# Rose Rocketry

## Project Kirkpatrick
## Critical Design Review

Rose-Hulman Institute of Technology
January 9, 2023

5500 Wabash Ave, Terre Haute, IN 47803

# Table of Acronyms

| Acronym | Definition |
|---|---|
| VDF | Vehicle Demonstration Flight |
| VCS | Version Control System |
| USLI | University Student Launch Initiative |
| USB | Universal Serial Bus |
| TNC | Terminal Node Controller |
| STEM | Science, Technology, Engineering, and Mathematics |
| STDIN/STDOUT | Standard input/Standard output |

| | |
|---|---|
| SNR | Signal to Noise Ratio |
| SL | Student Launch |
| SGA | Student Government Association |
| SDR | Software-Defined Radio |
| SDK | Software Development Kit |
| SBC | Single Board Computer |
| RTL-SDR | RealTek Software-Defined Radio |
| RSO | Range Safety Officer |
| RRC | Rocket Recovery Controller |
| RR-SL | Rose Rocketry - Student Launch |
| RF | Radio Frequency |
| PPE | Personal Protective Equipment |
| PLAR | Post-Launch Assessment Review |
| PDR | Preliminary Design Review |
| PDF | Payload Demonstration Flight |
| OS | Operating System |
| OpenCV | Open Computer Vision |
| NASA | National Aeronautics and Space Administration |
| NAR | National Association of Rocketry |
| ME | Mechanical Engineering |
| MBC | Merit Badge Counselor |
| MATLAB | Matrix Laboratory |
| LCD | Liquid-crystal Display |
| HTD | High-torque drive |
| HPR | High Powered Rocketry |
| HB | Handbook |
| GPS | Global Positioning System |
| FRR | Flight Readiness Review |
| FPG-9 | 9-inch Foam Plate Glider |
| FMEA | Failure Modes and Effects Analysis |
| FM | Frequency Modulation |
| FIRST | For Inspiration and Recognition of Science and Technology |
| FAA | Federal Aviation Administration |
| ESD | Electrostatic Discharge |
| EDGE | Explain, Demonstrate, Guide, and Enable |
| ECE | Electrical and Computer Engineering |
| DC | Direct Current |
| CPU | Central Processing Unit |
| CP | Center of Pressure |

| | |
|---|---|
| COTS | Commercial Off-The-Shelf |
| COTF | Commercial Off the Shelf |
| CG | Center of Gravity |
| CDR | Critical Design Review |
| CAD | Computer-aided design |
| BIC/KIC | Branam and Kremer Innovation Center |
| APRS | Automatic Packet Reporting System |
| ADC | Analogue to Digital Converter |

# 1. Summary of CDR Report

## 1.1. Team Summary

Table 1.1: Team Name and Launch Plans

| | |
|---|---|
| **Team Name** | Rose Rocketry |
| **Mailing Address** | 5500 Wabash Ave, Terre Haute, IN 47803 |
| **Mentor Information** | Randy Milliken<br>randy@milliken.org<br>NAR#86429 - Level 3 |
| **NAR/TRA Sections** | Indiana Rocketry Group Tripoli #132<br>NAR Section #711 |
| **Launch Window Plan** | SL Launch Field at Bragg Farm<br>Toney, Alabama<br>April 15, 2023 |
| **Hours Spent on CDR** | 366 hrs |

Table 1.3: Subsystem Size and Mass

| | | |
|---|---|---|
| **Payload** | 42 in. | 7.75 lbm. |
| **Recovery** | 24 in. | 4.16 lbm. |
| **Booster (Wet)** | 36 in, | 8.12 lbm. |
| **Booster (Dry)** | | 3.95 lbm. |

## 1.2. Launch Vehicle Summary

Table 1.2: Motor, and Recovery Summary

| | |
|---|---|
| **Target Altitude** | 5000 ft. |
| **Final Motor Choice** | CTI K600-WH |
| **Recovery System** | Dual-Deploy |
| **Rail Size** | 8 ft. 1010 |
| **Vehicle Length** | 102 in. |
| **Vehicle Dry Mass Without Ballast** | 259 oz. |
| **Vehicle Dry Mass With Ballast** | 259 oz. |
| **Vehicle Wet Mass** | 20 oz. |
| **Vehicle Burnout Mass** | 279 oz. |
| **Vehicle Landing Mass** | 279 oz. |

## 1.3. Payload Summary

The payload title is “A View to a Kill” credited to the fourteenth James Bond movie. The payload will deploy a camera upon landing, receive Automatic Packet Reporting System (APRS) commands, and execute the received commands within a maximum time of 30 seconds. The camera must be deployed such that it has a clear image of the terrain and sky, with the horizon in the center of the frame, and be capable of rotating 360°. In order to accomplish this, upon landing a section of airframe located at the fore of the launch vehicle will deploy external supports to fix the ends of the airframe to the ground while the airframe in between the supports rotates to orient the camera with the horizon. Once the proper orientation is achieved the camera and APRS antenna will be external deployed to receive APRS packets and manipulate the camera.

# 2. Changes Made Since PDR Report

## 2.1. Vehicle Criteria

### 2.1.1. Motor

The motor choice in the PDR was the K780BS. Updated simulation techniques to be detailed further in the subscale report means the estimated apogee of the vehicle using this motor is 5761 feet, well over the team's target apogee of 5000 feet. The final motor selection is the K600-WH. This motor is simulated to take the vehicle to an apogee of 5340 feet, which is much closer to the target apogee allowing room for small changes in actual payload and vehicle weight and the addition of ballast to tune the projected apogee. Also, this motor is more widely available for purchase than the K780BS.

### 2.1.2. Aerodynamics

The motor change has induced a rearwards shift which caused an unacceptable drop in stability margin effectively making the team change the height of the fins from 3 inches to 3.75 inches. The original stability was just over 1 caliber, and while stable, it did not satisfy the handbook requirement for a static stability of 2. The new stability is 2.13 calibers, satisfying the handbook requirement.

## 2.2. Payload Criteria

### 2.2.1. Payload Mechanics

The COTS hinges were changed for smaller hinges with smaller stiffness torsional springs to avoid pinching. The scissor lift was replaced with a 4-bar lift due to size constraints.

### 2.2.2. Payload Electronics

The requirements for the electronics on the payload had few changes since the PDR. The payload team decided to add a buzzer for audio cues for launch day status updates. Another change we had was to send video data across a common and easy to use cable.

## 2.3. Project Plan

The budget is updated to include all full-scale parts rather than just estimates. It also includes an updated budget for travel to Huntsville.

The project plan now includes a day-by-day breakdown of team activities and durations. The Gantt Chart is also updated to include the activities up to the PLAR.

# 3. Vehicle Criteria

## 3.1. Design and Verification and Launch Vehicle

### 3.1.1. Mission Statement

The objective of the vehicle system is to create a rocket that safely and reliably reaches the target altitude in a variety of launch conditions, deploys recovery systems that allow a safe return to the ground, and allows the payload to be deployed in an effective manner upon landing.

A successful vehicle mission meets all of the following criteria:

1. Launch vehicle lands successfully and allows payload to deploy completely
2. The launch vehicle is launched on a safe, stable, and predictable trajectory
3. The launch vehicle is recovered in a state suitable for immediate reuse
4. All members abide by all safety regulations created by NAR, the FAA, Rose-Hulman, and Rose Rocketry

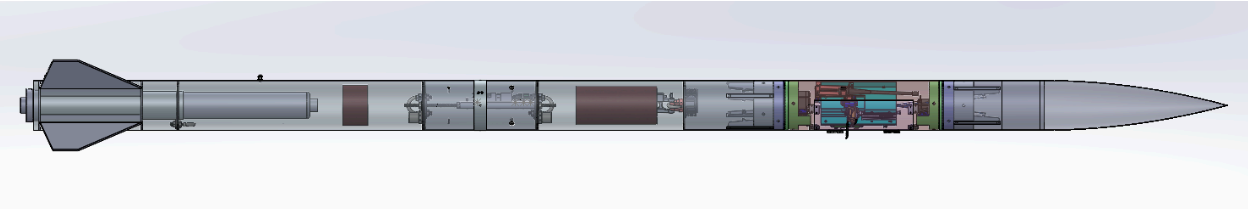


**Figure 3.1: Planned vehicle layout**

### 3.1.2. Design Choices

The following table discusses the final design choices for the vehicle. These decisions are based on research from the PDR as well as experience from the subscale flight test (Section 3.2). Table 3.1 discusses each decision, and justification is further discussed in the following sections.

**Table 3.1: Vehicle Design Choices Summary**

| Vehicle Characteristic | Choice | Justification |
|---|---|---|
| Airframe material | Fiberglass | • Lightweight and durable<br>• Affordable and accessible<br>• Easy to machine |
| Vehicle Stack Layout | Dual Separation with Central Avionics | • Backup motor ejection charge to deploy drogue parachute<br>• Easy to manufacture |
| Airframe Construction | Cylindrical Monocoque | • Easy to manufacture<br>• Durable |

| | | |
|---|---|---|
| | Airframe | - Lots of internal space |
| Fin Shape | Trapezoidal Fins | - Very strong<br>- Team is experienced with using them<br>- Decent aerodynamic efficiency |
| Nose Cone Shape | Long Ogive Nose Cone | - Very good aerodynamic efficiency<br>- Readily available<br>- Plenty of space for GPS |
| Motor Choice | K600-WH Motor | - Very close to target apogee with initial simulations<br>- Adequate velocity off of rod<br>- Currently have all motor hardware |

### 3.1.2.1. Material Selection

The final selection for airframe material is G12 Fiberglass. G12 Fiberglass will be used for the body tubes, while G10 will be used for flat sheets, centering rings, bulkheads, fins. The glass fiber and resin composite has a high material toughness meaning it is easier to machine, and any dust produced in the machining process can be mitigated by machining fiberglass in a sanding booth with good ventilation and using proper PPE. The material is not susceptible to water damage and was undamaged during the subscale flight, which means we are confident that using the material would mean the vehicle will be recoverable and could be re-flown on the same day. With previous team experience using fiberglass and with experience using fiberglass for the subscale flight, it is a safe and confident material choice.

### 3.1.2.2. Vehicle Stack Layout

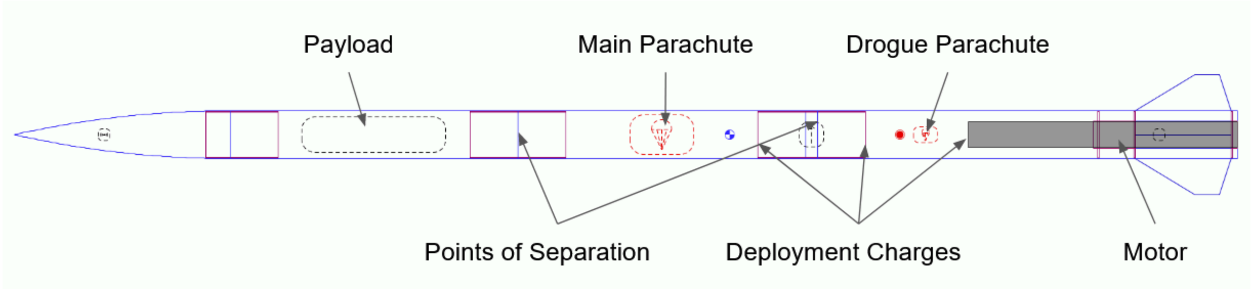


**Figure 3.2: Planned vehicle stack layout**

The dual separation with central avionics layout is the layout of choice. The payload location in the foremost tube increases stability by moving the center of gravity towards the tip. This location also means the payload and GPS can be connected to one side of the main parachute. The benefit of this is that they can be disconnected from the harness to prevent dragging. The location of the parachutes and avionics bay is optimal because the drogue parachute is located in the booster tube. In the subscale launch the team conducted in the 2021-2022 season, the avionics were not operational, so neither of the parachutes were deployed resulting in complete destruction of the vehicle when it crashed. In this design, the motor ejection charge is able to separate the vehicle and deploy the drogue parachute in case of complete avionics failure. This would mean the vehicle would be easier to investigate for failure after landing as it would be more intact.

