw pushing mechanism
9. Run the lead screw pushing mechanism until ZOMBIE is fully ejected from the nosecone
10. Initiate the code in ZOMBIE that deploys the landing legs
11. Run an orientation check using the INS data
12. If the vectors are not aligned, retract the legs and re-extend
13. If the vectors are aligned, begin the drilling operation
14. Extend and rotate the auger to drill into the soil
15. Within 15 minutes of simulated landing, cease drilling and retract the auger
16. Record soil sensor readings
17. Remove the soil collection chamber and verify the volume of collected soil

**Expected Results** The artificial landing trigger is recognized and the GrAVE ejection systems work. Once separated, ZOMBIE will self-right and drill into the soil. ZOMBIE remains upright for the duration of the drilling process. More than 75 (mL) of soil is collected within 15 minutes and the soil sensor records pH, electrical conductivity, and Nitrate-Nitrogen content.

### 7.3.5 Air Brakes Deployment Test

The air brakes deployment test will verify that the air brakes mechanism can reliably deploy and retract under representative aerodynamic loading without structural damage or loss of functionality. This test will simulate the expected drag forces on the air brake fins by applying external loads (weights) at defined attachment points to approximate flight loading. Verifying successful deployment under load is necessary to ensure the launch vehicle maintains stable, predictable flight behavior and that the air brake system will not induce adverse moments on the vehicle to partial deployment, servo stall, or mechanical failure. Success requirements are presented in Table 7.15.

Table 7.15: Air brakes deployment test success criteria.

| Success Criteria | Status |
|---|---|
| Air brakes fully deploy and retract under representative applied loading with the desired factor of safety without stalling the servo | Not Verified |
| Servo current draw during deployment does not exceed what a 4S LiPo battery can provide | Not Verified |
| Air Brake’s mechanism remains functional after testing with little to no gear damage, binding, or permanent deformation | Not Verified |

**Controllable Variables**

- Method of simulating aerodynamic drag force
- Load magnitude and distribution across fins
- Weight attachment points and lever arm relative to fin hinge line
- Servo selection and operating voltage in the Air Brakes’ assembly
- Air Brakes’ assembly design
- Data collection method for deployment angle, deployment time, and current draw
- Test repeatability and number of cycles performed

**Required Facilities, Equipment, Tools, and Software**

- Fully assembled Air Brakes system
- Assorted calibrated weights
- Weight attachment method
- 4S Li-Po Battery connected for power
- Inline current measurement device integrated with the Pi Hat.
- Laptop for logging purposes and data analysis
- Basic hand tools and safety glasses

**Methodology**

1. Assemble the Air Brakes system in the flight-representative configuration and verify free motion of the mechanism without applied loading.
2. Determine the expected drag force on the air brakes fins during flight for the target deployment condition and select test loads that bound this value with a factor of safety of 2.
3. Attach weights to each fin at predefined attachment points such that the applied load approximates the expected aerodynamic drag direction and magnitude.
4. Command the fins to deploy and retract while recording servo current draw, deployment time, and maximum achieved deployment angle.
5. Inspect the mechanism after each deployment cycle for binding, gear wear, fastener loosening, cracking, or permanent deformation.
6. Repeat the deployment and retraction cycles for multiple trials to verify repeatability and confirm no degradation in performance.

**Expected Results** The Air Brakes fins are expected to fully deploy and retract under the representative loads. The servo should operate smoothly without stalling, and the measured current draw should remain within the practical capability of the 4S Li-Po power system. The mechanism is expected to remain fully functional after repeated cycles, with no evidence of gear damage or structural failure. If the air brakes do not meet the success criteria, the air brakes design (servo selection, gearing, tolerances, or structural design) will be revised, and the test will be repeated.

### 7.3.6 Air Brakes Effectiveness Flight Test

The Air Brakes effectiveness flight test will evaluate the effectiveness of the Air Brakes system in reducing apogee and ascent velocity relative to a baseline flight without deployment. This test will be conducted by launching the Fullscale configuration of the launch vehicle equipped with the Air Brakes, payload, and recording in-flight data from onboard sensors. The measured reduction in ascent rate and change in apogee will be compared with simulated results to validate the aerodynamic effectiveness of the Air Brakes design. The Control system is expected not to deploy Air Brakes if the predicted apogee is lower than the target's. If the vehicle in its full ballasted configuration does not reach above 4600 (ft), Air Brakes should not deploy during the flight. If the Air Brakes are deemed ineffective or do not meet the success criteria, the fin geometry and deployment approach will be revised, and the test will be repeated at the next available launch opportunity. Success requirements are presented in Table 7.16.

Table 7.16: Air Brakes effectiveness flight test success criteria.

| Success Criteria | Status |
|---|---|
| Launch vehicle is successfully recovered | Not Verified |
| Deceleration rate is decreased by at least 5% relative to the baseline flight | Not Verified |
| Apogee is significantly reduced with Air Brakes deployment relative to the baseline flight | Not Verified |

**Controllable Variables**

- Air Brakes deployment timing
- Air Brakes deployment speed and actuation rate
- Deployment mechanism performance
- Launch vehicle mass and mass distribution
- Sensor calibration and sampling rate
- Launch Rail Cantilever
- Baseline flight configuration and repeatability
- Post-flight data processing and filtering parameters

**Required Facilities, Equipment, Tools, and Software**

- Certified launch site with appropriate range safety support
- Launch vehicle configured for flight test
- Air Brakes system and all associated mechanical and electrical components
- Onboard flight computer and Air Brakes avionics system
- Ground support equipment and tools listed in the Launch Day Checklist
- Recovery system and tracking equipment for post-flight retrieval
- Laptop for data download and post-flight processing
- MATLAB (or equivalent) for data processing and comparison to simulation outputs

**Methodology**

1. Prepare the launch vehicle and Air Brakes system for flight, verifying mechanical integrity, electrical continuity, and safe actuation on the ground.
2. Install and verify onboard sensors required to measure acceleration, ascent rate, altitude, and vehicle orientation.
3. Launch the vehicle and execute a controlled flight with Air Brakes deployment enabled.

4. Recover the launch vehicle and ensure that the Air Brakes hardware and avionics are retrieved intact.
5. Download and archive flight data, then process the data to extract ascent velocity, deceleration behavior, and apogee.
6. Compare the measured flight response to baseline results and to simulated predictions, documenting percent differences and overall performance.

**Expected Results** The launch vehicle is expected to be launched and recovered successfully, with measurable reductions in both ascent velocity and apogee upon deployment of the Air Brakes. The flight data should show a clear change in the slope of the ascent-rate curve and an overall reduction in peak altitude relative to a baseline flight. The measured performance is expected to resemble the simulated flight behavior presented in Section 3.6 within reasonable uncertainty, given atmospheric variability and flight-to-flight dispersion. If the Air Brakes do not function as intended on launch day or fail to meet the success criteria, the Air Brakes design and deployment logic will be revised, and the flight test will be repeated at the next available launch date.

## 7.4 Requirements Compliance

### 7.4.1 Verification Plan

NASA and Team Derived requirements are verified using Requirement Verification Matrices (RVMs), which ensure all project requirements are satisfied and maintain traceability between requirements, design elements, and verification activities throughout the project lifecycle. Each RVM includes columns identifying the requirement (ID and SHALL Statement), the planned verification approach, the verification method and success criteria, verification status (as defined in Table 7.17), the responsible subsystem, and the location of verification evidence. Team Derived RVMs also include justification entries describing the rationale for each requirement.

Table 7.17: Requirement Status Key

| Verification Level | Description | Key |
|---|---|---|
| Verified | All verification success criteria has been met. | V |
| Partially Verified | Some verification success criteria has been met, some criteria may still be in progress. | PV |
| In Progress | None of the verification success criteria has been met, but the verification process has begun. | IP |
| Not Verified | None of the verification success criteria has been met. | NV |

Table 7.18 below shows the completion status of both the NASA requirements and the Team Derived requirements.

Table 7.18: Requirements Completion Status

| Requirement Type | Verified | Partially Verified | In Progress | Not Verified |
|---|---|---|---|---|
| NASA Requirements | 47.30 %<br>(35) | 10.81 %<br>(8) | 40.54%<br>(30) | 1.35 %<br>(1) |
| Team Derived Requirements | 29.73%<br>(22) | 8.11%<br>(6) | 59.46%<br>(44) | 2.70%<br>(2) |

### 7.4.2 Requirements Removed since PDR

Since PDR, Team-Derived Requirements have been further refined to better align with NASA guidance that TDRs be non-redundant, verifiable, and directly traceable to hazards or higher-level requirements. Several requirements were removed or consolidated where they duplicated handbook rules, overlapped with other team-derived requirements, or could not be meaningfully verified without excessive assumptions. These changes do not reduce safety or mission assurance; rather, they improve clarity, traceability, and verification as the design matured from PDR to CDR.

- **LVD 8** was removed because a meaningful fin flutter requirement could not be derived without relying on assumptions for Shear Modulus that cannot be directly verified with available analysis or test methods. Given these uncertainties, the resulting flutter velocity estimate would not be sufficiently defensible or traceable to measurable parameters. Fin structural integrity and aerodynamic stability are instead ensured through fin stiffness and strength requirements, and aerodynamic stability requirements that are verifiable. This approach provides a more reliable mitigation of fin-related structural and stability hazards.
- **RF 2** was removed because ground ejection testing is already mandated by NASA Student Launch Rule 3.1. Since Team Derived Requirements are intended to supplement, not duplicate, handbook requirements, retaining RF 2 would result in redundancy rather than additional risk mitigation. Ejection testing will still be conducted in full compliance with Rule 3.1, and recovery reliability is further addressed through team-derived requirements governing black powder calculation methods and verification.
- **PF 4** was removed following refinement of the payload system architecture. Further analysis demonstrated that explicit detection of all flight states is not required for successful or safe payload operation, as payload deployment and operation are instead governed by simpler, condition-based triggers tied to landing and system readiness. Retaining PF 4 would unnecessarily constrain implementation without providing additional hazard mitigation or mission benefits.
- **PF 7** was removed because its intent is fully captured by PF 3, which requires the payload lander to autonomously recognize orienta-

tion and self-right after landing. Successful self-righting inherently ensures the lander achieves and maintains an upright orientation prior to soil collection. Retaining PF 7 would duplicate verification of the same functional behavior without adding additional hazard mitigation or design constraints.

- **PD 1** was removed because its requirements are fully addressed by PF 1, which governs payload packaging and retention within the nose cone. PF 1 already ensures the payload fits within the available volume and does not interfere with recovery system components. Maintaining PD 1 as a separate requirement would duplicate both intent and verification without improving system safety or integration assurance.

### 7.4.3 Competition Requirements

Table 7.19: 2025-2026 General Requirements

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 1.1 | Teams shall engage with their communities in STEM industry or STEM education. To satisfy this requirement teams shall complete either a STEM Industry Engagement Plan and Summary OR a Community STEM Engagement Plan and Summary. Requirements for each can be found in the Engagement section pages 38–40. | The elected Outreach Officer, identified in Section 1.5.1 of Proposal, will create a plan where they identify local organizations to visit, activities to implement, and potential dates and/or schedules to engage communities throughout the fall and spring semesters. They will keep a record of communication, counts of individuals impacted, and photos of events to be shared with the Team Lead before and after the event. | **(1) Inspection:** The Elected Outreach Lead is identified in Proposal.<br>**(2) Demonstration:** The Outreach Officer keeps records of communication throughout the year and runs STEM Engagement activities. | IP | Project Management | **(1)** Proposal [5] (Section 1.5.1) identifies the Outreach Officer.<br>**(2)** As of 7 January 2026, the Outreach Officer has conducted and documented seven outreach events, reaching 670 individuals. |
| 1.2 | The team shall establish and maintain a social media presence to inform the public about team activities | The elected Social Media Officer, identified in section 1.5.1 of Proposal, will maintain and use the team's social media platforms to document progress and events. Platforms include but are not limited to Instagram, Facebook, and LinkedIn. | **(1) Inspection:** The Elected Social Media Officer is identified in Proposal.<br>**(2) Demonstration:** The Social Media Officer posts regularly, keeping members updated on team activities in an engaging and informative way. | IP | Project Management | **(1)** Proposal [5] (Section 1.5.1) identifies the Social Media Officer.<br>**(2)** The Social Media Officer publishes weekly updates and posts content at major project milestones, including launches. |
| 1.3 | Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, supports 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 must adhere to the following requirements: | The Team Lead will identify a mentor who is not affiliated with the team's school. | **(1) Inspection:** The Mentor is identified in Proposal.<br>**(2) Demonstration:** The Team Lead keeps in regular contact with the mentor, utilizing them for design advice. | V | Project Management | **(1)** Proposal [5] (Section 1.2) identifies the team mentor.<br>**(2)** The Team Lead maintains regular communication with the mentor to provide project status updates and design decisions. |
| 1.3.1 | The mentor shall maintain a current certification and be in good standing with the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse class the team intends to use. | The chosen mentor will maintain both good standing with either Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) as well as certification for the motor impulse class that the Aerodynamics Lead decides to use. | **Inspection:** The mentor has a minimum level 2 rocketry certification and is in good standing with TRA officials. | V | Project Management | The selected mentor holds a Level 3 certification and maintains regular contact with the TRA organization. |
| 1.3.2 | The mentor shall have flown and successfully recovered (using electronic, staged recovery) a minimum of two flights in the motor impulse class (or higher) the team intends to use, prior to PDR. | The chosen mentor will have either flown or provided logs of at minimum two successful flights utilizing electronic staged recovery in the motor class the team intends to use. | **Inspection:** The chosen mentor has flown and has a record of two successful flights with electronic deployment. | V | Project Management | The chosen mentor has provided the Team Lead with proof of two successful flights with electronic deployment. |
| 1.3.3 | The mentor must attend all team launches throughout the project year, including launch week, as the mentor is designated the individual owner of the rocket for insurance and liability purposes. | The chosen mentor shall attend all team launches including the competition launch throughout the year as the flyer of record | **Demonstration:** The chosen mentor attends all club launches and is the flyer of record for each competition launch. | PV | Project Management | The chosen mentor has attended the subscale launch and was identified as the flyer of record. |

Table 7.20: 2025-2026 Vehicle Requirements

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 2.1 | The vehicle shall deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). Teams flying below 3,500 feet or above 6,500 feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award. | The Structures and Aerodynamics Leads will design the full Launch vehicle to be capable of delivering the Payload to an apogee between 4,000 and 6,000 ft. AGL. The Structures Lead will facilitate the manufacturing of the launch vehicle with the team. | **(1) Analysis:** Simulations run by the Aerodynamics Lead show the launch vehicle reaching an apogee between 4,000 and 6,000 ft. AGL<br>**(2) Demonstration:** The launch vehicle's recovery altimeter data shows between 4,000 and 6,000 ft. for the VDF and PDF flights | PV | Aerodynamics & Structures | **(1)** Section 3.6.1 shows the launch vehicle reaching a minimum apogee of 4500 (ft) and a max apogee of 5000 (ft), putting the Launch Vehicle inside the NASA Required Range.<br>**(2)** VDF and PDF flights are planned for the spring, see Section 7.5. |
| 2.2 | 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 Recovery Lead and Payload Team will use batteries that have a large enough capacity that they can power all avionic and payload electronics for a minimum of 3 hours without losing the capability of any critical components. The Integration will verify the batteries will function via a ground test before launch | **(1) Analysis:** Electronic power draw combined with battery capacity calculations confirm functionality for >3 hours.<br>**(2) Demonstration:** All avionics and payload electronic systems maintain full operational functionality for > 3 hours. | PV | Payload & Recovery | **(1)** Recovery battery analysis is located in Section 3.5.3. Preliminary payload battery analysis is located in Section 4.5.1.<br>**(2)** VDF and PDF flights which will confirm battery functionality are planned for the spring, see Section 7.5. |
| 2.3 | 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 Aerodynamic lead will perform simulations based off of the Designed Launch Vehicle and determine a target altitude specified in the CDR Report. | **Inspection:** A single, defined target altitude is defined in the CDR report. | IP | Aerodynamics | Declared Apogee and calculations related are located in Section 3.6. |
| 2.4 | 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 will construct a Vehicle capable of withstanding the launch loads expected and the Recovery Lead will design a recovery system that will safely bring the launch vehicle to the ground, with the vehicle being able to launch again within the same day. | **Demonstration:** The launch vehicle is successfully recovered following both VDF and PDF with no structural damage that would deem the vehicle non-launchable. All recovery, payload and Air Brakes electronics are fully functional. | IP | Recovery & Structures | The structure of the launch vehicle is described in Sections 3.2 and 3.3. The recovery system is described in Section 3.5. |
| 2.5 | 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 Structures Lead and Recovery Lead will design the separating points of the rocket for recovery such that there is a maximum of four (4) independent sections, those being defined by NASA Req. 2.5. | **Inspection:** Completed and assembled launch vehicle shows no more than four independent sections. | IP | Recovery & Structures | The locations of the launch vehicle independent sections is described in Section 3.2.2. |
| 2.5.1 | 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). | Structures Lead shall design and manufacture the launch vehicle such that any coupler/airframe shoulders at in-flight separation points shall be at least two airframe diameters in length. | **Inspection:** Completed and assembled launch vehicle shows each in-flight separation point coupler/shoulder is at least two airframe diameters in length. | IP | Structures | The locations and dimensions of the launch vehicle Coupler/airframe shoulders located at in-flight separation points are described in Section 3.2.2. |

Table 7.20: 2025-2026 Vehicle Requirements (continued)

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 2.5.2 | 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.) | Structures Lead shall design and manufacture the launch vehicle such that any coupler/airframe shoulders at in-flight separation points will be at least 1.5 airframe diameters in length. | **Inspection:** Completed and assembled launch vehicle shows each non in-flight separation point coupler/shoulder is at least 1.5 airframe diameters in length. | IP | Structures | The locations and dimensions of the launch vehicle Coupler/airframe shoulders located at non-in-flight separation points are described in Section 3.2.2. |
| 2.5.3 | Nosecone shoulders shall be at least ½ body diameter in length | Structures Lead shall design and manufacture the nosecone such that its shoulder will be at least ½ body diameter in length. | **Inspection:** Completed and assembled launch vehicle shows the nosecone shoulder is at least ½ airframe diameters in length. | IP | Structures | The locations and dimensions of the launch vehicle nosecone shoulder is described in Section 3.2.2. |
| 2.6 | 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 Aerodynamics Lead shall select a motor ignitor that is capable of being launched using the NASA-designated 12-volt direct firing system. | **Demonstration:** The selected motor ignitor reliably initiates motor ignition when connected to a 12 V DC source with a current output of the NASA-designated firing system used during competition. | V | Aerodynamics | Ignitor for motor ignition is identified in Section 3.6.2. |
| 2.6.1 | Each team shall use commercially available ematches or igniters. Hand-dipped igniters shall not be permitted. | The Aerodynamics and Recovery Leads will use commercially available ematches for all pyrotechnic initiations. | **Inspection:** The selected ematches for recovery systems and propulsion systems are commercially available. | V | Aerodynamics & Recovery | Selected E-matches for black powder deployment are identified in Section 3.5.4. Ignitor for motor ignition is identified in Section 3.6.2. |
| 2.7 | 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 motor that uses ammonium perchlorate composite propellant certified by the National Association of Rocketry and/or Tripoli Rocketry Association. | **Inspection:** The chosen Motor shall use ammonium perchlorate composite propellant. The Motor will be sold by a vendor recognized by the National Association of Rocketry and/or Tripoli Rocketry Association. | V | Aerodynamics | The primary and secondary motor choices are identified in Section 3.6.2. |
| 2.8 | The launch vehicle shall be limited to a single motor propulsion system. | The Aerodynamics and Structures Lead will design the launch vehicle such that it utilizes a single motor propulsion. | **Inspection:** The Launch Vehicle design utilizes a single motor propulsion system. | V | Aerodynamics & Structures | The propulsion system is identified in Section 3.6.2. |
| 2.9 | The total impulse provided by a College or University launch vehicle shall not exceed 5,120 Newton-seconds (L-class). | The Aerodynamics will select a motor that does not exceed 5120 Newton-seconds of impulse. | **Inspection:** The motor for the launch vehicle does not exceed 1520 newton-seconds of impulse. | V | Aerodynamics | The primary and secondary motor choices are identified in Section 3.6.2. |
| 2.10 | Pressure vessels on the vehicle must be approved by the RSO and shall meet the following criteria | The Team Lead will inform the RSO of any and all pressure vessels onboard the launch vehicle. | **Inspection:** The launch vehicle is designed such that no pressure vessel system is utilized in the launch vehicle. | V | Project management | Section 3.5 shows the vehicle design with no pressure vessels. |