#### 3.1.2.3. Airframe Construction

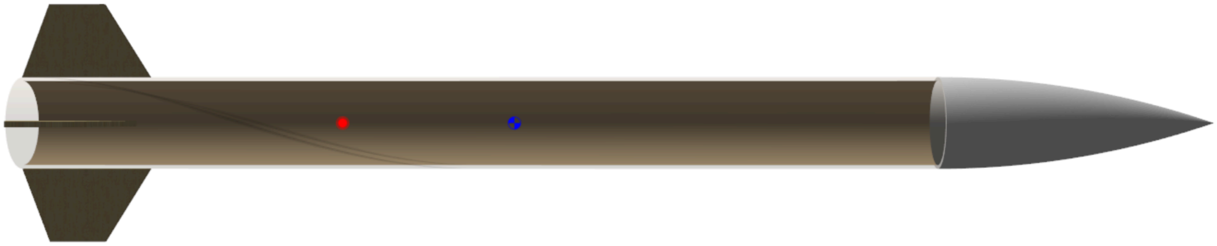


**Figure 3.3: Example of a cylindrical monocoque airframe**

The airframe shall be a cylindrical monocoque airframe, which means the outer skin of the airframe acts as the structure of the airframe. Research documented in the PDR, as well as team experience demonstrates that the readily accessible fiberglass tubes should be structurally sound for supporting the stresses during launch. The benefits of fiberglass as astIt is significantly easier to manufacture than alternative structures.

#### 3.1.2.4. Fin Shape

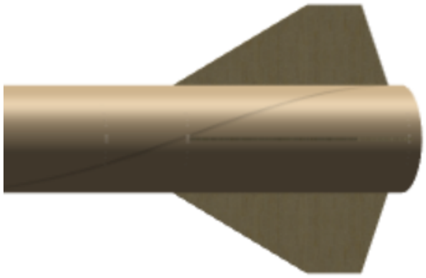


**Figure 3.4: Example of trapezoidal fins**

Trapezoidal fins are the best option for our vehicle due to their aerodynamic efficiency and reliability. The team has significant experience using this fin shape and it has proven to be very strong due to the upward angle on the trailing edge which helps prevent damage during landing. The leading edge is a steep slope which increases aerodynamic efficiency. These fins were used in the subscale vehicle and were successful during the flight documented in Section 3.2. Because of extensive team experience, robustness, and efficiency, this is the best fin shape for the vehicle.

#### 3.1.2.5. Nose Cone Shape

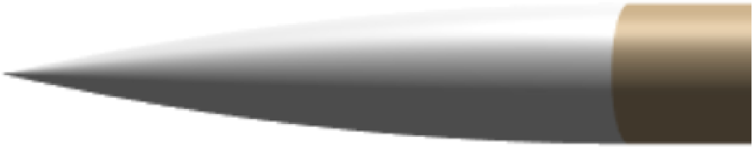


**Figure 3.5: Example of a long-ogive nose cone**

The long-ogive nose cone is the final shape selection for the nose cone. It has very high aerodynamic efficiency especially at subsonic speeds and has plenty of space for the GPS and its antenna. This style of nose cone was used on the subscale flight documented in section 3.2 as a justification of its selection.

#### 3.1.2.6. Motor Choice

The motor selection for this vehicle is the K600. After updating the simulations using data from the subscale flight as discussed in Section 3.2.8, use of the K780BS (leading motor alternative from the PDR) resulted in a simulated apogee of 5,506 feet, which is far above the target apogee and would require use of all allowable ballast in order to reach closer to 5000 feet. In addition, problems were found with the availability of the motor. The K600 results in an estimated apogee of 5,340 feet using OpenRocket, which is closer to the target apogee and allows flexibility for small changes in the actual mass of the vehicle and payload. The final apogee can be tuned using ballast. Simulated speed off of the rail is 57.9ft/s, which is 5.9ft/s over the NASA handbook requirement. See section 3.4 for detailed mission performance predictions.

### 3.1.3. Dimensional CAD Drawings

The CAD drawings highlight the manufactured components of the vehicle. COTS components drawings are not provided. In addition, drawings of assemblies like the avionics bay will also be concluded. These components are separated by an airframe section. Booster includes the motor and drogue, the main section includes avionics bay and the main parachute, and the payload section includes the nose cone and all payload components. Payload components will be detailed in section 4.1.1.

### 3.1.3.1. Booster Section

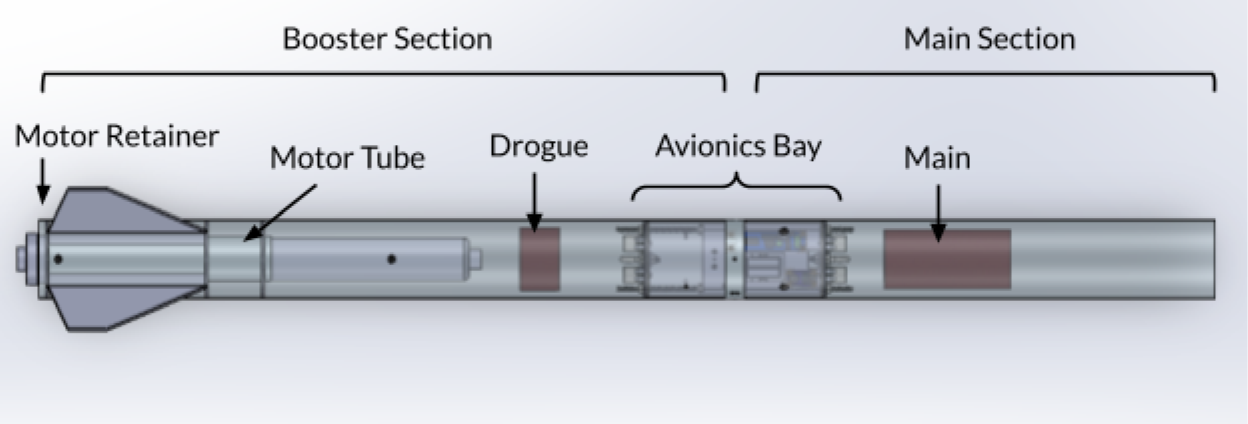


**Figure 3.6: Booster Section Layout**

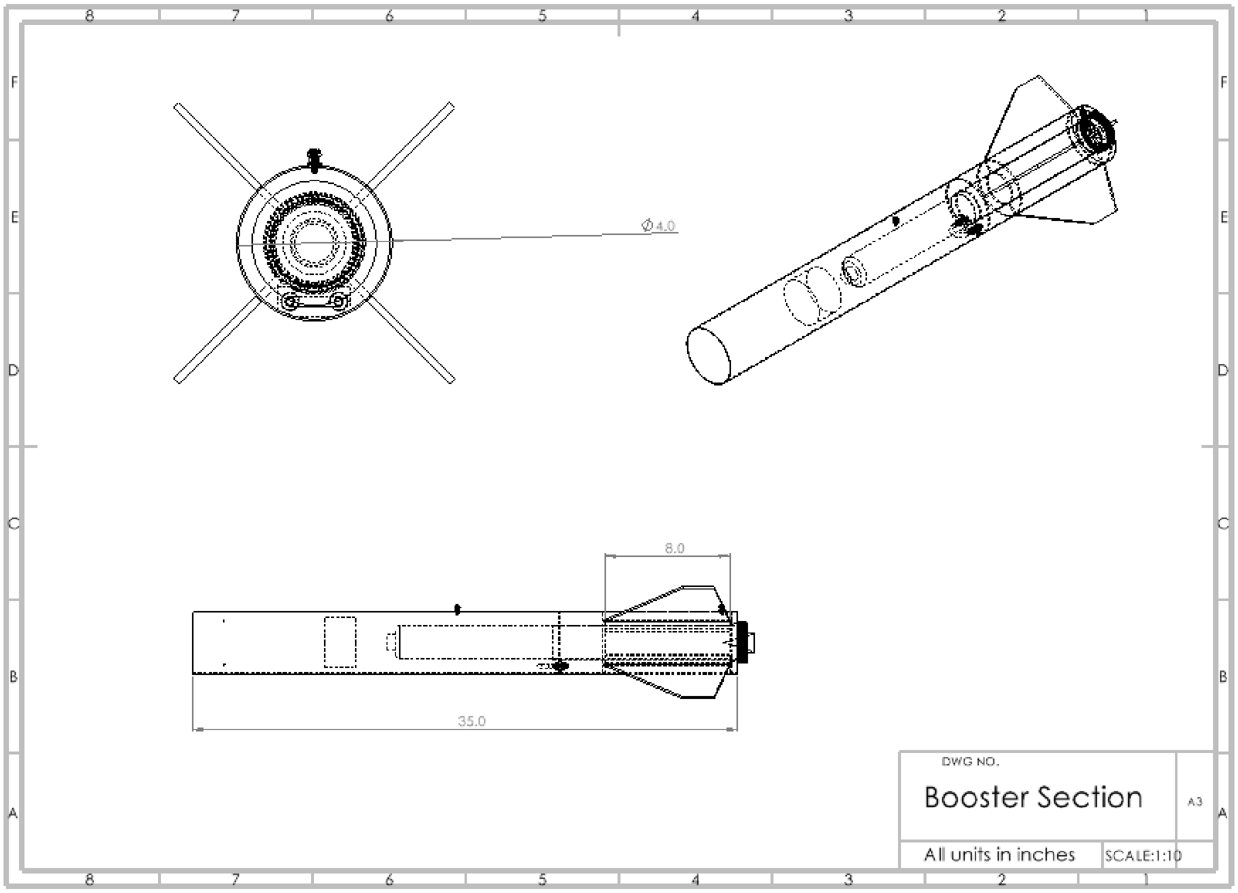


**Figure 3.7: Booster Section Assembly Dimensional Drawing part 1**

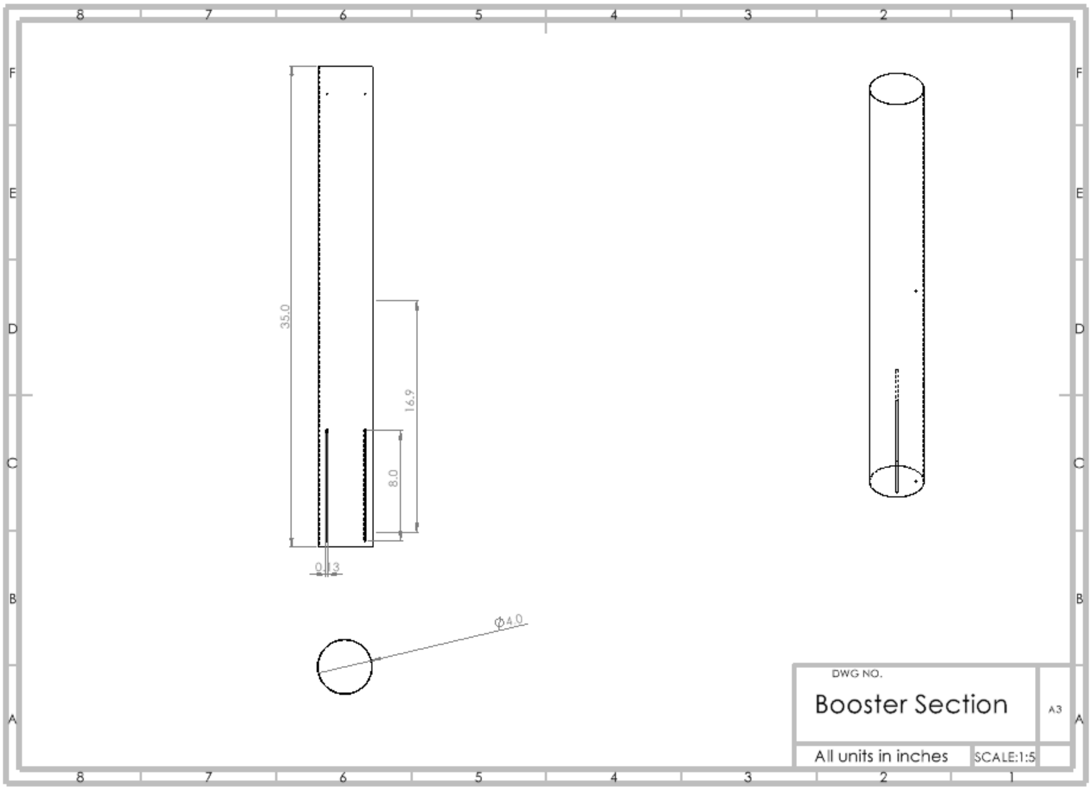


Figure 3.8: Booster Section Dimensional Drawing part 2

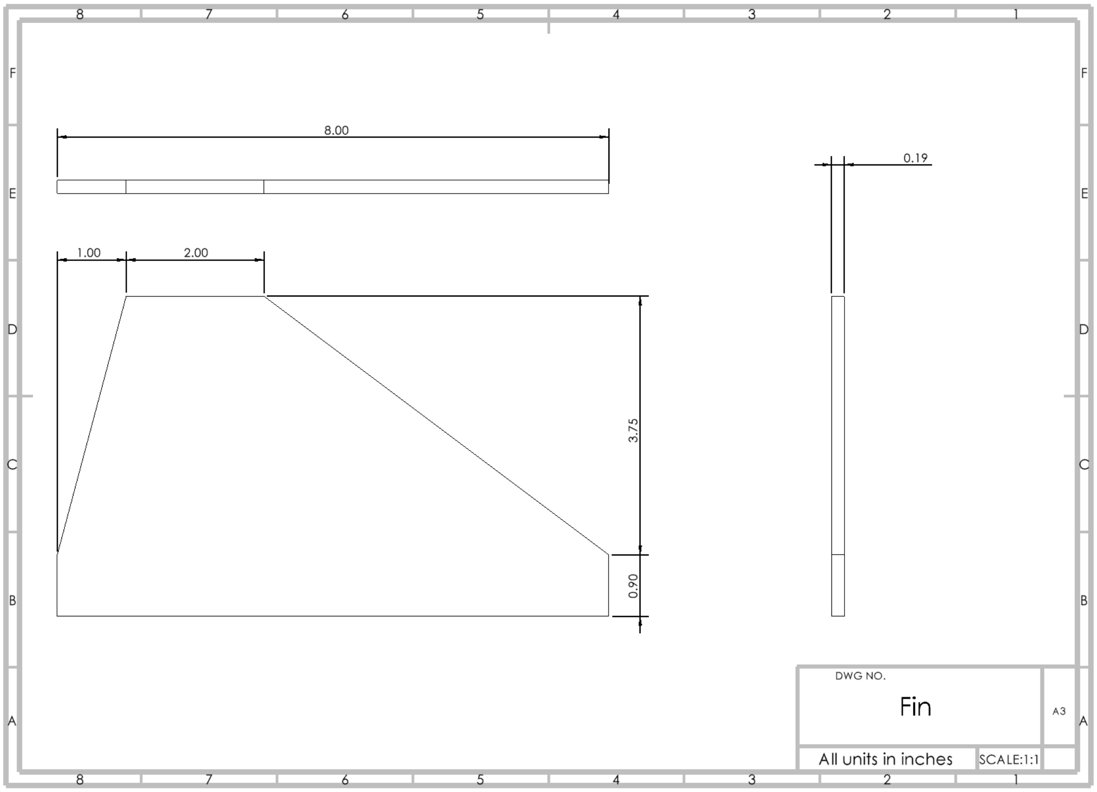


**Figure 3.9: Fin Dimensional Drawing**

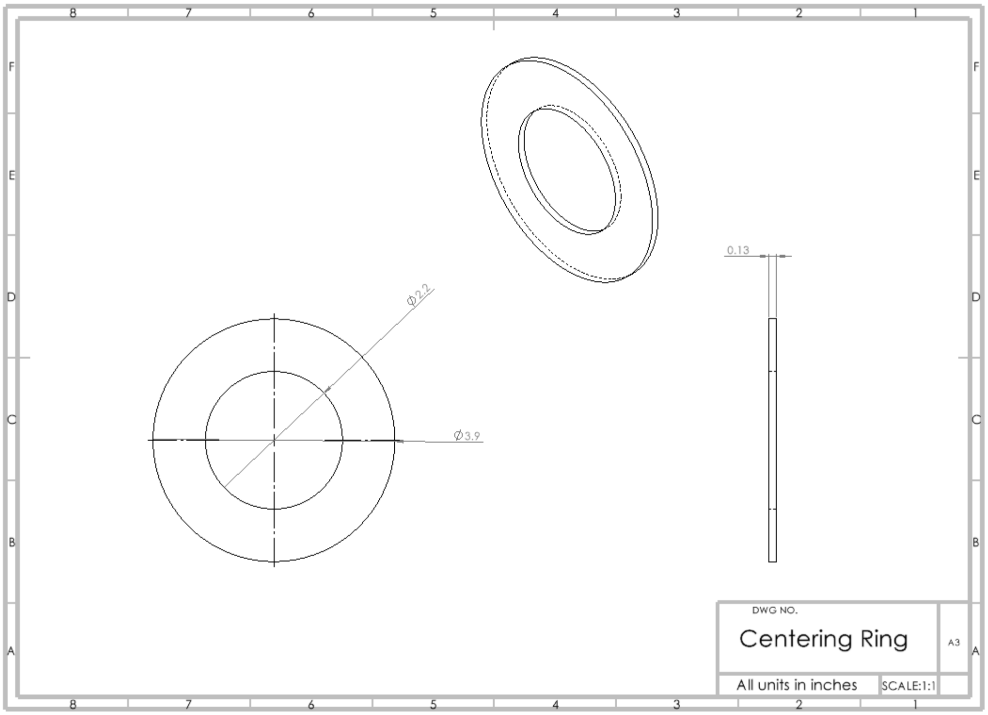


**Figure 3.10:Center Ring Dimensional Drawing**

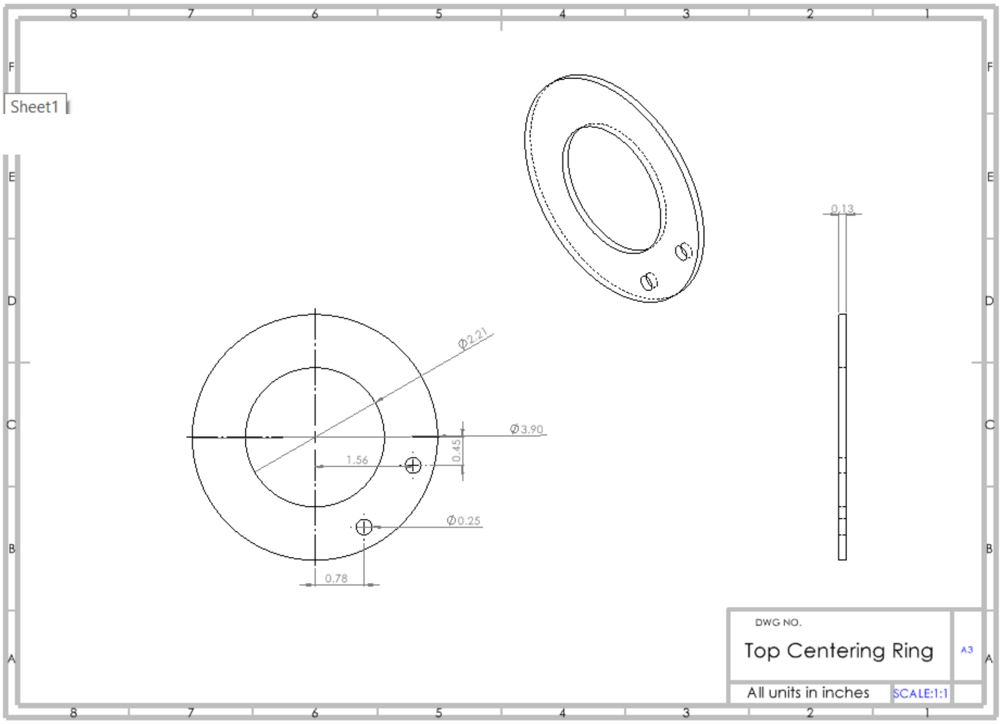


**Figure 3.11: Top Centering Ring Dimensional Drawing**

### 3.1.3.2. Main Section

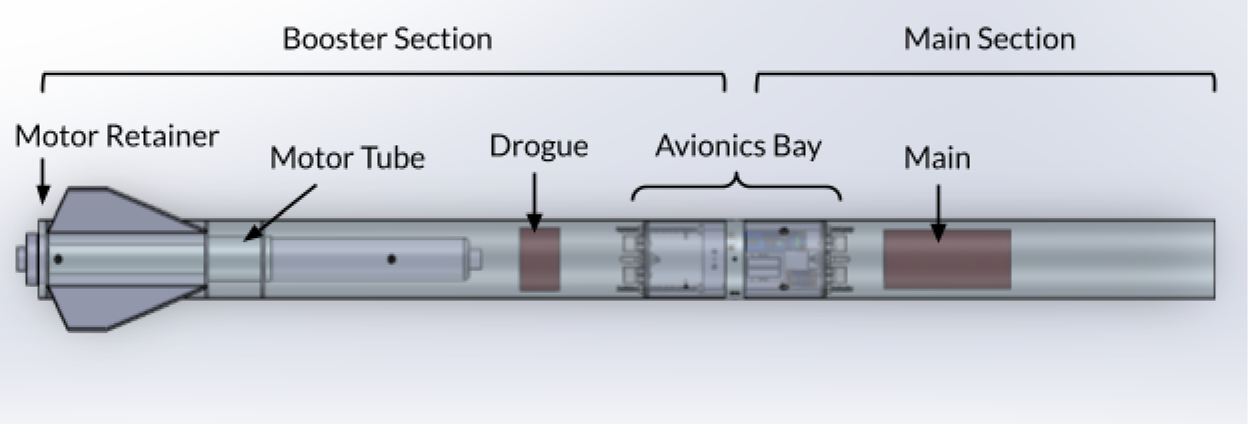


Figure 3.6: Booster Section Layout (repeat)