Table 7.20: 2025-2026 Vehicle Requirements (continued)

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 2.10.1 | The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews | The Structures Lead and Safety team will verify that any and all pressure vessels are designed with a factor of safety of 4:1. | **Inspection:** No pressure vessel system is utilized in the launch vehicle. | V | Recovery & Safety | Section 3.5 shows the vehicle design with no pressure vessels. |
| 2.10.2 | 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 Recovery Lead will design the recovery system such that every pressure vessel will include pressure relief valves that see the pressure of the tank and will be capable of withstanding the maximum pressure and flow rate of the tank. | **Inspection:** No pressure vessel system is utilized in the launch vehicle. | V | Recovery & Safety | Section 3.5 shows the vehicle design with no pressure vessels. |
| 2.10.3 | The full pedigree of the tank shall be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event. | The Safety Team will work with the Recovery team to document all pressure vessels including the number of pressure cycles, dates of pressurization/depressurization, and the name of the person/entity administering each pressure event. | **Inspection:** No pressure vessel system is utilized in the launch vehicle. | V | Recovery & Safety | Section 3.5 shows the vehicle design with no pressure vessels. |
| 2.11 | The launch vehicle shall have a minimum static stability margin of 2.0 while sitting on the pad. | The Aerodynamics Lead shall design the launch vehicle such that it will have a minimum static stability margin of 2.0 while on the pad. | **(1) Analysis:** Analysis shows the projected launch vehicle has a stability a minimum of 2.0 in its launch ready configuration.<br>**(2) Demonstration:** The Launch Vehicle design has a static stability of greater than 2 in its launch ready configuration. | PV | Aerodynamics | **(1)** Section 3.6.5 shows the projected stability margin of the launch vehicle.<br>**(2)** Stability will be confirmed during the VDF flight, scheduled in Section 7.5. |
| 2.12 | The launch vehicle shall have a minimum thrust to weight ratio of 5.0:1.0. | The Aerodynamics Lead and Structures Lead will design the Launch Vehicle to have a minimum thrust to weight ratio of 5.0:1.0. | **Analysis:** The selected motor provides the launch vehicle with a minimum thrust to weight ratio of 5.0:1.0. | V | Aerodynamics & Structures | Section 3.6.2shows the projected thrust to weight of the launch vehicle. |
| 2.13 | Any structural protuberance on the rocket shall be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability. | The Aerodynamics Lead will ensure that any systems that have any structural protuberances are located aft of the center of gravity of the launch vehicle, as well as confirm that any necessary cameras that are located forward of the burnout center of gravity will cause minimal aerodynamic effect to the launch vehicle's stability. | **(1) Inspection:** Any structural protuberance is located aft of the center of gravity.<br>**(2) Analysis:** Any camera housings located forward of the burnout center of gravity cause minimal aerodynamic effect to the launch vehicle's stability. | V | Aerodynamics | **(1)** Section 3.2 shows the location of the Air Brakes system.<br>**(2)** Camera locations is described in Section 5.3. |
| 2.14 | The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit | The Aerodynamics Lead will select a commercially available motor that provides enough thrust such that the velocity of the launch vehicle at the exit of the rail is at minimum 52 fps. | **Analysis:** The selected motor provides the launch vehicle with a velocity off the rod of a minimum of 52 fps. | IP | Aerodynamics | Velocity off the rod analysis is included in Section 3.6.2. |

Table 7.20: 2025-2026 Vehicle Requirements (continued)

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 2.15 | Subscale rockets are required to use a minimum motor impulse class of E | The Aerodynamics Lead will select a Motor with a minimum motor impulse class of E for the subscale launch vehicle. | **Inspection:** The selected motor for subscale has a minimum impulse class of E. | V | Aerodynamics | Subscale motor is outlined in Section 3.4.1. |
| 2.16 | 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 Aerodynamic Lead and Structures Lead will design the subscale launch vehicle to not exceed 75% the dimensions of the full-scale launch vehicle. | **Inspection:** The design of the subscale launch vehicle does not exceed 75% of the dimensions of the full-scale launch vehicle. | V | Aerodynamics & Structures | Subscale launch vehicle design is described in Section 3.4.3. |
| 2.18 | Vehicle Demonstration Flight—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.). | Project Management will ensure that the launch Vehicle Performs a Vehicle Demonstration flight, wherein all associated subsystems (Recovery, Structures, Aerodynamics, etc) perform as intended and in the same configuration as the competition prior to the FRR Deadline. | **Demonstration:** The VDF flight confirms the full functionality of the launch vehicle including the recovery system and structural components. | NV | Project Management | VDF flight is scheduled in the spring, described in Section 7.5. |
| 2.19 | All Lithium Polymer batteries shall be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware. | All Lithium Polymer Batteries used in the launch vehicle will be designed to have adequate housing and labeling to ensure that they are protected from impact as well as identifiable from payload hardware. The Safety Officer and Integration lead will ensure that housings meet these requirements. | **Inspection:** All Lithium Polymer Batteries are adequately housed in the launch vehicle and are identifiable from payload hardware. | IP | Integration & Safety | Recovery batteries are identified in Section 3.5.3. Payload batteries are described in Section 4.5.1. |
| 2.20.1 | The launch vehicle shall not utilize forward firing motors | The Aerodynamics Lead will design the rocket such that it will not utilize forward firing motors. | **Inspection:** The launch vehicle design does not utilize forward firing motors. | V | Aerodynamics | The propulsion system is identified in Section 3.6.2. |
| 2.20.2 | The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.) | The Aerodynamics Lead will design the rocket such that it will not utilize motors that expel titanium sponges. | **Inspection:** The launch vehicle design does not utilize motors that expel titanium sponges. | V | Aerodynamics | The primary and secondary motor choices are identified in Section 3.6.2. |
| 2.20.3 | The launch vehicle shall not utilize hybrid motors | The Aerodynamics Lead will design the rocket such that it will not utilize hybrid motors. | **Inspection:** The launch vehicle design does not utilize hybrid motors. | V | Aerodynamics | The primary and secondary motor choices are identified in Section 3.6.2. |
| 2.20.4 | The launch vehicle shall not utilize a cluster of motors. | The Aerodynamics Lead will design the rocket such that it will not utilize a cluster of motors. | **Inspection:** The launch vehicle design does not utilize cluster motors. | V | Aerodynamics | The propulsion system is identified in Section 3.6.2. |
| 2.20.5 | The launch vehicle shall not utilize friction fitting for motors | The Structures Lead will design a motor retention system that does not utilize friction fitting for the selected motor. | **Inspection:** The launch vehicle design does not utilize friction fitting for motor retention. | IP | Structures | The motor retention system is identified in Section 3.2.8. |

Table 7.20: 2025-2026 Vehicle Requirements (continued)

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 2.20.6 | The launch vehicle shall not exceed Mach 1 at any point during flight | The Aerodynamics Lead will select a motor such that the designed Launch Vehicle does not exceed Mach 1 at any point during its flight. | **(1) Analysis:** The launch vehicle is simulated to reach velocities below mach 1.<br>**(2) Demonstration:** During the VDF flight, altimeter data shows the launch vehicle does not reach velocities above Mach 1. | PV | Aerodynamics | **(1)** Flight profiles depicting velocities during flight are identified in Section 3.6.3.<br>**(2)** VDF flight is planned for the spring, scheduled in Section 7.5. |
| 2.20.7 | Vehicle ballast shall not exceed 10% of the total un-ballasted weight of the rocket, as it would sit on the pad (i.e., a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast). | The Aerodynamics Lead and Structures Lead will Design the Rocket such that any and all potential ballast needed will not exceed 10% of the total Launch Vehicle's un-ballasted weight. | **Inspection:** The launch vehicle's ballast is measured to be less than 10% of the launch vehicle's un-ballasted weight. | IP | Aerodynamics & Structures | Ballast calculations are described in Section 3.6.4. |
| 2.20.7.2 | Ballast must be mechanically retained. Friction fit is not a permissible form of retention. | The Structures Lead will ensure that any and all ballast needed will be mechanically retained without the use of friction fitting. | **Inspection:** The launch vehicle's ballast is designed to be mechanically retained. | IP | Structures | Ballast retention is described in Section 3.2.3. |
| 2.20.7.3 | Ballast shall be removable | The Structures Lead will ensure that any and all ballast needed will be removable. | **Inspection:** The launch vehicle's ballast is designed to be removable. | IP | Structures | Ballast configurations are described in Section 3.2.3. |
| 2.20.7.4 | All requirements found in sections 1 through 5 of this handbook shall be met in both the minimum and maximum design ballast configurations. Where applicable, teams are expected to present calculations and performance metrics for both minimum and maximum design ballast configurations. | Ballast configuration will be identified in the CDR document. | **Analysis:** The launch vehicles minimum and maximum ballast configurations along with associated calculations are located in the CDR report. | V | Aerodynamics | Ballast calculations are described in Section 3.6.4. |
| 2.20.8 | Transmissions from on-board transmitters, which are active at any point prior to landing, shall not exceed 250 mW of power (per transmitter). | The Recovery Lead, Payload Team, and Integration lead will ensure that any Transmissions from on-board transmitters will not exceed 250 mW of power. | **Inspection:** The launch vehicle's design does not utilize any transmissions from on-board transmitters that exceed 250 mW of power. | IP | Integration, Payload, & Recovery | Transmitters for the Recovery System is described in Section 3.5.3. |

Table 7.21: 2025-2026 Recovery Requirements

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|

Table 7.21: 2025-2026 Recovery Requirements (continued)

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | 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 recovery system such that the drogue parachute is deployed at apogee and the main parachute is deployed at a lower altitude. | **Demonstration:** The launch vehicle's altimeters are pre-programmed to deploy its drogue parachute at apogee and main parachute at a specified altitude during descent. This is verified during the VDF flight | IP | Recovery | The recovery system deployment design is located in Section 3.5.1. VDF flight is planned for in the spring, identified in Section 7.5. |
| 3.1.1 | The main parachute shall be deployed no lower than 500 feet. | The Recovery Lead will design the recovery system such that the main parachute is deployed at no lower than 500 feet. | **Demonstration:** The Launch vehicle's altimeters are pre-programmed to deploy its main parachute at an altitude greater than 500 ft during descent. This is verified during the VDF flight. | IP | Recovery | The main parachute deployment design is located in Section 3.5.1. VDF flight is planned for in the spring, identified in Section 7.5. |
| 3.1.2 | The apogee event shall contain a delay of no more than 2 seconds. | The Recovery Lead will design the recovery system such that the drogue event will contain a delay of no more than 2 seconds. | **Demonstration:** The launch vehicle's altimeters are pre-programmed to deploy its drogue parachute no more than 2 seconds after apogee. This is verified during the VDF flight. | IP | Recovery | The drogue parachute deployment design is located in Section 3.5.1. VDF flight is planned for in the spring, identified in Section 7.5. |
| 3.1.3 | Motor ejection is not a permissible form of primary or secondary deployment | The recovery system design will not utilize motor ejection for any deployment events in the recovery system. | **Inspection:** The recovery system design does not utilize motor ejection for any events. | V | Recovery | The recovery system deployment design is located in Section 3.5.1. |
| 3.2 | 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 select or manufacture parachutes such that each independent section will have a maximum kinetic energy of 75 ft-lbf at landing. | **(1) Analysis:** Kinetic energy calculated for each section has a maximum kinetic energy of 75 ft-lbf.<br>**(2) Demonstration:** During VDF the drogue and main parachute delivers each individual launch vehicle section to the ground with a maximum kinetic energy of 75 ft-lbf. | PV | Recovery | **(1)** Kinetic energy calculations are described in Section 3.6.7.<br>**(2)** VDF flight is planned for in the spring, identified in Section 7.5. |
| 3.3 | The recovery system shall contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. The term "altimeters" includes both simple altimeters and more sophisticated flight computers. | The Recovery Lead will design the recovery system such that they utilize commercially available barometric altimeters for the initiation of recovery events. | **Inspection:** The recovery system design utilizes commercially available barometric altimeters for recovery events. | V | Recovery | Recovery altimeters are described in Section 3.5.3. |
| 3.4 | 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 avionics system for the recovery system such that each altimeter has a dedicated power supply utilizing commercially available batteries. | **Inspection:** The recovery system avionics are designed to be powered with individual and commercially available batteries. | V | Recovery | Batteries used for the recovery system are identified in Section 3.5.3. |

Table 7.21: 2025-2026 Recovery Requirements (continued)

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 3.5 | 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 it may be armed using mechanical arming switches that are accessible from the exterior of the launch vehicle while it is on the launch pad. | **Demonstration:** The recovery system design utilizes mechanical arming switches accessible from outside the launch vehicle. | IP | Recovery | Mechanical arming switches used in the recovery system are identified in Section 3.5.3. |
| 3.6 | 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 utilize arming switches such that they are capable of being locked in the on position regardless of flight forces experienced during the launch. | **Demonstration:** The recovery system design utilizes mechanical arming switches that lock into the ON position for the duration of the flight and are incapable of being disarmed due to flight forces. | IP | Recovery | Mechanical arming switches used in the recovery system are identified in Section 3.5.3. |
| 3.7 | 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 any and all avionics used in the system are completely independent of any and all payload electrical circuits. | **Inspection:** All recovery system electrical circuits are separate from any payload electrical circuits. | V | Recovery | The recovery system electrical circuits are located in Section 3.5.3. |
| 3.8 | 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 such that shear pins will be used for both main and drogue parachute compartments. The Structures Lead will ensure the launch vehicle is designed such that shear pins will be to retain the main and drogue compartments. | **Inspection:** The recovery system is designed such that separating sections utilize shear pins. | V | Recovery & Structures | The shear pin use is described in Section 3.5.4. |
| 3.9 | Bent eyebolts shall not be permitted in the recovery subsystem. | The Structures Lead will ensure that any connection points between shock cord and structural elements of the launch Vehicle (bulkheads) will not utilize bent eyebolts. | **Inspection:** The launch vehicle design ensures no connection points between the shock cord and elements of the launch vehicle utilizes bent eyebolts. | V | Structures | Section 3.2.5 details connection points between shock cord and structural elements of the launch vehicle. |
| 3.10 | The recovery area shall be limited to a 2,500 ft. radius from the launch pads. | The Recovery Lead will select appropriately sized parachutes to be used for the recovery system such that the Launch Vehicle does not drift more than 2,500 ft. from the launch pads. | **(1) Analysis:** The Recovery system calculates lateral drift distance from the launch pad under the maximum allowable wind speed to be less than 2,500 ft.<br>**(2) Demonstration:** Drift distance is verified using GPS coordinates obtained during VDF. | PV | Recovery | **(1)** Drift distance calculations are described in Section 3.6.9.<br>**(2)** Drift distances will be verified during VDF, scheduled in Section 7.5. |
| 3.11 | Descent time of the launch vehicle shall be limited to 90 seconds (apogee to touch down). Teams whose launch vehicle descent, as verified by vehicle demonstration flight data, stays under 80 seconds will be awarded bonus points. | The Recovery Lead will select appropriately sized parachutes to be used for the recovery system such that the launch vehicle's descent time is under 90 seconds. | **(1) Analysis:** The recovery system is designed such that the parachutes will deliver the launch vehicle to the ground in under 90 seconds.<br>**(2) Demonstration:** VDF flight confirms descent time is under 90 seconds. | PV | Recovery | **(1)** Descent time calculations are described in Section 3.6.8.<br>**(2)** Descent will be verified during VDF, scheduled in Section 7.5. |

Table 7.21: 2025-2026 Recovery Requirements (continued)

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 3.12 | Electronic GPS Tracking device(s) shall be installed in the launch vehicle and will transmit the position of the tethered vehicle and any independent section(s) to a ground receiver. | The Recovery Lead will utilize electronic GPS tracking devices in every untethered independent section of the launch vehicle that are capable of transmitting position of the section to a ground receiver. | **(1) Inspection:** The recovery system is designed with GPS tracking devices in each untethered independent section.<br>**(2) Test:** GPS transmitters are ground tested to confirm functionality.<br>**(3) Demonstration:** VDF confirms functionality of GPS tracking devices. | IP | Recovery | **(1)** GPS tracking devices are specified in Section 3.5.3.<br>**(2)** Ground testing procedures are described in Section 7.2.3.<br>**(3)** GPS tracker functionality will be verified during VDF, scheduled in Section 7.5. |
| 3.13.1 | 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 an avionics system such that any altimeters used will be physically separated from any radio frequency transmitting device or magnetic wave producing device. | **Inspection:** The launch vehicle is designed such that all radio frequency transmitting devices and/or magnetic wave producing devices are located separate from any recovery avionics. | V | Recovery | Sections 5, 3, and 4 shows besides the Recovery transmitter, there are no other radio frequency transmitting devices or magnetic wave producing device. |
| 3.13.2 | 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 an avionics system such that any recovery electronics used will be shielded from any transmitting devices. | **Inspection:** Recovery system electronics are physically and electrically isolated from all onboard transmitters. | V | Recovery | Sections 5, 3, and 4 shows besides the Recovery transmitter, there are no other radio frequency transmitting devices or magnetic wave producing device. |
| 3.13.3 | 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 an avionics system such that any recovery electronics are shielded from any magnetic wave producing devices. | **Inspection:** Recovery system electronics are physically and electrically isolated from all onboard devices that generate magnetic waves. | V | Recovery | Sections 5, 3, and 4 shows besides the Recovery transmitter, there are no other radio frequency transmitting devices or magnetic wave producing device. |
| 3.13.4 | 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 avionics system such that any recovery electronics are shielded from any devices on the launch vehicle that may affect the proper operations of the recovery system electronics. | **Inspection:** Recovery system electronics are physically and electrically isolated from all onboard devices that might adversely affect the operation of the recovery system. | V | Recovery | Sections 5, 3, and 4 shows besides the Recovery transmitter, there are no other radio frequency transmitting devices or magnetic wave producing device. |

Table 7.22: 2025-2026 Payload Requirements

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 4.1 | After landing, teams shall autonomously collect and retain a soil sample of at least 50 milliliters. | The Payload Team will design a payload that can autonomously collect 50 ml of soil from the landing site. | **Demonstration:** Upon landing the payload collects a minimum of 50 ml of soil from the landing site. | IP | Payload Team | Payload soil collection is described in Section 4.4.1. |
| 4.1.1 | All soil collection and analysis must be completed within 15 minutes of landing. | The Payload Team will design the payload such that it will collect the soil sample within 15 minutes of the launch vehicle landing. | **Demonstration:** Upon landing the payload collects a minimum of 50 ml of soil from the landing site within 15 minutes. | IP | Payload Team | Payload Concept of Operation s is described in Section 4.3. |

Table 7.22: 2025-2026 Payload Requirements (continued)