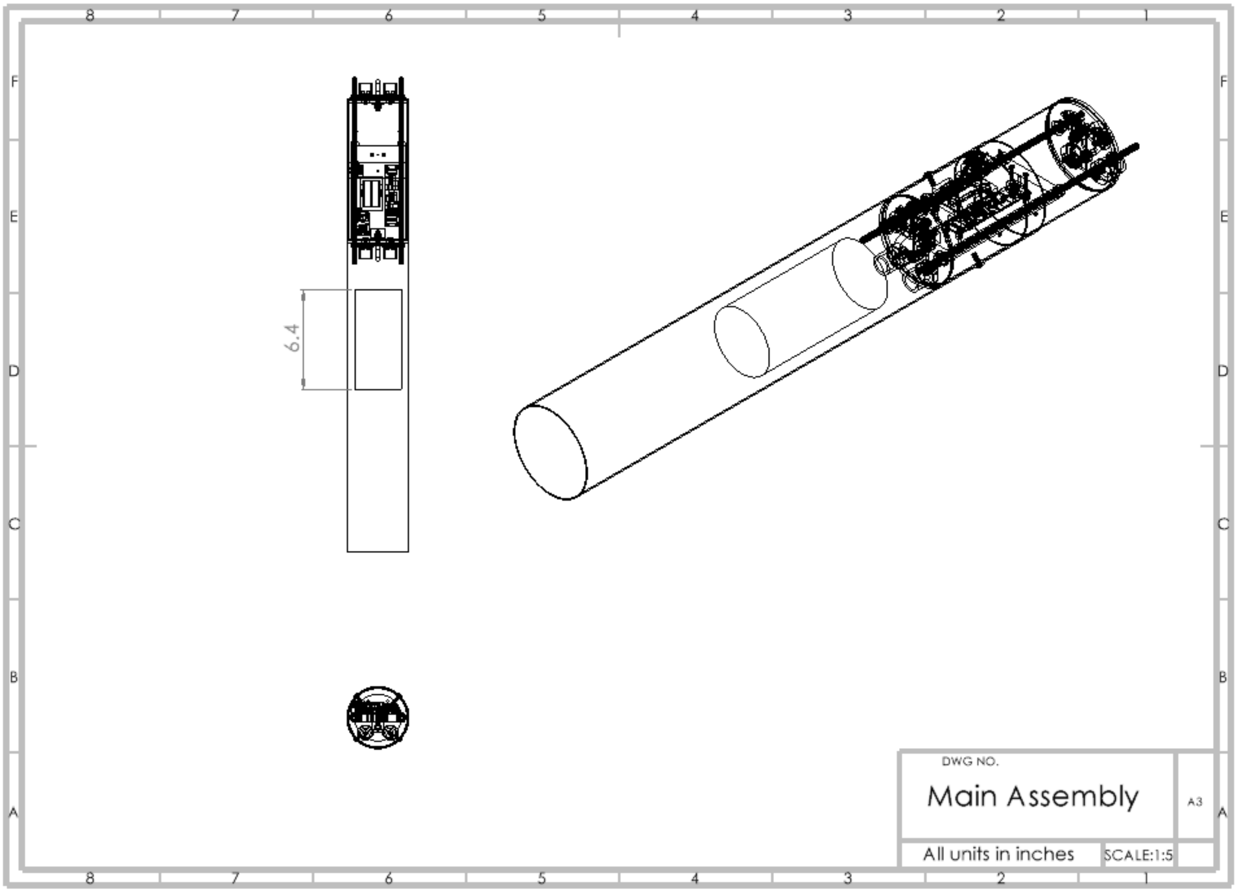


Figure 3.12: Main Section Assembly Drawing

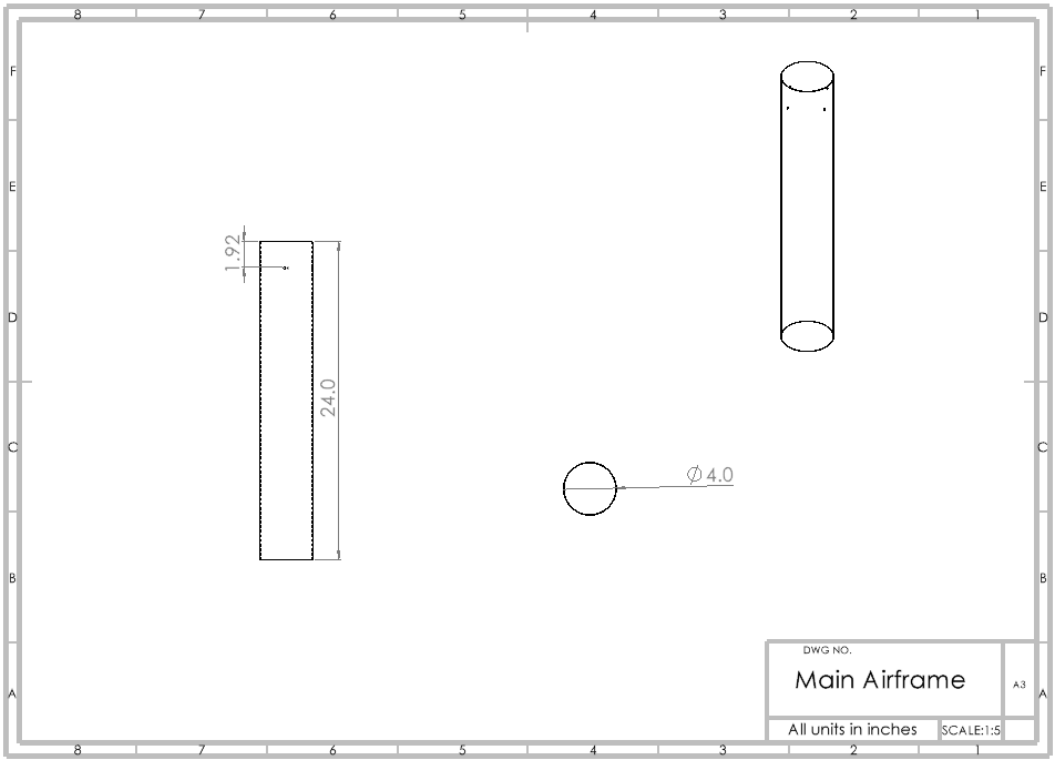


Figure 3.13: Main Airframe Dimensional Drawing

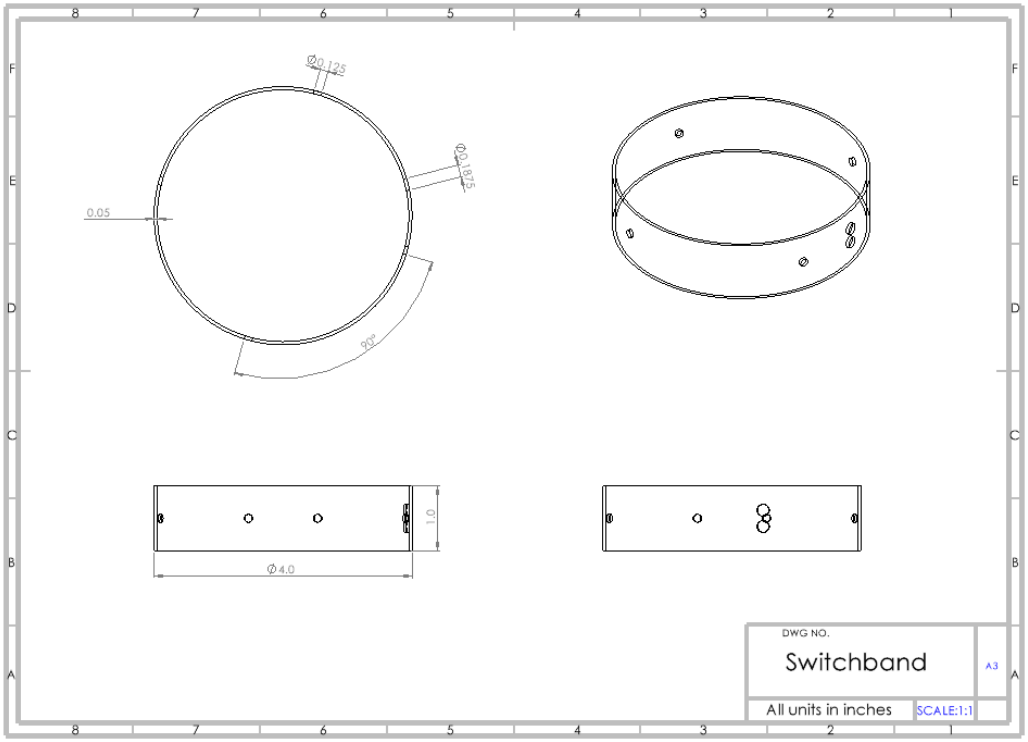


Figure 3.14: Switchband Dimensional Drawing

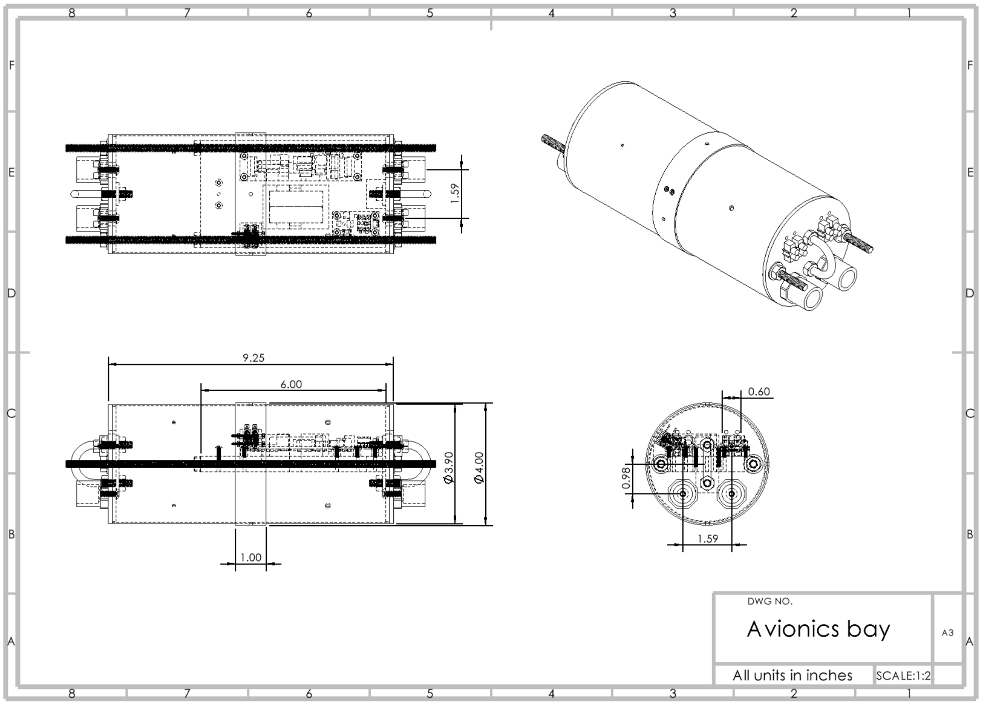


Figure 3.15: Avionics Bay Dimensional Drawing

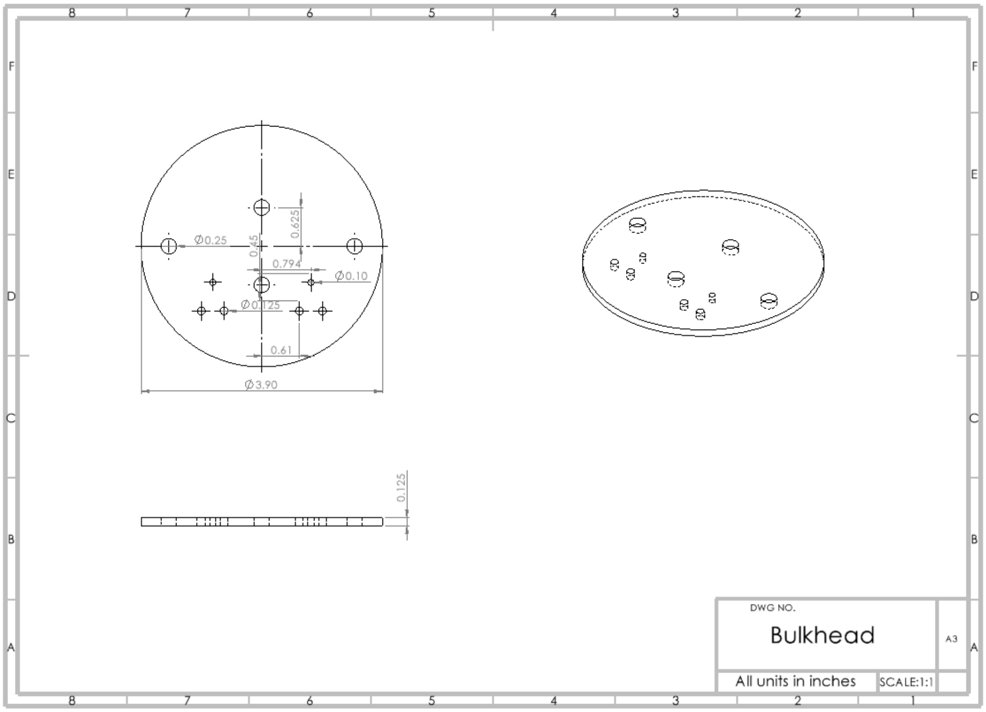


Figure 3.16: Bulkhead Dimensional Drawing

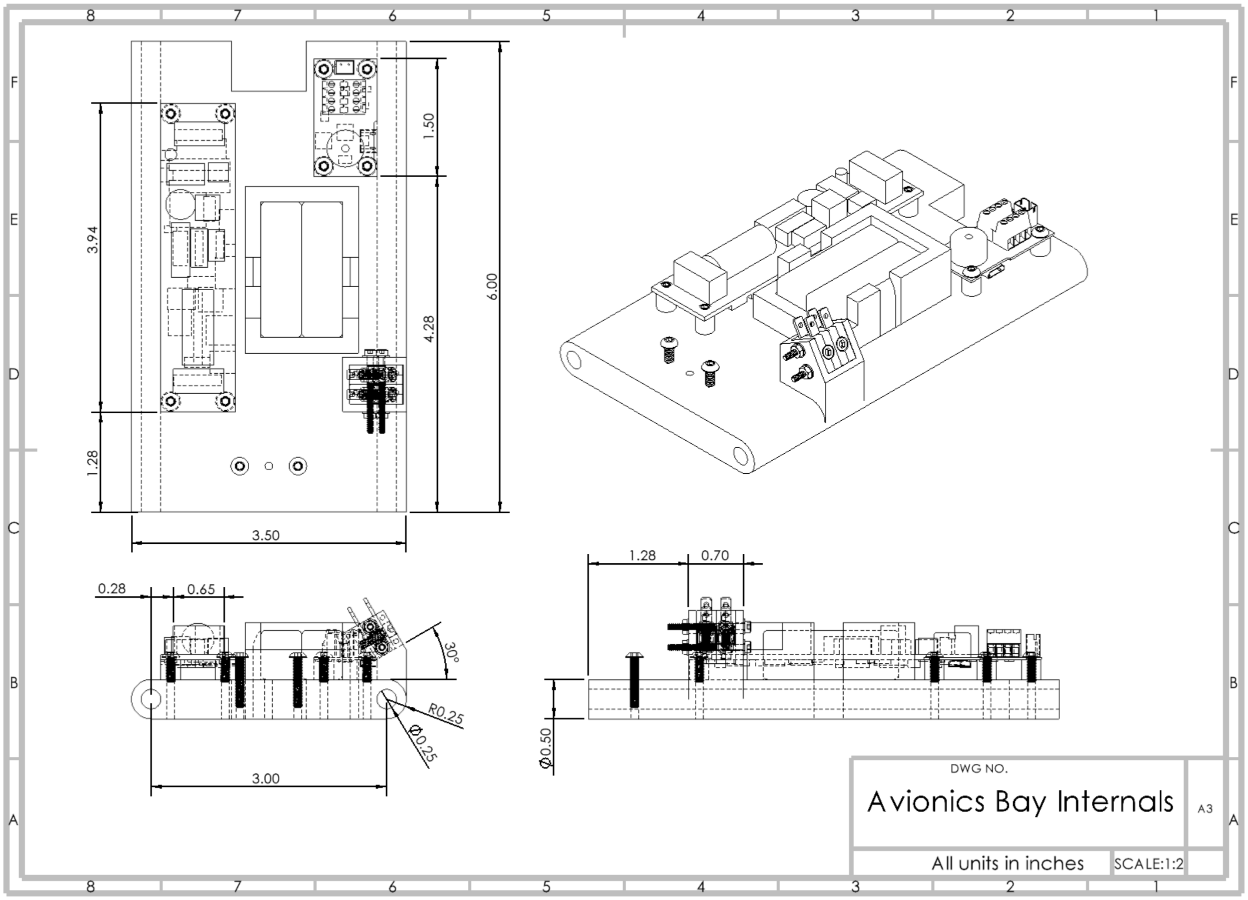


Figure 3.17: Avionics Bay Internals Dimensional Drawing

### 3.1.3.3. Payload Section

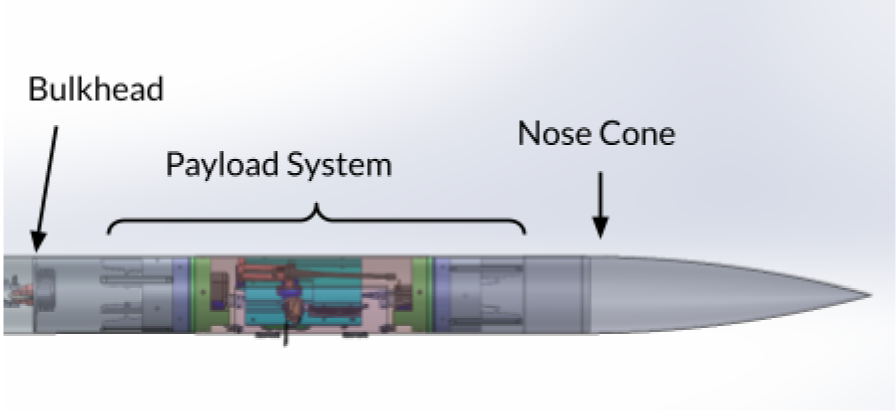


Figure 3.18: Payload Section Layout

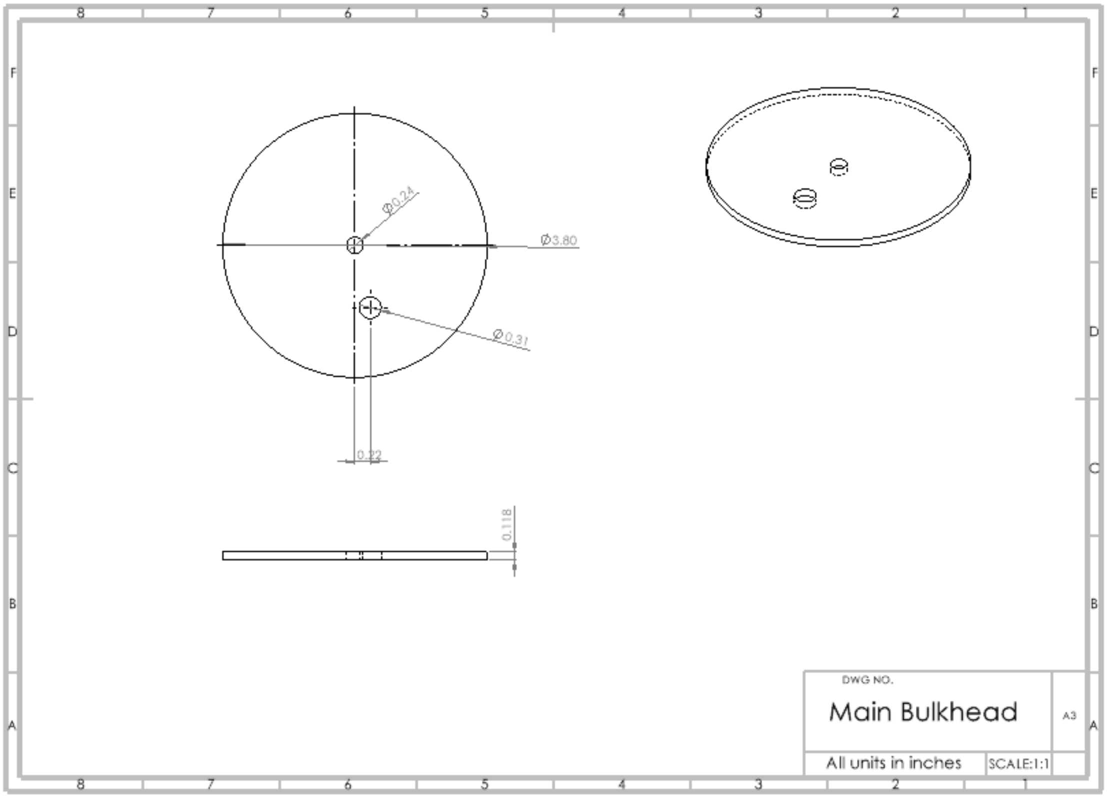


Figure 3.19: Main Bulkhead Dimensional Drawing

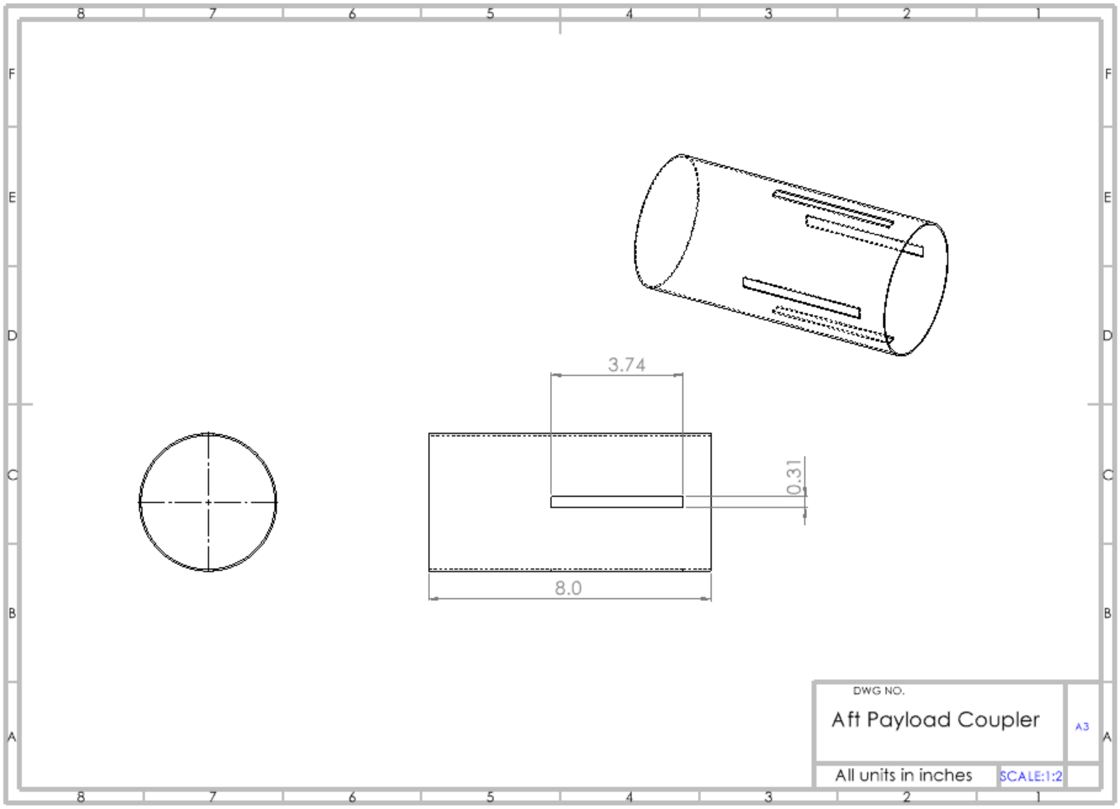


Figure 3.20: Payload Airframe Dimensional Drawing

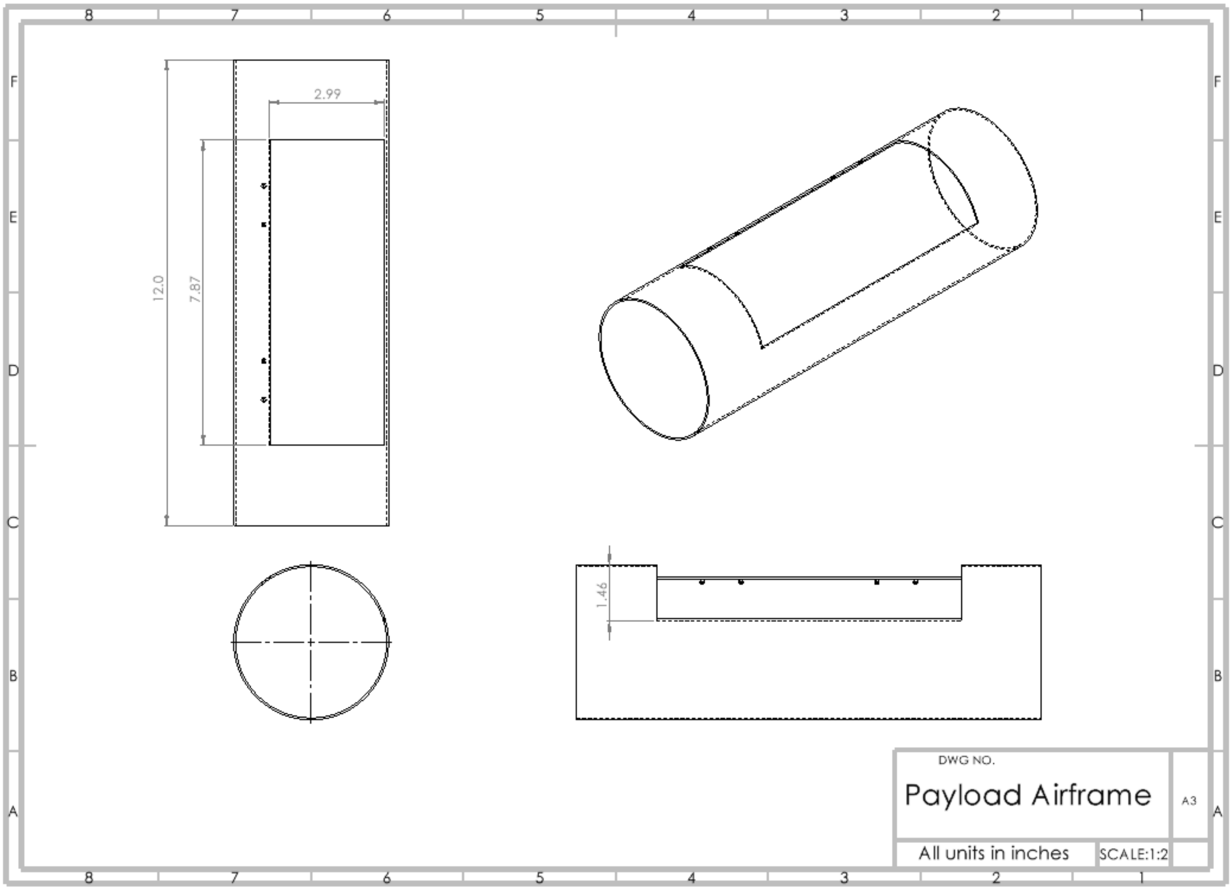


Figure 3.21: Payload Airframe Dimensional Drawing

### 3.1.4. Points of Separation

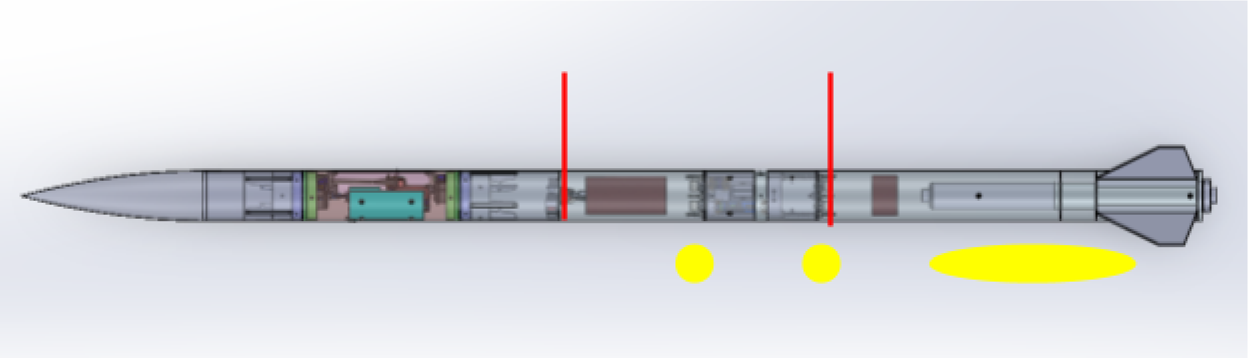


Figure 3.22: Points of Separation (red) and energetics (yellow)

### 3.1.5. Manufacturability of Designs

**Table 3.2: Component Manufactuability**

| Component | Manufacturing Plan | Concerns | Mitigations |
|---|---|---|---|
| Nose cone | Purchase COTS Components | None | None |
| Cut-to-length fiberglass tubes | Components will be cut out of G12 wound fiberglass tubes purchased from Wildman Rocketry using the horizontal band saw available in the BIC. | Improper length | Additional tubing will be provided in case of a mis-cut. |
| | | Cuts are not flat, ends are frayed | Tube cuts can be corrected via sanding. |
| Booster tube with fin slots | The cut-to-length booster tube will be secured in a pre-existing, standardized fin slotting jig and slots will be cut using a plunge router. Utilization of this fin slotting jig will be documented in detail in the FRR. | Fiberglass tube rotates or slides in the jig | Secure clamps very tightly to all parts of the jig and the tube. |
| Motor centering rings | Components will be cut out of G10 fiberglass purchased from Wildman Rocketry using a waterjet cutter available in the BIC. Components will be cut using the DXF profiles in 3.1.3. | Fiberglass delamination | The waterjet nozzle will be inspected to ensure it is clean before use. |
| U-bolts | Purchase COTS Components | None | None |
| Booster tube U-bolt plate | A COTS load-distributing plate will be purchased and modified for this application. The plate corners will be marked to remove material in order to produce the profile shown in 3.1.3. A benchtop belt sander will be used to remove the corners. | Overcut corners | Light pressure will be applied to the plate and remove material slowly. |
| Motor centering rings | The U-bolt will be fastened through the cut holes in the fiberglass mounting plate (bulkhead) and fastened using a COTS u-bolt plate and nuts. A | Overtightened nuts damage the fiberglass ring | Nuts will be tightened until they are very snug, then use threadlocker to ensure nuts are secure. |

| | | | |
|---|---|---|---|
| | short strap of kevlar will be run through the booster tube for ease of quicklink attachment and will be tied to the U-bolt. | | |