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 4.2 | Teams shall autonomously test the collected sample for at least one of the following: Nitrate-Nitrogen content, pH level, or electrical conductivity | The Payload Team will design the payload such that it is able autonomously test soil samples for its Nitrate-Nitrogen content, pH level, and Electrical Conductivity. | **Demonstration:** The payload tests collected soil sample for Nitrate-Nitrogen content, pH level, and Electrical Conductivity. | IP | Payload Team | Payload Sensor is described in Section 4.5.1. |
| 4.2.1 | Analysis results shall include time stamps for verification. | The Payload will be programmed such that it includes timestamps for every important Analysis result. | **Demonstration:** The payload logs and collects timestamps for each state change. | IP | Payload Systems Lead | Payload Software design is described in Section 4.3. |
| 4.2.2 | The results of these tests shall be included in the PLAR. Preliminary results shall be made available for confirmation by the NASA Student Launch management team at the competition launch. | The Payload Team will extract and document all analysis from any tests conducted by the payload in the PLAR Document. | **Inspection:** The PLAR document contains all test results from the competition flight. | IP | Payload Team | The PLAR document will contain all test results from the competition flight. |
| 4.4 | The HAUS's structure shall include an atmosphere isolated compartment to serve as living quarters for 4 STEMnauts. The compartment shall be enclosed and separated from the external atmosphere;No additional requirements for "living conditions" are included, ... | The Payload Structures Lead will design a HAUS enclosure to serve as living quarters for 4 STEMnauts. The HAUS enclosure will be separate from the external atmosphere, with a hole to equalize pressure if deemed necessary. | **Inspection:** The Payload contains the HAUS enclosure where STEMnauts live separate from the external atmosphere. | IP | Payload Structures | HAUS design is located in Section 4.4.1. |
| 4.4.1 | The HAUS enclosure shall not incorporate or rely on the structural airframe (including couplers) of the launch vehicle to meet requirement 4.4. | The Payload Structures Lead will design the HAUS enclosure such that it does not incorporate or rely on any structural components of the launch vehicle. | **Inspection:** The HAUS enclosure does not incorporate or rely on any structural components from the launch vehicle. | IP | Payload Structures | HAUS design is located in Section 4.4.1. |
| 4.5 | The STEMnauts shall be safely retained within the HAUS during flight (no alternative launch seating or location is permitted). | The Payload Structures Lead will design the HAUS enclosure such that all STEMnauts are safely retained during the flight. | **Inspection:** The HAUS enclosure contains seating such that STEMnauts are safely secured for flight operations. | IP | Payload Structures | STEMnaut housing is described in Section 4.4.1. |
| 4.6 | 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 Structures Lead will design the payload such that there are no protrusions that extend more than a quarter inch outside the exterior of the airframe. | **Demonstration:** The payload is designed such that it does not protrude from the launch vehicle more than a quarter inch. | V | Payload Structures | Payload Design in Section 4.2 confirms no protrusion from the launch vehicle. |
| 4.7.1 | Black powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations. | The Payload Team will design the Payload such that it does not use Black Powder or any other similar energetics for any surface operations of the Payload. | **Inspection:** The payload will not utilize black powder or similar energetics to deploy. | V | Payload Team | See Section 4.2, showing that the payload design does not utilize black powder or similar energetics. |
| 4.7.2 | Any UAS weighing more than .55 lbs. shall be registered with the FAA and the registration number marked on the vehicle. | The Payload Team will register any UAS that weighs more than .55 lbs with the FAA and will follow all rules and regulations set by the FAA including labeling and markings on the UAS. | **Inspection:** The payload will not jettison from the launch vehicle. | V | Payload Team | See Section 4.2, detailing how the payload design does not utilize jettisoning components. |

Table 7.23: 2025-2026 Safety Requirements

| ID | SHALL Statement | Planned Action | Verification Method & Success Criteria | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|
| 5.1 | The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations. | The Project Management Lead alongside the Integration Lead and Safety Officer will write a final checklist for launch operations to be used during launch days. This Checklist will be included in FRR report, present during the LRR, and during any Launch Day operations. | **(1) Inspection:** The launch day checklist is located in the FRR and is present during LRR.<br>**(2) Demonstration:** The final launch day checklist is used during launch day including during VDF and PDF. | V | Project Management, Integration & Safety | Launch Checklists are located in Section 6.1. |
| 5.2 | Each team shall identify a student safety officer. See rule 5.2 for all guidelines pertaining to the student safety officer. | The team will democratically elect a Safety Officer. The Safety Officer will follow all rules in the NASA SL Handbook rule 5.2. | **(1) Inspection:** Elected Safety Officer is defined in Proposal.<br>**(2) Demonstration:** The Safety Officer follows all rules defined by rule 5.2 in the NASA SL Handbook. | IP | Project Management | **(1)** See Proposal [5] (Section 1.5.1) for identified Safety Officer.<br>**(2)** The Safety Officer continues to follow all rules described in the NASA SL Handbook rule 5.2. |

### 7.4.4 Vehicle Team Derived Requirements

Table 7.24: 2025-2026 Team Derived Vehicle Requirements

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| | | | Functional Requirements | | | | |
| LVF 1 | All composite structural components made for the launch vehicle SHALL be manufactured such that no major defects (voids, delaminations, or dry spots) are present in load bearing areas. | The Structural Design Hazard Analysis identifies composite manufacturing defects (DHZ 6-10) as credible risks that can lead to structural failure or loss of stability. Ensuring composite quality directly mitigates these hazards and preserves required structural integrity during flight. | Composite components will be manufactured using documented layup and curing procedures. Each part will undergo visual inspection. Any part not meeting acceptance criteria will be repaired or rejected prior to integration. | **Inspection:** No defects exceeding acceptance criteria detected in any load-bearing composite region. | IP | Structures | Detailed manufacturing processes for composite components are described Section 3.3. Reference [3] lists composite manufacturing standards. |
| LVF 2 | The Launch Vehicle SHALL contain uniform fin size and geometry | The Structural Design Hazard Analysis identifies fin instability and structural risks (DHZ 7, 8) as credible hazards that can lead to unstable or unpredictable flight. Consistent fin geometry and mass ensure the aerodynamic center and stability margins match trajectory predictions. Maintaining uniform fins mitigates asymmetric aerodynamic loading, reduces the likelihood of instability, and preserves the stability margin assumed in analysis. | Each manufactured fin will be measured, weighed and documented. Any fin outside a tolerance of +- 2mm geometry or 5% weight difference will be reworked or rejected. | **Inspection:** Fins are compared and shown to have the same mass and geometry with negligible differences. | IP | Structures & Aerodynamics | Section 3.2.8 describes fin design and Section 3.3.5 describes Fin manufacturing. |

Table 7.24: Team Derived Vehicle Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| LVF 3 | All bonded structural joints SHALL undergo documented surface preparation including abrasion, cleaning, and solvent wipe prior to epoxy bonding. | Bonded joints are points of structural loading, and if they fail high risk failures could occur (DHZ 6, 16, 17). Proper surface preparation mitigates these hazards and supports structural integrity. | A standard surface prep procedure for bonded components will be implemented. Bonded surfaces will be prepared and inspected prior to epoxy joining. | **Inspection:** Standard surface preparation procedures for bonding surfaces will be followed. | IP | Structures | Detailed surface preparation processes for composite components are described in Reference [3]. |
| LVF 4 | Airframe, fins, and nosecone SHALL be manufactured such that the external surface is smooth. | Aerodynamic modeling used to predict flight characteristics benefit from assuming smooth external surfaces. Surface roughness can alter these characteristics so ensuring a smooth surface allows for better predictions. | Final finishing and surface sanding will be applied to all external launch vehicle surfaces. Inspection will verify smooth surfaces across seams. | **Inspection:** No visible ridges, rough surface texture, or discontinuities is seen across seams or transitions. | IP | Structures | Section 7.5 details the manufacturing timeline for full-scale. |
| LVF 5 | Apogee predictions SHALL be validated with at least three separate analysis programs. | NASA Requirement 2.3 states that teams must state their predicted apogee. Using different apogee prediction software reduces errors that may be prone in any one software. Increasing the accuracy of our predicted apogee and trajectory allows for a better understanding of how the launch vehicle will performs, allowing a more likely apogee to be chosen. | Aerodynamics Lead will run simulations in OpenRocket, RocketPy, and RasAERO | **Analysis:** Apogee predictions from OpenRocket, RocketPy, and RasAERO will be included in CDR. | V | Aerodynamics | Apogee predictions from OpenRocket, RocketPy, and RasAERO are included in section 3.6. |
| LVF 6 | The Launch Vehicle Shall not be overstable, defined as having a static stability >4. | NASA Requirement 3.10 requires the launch vehicle drifts less than 2,500 (ft) from the launch pad. Vehicles with excessive stability are more likely to weathercock, increasing horizontal travel and creating greater risk of violating this requirement. Setting the bound at 4 calipers maintains compliance with NASA Requirement 2.11 as well. | Final center of gravity and center of pressure will be determined using mass properties and aerodynamic simulation. Stability will be calculated prior to flight. | **(1) Demonstration:** The launch vehicle has a stability less than 4 in its final launch configuration.<br>**(2) Analysis:** Simulated static margins are < 4 for all configurations. | PV | Aerodynamics | **(1)** VDF and PDF flights are described scheduled in Section 7.5.<br>**(2)** Stability calculations are described in Section 3.6.5. |
| Design Requirements | | | | | | | |
| LVD 1 | Fins SHALL withstand an impact event of 75 ft-lbf kinetic energy without structural failure or permanent deformation that degrades aerodynamic stability. | Fins structural integrity is critical to ensuring the launch vehicle is both stable and reusable (NASA Req 2.4 and 2.11). Structural Design Hazards also show a high risk if any composite component (fins included) fail (DHZ 6, 8, 9, 10, 16 and 17). Ensuring fins withstand an impact of 75 ft-lbf mitigates these hazards and preserves required flight stability and reusability. | The Fin Can assembly will be subjected to controlled drop-impact testing to evaluate survivability under a 75 ft-lbf impact event. | **Test:** Fin Can Drop test shops survivability under a 75 ft-lbf impact event. | IP | Structures | Three point bending tests are described in Section 3.2.4 of PDR. Fin Structural integrity is described in Section 3.2.11. Fin Can Drop test is described in Section 7.2.8. |

Table 7.24: Team Derived Vehicle Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| LVD 2 | Composite airframes and centering rings SHALL be designed to withstand axial compressive loads equivalent to at least twice the motor's maximum thrust. | Airframe deforming would result in failure to meet NASA Req 2.4 requiring the launch vehicle is reusable. Axial compressive integrity is necessary to prevent the airframe from buckling or collapsing during flight. Designing composites to withstand twice the amount of loading from the motor ensures the launch vehicle will not deform. | Compression testing will be done on sample composite airframe material and verified to withstand twice the motors thrust forces. | **Test:** Compressive testing on sample composites show a breaking point of more than twice the motors thrust. | V | Structures | Compressive tests are described in Section 7.2.7. |
| LVD 3 | Composite bulkheads SHALL be designed to withstand tensile loading of at least 621 (lbf). | In order for a successful launch meeting reusability and recovery requirements, bulkheads must be capable of withstanding parachute deployment shocks without failure. Failure of bulkheads not only results in failure of NASA Requirements, but also causes risks identified in the Design Hazard risks (DHZ 26). By requiring bulkheads to withstand loading of a minimum of 624 (lbf), A factor of safety of 1.5 is applied (Section sec:Recovery Hardware). | A universal tensile testing machine will be utilized and confirmed to withstand at minimum 621 lbs of force. | **Test:** Tensile tests show Bulkheads withstanding loads greater than 300 lbs. | IP | Structures | Bulkhead testing is described in Section 7.2.6. |
| LVD 4 | Radio-frequency transparent materials SHALL be used on all launch vehicle sections through which RF signals must be transmitted or received. | NASA Requirement 3.12 requires that GPS tracking devices to be used on the launch vehicle. RF-opaque materials such as carbon fiber can damage GPS and telemetry signals, risking loss of the loss vehicle. Using RF-transparent materials in transmitting sections mitigates these risks and supports compliance with NASA tracking and telemetry requirements. | All rocket sections that house GPS, telemetry, or communications devices will be constructed from fiberglass or other RF-transparent composite instead of carbon fiber. | **Inspection:** All vehicle sections containing RF transmitters or receivers are constructed from RF-transparent material such as fiberglass. | IP | Structures | Material selection for the launch vehicle components is described in Section 3.2.11. |
| LVD 5 | All airframe attachments points for rail buttons SHALL be reinforced | Before launch, the launch vehicle relies on the rail buttons in order to stay on the launch rail, and after ignition of the motor, the the rail buttons carry loads as the launch vehicle accelerates. The launch rail keeps the launch vehicle steady and directed upwards while the launch vehicle accelerates to the NASA Required rail exit velocity of 52 fps (NASA Requirement 2.14). Failure or deformation at rail button interfaces could cause rail binding, or trajectory deviation. Reinforcing rail button attachment locations mitigates this structural hazard and supports compliance with NASA Requirement 2.14. | The fin can and surrounding airframe structure will incorporate localized reinforcement as epoxy filets or mounted inside centering rings at rail button mounting locations to distribute load and prevent structural damage. | **Inspection:** Reinforcement is visibly present and documented at all rail button attachment locations in the built vehicle. | IP | Structures | Fin can manufacturing including rail button attachments are described in Section sec:Fin Can Manufacturing. |

Table 7.24: Team Derived Vehicle Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| LVD 6 | Any hardware used to secure sections of the Launch Vehicle SHALL be designed to minimize drag on the launch vehicle. | Aerodynamic modeling used to predict flight characteristics benefit from assuming smooth external surfaces. Reducing unnecessary drag by utilizing hardware flush with the outer airframe helps maintain agreement between predicted and actual performance and supports stable flight behavior. | All hardware chosen to adjoin any different airframe sections will only protrude at max 1/8 (inch), causing minor drag. | **Inspection:** No adjoining hardware protrudes more than 1/8 (inch) from the external vehicle surface. | IP | Structures | Adjoining section hardware are described in Section 3.2.2. |
| LVD 7 | The motor mount SHALL be designed to securely retain the selected motor and transmit thrust loads to the airframe. | Loss of motor retention can cause the motor to either push through the launch vehicle, damaging the internal components or causing the motor to fall out of the launch vehicle after burnout (DHZ 5). Secure motor retention is critical to prevent in-flight structural failure and vehicle instability. A secure motor retention system ensures these hazards are mitigated. | The motor mount will be designed to withstand all expected loading during flight. | **Inspection:** The installed motor cannot translate or rotate within the motor mount; all retention hardware is secure and properly installed. | IP | Structures | Motor retention is described in Section 3.2.8. |
| Environmental Requirements | | | | | | | |
| LVE 1 | All leftover epoxy-resin materials SHALL be properly disposed of per manufacturer's instructions. | Improper disposal of epoxy materials presents chemical exposure risk to personnel and potential environmental harm (EHZ 1). Safety Data Sheets specify disposal procedures to prevent hazardous exposure, accidental contact, and unsafe material handling. Following manufacturer and SDS disposal guidelines mitigates these risks and supports safe laboratory and fabrication operations. | Team members will follow the manufacturer's disposal guidelines for all leftover epoxy and resin materials. Containers will be labeled, and epoxy waste will be collected in designated waste areas. | **Inspection:** All epoxy waste is stored in clearly labeled containers, handled per SDS instructions, and disposed of properly once cured. | IP | Structures & Safety | Proper epoxy handling procedures are based off of SDS Sheets located in Reference [13]. |
| LVE 2 | All structural components SHALL be designed to operate nominally with an ambient temperature range of 25°F to 100°F | Launch day conditions can vary in temperature, historically between 25°F to 100°F. Designing structural components to remain functional across 25°F to 100°F ensures consistent structural integrity and safe vehicle operation across expected environmental conditions. Composite property materials can be affected by differences in temperature, which is why materials chosen must be operational during all potential launch day conditions. | Materials such as fiberglass, carbon fiber, and compatible adhesives with demonstrated performance across 25°F to 100°F will be selected for structural components. | **(1) Analysis:** Structural materials and adhesives are verified through documentation or engineering analysis to maintain sufficient strength and performance from 25°F to 100°F.<br>**(2) Demonstration:** Structural components experience no failure or degradation during ground and flight operations conducted within the specified temperature range. | PV | Structures & Safety | **(1)** Material properties are described in Section 3.2.11.<br>**(2)** VDF is scheduled for the spring, detailed in Section 7.5 . |

Table 7.24: Team Derived Vehicle Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| LVE 3 | All structural components SHALL be resistant to ambient humidity up to 90% relative humidity without degradation in adhesive or performance. | Launch day humidity conditions can vary and may affect composite materials . High humidity can reduce adhesive strength and degrade structural margin if not accounted for. Selecting materials and adhesives proven to perform at up to 90% relative humidity when cured mitigates these risks. A 90% relative humidity threshold was selected to represent near-saturation ambient conditions while avoiding unrealistic condensation scenarios not expected during launch day operations. | Materials and adhesives will be selected based on documented manufacturer data and prior aerospace use demonstrating structural stability and adhesive performance at up to 90% relative humidity. | **(1) Analysis:** Documentation or engineering analysis confirms that selected structural materials and adhesives maintain required performance at humidity levels up to 90%.<br>**(2) Demonstration:** Structural components exhibit no structural degradation, adhesive weakening, or failure attributed to ambient humidity during ground and flight operations. | PV | Structures | **(1)** Material properties are described in Section 3.2.11.<br>**(2)** VDF is scheduled for the spring, detailed in Section 7.5. |
| LVE 4 | Structural components SHALL be capable of withstanding ground impact from soil, gravel or sparse vegetation without compromising future reusability. | Launch vehicle landings can occur on variable terrain including soil, gravel, or light vegetation, and structural components must survive impact without critical damage to ensure reusability and kinetic energy requirements (NASA Req 2.4, 3.2). Maintaining structural integrity upon landing supports recovery requirements and mitigates structural damage. | Structural components will be designed using impact-resistant composite materials with adequate toughness. Drop will be performed on representative components to verify survivability. | **(1) Testing:** Drop testing demonstrates structural components withstand expected landing impact loads without structural failure or permanent damage affecting reuse.<br>**(2) Demonstration:** Vehicle Demonstration Flight confirms that structural components remain intact and reusable following landing. | IP | Structures | **(1)** Fin can drop test is described in Section 7.2.8.<br>**(2)** VDF is scheduled for the spring, detailed in Section 7.5 . |
| LVE 5 | Aerodynamics simulations SHALL perform analysis quantifying apogee variation for wind speeds up to 20 mph | Wind can greatly affect flight trajectory and apogee. By performing simulations under extreme environmental conditions allows for the team to ensure the launch vehicle will perform during adverse wind conditions. | Aerodynamics Lead will conduct simulations with wind speeds up to 20 mph | **Analysis:** Trajectory simulations clearly document apogee variation from 0 to 20 mph wind speeds and are reviewed to confirm implications for safe launch operations. | V | Aerodynamics | Trajectory simulations with varying wind speeds are described in Section 3.6.4. |
| Safety Requirements | | | | | | | |
| LVS 1 | All structural elements of the Launch Vehicle SHALL be designed to withstand expected launch loads with a minimum factor of safety of 1.5. | The Structural Design Hazard Analysis identifies Composite Component Failure, Fin Flutter and Fracture, and Delamination/Bond Failure (DHZ 6-9) as high-severity risks that could result in structural failure, fin loss, or unstable flight. Structural loads can exceed nominal predictions due to aerodynamic uncertainty, vehicle dynamics, and manufacturing variability. Designing all structural elements with a minimum factor of safety of 1.5 provides margin against these uncertainties, reducing the likelihood of these hazards occurring and supporting safe flight performance. | All structural components will be sized using expected internal and external launch loads. Structural analyses will confirm a minimum factor of safety of 1.5. | **Analysis:** Structural analysis demonstrates each component achieves a factor of safety ≥ 1.5 under expected flight loads. | V | Structures | Structural component strength calculations are shown in Section 3.2.9. |