| Bulkheads | Components will be cut out of G10 fiberglass purchased from Wildman Rocketry using the waterjet cutter available in the BIC. Components will be cut using the DXF profiles in 3.1.3 | Fiberglass delamination | The waterjet nozzle will be inspected to ensure it is clean before use. |
| Fins | Components will be cut out of G10 fiberglass purchased from Wildman Rocketry using [model] waterjet cutter available in the BIC. Components will be cut using the DXF profiles in 3.1.3 | Fiberglass delamination | The waterjet nozzle will be inspected to ensure it is clean before use. |
| Joints between fiberglass components | Surfaces will be lightly sanded and then cleaned using isopropyl alcohol (where appropriate). Two-part epoxy will be measured out by weight, combined, and applied to the bonding surfaces. The surfaces will be held in contact for 24 hours to allow it to cure. | Disturbance of parts during curing | A designated workspace will be labeled for curing epoxy and warn members to not disturb parts. |
| Fin attachment to booster tube | Surfaces on the fins and fiberglass tube will be cleaned using isopropyl alcohol. Two-part epoxy will be measured out by weight, combined, and applied to the bonding surfaces. Fixture fins perpendicular to the body of the launch vehicle utilizing a fin positioning jig which will be documented in detail in the FRR. | Disturbance of parts during curing | A designated workspace will be labeled for curing epoxy and warn members to not disturb parts. |
| | | Epoxy on the components cures to the fin jig | After inserting the fins into the tube, wipe away excess epoxy using a paper towel. Apply masking tape to the surfaces of the fin jig before mounting the booster section to it. After mounting, peel the tape to remove |