Table 7.24: Team Derived Vehicle Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Sta-tus | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| LVS 2 | When cutting or sanding composites, proper particulate masks shall be worn at all times, accumulation of dust in air shall be minimized | Composite dust and particulate debris present respiratory and health hazards and can cause irritation or injury if inhaled or contacted (PHZ 6, 13,26). Safety Data Sheets warn of toxic particulate exposure if proper respirators and dust-control measures are not used. Wearing PPE and minimizing dust accumulation mitigates these hazards ensuring safe fabrication practice. | When cutting or sanding composites, all members will be required to wear proper particulate masks. When dust accumulation is expected to be large, the vacuum will be used as a mitigation measure. All workspaces will be cleaned after use. | **(1) Inspection:** Workspace is inspected after composite work; debris and dust accumulation are removed and area is clean.<br>**(2) Demonstration:** Team members cutting or sanding composites are observed wearing appropriate particulate masks and PPE. | IP | Structures & Safety | **(1) & (2)** Proper composite manufacturing procedures are based off of SDS Sheets located in Reference [13]. Detailed composite manufacturing processes for composite components are described in Reference [3]. |
| LVS 3 | Manufacturing of the Launch Vehicle SHALL be completed a minimum of 24 hours before any and all launches. | Composite failures are identified as high-severity risks (DHZ 6,9,10,15-17), as well as high stress (PHZ 56), allowing adequate time for curing and inspection directly mitigates these hazards and supports safe launch operations. Completing manufacturing at least 24 hours before launch allows time for adhesive curing, final inspection, and quality assurance without schedule pressure. | The manufacturing schedule will be structured so all fabrication, structural bonding, and curing operations are completed at least 24 hours prior to launch to allow final review and inspection. | **Inspection:** All launch vehicle structural components are ready for assembly at least 24 hours before launch. | IP | Structures & Safety | See Section 7.5 for full-scale manufacturing schedule. |
| LVS 4 | When cutting any components using any power tool, components SHALL be properly secured such that they do not move due to any forces from the power tool. | Personnel Hazards (PHZ 12) unsecured components can shift, vibrate, or spin unexpectedly under power-tool loading, causing risk of personal injury and potentially damaging parts. Securing components prior to machining directly mitigates these documented hazards and ensures safe fabrication practices. | All components will be clamped, held in jigs, or otherwise secured before any cutting or machining operations. Personnel will be trained in proper techniques and use of clamps, vises, and other securing tools. | **Demonstration:** Prior to cutting or machining, each component is visibly secured (clamped, jigged, or fixtured) such that it does not move during operation. | IP | Structures & Safety | Proper power tool usage is described in Reference [11]. |
| LVS 5 | When using any power tools, proper PPE such as safety glasses SHALL always be enforced. | Power tool usage present risk of impact injury, laceration, and eye damage from debris and sudden tool motion (PHZ 8-12, 16,19-20). Enforcing PPE such as safety glasses mitigates these hazards and ensures safe manufacturing operations. | All personnel using power tools of any kind will be properly trained and proper PPE will be worn at all times. | **(1) Inspection:** All team members pass a safety quiz documented by the Safety Officer; PPE requirements are clearly communicated and acknowledged.<br>**(2) Demonstration:** Any team member using power tools is observed correctly wearing required PPE and following approved safe operating procedures. | IP | Safety | **(1)** Safety quiz is documented in Reference [12].<br>**(2)** Proper power tool usage is described in Reference [11]. |

Table 7.24: Team Derived Vehicle Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| LVS 6 | All solvent-based cleaning methods SHALL be conducted in a well ventilated area. | Solvent-based cleaners release volatile organic compounds that can create inhalation, respiratory, and ignition hazards if used in confined or poorly ventilated spaces (PHZ 5). Conducting solvent cleaning only in well-ventilated areas mitigates these hazards and ensures safe working conditions. | All solvent based cleaning operations will be performed either outside or in a well ventilated area. | **Demonstration:** Cleaning operations are conducted in designated ventilated areas. | IP | Structures & Safety | Proper solvent based cleaning procedures is described in Reference [11]. |

### 7.4.5 Recovery Team Derived Requirements

Table 7.25: 2025-2026 Team Recovery Vehicle Requirements

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| Functional Requirements | | | | | | | |
| RF 1 | Parachutes SHALL be packed using reputable rocketry manufacturers guidelines for folding and packing. | Improper packing techniques can cause parachutes to partially inflate, shroud lines to be tangled, or delayed deployment. This can cause an increase in descent rate, causing the launch vehicle to fail to meet kinetic energy requirements (NASA Req 3.2), this can also cause the launch vehicle to come in ballistic (DHZ 26). Using manufacturer-recommended folding and packing methods mitigates these risks. | All team members responsible for packing parachutes will be trained in manufacturer recommended packing methods, and each packed parachute will undergo visual inspection prior to flight. | **(1) Inspection:** Parachutes are visually inspected by a Recovery Lead after packing to verify correct folding, line routing, and stow placement.<br>**(2) Demonstration:** Parachutes used in flight are confirmed to have been packed using manufacturer-recommended procedures. | IP | Recovery | **(1)** and **(2)** Parachute folding and packing is described in Pre-flight checklists, described in Section 6.1. Proper packing is also described in Reference [7], [6]. |
| RF 3 | GPS Recovery electronics SHALL be tested before use on the launch vehicle. | NASA Requirement 3.12 requires that GPS tracking devices to be used on the launch vehicle. Loss of tracking capability may lead to a delayed or failed recovery and failure to meet NASA tracking requirements. Pre-flight testing verifies correct GPS acquisition, communication, and data reception reliability, reducing the likelihood of recovery GPS failure. | Prior to launch, GPS recovery electronics will undergo ground testing to verify signal acquisition, communication reliability, location accuracy, and ground station functionality. | **Test:** Ground testing confirms GPS units power on, acquire satellites, transmit valid coordinate data, and display correct location information. | IP | Recovery | Ground testing is described in Section 7.2.3. |
| RF 4 | Post-flight inspections SHALL be done for any and all recovery components including parachutes, harnesses and altimeter housings. | NASA Requirement 2.4 requires that the launch vehicle is completely reusable, thus all recovery components must also be able to be reused. Recovery components experience significant loading during deployment, inflation, descent, and landing. Inspection allows confirmation that the Recovery system survived all loads and is reusable. | After each flight, the Recovery Lead will inspect all recovery components for fraying, tearing, deformation, thermal damage, hardware deformation, or electronic enclosure damage. Any damaged components will be repaired or replaced prior to future flight use. | **Inspection:** Post-flight inspection is documented for all recovery components. Visual inspection confirms no unacceptable wear or structural degradation; any damaged components are removed from service and repaired or replaced prior to reuse. | NV | Recovery | VDF is scheduled for the spring, detailed in Section 7.5 . |

Table 7.25: Team Derived Recovery Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| RF 5 | The full recovery system SHALL be dry fitted at least once before Launch Day. | Mechanical tolerances, component interfaces, and harness routing can lead to interference or misalignment that may only become apparent during final assembly. Such issues can prevent proper separation or parachute deployment, resulting in unsafe descent or recovery failure (DHZ 26-28). Performing a full dry fit prior to launch mitigates these risks. | A complete dry fit of the recovery system will be conducted prior to launch day. Any identified fitment or interference issues will be corrected and verified through a follow-up inspection. | **Inspection:** Successful full recovery system dry fits prior to launch. All components assemble and disassemble without interference and no additional modifications are required. | IP | Recovery | VDF is scheduled for the spring, detailed in Section 7.5 . |
| RF 6 | Black powder separation charge calculations SHALL utilize reputable, validated calculation methods. | Failure to correctly size black powder charges can lead to an incomplete separation, which causes the launch vehicle to enter a ballistic descent (NASA Req 3.2, DHZ 31 and 32), and can also lead to internal components being damaged from ejection gases (DHZ 61).Using reputable, validated charge-calculation methods mitigates the risk of uncertainty in ejection performance, ensuring a safe recovery. | All black powder charge calculations will be performed using established and validated tools. Each calculation will be independently checked using Chuck Pierce's Black Powder Ejection Charge Calculator to confirm accuracy. | **Analysis:** Documented black powder charge calculations demonstrate appropriate ejection pressurization and are verified using Chuck Pierce's Ejection Charge Calculator. | V | Recovery | Black powder calculations are described in Section 3.5.4. |
| RF 7 | All team-fabricated parachutes SHALL be tested and verified to withstand all expected deployment and descent loads prior to use on the launch vehicle. | If team-fabricated parachutes are not properly tested, they may experience failure during deployment or descent, which could result in loss of controlled recovery (DHZ 33-34) or an increase in kinetic energy above the NASA Requirement of 75 ft-lbf (NASA Req 3.2). Verifying team-fabricated parachutes using analysis or testing helps mitigate risks. | Team-fabricated parachutes will undergo controlled deployment and load testing to confirm canopy strength, seam durability, and shroud-line integrity. Descent performance metrics will be recorded and compared to predicted values. | **Test:** Deployment testing verifies correct performance; no tearing, seam failure, shroud-line failure, or damage occurs during testing. | IP | Recovery | Parachute testing is described in Section 7.2.4. |

Table 7.25: Team Derived Recovery Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| RF 8 | Descent velocity SHALL be kept below 135 fps at all times during descent. | If descent velocity is too high, the main parachute and harness can see excessive opening shock, increasing the risk of canopy damage, shroud-line failure, or zippering damage to the airframe; if descent velocity under drogue is too low, the vehicle spends more time aloft, increasing drift and the chance of landing outside the safe recovery area. NASA limits kinetic energy for each independent section to 75 ft-lbf or less (RequirementRequirement 3.2) and caps drift distance at 2,500 ft (hyperref[sec:Competition Requirements]Requirement 3.10), while also requiring that total descent time be kept within competition limits (hyperref[sec:Competition Requirements]Requirement 3.11). Subscale flight data showed that a larger drogue and in gusty winds led to an extended drogue descent, showing that a higher drogue descent rate is needed to better meet these NASA constraints. Setting a 135 fps upper limit allows the Recovery Lead to size a smaller drogue to reduce descent time while still bounding the maximum descent speed to a value that combined with proper main sizing maintains landing kinetic energy and opening loads within acceptable limits. | The Recovery Lead will select appropriately sized drogue and main parachutes to ensure the total descent profile remains under 135 fps. Analysis will be done to verify that descent velocities remain within the limit. | **(1) Analysis:** Predicted descent rates under the selected drogue and main parachutes show that the vehicle remains below 135 fps during all descent phases.<br>**(2) Demonstration:** Flight data from the Vehicle Demonstration Flight confirms that measured descent velocities remain below 135 fps throughout descent. | PV | Recovery | **(1)** Descent velocity is calculated and described in Section 3.6.7.<br>**(2)** VDF is scheduled for the spring, detailed in Section 7.5. |
| RF 9 | Voltages in the batteries selected for recovery systems SHALL be tested using a multimeter and must remain within manufacturer recommendations. | If recovery system batteries are under-voltage, degraded, or outside manufacturer operating limits, recovery electronics may fail to activate during deployment time, which results in delayed parachute deployment, no deployment, ballistic descent, and loss of vehicle and safety risk to personnel (PHZ 39, DHZ 26 32 36 37, NASA Req 3.1.1 3.2 3.11). Verifying that recovery batteries are operating within appropriate voltage limits prior to launch reduces the probability of recovery electronics malfunctioning ensuring parachute deployment. | During launch preparation, recovery-system batteries will be measured using a multimeter. Measured voltages will be compared to manufacturer operating limits, and any battery outside its acceptable range will be replaced prior to flight. | **Inspection:** Launch checklist documentation confirms that each recovery battery was measured prior to flight and verified to be within the manufacturer's recommended voltage range. | IP | Recovery | Launch day checklists are located in Section 6.1. |
| Design Requirements | | | | | | | |

Table 7.25: Team Derived Recovery Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| RD 1 | Wires for Recovery SHALL be color coded | If recovery wiring is not clearly distinguishable, it becomes easier to misroute or misconnect recovery electronics, which can result in igniters firing at the wrong time, not firing at all, or the wrong channel being armed. This can lead to recovery system failure and hazards to personnel and the launch vehicle (PHZ 39, DHZ 27 28 32). Using a color coding scheme mitigates the risk of altimeters being connected incorrectly. | The Recovery Lead will implement a standardized wiring color scheme for recovery electronics. The meaning of each color will be documented and enforced during assembly checklists. | **Inspection:** The implemented color-coding scheme is documented in the launch day checklists. | V | Recovery | Color codes for recovery electronics are described in the launch day checklists, described in Section 6.1. |
| RD 2 | Electrical connectors used in the recovery system SHALL not be used as structural load-bearing elements. | If electrical connectors are allowed to carry structural loads, they can loosen, deform, disconnect, or fracture under loading, which can disrupt electrical continuity to altimeters or igniters and cause recovery system failure. Failure of the recovery system due to connections being compromised can lead to several recovery failures such as ballistic descent, increased descent time, and hazards to personnel (PHZ 39, DHZ 26 28 32 36 39, NASA Req 3.1.1 3.10 3.11). Preventing electrical connectors from experiencing structural loads mitigates the likelihood of damaged connector related failures. | Electrical connections will be installed solely for electrical connections. Electrical routing may be secured with zip ties or other mounting hardware but will not be used to transmit mechanical forces. | **Inspection:** Avionics bay and recovery system integration confirms that no electrical connectors are positioned or installed such that they carry structural loads. | V | Recovery | Avionics bay design is described in Section 3.5.3. |
| RD 3 | Secondary black powder charges SHALL generate a peak pressure at the separation interface of at least 150% of the minimum pressure required to separate the vehicle. | If separation charges do not produce sufficient pressure, airframe sections may fail to separate, which can result in the vehicle descending ballistically. This failure can lead to hazards to personnel, kinetic energy past NASA Requirements and damage to the launch vehicle (PHZ 39, DHZ 26 32, NASA Req 3.1.1 3.10 3.11). Designing secondary charges to produce at least 150% of the minimum required separation pressure mitigates the chances that the secondary charge will not seperate the vehicle. | Minimum separation pressure for each separation interface will be calculated. Secondary black powder charges will then be sized to produce ≥ 150% of that required pressure. | **Inspection:** Secondary black powder charge calculations verify that the charge mass produces ≥ 150% of the minimum required separation pressure for each separation event. | V | Recovery | Secondary black powder charge calculations are described in Section 3.5.4. |
| RD 4 | The use of twist wire nuts SHALL not be allowed. | If twist-on wire nuts are used, vibration and shock during flight can cause loosening or complete disconnection, which can prevent deployment charges from firing. This causes the same failures as RD 2, failures such as ballistic descent, increased descent time, and hazards to personnel (PHZ 39, DHZ 26 28 32 36 39, NASA Req 3.1.1 3.10 3.11). By eliminate vibration compromisable connectors like twist wire nuts these failures are mitigated. | All electrical connections in the recovery system will use soldered, crimped, or other vibration-resistant methods. Twist-on wire nuts will not be utilized. | **Inspection:** Visual inspection confirms that no twist-on wire nuts are used in recovery wiring and all electrical connections use approved secure methods. | V | Recovery | Avionics bay design is described in Section 3.5.3. |

Table 7.25: Team Derived Recovery Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| RD 5 | All recovery Shock Cords SHALL be chosen to receive expected strain loads from recovery events with a factor of safety of at least 10. | If shock cords are not selected with sufficient strength, they may experience overstress and fail during high-load recovery events leading to separation of vehicle sections and ballistic descent. This failure would cause a fail to meet NASA's kinetic energy requirement and causes risks to the structure of the launch vehicle and personnel (NASA Req 3.2, PHZ 39, DHZ 8 34). A factor of safety of 10 provides a comfortable margin against any uncertainties and mitigates these hazards. | Only shock cords with a manufacturer-rated tensile strength ≥ 10× the expected maximum load will be used. | **Analysis:** Documentation confirms that each installed shock cord has a manufacturer-rated tensile strength at least 10 times the calculated maximum recovery load. | V | Recovery | Shock cord selection is described in Section 3.5.2. |
| RD 6 | Shock cord lengths SHALL be chosen such that distances between separating sections will be a minimum of 8 (ft) during descent. | If separating rocket sections remain too close during descent, they can collide with each other, which can damage airframe structure, tangle parachutes, or prevent proper inflation, resulting in recovery failure. This would cause damage to vehicle sections, which might make the launch vehicle unable to be reused (NASA Req 2.2 DHZ 30). By using a separation distance a minimum of 8 (ft), the risk of sections colliding with each other or shock cord getting tangled is mitigated. | Shock cord lengths will be calculated so that, during descent under both drogue and main parachutes, independent vehicle sections remain separated by more than 8 (ft). | **Inspection:** Installed shock cord lengths are measured and confirmed to provide ≥ 8 (ft) clearance between all independent rocket sections during descent configuration. | V | Recovery | Shock cord lengths are described in Section 3.5.2. |
| Environmental Requirements | | | | | | | |
| RE 1 | All Recovery insulation SHALL be biodegradable. | During recovery events, insulation falls from the rocket such that it is not recoverable and contaminates the launch field. Contaminating the environment with non-biodegradable insulation is unsafe for any wildlife or vegetation, as well as disrespectful to those who allow their land to be used for rocketry. Using biodegradable insulation ensures that any unrecoverable material will naturally decompose rather than persist as plastic or synthetic debris, reducing environmental pollution and maintaining respectful relations with those who allow their field to be used. | Cellulose-based, biodegradable insulation will be used in all recovery packing. | **Inspection:** All insulation used in recovery systems is inspected to be biodegradable. | V | Recovery | Insulation packing is described in launch day checklists, described in Section 6.1 |

Table 7.25: Team Derived Recovery Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| RE 2 | Avionics housings SHALL be protected against dust and debris during transport, launch and field recovery. | Dust, dirt, and other small particulate matter can interfere with connectors, switches, and other electrical components on recovery electronics, preventing them from working properly or at all. This can lead to recovery related failures and risks including black powder failing to separate the launch vehicle causing ballistic descent, increased kinetic energy on landing, and risk to personnel (NASA Req 3.1 3.10 3.11 PHZ 39, DHZ 26 28 32 36 39). By protecting the Avionics Bay from small particulate matter, these risks are mitigated. | The avionics bay will be In anti-static bags during assembly and transportation to launch fields and inspected for debris. | **Inspection:** Avionics bay launch handling procedures confirm the presence of utilizing anti-static bags as a dust-mitigation measure during transport and field operations. | V | Recovery | Avionics bay design is described in Section 3.5.3. Launch checklists are described in Section 6.1. |
| RE 3 | All recovery electronics SHALL deliver nominal voltage across ambient temperatures ranging from 25 °F to 100 °F. | Launch day conditions can vary in temperature, historically between 25°F to 100°F. If batteries or recovery electronics cannot maintain proper operating voltage across expected environmental temperatures, they may experience reduced output, unstable power delivery and fail to deliver sufficient power to recovery electronics. This can lead to electronics not functioning properly, which cause cause failures and risks such as ballistic descent, main deployment prematurely, and risk to personnel (NASA Req 3.1 3.10 3.11, PHZ 39,DHZ 36 27 28 32 36 37). By selecting batteries that have stable voltage between 25 °F and 100 °F risk of this failure is mitigated. | Batteries and recovery electronics will be selected based on manufacturer specifications confirming stable operation and voltage output within the 25 °F - 100 °F range. | **Inspection:** Manufacturer specifications confirm batteries operate correctly across the full temperature range. | V | Recovery | Recovery batteries are specified in Section 3.5.3. |
| RE 4 | All disposable recovery materials SHALL collected and disposed of in accordance with NAR/Tripoli range safety and environmental rules. | If expendable recovery materials such as tape burn-tape remnants and other single-use components are left on the field, they create environmental litter, pose hazards to wildlife, and be disrespectful to those who allow their field for rocketry use (EHZ 2,5). By being sure to clean any disposable material used, risk of pollution and harm to wildlife is mitigated. | All disposable recovery will be collected on launch day and properly disposed of according to environmental guidelines. | **Demonstration:** All disposable materials are collected and properly disposed of per launch range rules. | V | Recovery | Launch day checklists describing disposable material clean up is described in Section 6.1. |

Table 7.25: Team Derived Recovery Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| RE 5 | All unusable black powder charges SHALL be neutralized and disposed of in accordance with manufacturer and environmental standards. | If unused or damaged black powder charges are not properly neutralized and disposed of, they remain as uncontrolled energetic material, posing a risk of accidental ignition, injury to personnel, and potential fire hazards (PHZ 3 4 38, EHZ 7). By following manufacturer instructions for proper disposal, unblown black powder charge risk are mitigated. | Any black powder charges deemed unusable will be neutralized following the manufacturer's instructions and then disposed of according to applicable environmental disposal guidelines. | **Inspection:** Launch day checklist confirms that all unusable black powder charges are neutralized per manufacturer guidelines and disposed of in. | V | Recovery | Proper black powder disposal procedures based off of SDS Sheets located in Reference [13] [13]. Launch day checklists describing proper black powder disposal is described in Section 6.1. |
| Safety Requirements | | | | | | | |
| RS 1 | Arming devices SHALL be accessible without having your head within 12 (in) from the outer diameter. | If arming switches require personnel to place their head close to the rocket, accidental activation of deployment charges could subject them to impact from separating components and dangerous loud noises, presenting a direct risk of injury (PHZ 29 42). By allowing recovery electronics to be armed from at least 12 (in) from the launch vehicle's diameter limits exposure to any inadvertent deployment of energetics. | Recovery electronics will be chosen and placed in the avionics bay such that operation is capable at a minimum of 12 (in) away from the exterior of the launch vehicle. | **Inspection:** Arming devices are positioned such that team members can access them while maintaining ≥ 12 (in) distance. | V | Recovery | Avionics bay arming mechanism is described in Section 3.5.3. Launch day checklist including arming energetics is described in Section 6.1. |
| RS 2 | All LiPo Batteries used SHALL be stored in approved storage containers for storage and transportation. | If LiPo batteries are stored or transported without proper containment, physical damage or electrical faults may lead to thermal runaway, resulting in fire, smoke release, and potential explosion hazards. This can cause severe burns to personnel (PHZ 23). Storing and transporting LiPo batteries in approved fire-resistant containers reduces the probability and consequence of battery-related fire events by containing flames and directing hot gasses safely. | All LiPo batteries utilized will be stored and transported in fire-resistant LiPo bags or containers. Storage containers will be labeled. | **Inspection:** LiPo batteries are stored and transported in approved containers. | V | Recovery & Safety | LiPo Storage is described in launch day checklists in Section 6.1. |
| RS 3 | All ejection testing SHALL be conducted more than 24 hours before intended launch. | If ejection testing is performed too close to launch, there may not be time to evaluate results and correct black powder charges that fail to separate the vehicle. Additionally if ejection testing takes place too close to launch, it causes stress on personnel which can lead to a decrease in quality of work and poor decision making (PHZ 56). Requiring ejection testing more than 24 hours before launch ensures time for proper assessment of potential errors in design without causing unnecessary stress on personnel. | Ejection tests will be scheduled and completed at least 24 hours prior to launch to allow time for inspection, evaluation, and mitigation of any identified issues before flight. | **Inspection:** Ejection testing is scheduled and completed >24 hours before launch. | PV | Recovery | Ejection testing schedule is described in Section and 7.2.5. |

Table 7.25: Team Derived Recovery Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| RS 4 | All altimeter arming procedures SHALL be documented and known by all necessary personnel including altimeters beeps and programming. | If personnel do not have clearly documented and well-understood altimeter procedures, recovery electronics may be armed incorrectly, left unarmed, or programmed improperly. This can lead to recovery failure such as ballistic descent, main deployment prematurely, and risk to personnel (NASA Req 3.1 3.10 3.11, PHZ 39,DHZ 36 27 28 32 36 37). By training and including documentation for altimeter arming, disarming and programming, risk of improperly programmed altimeters is mitigated. | All necessary altimeter procedures will be documented in the launch checklist. Team members responsible for launch operations will receive training and demonstrate competency in arming, disarming, and programming altimeters. | **Inspection:** Launch day checklists confirms that altimeter procedures are fully documented and accessible. | V | Recovery | Altimeter arming procedures are described in launch day checklists in Section 6.1. |
| RS 5 | All Altimeters programmed SHALL be verified by at least two additional personnel other than the Recovery Lead. | If recovery altimeters are programmed incorrectly or incompletely verified, recovery events could occur at the wrong altitude, in the wrong sequence, or not at all, leading to ballistic descent, higher descent times and risk to personnel (NASA Req 3.10 3.11, PHZ 39, DHZ 26 27 28 32). Requiring two independent verifications removes single-point failure in programming, reducing the likelihood of configuration errors and directly improves recovery reliability and personnel safety. | After initial programming, two additional personnel not involved in the initial programming will verify recovery altimeters are programmed correctly. | **Demonstration:** Two independent personnel confirm altimeter programming matches flight requirements. | IP | Recovery | Recovery schedule including electronics armig is described in 7.5. |
| RS 6 | All personnel recovering the launch vehicle SHALL wear proper PPE and fire-proof gloves if they are handling the launch vehicle. | If personnel attempt to recover the rocket without proper PPE, they may be exposed to sharp edges, tangled shock cords under tension, residual black powder residue, or still-warm components, any of which can result in burns, cuts, or other injuries (PHZ 3 8). Requiring PPE and fire-resistant gloves for anyone handling the rocket ensures that personnel are protected. | Launch procedures and checklists will require field recovery personnel to wear PPE, including fire-resistant gloves, during rocket handling and component retrieval. | **Inspection:** All field recovery personnel are observed wearing proper PPE during recovery operations. | V | Recovery & Safety | Field recovery operations are described in launch day checklist described in Section 6.1. |

### 7.4.6 Air Brakes Team Derived Requirements

Table 7.26: Team Derived Air Brakes Requirements

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| Functional Requirements | | | | | | | |

Table 7.26: Team Derived Air Brakes Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| AF 1 | Air Brakes Systems SHALL only be capable of braking, no controlling pitch, yaw or roll. | If the Air Brakes are capable of producing asymmetric drag or moments, they may alter pitch, yaw, or roll, which can destabilize the rocket, compromising stability margins and cause unsafe flight (DHZ 19). Limiting the Air Brakes strictly to drag production eliminates their ability to act as a control surface ensuring they cannot introduce moments or directional control, mitigating this risk. | The Air Brakes system is designed such that they only affect drag and do not introduce any moments to the launch vehicle while deployed. | **Analysis:** Aerodynamic modeling and simulation demonstrate that the Air Brakes introduce net deceleration forces only and do not generate measurable pitch, yaw, or roll moments across expected deployment conditions. | V | Aerodynamics | Section 3.6.1 details the effects of the air brake system on the launch vehicle. |
| AF 2 | The Launch Vehicle SHALL include a camera to verify deployment of the Air Brakes system. | If Air Brakes deployment is verified only through acceleration data or software, a false-positive confirmation may occur in scenarios such as partial deployment or code reporting success without physical actuation. If the system is programmed based off of incorrect deployment, it can lead to the launch vehicle failing to reach the intended apogee (DHZ 20). Providing visual verification ensures that deployment is physically confirmed, and distinguishes between successful and failed deployment states, mitigating these hazards. | An on board camera will be integrated into the launch vehicle with a clear view of the Air Brakes deployment. | **(1) Inspection:** Camera mount and placement are confirmed to provide a clear field of view of the Air Brakes system.<br>**(2) Demonstration:** VDF flight footage confirms capture of Air Brakes deployment. | IP | Structures & Aerodynamics | **(1)** Preliminary camera design is located in 5.3.<br>**(2)** VDF is scheduled for the spring, detailed in Section 7.5. |
| AF 3 | The Air Brakes system SHALL remain retracted until the launch vehicle's boost phase has ended. | If the Air Brakes deploy during the boost phase, they introduce significant drag while the rocket is still under high thrust loading, which can create unexpected aerodynamic forces, high stress on the Air Brake components, potentially causing them to break. Air Brake fins breaking could result in unexpected moments and failure to deploy at all, causing the launch vehicle to fail to reach its intended apogee (DHZ 19, 20). By Ensuring that Air Brakes cannot deploy during the boost phase of flight prevents Air Brakes from deploying under extreme loading, mitigating these risks and ensuring the launch vehicle reaches its intended apogee. | Air Brakes control logic will incorporate a burnout detection condition, preventing deployment commands until burnout has been confirmed. | **Inspection:** VDF onboard camera footage and flight data confirm that Air Brakes remain fully retracted during boost and deploy only after burnout. | NV | Aerodynamics | VDF is scheduled for the spring, detailed in Section 7.5. |

Table 7.26: Team Derived Air Brakes Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| AF 4 | In deployed state Air Brakes SHALL not be directly forward of launch vehicle fins. | If the Air Brakes deploy directly ahead of the launch vehicle fins, the disturbed airflow, turbulent wake, and separated flow they generate could impair fin aerodynamic effectiveness, reducing stability margin resulting in asymmetric control effects (DHZ 7 24). By ensuring that the Air Brakes fins do not deploy directly in front of the fins, the risk of turbulent flow negatively affecting the fins is mitigated, allowing Air Brakes to perform their intended role only. | Structures and Aerodynamics Lead will design the Air Brakes system and the Launch Vehicle structure such that Air Brake fins will not deploy directly forward of the launch vehicles fins. | **Inspection:** Deployed fin location for the Air Brakes system are not directed immediately forward of the launch vehicle fins. | IP | Structures & Aerodynamics | Air Brake system location is described in Section 5.3.1. |
| Design Requirements | | | | | | | |
| AD 1 | Air Brakes gear mechanisms SHALL be designed such that all fins retract and deploy simultaneously. | If the Air Brakes deploy or retract asymmetrically, one side of the rocket may experience greater drag than the other, which can introduce unintended roll, yaw, pitch disturbances, or loss of aerodynamic stability. This would result in instability and unpredictable flight path due to moments acting on the launch vehicle (DHZ 19 20). By designing the Air Brakes to only deploy simultaneously, they will not induce moments on the launch vehicle, allowing for a successful and predictable flight. | The Air Brakes mechanism will utilize a mechanical gear system that physically couples all fins, ensuring simultaneous actuation. | **(1) Test:** Ground testing confirms that all Air Brakes fins deploy and retract simultaneously.<br>**(2) Demonstration:** VDF flight testing confirms synchronized fin deployment and retraction under flight conditions. | IP | Aerodynamics | **(1)** Ground testing for Air Brakes deployment is located in 7.3.5.<br>**(2)** VDF is scheduled for the spring, detailed in Section 7.5. Air Brakes fin deployment is described in Section 5.3.1. |
| AD 2 | The Air Brakes system SHALL utilize state-based software. | If the Air Brakes software responds directly to raw sensor inputs without defined operating states, noise or incorrect measurements can trigger unintended or incorrect deployment behavior, leading to the Air Brakes failing to bring the Launch Vehicle to the intended apogee (DHZ 21). Employing a state based architecture ensures deterministic behavior by restricting Air Brakes actions to well-defined flight phases (e.g., standby, boost, coast, descent), preventing unintended actuation due to transient data and directly mitigating these hazards. | The Air Brakes software will be implemented as a state machine with clearly defined states such as standby, motor burn, coast, free fall, and landing. Transitions will occur only under verified conditions, and each state will explicitly define allowed Air Brakes actions. | **(1) Inspection:** Software documentation and code review confirm use of a state-based architecture with clearly defined states and transitions.<br>**(2) Demonstration:** During VDF, Air Brakes behavior is observed to transition deterministically according to flight states with no unintended deployment responses. | PV | Aerodynamics | **(1)** Air Brakes software design is described in Section 5.4.<br>**(2)** VDF scheduled for the spring, Section 7.5. |

Table 7.26: Team Derived Air Brakes Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| AD 3 | Air Brake aerodynamic surfaces SHALL have a minimum safety factor of 2.0 under expected aerodynamic loads experienced during ascent. | If the Air Brakes aerodynamic surfaces are not designed to handle loading conditions, aerodynamic forces could cause fin deformation or breaking during flight, making the launch vehicle unable to be reflown failing to comply with NASA Req 2.4. Depending on the failure, the Air Brakes could then either not deploy or deploy asymmetrically, causing the launch vehicle to fly unstable or fail to reach the intended apogee (DHZ 19 20). A minimum safety factor of 2.0 provides a margin against uncertainties in material performance and aerodynamic forces experienced. | Aerodynamic surfaces of the Air Brakes will be designed and tested to withstand twice the expected aerodynamic loads during deployment. | **Test:** Physical testing demonstrates that Air Brakes aerodynamic surfaces withstand twice the expected aerodynamic load with no structural failure, cracking, or permanent deformation. | IP | Aerodynamics | Air Brake Testing is described in section 7.3.5. |
| AD 4 | The Air Brakes System SHALL be sealed such that Air Brakes barometric pressure data will not be adversely affected from deployment. | If the Air Brakes are not properly sealed, Air Brakes Deployment can cause pressure spikes inside the Air Brakes sensor housing. This can cause incorrect readings to influence the software, causing Air Brakes to perform incorrectly, meaning the launch vehicle fails to reach its intended apogee (DHZ 22). By properly sealing the Air Brakes sensors, the risk of inaccurate barometric pressure data is reduced. | Air Brakes are designed using an o-ring to isolate the barometric pressure sensor used in Air Brakes. Sealing methods will be verified during ground testing. | **(1) Test:** Ground testing verifies that Air Brakes deployment does not introduce pressure spikes or instability in sensor readings.<br>**(2) Inspection:** Post-flight barometric data review confirms stable and reliable sensor performance throughout deployment events during VDF. | IP | Aerodynamics | **(1)** Air Brakes testing is described in Section 7.3.6.<br>**(2)** VDF is scheduled for the spring, detailed in Section 7.5. |
| Safety Requirements | | | | | | | |
| AS 1 | All Air Brakes systems SHALL be designed and fabricated more than 24 hours before planned Launch. | If the Air Brakes system is fabricated too close to launch, there may not be sufficient time to perform dry fits, resolve integration issues, verify operation, or correct these issues. This increases the likelihood of installation errors, rushed decision-making, and reduced quality of work due to high stress resulting in unpredictable flight and failure to reach target apogee (PHZ 56, DHZ 19 20). Completing fabrication and assembly at least 24 hours in advance ensures time for inspection, confirmation, and troubleshooting, reducing these hazards and correct Air Brakes operation. | Fabrication and final assembly schedules will ensure the Air Brakes system is completed and installed at least 24 hours prior to launch, with time allocated for inspection and verification activities. | **Inspection:** Documentation shows that Air Brakes manufacturing is completed more than 24 hours prior to launch. | IP | Aerodynamics | Air Brakes development timeline is described in Section 7.5. |

Table 7.26: Team Derived Air Brakes Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| AS 2 | The Air Brakes System SHALL default to a neutral state if primary system power is lost. A neutral state is defined as one which does not apply any moments to the launch vehicle. | If Air Brakes are designed such that a power loss could results in a non-neutral state, then moments could be induced on the launch vehicle causing the launch vehicle to fly unstable and fail to reach the intended apogee (NASA Req 2.1, DHZ 19 24). By designing Air Brakes such that they default to a neutral state if power is lost mitigates these risks and ensures our intended apogee is reached. | The Air Brakes will be designed such that loss of power results in a neutral state. | **Analysis:** Aerodynamic simulations and design validation demonstrate that the defined neutral state introduces no measurable pitch, yaw, or roll moments. | V | Aerodynamics | Section 5.4.1 details the forces of the air brake system on rocket. |
| AS 3 | The Air Brakes System SHALL be capable of being disarmed using a physical switch. | If the Air Brakes cannot be physically disarmed, the system may remain powered during transportation, handling, and pre-launch preparation, increasing the risk of battery depletion prior to flight (DHZ 20). This would cause the launch vehicle to be forced to fly without Air Brakes, causing the launch vehicle to fail to reach its target apogee (NASA Req 2.1). By including a mechanical arming switch, Air Brakes battery is less likely to be depleted during transportation and assembly. | A mechanical arming/disarming switch will be integrated into the Air Brakes electronics system. | **Inspection:** The Air Brakes system is demonstrated to arm and disarm via a physical hardware switch. | IP | Aerodynamics | Air Brakes arming mechanism is described in Section 5.3.2. |

### 7.4.7 Payload Team Derived Requirements

Table 7.27: Team Derived Payload Requirements

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| Functional Requirements | | | | | | | |
| PF 1 | The Payload SHALL be capable of being fully retained in the nose cone section of the launch vehicle. | If the payload is not fully retained within the nose cone section, it may shift or interfere with its mounting/retention components, which can prevent intended deployment motion and create an undesirable mass distribution that harms vehicle stability. This would cause the Lander to be unable to eject smoothly, potentially compromising the Payload mission (NASA Req 4.1, DHZ 56). By Securing the Payload in the nosecone, the risk of imbalances and inability to eject is mitigated. | Payload will be designed such that it fits completely and securely inside the nose cone section. | **Inspection:** Payload fits completely and securely inside the nose cone section and retention is confirmed during launch vehicle assembly. | IP | Payload Structures | Payload location and sizing is described in Section 4.2. |

Table 7.27: Team Derived Payload Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| PF 2 | The payload lander system SHALL be capable of fully removing itself from the nosecone section autonomously. | If the payload lander cannot autonomously separate from the nose cone, separation would rely on external radio commands, introducing additional points of failure such as communication losses or timing errors. If the Lander is unable to eject, the Payload mission would be unable to collect and test soil (NASA Req 4.1 -4.3). By designing the Payload to eject autonomously, the failure point of loss of communication is removed. | The payload lander will be equipped with a mechanical release mechanism triggered by a state-based command. Ground testing will verify successful autonomous separation under various conditions. | **(1) Test:** Ground testing shows autonomous ejection of the payload lander.<br>**(2) Demonstration:** PDF verifies the autonomous ejection of the payload lander. | IP | Payload Team | **(1)** Payload testing schedule is outlined in Section 7.3.3.<br>**(2)** PDF is planned for the spring, outlined in Section 7.5. |
| PF 3 | The payload lander SHALL be capable of recognizing and orienting itself upright upon landing and deploying from the nosecone section. | If the payload lander cannot determine its orientation or self-right after landing, it may remain tipped, preventing deployment of the auger and resulting in inability to collect soil. Balance could also be lost during drilling operation by environmental or drag from the main parachute (DHZ 40 & 59). Providing autonomous orientation recognizing and self-righting capability ensures the payload can recover from off-nominal landing attitudes and potential losses of balance ,successfully completing its mission. | The payload lander will utilize sensors and a self-righting mechanism capable of detecting landing orientation and correcting orientation prior to payload operation. Ground testing will verify functionality. | **(1) Test:** Testing shows autonomous ejection of the payload lander.<br>**(2) Demonstration:** PDF verifies the autonomous ejection of the payload lander. | IP | Payload Team | **(1)** Payload uprighting testing schedule is outlined in Section 7.3.1.<br>**(2)** PDF is planned for the spring, outlined in Section 7.5. Payload lander self-righting design is described in Section 4.3. |
| PF 5 | The Payload SHALL have a combined weight of no more than 8.5 (lbs). | If the payload mass increases too much, the launch vehicle mass properties, stability margin, and predicted apogee will deviate from analysis, potentially leading to inaccurate apogee control, off-nominal flight behavior, or recovery performance issues (DHZ 58). Not allowing for uncontrolled mass growth ensures that simulations can be valid up until the cap set. 8.5 lbs is the maximum allowable weight for the Payload before the launch vehicle becomes over-stable, failing to comply with LVF 6 | The payload will be designed using lightweight materials and components, and mass will be tracked throughout design and fabrication to ensure the total payload mass remains below 8.5 lb. | **Inspection:** The fully assembled payload mass is measured using a scale and verified to be ≤ 8.5 lb . | IP | Payload Team | Payload mass is described in Section 4.7. |
| PF 6 | The Payload SHALL retain the soil in a contaminant free chamber for testing. | Contamination from flight residue, airborne particulates and other launch vehicle specific chemicals could alter the pH, nitrate content, or electrical conductivity of collected soil samples. This would lead to the sensors picking up false data, compromising the mission (DHZ 53, 55). By keeping the chamber free of contaminants, the risk of contamination is mitigated. | The payload soil chamber will be designed such that it minimizes contaminants. | **Inspection:** Collected soil samples are examined after retrieval and show no visible contamination or only negligible contaminant is found. | IP | Payload Structures | Payload soil chamber design is described in Section 4.4.1. |
| Design Requirements | | | | | | | |