|  |  |  |  |
|---|---|---|---|
|  |  |  | epoxy that leaked onto the tape. |
| Motor retainer | Purchase COTS Components | None | None |
| Rear of booster section | Lay the fore part of the 2-piece motor retainer into the bottom of the booster tube on top of the aft centering ring. Two-part epoxy will be measured out by weight, combined, and applied to the bonding surfaces. | Epoxy leaks inside the motor tube | Ensure the motor retainer is flush with all surfaces before applying epoxy. After epoxy cures, use a file to clear any dribbles that may exist in the tube. |
| Main parachute | Purchase COTS Components | None | None |
| Drogue parachute | Purchase COTS Components | None | None |
| Recovery harness | Purchase COTS Components | None | None |
| Recovery attachment hardpoints | Purchase COTS Components | None | None |
| Payload Section Quick Release | Purchase COTS Components | None | None |
| Quick Release Mounting Bracket | The horizontal and saw will be used to cut 1”square  bar stock to the appropriate length. The bar will be machined to a square profile using a mill and rounded using the belt sander. All tools are available in the BIC. | Overcutting or undercutting material | The part will be machined slowly and with care. Each measurement will be checked by 2 team members and at least 2 team members will be present for every machining operation. |
| Avionics bay sled | The 3D model shown in Figure 3.17 will be 3D printed on the team’s Voron 2.4 using Overture 3D PETG filament. | Printer fails, or cannot complete print at desired quality | Maintain team equipment in good working order, train members on use. Ensure other printing resources remain available. |
| Threaded rods for avionics bay | Use COTS threaded rods purchased from McMaster-Carr, | None | None |

| | | | |
|---|---|---|---|
| | cut to length using a hacksaw. | | |
| Washers for avionics bay retention | Purchase COTS Components | None | None |
| Nuts for avionics bay retention | Purchase COTS Components | None | None |
| RRC3 Altimeter | Purchase COTS Components | None | None |
| EasyMini Altimeter | Purchase COTS Components | None | None |
| Screw terminals | Purchase COTS Components | None | None |
| Screw switches | Purchase COTS Components | None | None |
| Screw switch retainer | The 3D model shown in Figure 3.17 will be 3D printed on the team's Voron 2.4 in the BIC using Overture3D PETG filament. | Printer fails, or cannot complete print at desired quality | Maintain team equipment in good working order, train members on use. Ensure other printing resources remain available. |
| 18" stranded wire | Purchase COTS Components | None | None |
| Wire Packing | Clay will be packed over wire holes on the outside of each avionics bay bulkhead to prevent dust pressurized gas ingress which could interfere with the altimeters. | Incomplete seal over hole | Clay will be visually inspected on launch day. |
| E-matches for black powder charges | Purchase COTS Components | None | None |
| Payload | Design and manufacturing of the payload is discussed in detail in Section 4. | See section 4 | See section 4 |

### 3.1.6. Design Integrity

#### 3.1.6.1. Fin Shape and Style

Fin integrity is discussed in detail in section 3.1.2.4.

#### 3.1.6.2. Materials

Material selection for the airframe is discussed in detail in section 3.1.2.1.

#### 3.1.6.3. Motor Mounting and Retention

The motor is mounted in a G12 fiberglass tube using three waterjet cut G10 fiberglass centering rings all attached by epoxy. This mounting method has been used on all previous team vehicles. The method has proven robust, and has been shown to survive the expected worst-case loading for the system. The subscale vehicle developed for the 2021-2022 season experienced avionics malfunction, resulting in no parachute deployment and an uncontrolled descent. While most of the vehicle was destroyed, the booster section was recovered intact, inspected for integrity, qualified for future flights, and continues to fly team training missions as displayed in Figure 23.

**Figure 23: 2021-2022 Subscale Vehicle Recovery (left upper and lower) and Rebuilt Training Vehicle Using Outlined Booster Section (center and right)**

For motor retention, a COTS 54mm Aero Pack aluminum quick change motor  is secured with epoxy to the bottom of the motor tube and the aft centering ring. This secure mounting method has also proved effective in all previous vehicles built for USLI.

#### 3.1.6.4. Vehicle Masses

**Table 3.3: Vehicle and Section Masses**

| Vehicle Mass (lbs) | |
|---|---|
| **20** | |
| **Vehicle Sections** | **Mass (lbs)** |
| Booster (Wet) | 8.12 |
| Booster (Dry) | 3.95 |
| Main Tube | 4.16 |
| Payload | 7.75 |

**Table 3.4: Vehicle Subsystem Masses**

| Vehicle Subsystem | Subsystem Description | Mass (lbs) |
|---|---|---|
| Airframe | All cylindrical fiberglass tubes including outer airframe and coupler tubes (includes avionics coupler tube and switch band) | 4.56 |
| Aerodynamics | Includes fins and nose cone | 1.37 |
| Motor | Motor before launch | 4.17 |
| Recovery | Includes all recovery hardware:<br>● Main and drogue parachute<br>● Recovery harness<br>● Attachment hardpoints<br>● GPS  and GPS bay | 2.73 |
| Avionics | Includes avionics sled with all electronics, sled mounting hardware, bulkheads, and black powder charges | 2 |

| | | |
|---|---|---|
| Motor mounting | Includes motor tube and centering rings | .43 |
| Payload | Includes all payload components discussed in detail in section 4.1.1 | 4.5 |

## 3.2. Subscale Flight

**Figure 3.24: “Lynx” - Rose Rocketry USLI Subscale Vehicle Program Patch 2022-23**

### 3.2.1. Flight Performance

The subscale launch vehicle showed satisfactory flight performance. The subscale achieved an altitude of 6160 ft. The descent rate under drogue was 75.9ft/s and main descent rate was 25.6ft/s, both of which were in expected bounds. The vehicle drifted 1699ft after a descent time of 106.7s. The results and analysis of the subscale flight are described below.

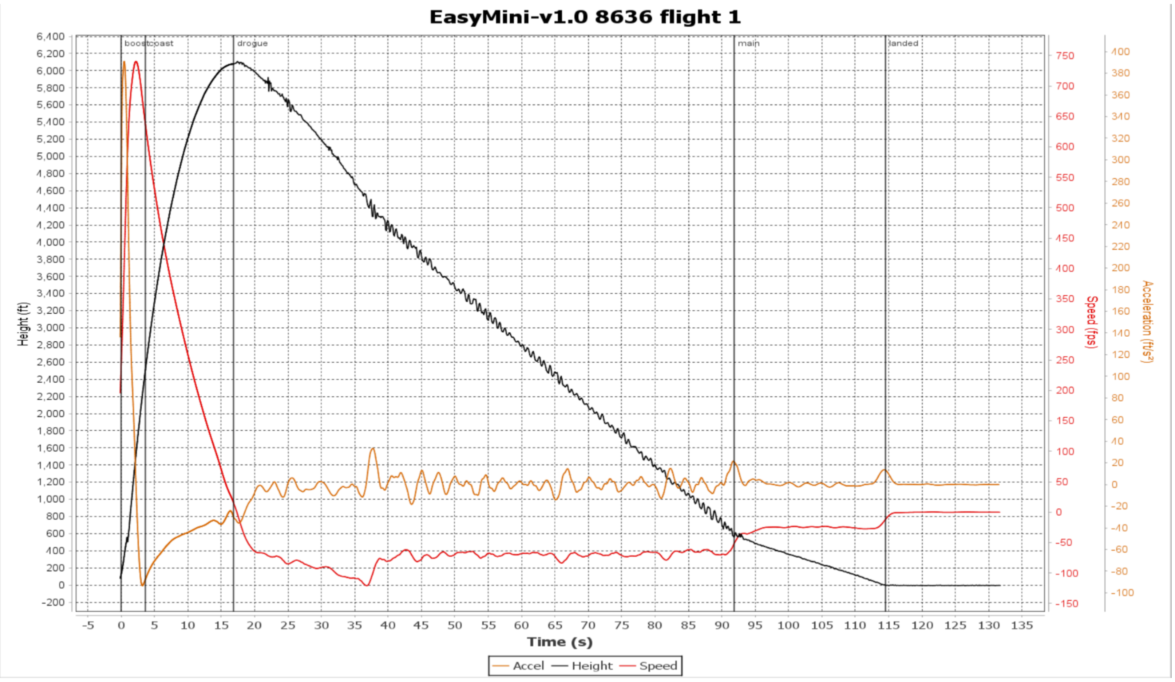
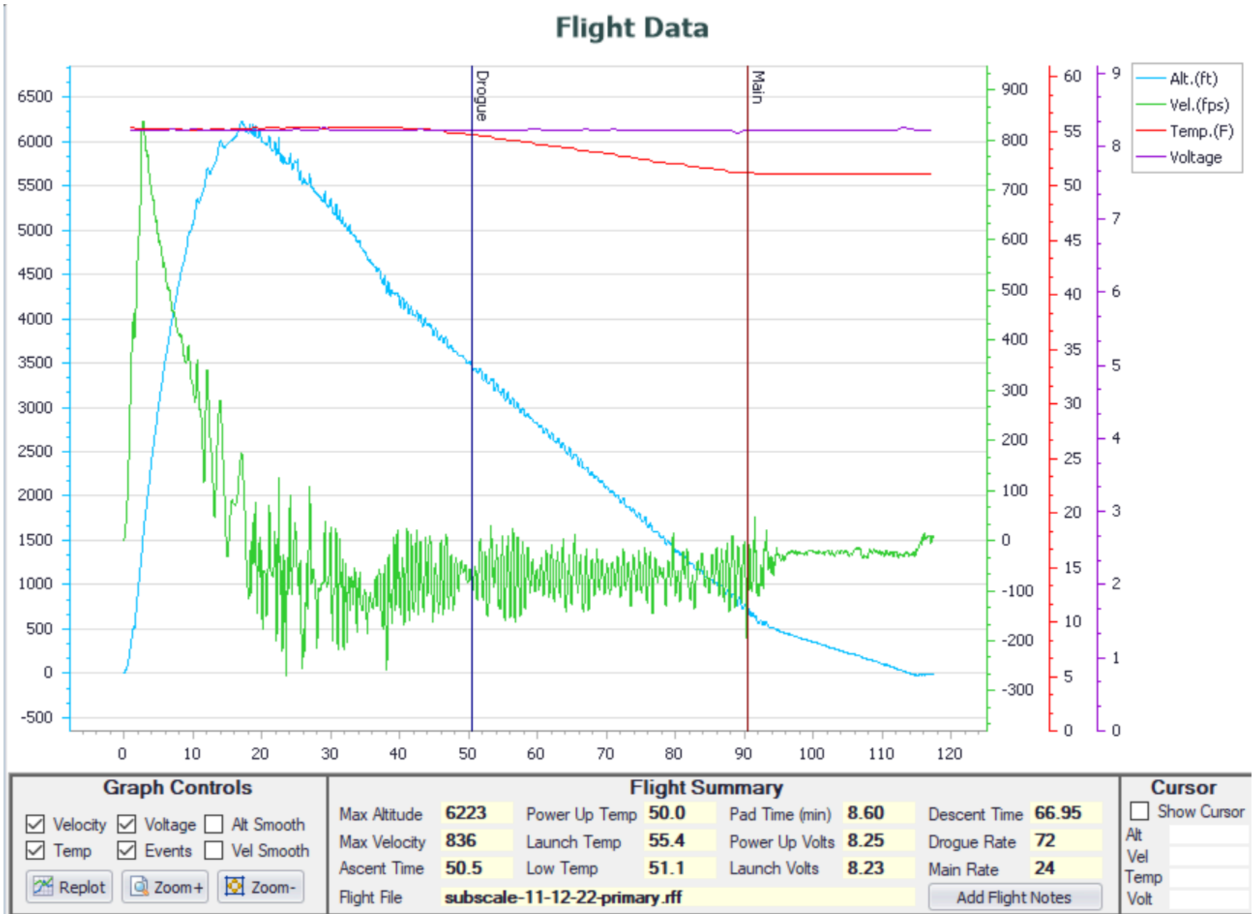