Table 7.27: Team Derived Payload Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| PD 2 | The Soil containment chamber SHALL hold a minimum of 75 (mL) of soil. | If the soil containment chamber holds at most 50 ml of soil, then any breaking or damage to the chamber or sample spillage would result in a failure to meet NASA Requirements for the amount of soil needed (NASA Req 4.1, DHZ 47). Designing the chamber to hold 150% of the required sample volume provides margin against spillage, incomplete transfer, or chamber damage. | The soil collection chamber will be designed to hold a minimum of 75 (mL) of soil. | **Inspection:** Measured internal volume of the soil containment chamber meets or exceeds 75 mL prior to integration. | IP | Payload Structures | Soil collection chamber is described in Section 4.4.1. |
| PD 3 | The interface between the Payload and the nosecone SHALL include features to ensure smooth ejection. | If the Payload-nose cone interface does not provide alignment during separation, the payload may experience binding, jamming, or payload components shearing off, preventing the lander from separating completely and resulting in a failure to complete the mission (DHZ 46,48). Incorporating alignment features such as guides or rails ensures repeatable ejection from the nose cone and directly mitigates hazards. | The payload-nose cone interface will incorporate alignment features such as guides or rails to constrain motion during ejection. Ground testing will be conducted to verify consistent, smooth separation without binding or misalignment. | **(1) Test:** Ground testing demonstrates that the payload ejects smoothly and consistently with no binding, misalignment, or lateral interference across all tested scenarios.<br>**(2) Demonstration:** Payload Demonstration Flight (PDF) confirms smooth payload ejection upon landing under flight conditions. | IP | Payload Structures | **(1)** Payload lander ejection testing schedule is outlined in Section 7.3.3.<br>**(2)** PDF is planned for the spring, outlined in Section 7.5. Payload lander ejection mechanism is described in Section 4.4.2. |
| PD 4 | The payload SHALL log timestamps of all operations for NASA verification as well as post launch analysis. | If payload operations are not time-stamped, it becomes difficult to correlate behavior with launch vehicle flight states, making it challenging to verify correct performance from the system. Additionally, NASA Requires time stamps during solid collection (NASA Req 4.2.1). Logging timestamps for all major payload operations ensures traceability, verification and troubleshooting, and mitigates these hazards by providing evidence of payload behavior. | Payload software will integrate sensors and internal timing functions to record time-stamped logs for all major payload events, including state transitions, deployment actions, and sample collection. Logged data will be stored onboard and retrieved post-flight for analysis. Ground testing will validate timestamp accuracy and reliability. | **(1) Test:** Ground testing confirms the payload logs accurate timestamps for all commanded operations.<br>**(2) Demonstration:** Payload Demonstration Flight (PDF) data confirms that all critical payload operations are logged with timestamps during flight. | IP | Payload Team | **(1)** Payload software testing is outlined in Section 7.3.4.<br>**(2)** PDF is planned for the spring, outlined in Section 7.5. |
| PD 5 | Auger operation SHALL be controlled such that jamming and over-torquing is negligible. | If the auger experiences jamming or excessive torque during operation, the auger bit could break, gear components may deform or fail, all preventing soil collection and resulting in mission failure (DHZ 41, 44). By Preventing such jamming and over-torquing, these risks are mitigated. | The auger system will be designed such that jamming and over-torquing is negligible. | **(1) Test:** Ground testing demonstrates the auger operates without jamming or over-torquing across representative soil conditions and load cases.<br>**(2) Demonstration:** Payload Demonstration Flight (PDF) confirms the auger operates without jamming or over-torquing during soil collection. | IP | Payload Team | **(1)** Payload operation testing schedule is outlined in Section 7.3.2.<br>**(2)** PDF is planned for the spring, outlined in Section 7.5. |
| Environmental Requirements | | | | | | | |

Table 7.27: Team Derived Payload Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| PE 1 | No components of the payload SHALL be released into the environment. | If Payload components are released into the environment, they pose a risk as pollution and can be harmful to vegetation and wildlife (EHZ 2). By ensuring that all payload components are secured inside the launch vehicle, pollution is mitigated. | The payload will be designed such that components are securely attached to the launch vehicle. | **(1) Test:** Ground testing confirms that all payload components remain securely attached under representative handling, deployment, and operational conditions.<br>**(2) Demonstration:** Payload Demonstration Flight (PDF) confirms that no payload components are released into the environment during flight or payload operation. | IP | Payload Team | **(1)** Payload operation testing is outlined in Section 7.3.2.<br>**(2)** PDF is planned for the spring, outlined in Section 7.5. Payload retention systems are described in Section 4.2. |
| PE 2 | The payload lander SHALL be capable of up-righting on soil conditions ranging from dry loose sand to damp compacted dirt. | If the payload lander cannot self-right across the range of soil conditions present at the launch site, it may remain tipped or unstable after landing depending on the location of landing site. This would result in mission failure, as the inability to self-right prohibits the ability of the lander to collect soil (DHZ 40). Designing the self-righting mechanism to function across a range of soil types mitigates these hazards. | The self-righting mechanism will be designed and tested to operate on multiple soil types, including dry sand, loose dirt, and damp compacted soil. Ground testing will simulate a variety of conditions to verify functionality. | **Test:** Ground testing demonstrates that the payload lander consistently self-rights from different initial orientations across different soil conditions without manual assistance. | IP | Payload Team | Payload uprighting testing is outlined in Section 7.3.1. Payload lander self-righting mechanism is described in Section 4.4.1. |
| Safety Requirements | | | | | | | |
| PS 1 | All Payload systems SHALL be designed and fabricated more than 24 hours before planned Launch. | If payload fabrication or assembly is completed too close to launch, there may be insufficient time to verify fit, identify integration issues, correct defects, or address safety concerns, increasing the likelihood of rushed assembly, human error, or unverified payload behavior (PHZ 56, DHZ 48, 56, 58). By Ensuring Payload systems and designed and fabricated a minimum 24 hours before launch, time is left to access and fix any potential integration problems that may arise. | The payload will be completed, fully assembled and dry fitted at least 24 hours before launch. | **Inspection:** Payload is fully designed, fabricated, and assembled > 24 hours before launch. | IP | Payload Team | Payload manufacturing timeline is outlined in Section 7.5. |
| PS 2 | The payload lander SHALL not create pinch points that could injure personnel during handling or assembly. | If exposed pinch points exist on the payload lander, personnel may suffer hand or finger injuries during assembly, handling, transport, or field operations, particularly when interacting with moving mechanisms such as the self-righting system or auger (PHZ 7, 9, 34). By ensuring the Payload does not include pinch points, risk of damage to personnel is mitigated. | The payload lander and assembly checklist will be designed to eliminate exposed pinch points. | **Inspection:** No pinch points are present in the self-righting mechanism during assembly or handling. | IP | Payload Structures | The payload lander design is outlined in Section 4.4. Launch Day checklists are located in Section 6.1. |

Table 7.27: Team Derived Payload Requirements (continued)

| ID | SHALL Statement | Justification | Planned Action | Verification Method | Status | Performing Subsystem | Results |
|---|---|---|---|---|---|---|---|
| PS 3 | The Auger bit SHALL be retracted until needed after launch. | If the auger bit is exposed prior to intended deployment, it may present a laceration or puncture hazard to personnel during handling, transport, and assembly (PHZ 30). By Ensuring that the Auger bit is retracted until needed, risk to personnel is mitigated. | The auger system will be designed such that the auger bit is fully stowed until commanded for deployment. | **Demonstration:** Observation confirms the auger bit remains fully retracted during handling, integration, flight, landing, and recovery, and only deploys when commanded to. | IP | Payload Team | Auger mechanism and operation is described in Section 4.4.1. |

## 7.5 Budgeting and Timeline

Table 7.28 shows HPRC's year-long budget plan for the 2025-2026 academic school year. The table is organized in columns of Item, Vendor, Quantity, Price Per Unit, and Total Item Price. The rows are also grouped according to the club's seven major categories of spending. Highlighted in light gray at the end of each section is the summed total of all the prices for that category. At the bottom of the table, the total for the expenses of the club throughout the year is highlighted in dark gray. All of the items and prices are based on estimates made by the subteam leads and officers regarding what they believe they need for this year's competition vehicle. It is important to note that both the listed items and their prices may change slightly as the design for our rocket is finalized throughout this year. Any changes made could result in alterations to the items needed, the vendors used, and the total amount spent throughout the year.

Table 7.28: 2025-2026 NASA Student Launch Competition Budget

| | Item | Vendor | Quantity | Price Per Unit | Item Total |
|---|---|---|---|---|---|
| **Subscale Structure** | 8.9 oz/yd$^2$ S2 Fiberglass Cloth | US Composites | 10 | $ 9.50 | $ 95.00 |
| | 5.7 oz/yd$^2$ Carbon Fiber Cloth | US Composites | 5 | $ 18.50 | $ 92.50 |
| | 4 in Light Fiberglass Sleeve | Soller Composites | 15 | $ 2.50 | $ 37.50 |
| | Subscale Motor | Aerotech | 2 | $ 95.99 | $ 191.98 |
| | 1/8 in x 6 x 12 Aluminum Plate | McMaster | 1 | $ 19.16 | $ 19.16 |
| | Motor Casing | Aerotech | 1 | $ 98.86 | $ 98.86 |
| | Rail Button | Apogee Rockets | 2 | $ 4.25 | $ 8.50 |
| | 1/8 in x 6 x 24 Balsa Wood | Hobby Lobby | 2 | $ 5.99 | $ 11.98 |
| | U-Bolts | McMaster | 4 | $ 2.50 | $ 10.00 |
| | Screws | McMaster | 4 | $ 5.23 | $ 20.92 |
| | PLA Filament | Bambu | 2 | $ 15.99 | $ 31.98 |
| | | | | **Subtotal:** | **$ 618.38** |
| **Full Scale Structure** | 6 in. Nosecone 4:1 | PH | 1 | $ 159.99 | $ 159.99 |
| | 8.9 oz/yd$^2$ S2 Fiberglass Cloth | US Composites | 25 | $ 9.50 | $ 237.50 |
| | Full-scale Motor | Aerotech | 3 | $ 272.68 | $ 818.04 |
| | 1/8 in x 6 x 12 Aluminum Plate | McMaster | 1 | $ 19.16 | $ 19.16 |
| | Motor Casing | Aerotech | 1 | $ 526.45 | $ 526.45 |
| | Large Rail Button -1515 | Apogee Rockets | 2 | $ 4.25 | $ 8.50 |
| | U-Bolts | McMaster | 4 | $ 6.50 | $ 26.00 |
| | Double Pull Pin Switch | Apogee Rockets | 1 | $ 20.35 | $ 20.35 |
| | | | | **Subtotal:** | **$ 1815.99** |
| **Payload** | Barometric Pressure Sensor | Adafruit | 2 | $ 6.95 | $ 13.90 |
| | Magnetometer | Adafruit | 2 | $ 5.95 | $ 11.90 |
| | NPK Sensor | DFRobot | 1 | $ 59.00 | $ 59.00 |
| | pH & Electrical Conductivity Sensor | DFRobot | 1 | $ 62.00 | $ 62.00 |
| | Milling Aluminum | General | 1 | $ 19.99 | $ 19.99 |
| | Thrust Bearings | General | 4 | $ 24.99 | $ 99.96 |
| | Servo Motor | Amain Hobbies | 3 | $ 54.99 | $ 164.97 |
| | Linear Actuator | Vevor | 1 | $ 25.56 | $ 25.56 |
| | Raspberry Pi 5 | Sparkfun Electronics | 1 | $ 88.00 | $ 88.00 |
| | PETG Filament | Bambu | 1 | $ 29.99 | $ 29.99 |
| | Structural/Housing Materials | General | 1 | $ 300.00 | $ 300.00 |
| | | | | **Subtotal:** | **$ 875.27** |

Table 7.28: 2025-2026 NASA Student Launch Competition Budget

| | Item | Vendor | Quantity | Price Per Unit | Item Total |
|---|---|---|---|---|---|
| **Recovery and Avionics** | 1 yd Ripstop Nylon | Emma Kites | 15 | $ 7.95 | $ 119.25 |
| | 6 in. Deployment Bag | Fruity Chutes | 1 | $ 54.40 | $ 54.40 |
| | 4 in. Deployment Bag | Fruity Chutes | 1 | $ 47.30 | $ 47.30 |
| | 18 in. Nomex Chute Protector | Wildman Rocketry | 1 | $ 10.95 | $ 10.95 |
| | 12 in. Nomex Chute Protector | Wildman Rocketry | 1 | $ 8.95 | $ 8.95 |
| | Kevlar Shock Cord | Chris' Rocketry | 25 | $ 1.30 | $ 32.50 |
| | Quick Links | McMaster-Carr | 6 | $ 8.28 | $ 49.68 |
| | 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 |
| | WAGO Lever Wire Connector | Grainger | 50 | $ 0.67 | $ 33.50 |
| | | | | **Subtotal:** | **$ 425.73** |
| **Miscellaneous** | Paint | Krylon | 6 | $ 20.00 | $ 120.00 |
| | Birch Plywood 1/8 in.x2x2n | Rockler | 6 | $ 14.82 | $ 88.92 |
| | 635 Epoxy Resin | US Composites | 1 | $ 185.30 | $ 185.30 |
| | Filament Spool | Atomic Filament | 1 | $ 26.00 | $ 26.00 |
| | 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 |
| | Estimated Shipping | | | | $ 1,000.00 |
| | Incidentals (replacement tools, hardware, safety equipment, etc.) | | | | $ 1,500.00 |
| | | | | **Subtotal:** | **$ 3,049.07** |
| **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 | $ 2,694.00 |
| | | | | **Subtotal:** | **$ 10,993.66** |
| **Promotion** | T-Shirts | Core365 | 50 | $ 20.00 | $ 1000.00 |
| | Polos | Core365 | 20 | $ 26.00 | $ 520.00 |
| | | | | **Subtotal:** | **$ 1,520.00** |
| | | | | **Total Expenses:** | **$ 19,298.10** |

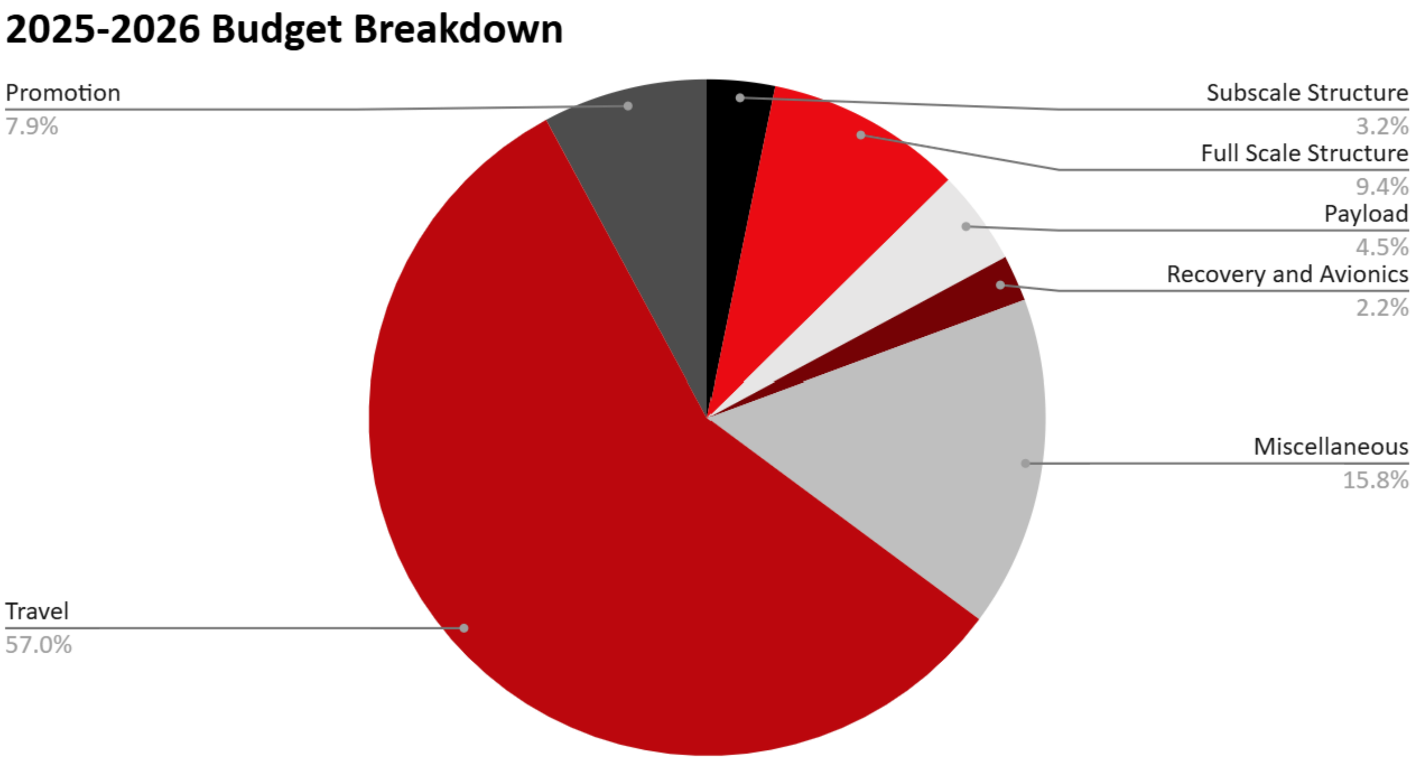


Figure 7.1: 2025-2026 Budget Breakdown

## 7.6 Funding Plan

The High-Powered Rocketry Club receives financial support from several NC State University resources as well as from the North Carolina Space Grant (NCSG). Each source contributes in different ways, and together they provide the foundation for the team's budget during the 2025–2026 academic year.

NC State's Student Government Association (SGA) allocates funding to more than 600 student organizations, including the club. At the start of each semester, the club submits an application outlining anticipated expenses, and SGA distributes funds based on those requests. For this academic year, the club will apply for $2,000 in both the fall and spring semesters. Despite these requests, the team expects to receive about $796 per semester, consistent with previous years. In the fall, these funds are typically devoted almost entirely to the subscale rocket, with little left over for full-scale materials. During the spring semester, SGA allocations usually support the purchase of remaining materials.

Additional funding comes from the College of Engineering Enhancement Funds through the Engineer Your Experience (EYE) department, which primarily supports engineering-related travel. All student travel expenses to Huntsville will be covered by this source. Based on the previous year's costs, the club estimates receiving approximately $8,500 this year to cover travel.

The Educational and Technology Fee (ETF) also provides funding aimed at enhancing academic experiences through student organizations. For the 2025–2026 academic year, the club expects to receive $3,500. These funds will be used for lab and safety equipment, as well as for covering the travel and lodging expenses of the team's faculty advisors during the Huntsville trip.

Beyond university sources, the North Carolina Space Grant (NCSG) provides a significant share of the team's resources. The club must apply in the fall semester for up to $5,000 in funding to support participation in the NASA SL Competition. The club has consistently received the maximum award in previous years, and the same outcome is expected for 2025–2026. These funds, typically available in November, are used primarily for the construction of the full-scale rocket and payload.

Sponsorships also supplement the team's budget. In the past, the club has received support from companies such as Collins Aerospace, Jolly Logic, and Fruity Chutes. The team continues to reach out to both new and past sponsors, though contributions are more commonly offered in the form of in-kind donations or discounts rather than direct financial support. For this academic year, the team anticipates receiving approximately $500 in goods and discounts, with the possibility of additional support as more sponsorships are secured.

All projected funding sources and allocations are summarized in Table 7.29, which provides a full overview of the expected revenue and expenditures for the 2025–2026 academic year.

Table 7.29: Projected Funding Sources

| Organization | Fall Semester | Spring Semester | Academic Year |
|---|---|---|---|
| NC State Student Government | $679 | $679 | $1,358 |
| North Carolina Space Grant | $5,000 | $0 | $5,000 |
| Engineer Your Experience | $0 | $8,000 | $8,000 |
| Educational and Technology Fee | $3,500 | $0 | $3,500 |
| Sponsorship/Fundraising | $1000 | $1000 | $2000 |
| **Total Funding:** | | | **$19358** |
| **Total Expenses:** | | | **$19,298.10** |
| **Difference:** | | | **$59.90** |

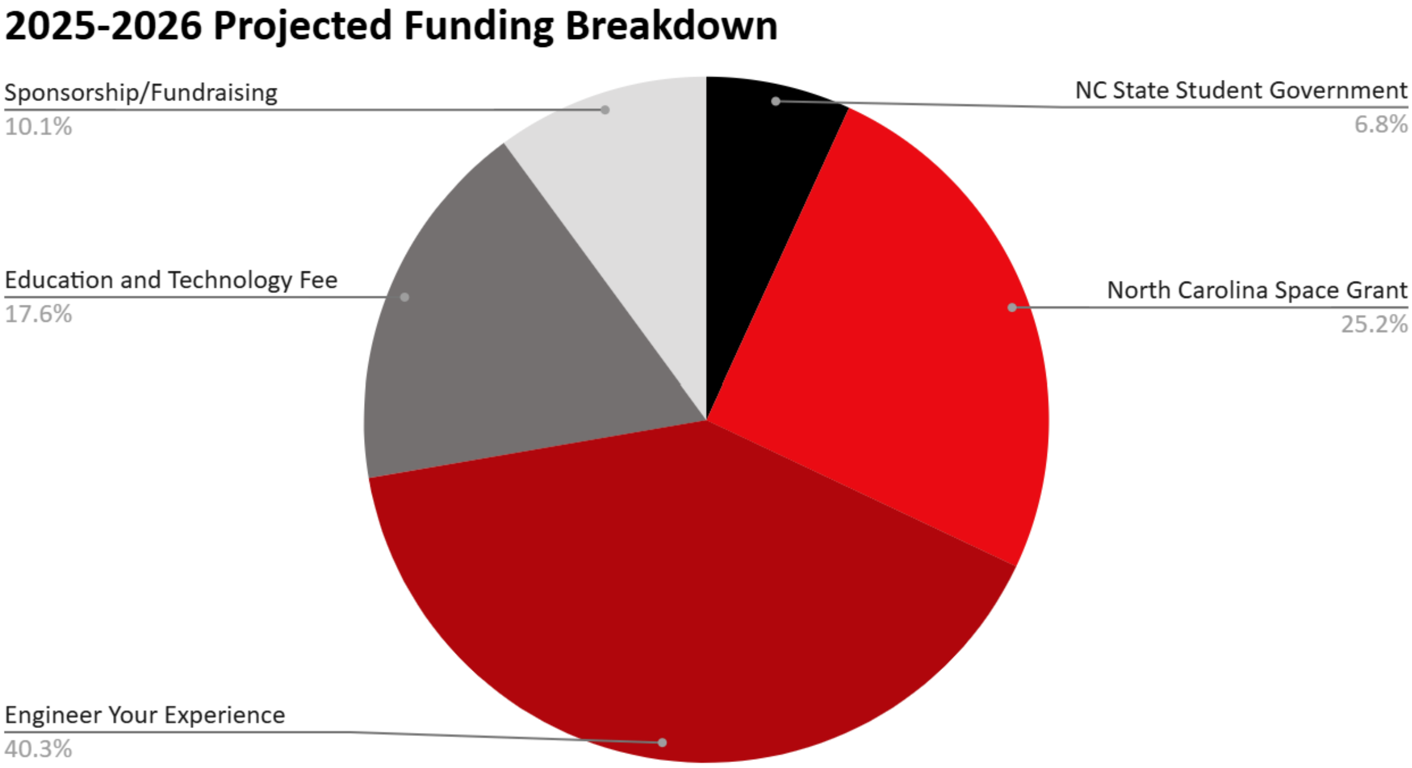


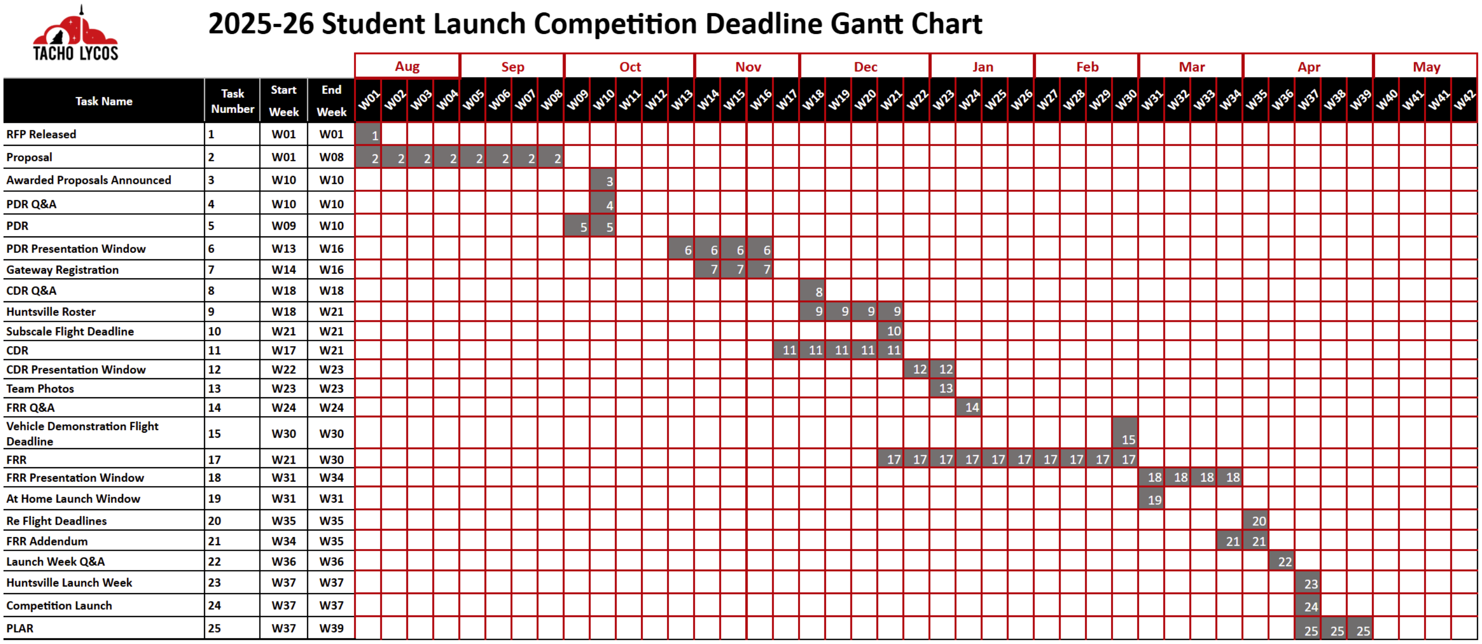
Figure 7.2: 2025-2026 Projected Funding Breakdown

## 7.7 Competition Timelines

### 7.7.1 Competition Deliverables

Table 7.30: Competition Deadlines

| Event/Task | Deadline/Date |
|---|---|
| Request for Proposal Released | August 8, 2025 |
| Proposal Due | September 22, 2025: 8:00 a.m. CT. |
| Awarded Proposals Announced | October 7, 2025 |
| Kickoff and PDR Q&A Teleconference | October 9, 2025: 10:00 a.m. CT and 2:00 p.m. CT |
| PDR Submission Due | November 3, 2025: 8:00 a.m. CT |
| PDR Video Teleconferences Window | November 10–21, 2025 |
| CDR Q&A | December 3, 2025 |
| Huntsville Rosters Due | December 15, 2025 |
| Subscale Flight Due | January 7, 2026: 8:00 a.m. CT |
| CDR Submission Due | January 7, 2026: 8:00 a.m. CT |
| CDR Video Teleconferences Window | January 14 – February 5, 2026 |
| Team Photos Due | February 9, 2026: 8:00 a.m. CT |
| FRR Q&A | February 11, 2026 |
| Vehicle Demonstration Flight (VDF) Due | March 9, 2026: 8:00 a.m. CT |
| FRR Submission Due | March 9, 2026: 8:00 a.m. CT |
| FRR Video Teleconferences Window | March 16 – April 3, 2026 |
| Payload Demonstration Flight Deadline | April 6, 2026: 8:00 a.m. CT |
| FRR Addendum Submission Due | April 6, 2026: 8:00 a.m. CT |
| Launch Week Q&A | April 15, 2026 |
| Teams Arrive in Huntsville | April 22, 2026 |
| Launch Week Events | April 23–24, 2026 |
| Launch Day | April 25, 2026 |
| Backup Launch Day | April 26, 2026 |
| PLAR Submission Due | May 11, 2026: 8:00 a.m. CT |



| Task Name | Task Number | Start Week | End Week |
|---|---|---|---|
| RFP Released | 1 | W01 | W01 |
| Proposal | 2 | W01 | W08 |
| Awarded Proposals Announced | 3 | W10 | W10 |
| PDR Q&A | 4 | W10 | W10 |
| PDR | 5 | W09 | W10 |
| PDR Presentation Window | 6 | W13 | W16 |
| Gateway Registration | 7 | W14 | W16 |
| CDR Q&A | 8 | W18 | W18 |
| Huntsville Roster | 9 | W18 | W21 |
| Subscale Flight Deadline | 10 | W21 | W21 |
| CDR | 11 | W17 | W21 |
| CDR Presentation Window | 12 | W22 | W23 |
| Team Photos | 13 | W23 | W23 |
| FRR Q&A | 14 | W24 | W24 |
| Vehicle Demonstration Flight Deadline | 15 | W30 | W30 |
| FRR | 17 | W21 | W30 |
| FRR Presentation Window | 18 | W31 | W34 |
| At Home Launch Window | 19 | W31 | W31 |
| Re Flight Deadlines | 20 | W35 | W35 |
| FRR Addendum | 21 | W34 | W35 |
| Launch Week Q&A | 22 | W36 | W36 |
| Huntsville Launch Week | 23 | W37 | W37 |
| Competition Launch | 24 | W37 | W37 |
| PLAR | 25 | W37 | W39 |

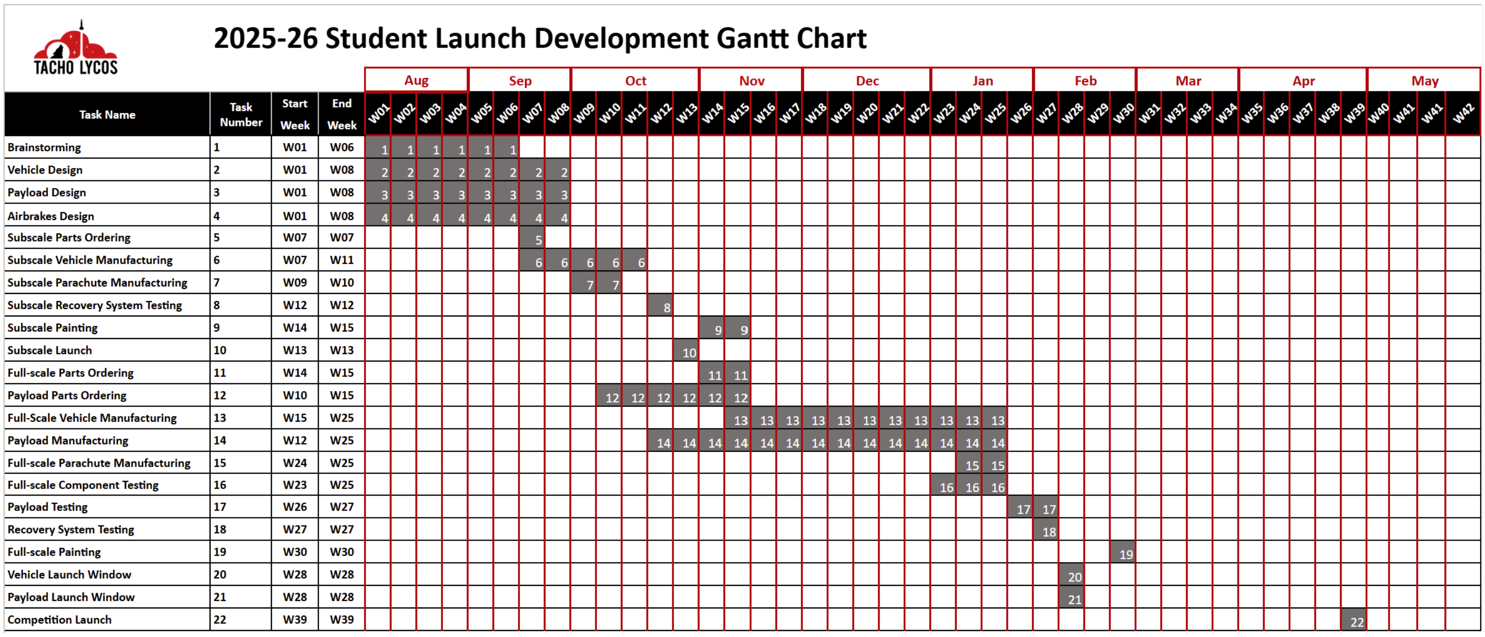
Figure 7.3: 2025-2026 Competition deadline Gantt chart.

### 7.7.2 Developmental Timeline

The Team will complete all deliverables during weekly subteam meetings, noted in Table 7.31. For these meetings, the Vehicle subteam is comprised of both the Structural lead and the Recovery lead. Pre-launch safety briefings occur during General body meetings, and at other miscellaneous times during the week when needed. Due to this nature, they are not included in Table 7.31. A weekly integration and safety meeting comprised of all the subteam leads and the Team's safety officer handles all safety matters and requirements verification. It also serves as a time for the Team Lead to discuss timeline and expectations. The timeline was adjusted since proposal by moving the painting of the subscale vehicle till after the subscale launch on November 1st. This will allow for more proper fabrication of a pre-flight checklist. The PDR deadline was also extended to November 3rd, due to a decision from NASA SL. The Project Timeline in Table 7.32 provides a more in-depth fabrication, testing, and launch timeline for the NASA SL deliverables, referenced in Table 7.30.

Table 7.31: Weekly Club Schedule

| | |
|---|---|
| Sunday | No scheduled activities |
| Monday | 6:00 pm - 7:30 pm: Vehicle Sub-team |
| Tuesday | 11:40 am - 1:20 pm: Integration and Safety Meeting<br>4:00 pm - 5:00 pm: Payload Subteam<br>7:00 pm - 8:00 pm: Outreach/Sponsorship Meeting |
| Wednesday | 10:30 am - 12:00 pm: Vehicle Subteam<br>3:00 pm - 4:00 pm: Aerodynamics Subteam<br>6:00 pm - 7:30 pm: Officer Meeting |
| Thursday | 12:00 pm - 1:00 pm: Payload Subteam<br>7:30 pm - 8:30 pm: Club General Body Meeting |
| Friday | 9:00am - 5:00pm: Launch Day Preparation (When applicable)<br>10:30 am - 12:00 pm: Vehicle Subteam |
| Saturday | Launch Day (When applicable) |



2025-26 Student Launch Development Gantt Chart

| 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 | W41 | W41 | W42 |
| Brainstorming | 1 | W01 | W06 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Vehicle Design | 2 | W01 | W08 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Payload Design | 3 | W01 | W08 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Airbrakes Design | 4 | W01 | W08 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Subscale Parts Ordering | 5 | W07 | W07 | | | | | | | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Subscale Vehicle Manufacturing | 6 | W07 | W11 | | | | | | | 6 | 6 | 6 | 6 | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Subscale Parachute Manufacturing | 7 | W09 | W10 | | | | | | | | | 7 | 7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Subscale Recovery System Testing | 8 | W12 | W12 | | | | | | | | | | | | 8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Subscale Painting | 9 | W14 | W15 | | | | | | | | | | | | | | 9 | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Subscale Launch | 10 | W13 | W13 | | | | | | | | | | | | | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Full-scale Parts Ordering | 11 | W14 | W15 | | | | | | | | | | | | | | 11 | 11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Payload Parts Ordering | 12 | W10 | W15 | | | | | | | | | | 12 | 12 | 12 | 12 | 12 | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Full-Scale Vehicle Manufacturing | 13 | W15 | W25 | | | | | | | | | | | | | | | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | | | | | | | | | | | | | | | | | | |
| Payload Manufacturing | 14 | W12 | W25 | | | | | | | | | | | | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | | | | | | | | | | | | | | | | | | |
| Full-scale Parachute Manufacturing | 15 | W24 | W25 | | | | | | | | | | | | | | | | | | | | | | | | 15 | 15 | | | | | | | | | | | | | | | | | | |
| Full-scale Component Testing | 16 | W23 | W25 | | | | | | | | | | | | | | | | | | | | | | | 16 | 16 | 16 | | | | | | | | | | | | | | | | | | |
| Payload Testing | 17 | W26 | W27 | | | | | | | | | | | | | | | | | | | | | | | | | | 17 | 17 | | | | | | | | | | | | | | | | |
| Recovery System Testing | 18 | W27 | W27 | | | | | | | | | | | | | | | | | | | | | | | | | | | 18 | | | | | | | | | | | | | | | | |
| Full-scale Painting | 19 | W30 | W30 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 19 | | | | | | | | | | | | | |
| Vehicle Launch Window | 20 | W28 | W28 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 20 | | | | | | | | | | | | | | | |
| Payload Launch Window | 21 | W28 | W28 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 21 | | | | | | | | | | | | | | | |
| Competition Launch | 22 | W39 | W39 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 22 | | | | |

Figure 7.4: 2025-2026 Competition development Gantt chart.

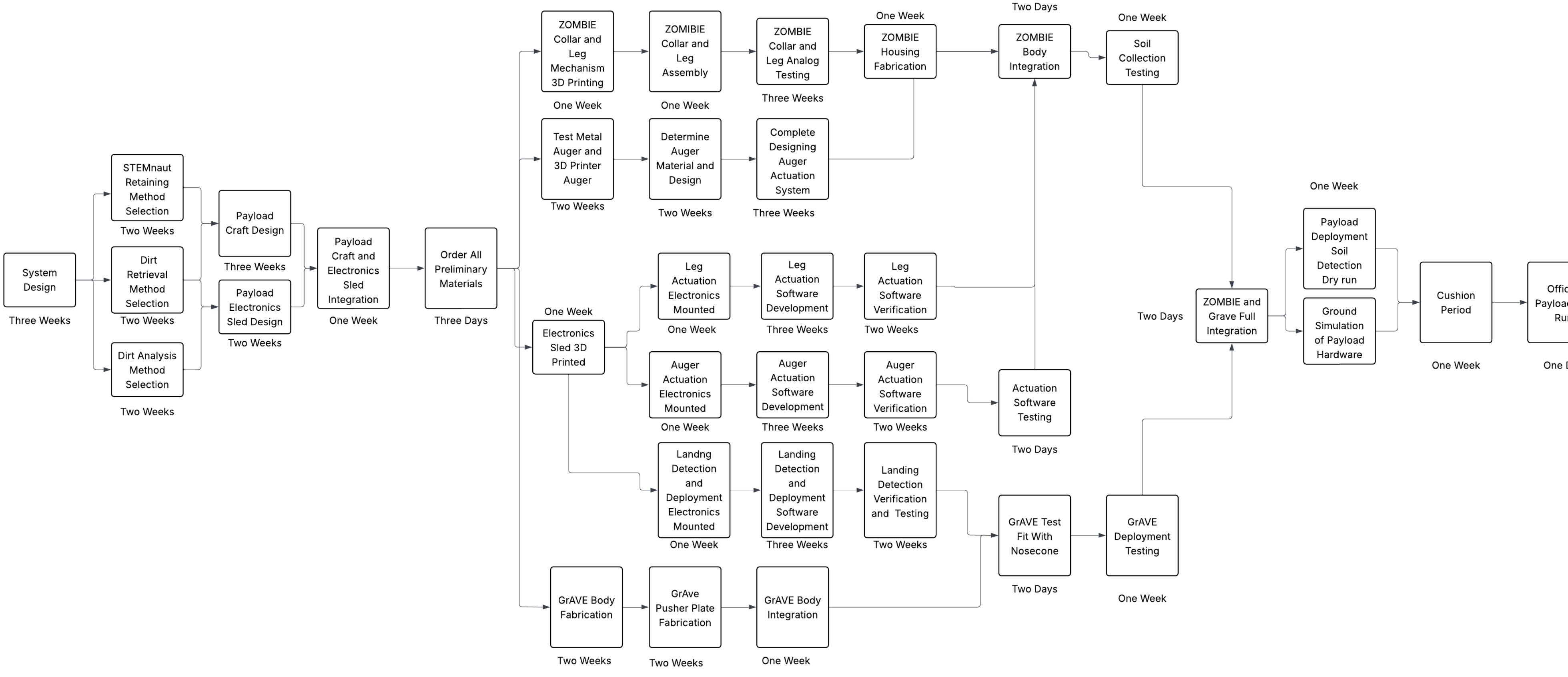


Figure 7.5: 2025-2026 payload PERT chart.

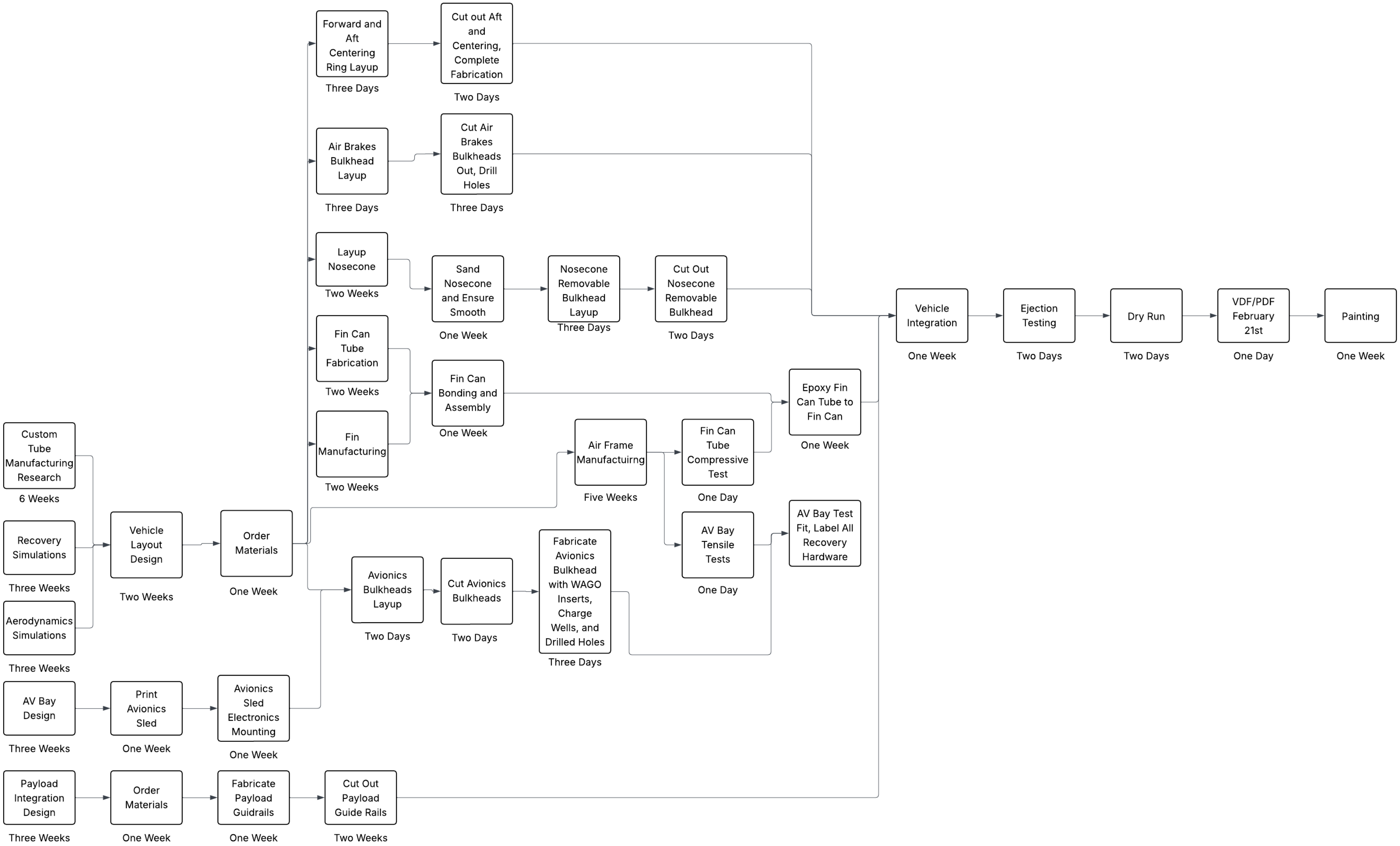


Figure 7.6: 2025-2026 full-scale vehicle PERT chart.

Table 7.32: 2025-2026 Project Timeline

| August 2025 | | | | | | |
|---|---|---|---|---|---|---|
| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
| | | | | | **1** | **2** |
| **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| **17** | **18**<br>• First day of classes | **19** | **20** | **21** | **22** | **23** |
| **24** | **25**<br>• All teams: Read NASA Handbook | **26** | **27** | **28** | **29** | **30** |
| **31** | | | | | | |

| September 2025 | | | | | | |
|---|---|---|---|---|---|---|
| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
| | **1**<br>• Labor Day - No classes | **2** | **3** | **4** | **5** | **6** |
| **7**<br>• All Teams: Proposal Writing | **8**<br>• All Teams: Proposal Writing | **9**<br>• All Teams: Proposal Writing | **10**<br>• All Teams: Proposal Writing | **11**<br>• All Teams: Proposal Writing | **12**<br>• All Teams: Proposal Writing | **13** |
| **14**<br>• All Teams: Proposal Writing | **15**<br>• All Teams: Proposal Writing<br>• University Wellness Day - No classes<br>• All Teams: Team Photos | **16**<br>• All Teams: Proposal Writing | **17**<br>• All Teams: Proposal Writing | **18**<br>• All Teams: Proposal Writing | **19**<br>• All Teams: Proposal Writing | **20** |
| **21** | **22** | **23**<br>• All Teams: Proposal Submission | **24** | **25** | **26** | **27** |
| **28**<br>• Vehicle: Custom tube manufacturing | **29** | **30** | | | | |

| October 2025 | | | | | | |
|---|---|---|---|---|---|---|
| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |

Table 7.32: 2025-2026 Project Timeline (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| | | **1** | **2**<br>• Vehicle: Subscale materials ordered<br>• Vehicle: Subscale Drogue parachutes to be fabricated | **3**<br>• Payload: Order Soil sensor, metal augers ordered | **4**<br>• Vehicle: 3-point bending tests for balsa and honeycomb composites<br>• Vehicle: Compressive tests on hand-rolled tubing | **5** |
| **6**<br>• Vehicle: Subscale fins and fincan fabricated | **7**<br>• Payload: Research programming dirt sensor | **8**<br>• Aerodynamics: Redesign electronics within housing for subscale<br>• All Teams: PDR Q and A | **9**<br>• Payload: Test 3D printed augers | **10**<br>• Vehicle: Finish subscale fincan | **11** | **12** |
| **13**<br>• All Teams: PDR Writing<br>• Fall Break<br>• Vehicle: Subscale bulkhead holes drilled<br>• Vehicle: Recovery sled printed | **14**<br>• All Teams: PDR Writing<br>• Fall Break<br>• Payload: CAD for PDR | **15**<br>• All Teams: PDR Writing<br>• Aerodynamics: Bend test on new fin design for Air Brakes<br>• Aerodynamics: Soldering for Air Brakes electronics<br>• Vehicle: Fin slots cut into Fincan | **16**<br>• All Teams: PDR Writing<br>• Payload: Test metal augers | **17**<br>• All Teams: PDR Writing | **18** | **19** |
| **20**<br>• All Teams: PDR Writing<br>• Vehicle: Ejection testing | **21**<br>• All Teams: PDR Writing | **22**<br>• All Teams: PDR Writing | **23**<br>• All Teams: PDR Writing | **24**<br>• All Teams: PDR Writing | **25**<br>• All Teams: PDR Writing<br>• Vehicle: Dry run | **26** |
| **27** | **28** | **29** | **30** | **31** | | |
| November 2025 | | | | | | |
| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
| | | | | | | **1**<br>• All Teams: Subscale Launch day |
| **2** | **3**<br>• All Teams: PDR due<br>• Vehicle: Review subscale recovery data | **4**<br>• Payload: Design auger actuation system | **5**<br>• Aerodynamics: Review subscale launch data<br>• Vehicle: Verify full scale structural calculations | **6**<br>• Payload: Finalize electronic parts for ordering | **7** | **8**<br>• All Teams: Paint Subscale |

Table 7.32: 2025-2026 Project Timeline (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| **9**<br>• All Teams: Paint Subscale | **10**<br>• All Teams: Prepare for PDR presentation<br>• Vehicle: Begin drogue parachute fabrication<br>• Vehicle: Sample fin for destructive testing | **11**<br>• Payload: Test auger drill setup<br>• Payload: Integrate lead screw | **12**<br>• Aerodynamics: Rewrite apogee prediction<br>• Vehicle: Construct avionics bulkhead | **13**<br>• Payload: Integrate live data<br>• Payload: Test leg deployment | **14**<br>• Vehicle: Complete construction of bulkhead | **15**<br>• Backup Subscale Launch day |
| **16**<br>• Vehicle: Complete destructive VV and T for sample fin | **17**<br>• Payload: Create lander electrical schematics<br>• Payload: Develop landing detection algorithm | **18**<br>• Aerodynamics: Finalize simulation methodology<br>• Aerodynamics: Start integration with OpenRocket | **19**<br>• Payload: Design latch-rail-pusher deployment<br>• Payload: Preliminary electronics sled | **20**<br>• Vehicle: Drogue Parachute fabrication | **21** | **22** |
| **23**<br>• Vehicle: Test drogue parachute | **24**<br>• Payload: Deployment system electrical schematic<br>• Payload: Test landing detection<br>• All Teams: Subteam integration verification | **25**<br>• Aerodynamics: FSI simulation integration<br>• Aerodynamics: VV and T Air Brakes fins | **26**<br>• Thanksgiving Break | **27**<br>• Thanksgiving Break | **28** | **29** |
| **30** | | | | | | |
| December 2025 | | | | | | |
| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
| | **1**<br>• Vehicle: Primary vehicle parts ordered<br>• All Teams: Complete Huntsville Roster | **2**<br>• Payload: Order all remaining parts | **3**<br>• Vehicle: Bulkhead design, WAGO inserts, charge wells<br>• Aerodynamics: CAD modeling for Air Brakes<br>• Aerodynamics: RocketPy Monte Carlo simulations<br>• Last day of classes<br>• All Teams: CDR Q and A | **4**<br>• University Reading Day - No classes<br>• Payload: Continue code verification | **5**<br>• Final Exams | **6**<br>• Final Exams |
| **7**<br>• All Teams: CDR Writing<br>• Final Exams | **8**<br>• All Teams: CDR Writing<br>• Final Exams | **9**<br>• All Teams: CDR Writing<br>• Final Exams<br>• Aerodynamics: Finalize drag calculation methodology | **10**<br>• All Teams: CDR Writing<br>• Vehicle: Manufacture Nosecone | **11**<br>• All Teams: CDR Writing<br>• Vehicle: Manufacture Nosecone | **12**<br>• Vehicle: Complete Manufacturing of Nosecone | **13** |

Table 7.32: 2025-2026 Project Timeline (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| **14**<br>• Vehicle: Drouge Bay airframe layup | **15**<br>• Vehicle: Complete fabrication of Drouge Bay airframe<br>• All Teams: Huntsville rosters due | **16**<br>• Vehicle: Forward and aft centering rings manufacturing | **17**<br>• Vehicle: Complete forward and aft centering rings<br>• Vehicle: Avionics and Air Brakes Bay bulkhead layup<br>• Vehicle: Nosecone removable bulkhead manufacturing | **18** | **19** | **20**<br>• Vehicle: Cut out Avionics and Air Brakes Bay bulkheads<br>• Vehicle: Cut out Nosecone removable bulkhead |
| **21**<br>• All Teams: CDR Writing<br>• Winter Break | **22**<br>• All Teams: CDR Writing<br>• Winter Break | **23**<br>• All Teams: CDR Writing<br>• Winter Break | **24**<br>• All Teams: CDR Writing<br>• Winter Break | **25**<br>• All Teams: CDR Writing<br>• Winter Break | **26**<br>• Winter Break | **27**<br>• Winter Break |
| **28**<br>• Winter Break | **29**<br>• Winter Break | **30**<br>• Winter Break | **31**<br>• Winter Break | | | |

January 2026

| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| | | | | **1**<br>• Winter Break | **2**<br>• Winter Break<br>• Vehicle: Fabricate Payload guide rails | **3**<br>• Winter Break |
| **4**<br>• Winter Break | **5**<br>• Winter Break<br>• Vehicle: Cut out payload guide rails | **6**<br>• Winter Break<br>• All Teams: Subscale Flight Deadline<br>• All Teams: CDR due | **7**<br>• Winter Break | **8**<br>• Winter Break<br>• Vehicle: Smooth nosecone surface | **9**<br>• Winter Break | **10**<br>• Winter Break |
| **11** | **12**<br>• Vehicle: Airframe tubing layups | **13**<br>• Payload: Research code integration with motors<br>• All Teams: Prepare for CDR presentations | **14**<br>• Vehicle: Bulkhead, centering rings, fin layups | **15**<br>• Payload: Payload structural fabrication | **16**<br>• Vehicle: Avionics bay wiring | **17**<br>• Payload: ZOMBIE self righting test |
| **18**<br>• Martin Luther King Jr. Day - No classes<br>• Vehicle: Airframe post-processing | **19**<br>• Payload: Payload structural fabrication<br>• Payload: Write code for motors | **20**<br>• Aerodynamics: System and integration testing for Air Brakes module<br>• Aerodynamics: Simulation verification<br>• Vehicle: Bullhead, centering ring, fin post-processing | **21** | **22** | **23**<br>• Vehicle: Test Altimeters and GPS, verify programming | **24**<br>• Payload: Drilling test |

Table 7.32: 2025-2026 Project Timeline (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| **25** | **26**<br>• Vehicle: Fin can bonding and assembly<br>• All Teams: Practice CDR Presentation | **27**<br>• Payload: Write code to deploy the lander | **28**<br>• Vehicle: Finalize vehicle masses and recovery calculations<br>• Aerodynamics: Finalize simulation predictions and verify target apogee<br>• All Teams: CDR Presentation | **29**<br>• Payload: Payload fabrication and electronics integration | **30**<br>• Vehicle: Composite three point bending test retrial<br>• Vehicle: Fincan tube compressive test<br>• All Teams: Take Team Photo | **31** |
| February 2026 | | | | | | |
| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
| **1** | **2**<br>• Vehicle: Assemble the Fin can to the airframe tubing assembly and add fillets<br>• Vehicle: Parachute drop test | **3**<br>• Payload: Test lander code, write auger code | **4**<br>• Vehicle: Shear pins, PEM nuts, vent holes, and alignment screw drilling<br>• Aerodynamics: Air Brakes coding | **5**<br>• Payload: Begin payload integration with the Launch Vehicle<br>• Payload: Begin deployment and soil collection testing | **6**<br>• Vehicle: Test fit Avionics bay, label all recovery hardware | **7**<br>• Payload: GrAVE deployment test |
| **8**<br>• Vehicle: Work on vehicle integration, to be finalized by the end of the week<br>• AV Bay tensile test | **9**<br>• Payload: Payload ZOMBIE and GrAVE full integration<br>• All Teams: Team Photos due | **10**<br>• Vehicle: Fin can drop test<br>• Aerodynamics: Air Brakes coding<br>• All Teams: FRR Q and A | **11**<br>• Payload: Payload deployment and soil collection dry run | **12**<br>• Vehicle: Ejection testing<br>• All Teams: Dry run | **13**<br>• All Teams: Paint Launch Vehicle | **14**<br>• Payload: Ground simulation of payload hardware |
| **15**<br>• All Teams: Paint Launch Vehicle | **16**<br>• All Teams: FRR Writing<br>• Aerodynamics: Air Brakes deployment test | **17**<br>• All Teams: FRR Writing<br>• Payload: Payload dry run | **18**<br>• All Teams: FRR Writing<br>• University Wellness Day - No classes<br>• Air Brakes assembly verification for VDF | **19**<br>• All Teams: FRR Writing | **20**<br>• All Teams: FRR Writing | **21**<br>• Vehicle Demonstration Flight and Payload Demonstration Flight<br>• Aerodynamics: Air Brakes effectivness flight test |
| **22**<br>• All Teams: FRR Writing | **23**<br>• All Teams: FRR Writing | **24**<br>• All Teams: FRR Writing<br>• Aerodynamics: Analyze data from VDF for Air Brakes altitude reduction | **25**<br>• All Teams: FRR Writing | **26**<br>• All Teams: FRR Writing | **27** | **28** |
| March 2026 | | | | | | |
| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |

Table 7.32: 2025-2026 Project Timeline (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4**<br>• Aerodynamics: Moment of inertia testing for FRR and VV and T | **5** | **6** | **7** |
| **8** | **9**<br>• All Teams: FRR due<br>• All Teams: VDF Deadline<br>• All Teams: FRR presentation practice | **10** | **11** | **12** | **13** | **14**<br>• Backup PDF/VDF launch day for re-flight |
| **15**<br>• Spring Break | **16**<br>• Spring Break | **17**<br>• Spring Break | **18**<br>• Spring Break | **19**<br>• Spring Break | **20**<br>• Spring Break | **21** |
| **22** | **23** | **24** | **25** | **26** | **27** | **28**<br>• Backup PDF/VDF launch day |
| **29** | **30** | **31** | | | | |
| April 2026 | | | | | | |
| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
| | | | **1** | **2** | **3** | **4** |
| **5** | **6**<br>• All Teams: VDF and PDF Re-flight deadline<br>• All Teams: FRR addendum due | **7** | **8**<br>• All Teams: FRR addendum writing | **9**<br>• All Teams: FRR addendum writing | **10**<br>• All Teams: FRR addendum writing | **11** |
| **12** | **13** | **14**<br>• All Teams: Launch week Q and A | **15**<br>• All Teams: Huntsville ejection testing | **16**<br>• All Teams: Huntsville dry run | **17** | **18** |
| **19** | **20** | **21**<br>• All Teams: Huntsville | **22**<br>• All Teams: Huntsville | **23**<br>• All Teams: Huntsville | **24**<br>• All Teams: Huntsville Launch Day | **25** |
| **26**<br>• All Teams: Huntsville Backup Launch Day | **27**<br>• All Teams: PLAR Writing | **28**<br>• All Teams: PLAR Writing | **29**<br>• All Teams: PLAR Writing<br>• Last day of classes | **30**<br>• All Teams: PLAR Writing<br>• Final Exams | | |
| May 2026 | | | | | | |
| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
| | | | | | **1** | **2** |

Table 7.32: 2025-2026 Project Timeline (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| **3** | **4** | **5** | **6** | **7** | **8** | **9**<br>• Final Exams<br>• Spring Commencement Exercises |
| **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| **10** | **11** | **12** | **13** | **14** | **15** | **16**<br>• All Teams: PLAR due |
| **17** | **18** | **19** | **20** | **21** | **22** | **23** |
| **24** | **25** | **26** | **27** | **28** | **29** | **30** |
| **31** | | | | | | |

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