Figure 3.25: Subscale EasyMini flight data



☑ Velocity ☑ Voltage ☐ Alt Smooth
☑ Temp ☑ Events ☐ Vel Smooth

Max Altitude 6223
Max Velocity 836
Ascent Time 50.5
Power Up Temp 50.0
Launch Temp 55.4
Low Temp 51.1
Pad Time (min) 8.60
Power Up Volts 8.25
Launch Volts 8.23
Descent Time 66.95
Drogue Rate 72
Main Rate 24
Flight File subscale-11-12-22-primary.rff

☐ Show Cursor

Figure 3.26: Subscale processed flight data

### 3.2.1.1. Altitude

**Table 3.7: Altimeter apogee data for subscale flight**

| Altimeter | Altitude AGL |
|---|---|
| RRC3 | 6223ft |
| EasyMini | 6096ft |
| Average | 6160ft |

For recovery redundancy, the subscale launch vehicle used two altimeters, an RRC3 Sport and EasyMini. The final altitude of 6,160ft is an average of two altimeters. The subscale significantly overshot the target altitude of 5,000 ft. The team uses this information to inform the full-scale team to increase accuracy, which can be done by running simulations.

#### 3.2.1.2. Descent Rate

The descent rates were calculated using the average velocity in each phase of descent based on altimeter data; the rates were then averaged between the two altimeters for the team's final descent rate. In all cases, the descent rates from the altimeters were within one foot per second of each other.

**Table 3.8: Descent Rate under Drogue Parachute**

| Altimeter | Descent Rate |
|---|---|
| RRC3 | 76.3ft/s |
| EasyMini | 75.4ft/s |
| Average | 75.9ft/s |

**Table 3.9: Descent Rate under Main Parachute**

| Altimeter | Descent Rate |
|---|---|
| RRC3 | 26ft/s |
| EasyMini | 25.1ft/s |
| Average | 25.6ft/s |

The subscale was launched with an 18-in X-form drogue parachute and a 40-inch Recon Recovery hemispherical main parachute installed. The descent rate under drogue was observed to meet the team's expectations, as it was in line with OpenRocket simulations of 87 ft/s. At a mass of 8.8 pounds after burnout, the main parachute was slightly overloaded, leading to a higher descent rate than planned on the full-scale design. It was still deemed acceptable by the team, as the subscale vehicle was strong enough to handle an impact at high speeds. It also ensures that the bearing design for the rotating airframe would be able to withstand landing on a full-scale vehicle.

#### 3.2.1.3. Drift Distance

The drift distance was calculated with the latitude and longitude of the GPS receiver of the vehicle, which was placed in the nose cone. The drift distance was determined to be 1,699ft from the launchpad and 1,776ft from Apogee, under the competition maximum of 2,500ft.

#### 3.2.1.4. Descent Time

Descent time was calculated as the time of landing subtracted from the time of apogee, taking 0 as the moment of launch. We used the data as-is to avoid losing information in the conversion process.

**Table 3.10: Descent times from each altimeter and the average**

| Altimeter | Descent Time |
|---|---|
| RRC3 | 99.1s |
| EasyMini | 114.2 |
| Average | 106.7s |

### 3.2.2. Scaling Factors

The scaling of the subscale launch vehicle was determined mainly by the ease of maintenance, such as the ability to stick hands inside the tube and fit recovery hardware inside. As such, the team chose to use the most significant allowable scaling factor of 75%, scaling the airframe length and diameter. The payload section of the vehicle was shortened to accommodate the nose cone, which was mounted to be larger than 75% of the height of the full-scale nose cone. The shortening of the payload section was deemed acceptable by the team, as the test payload did not require the volume provided. The fins retained a similar trapezoidal design but were scaled down less, approximately 83% of the full-scale size, to allow round numbers to ease by-hand manufacturing.

### 3.2.3. Initial Retroactive Simulation

After the flight, a retroactive simulation was conducted in OpenRocket with certain conditions. The conditions include the vehicle's weight, set as close as possible to launch day. The conditions set for the simulation are described in Table 3.11.

**Table 3.11: Launch Day conditions used in the simulation**

| Parameter | Value |
|---|---|
| Motor | CTI J760 |
| Finish | Regular Paint |
| Vehicle Mass (Wet) | 10.25lb |
| Vehicle Mass (Dry) | 8.98lb |

| | |
|---|---|
| Rail length | 96in |
| Rail angle (Vertical) | 0° (Straight Up) |
| Rail angle (Azimuth) | N/A |
| Average Wind Speed | 9.21 mph |
| Wind Direction | 270° |
| Temperature | 36° F |
| Pressure at Launch Site | 14.07 psi |

The results of the simulation are described in Table 3.12

**Table 3.12: Retroactive simulation results**

| Result | Value |
|---|---|
| Altitude | 5501 ft |
| Descent Time | 82.8 s |
| Descent Rate (Drogue) | 85 ft/s |
| Descent Rate (Main) | 21 ft/s |
| Drift Distance (Launchpad) | 693 ft |
| Drift Distance (Apogee) | 341 ft |
| Velocity Off Rod | 91.3 ft/s |
| Maximum Velocity | 812 ft/s |
| Time to Apogee | 17.2 s |
| Flight Time | 100 s |

### 3.2.4. Initial Retroactive Simulation Analysis

When compared to the actual flight performance, the initial retroactive simulation returned concerning results. As described in Table 13, no prediction was reasonably accurate.

**Table 3.13: Initial Comparison of SImulated and Actual Subscale Flight Data**

| Parameter | Simulated | Actual |
|---|---|---|
| Altitude | 5501ft | 6160ft |
| Descent Time | 82.8s | 106.7s |
| Descent Rate (Main) | 21ft/s | 25.6ft/s |
| Descent Rate (Drogue) | 85 ft/s | 75.9ft/s |
| Drift Distance (Launchpad) | 693ft | 1699ft |
| Time to Apogee | 17.2s | 15.3s |
| Descent Time | 82.8s | 106.7s |
| Flight Time | 100s | 122s |

Given the significant discrepancy, the team found that the only value that could have been reasonable for the margin of error was the time to apogee. All other variables were too significant of a deviation from actual flight data. Most noticeably and most importantly, the predicted altitude was 659ft lower than the actual flight altitude of 6,160ft.

As the initial simulation significantly deviated from the actual flight of the subscale vehicle, the team investigated the discrepancy. It was determined that the skin's smoothness was incorrectly set to regular paint, when the vehicle was very smooth, even in its unpainted state. The team changed the finish setting on the vehicle, and got a far more accurate and informative simulation, the results and impact of which are described below.

### 3.2.5. Finalized Retroactive Simulation

**Table 3.14: Launch Day conditions used in the simulation**

| Parameter | Value |
|---|---|
| Motor | CTI J760 |
| Finish | Smooth Paint |
| Vehicle Mass (Wet) | 10.25lb |
| Vehicle Mass (Dry) | 9.01lb |

| | |
|---|---|
| Rail length | 96in |
| Rail angle (Vertical) | 0° (Straight Up) |
| Rail angle (Horizontal) | N/A |
| Average Wind Speed | 9.21mph |
| Wind Direction | 270° |
| Temperature | 36° F |
| Pressure at Launch Site | 14.07psi |

The results of the simulation are described in Table 15

**Table 3.15: Retroactive simulation results**

| Result | Value |
|---|---|
| Altitude | 6168ft |
| Descent Time | 90.6s |
| Descent Rate (Drogue) | 85 ft/s |
| Descent Rate (Main) | 21ft/s |
| Drift Distance (Launchpad) | 719.5ft |
| Drift Distance (Apogee) | 399ft |
| Velocity Off Rod | 91.3ft/s |
| Maximum Velocity | 824ft/s |
| Time to Apogee | 18.4s |
| Flight Time | 109s |

### 3.2.6. Finalized Subscale Analysis

#### 3.2.6.1. Comparison to actual flight data

A comparison of the simulated performance and the actual performance is in Table 3.16.

**Table 3.16: Comparison of Subscale Simulation and Actual Data**

| Parameter | Simulated | Actual |
|---|---|---|
| Altitude | 6168ft | 6160ft |
| Descent Time | 90.6 s | 106.7 s |
| Descent Rate (Main) | 21 ft/s | 25.6 ft/s |
| Descent Rate (Drogue) | 85 ft/s | 75.9 ft/s |
| Drift Distance (Launchpad) | 719.5 ft | 1699 ft |
| Time to Apogee | 18.4 s | 15.3 s |
| Flight Time | 109 s | 122 s |

Based on the above comparison, the simulation was accurate in predicting altitude, somewhat accurate in descent rates, but was unreliable in timing and drift distances.

#### 3.2.6.1.1. Altitude

The altitude of the simulation is its most striking feature, being within 8ft, or less than one length of the full-scale rocket, off from the actual altitude. On this flight, the subscale flew without a payload mass ballast; instead, it passed with a much lighter, partially-complete payload. The reduction in weight caused by the omission of the full ballast led to a higher altitude than the intended 5,000ft. However, the team expected this overperformance since the decision to omit the ballast was intentional. Mitigations to avoid altitude overperformance are described in section 3.8.2.

#### 3.2.6.1.2. Descent Time

The descent time of the vehicle was underestimated by the simulation, with 90.6 seconds simulated compared to 106.7 seconds on the flight. While there is some uncertainty in the actual descent time, neither altimeter shows a descent time within a few seconds of the simulation. The team attributed the inaccuracy to difficulty in accurately simulating parachutes and body drag as the vehicle descends. The descent time is also over the competition limit of 90 seconds. Mitigations to ensure a shorter descent time is described in section 3.8.2.

###### 3.2.6.1.3. Descent Rates

The simulated descent rate was slower than predicted under drogue and faster than predicted under main. The slower descent rate under drogue can be attributed to the team's lack of knowledge regarding parachute performance and the measurement system of a X-form parachute, as well as the simulation using estimated drag coefficients for the drogue parachute. The fast descent rate under main was expected by the team, as parachutes do not always behave as expected when overloaded, though in this case, the parachute was rated for 8 pounds, and the descending vehicle was 8.8 pounds. The team determined that the exact performance of the parachutes was not relevant, as neither matches the shape or size of the full-scale parachutes described in section 3.3.1. However, the team understands that the descent rates partially led to the very long descent time, and mitigations are described in section 3.2.8.

###### 3.2.6.1.4. Drift Distance

The simulation did not accurately predict the drift distance from the launchpad, being less than half of the actual value. The team determined this was caused by the wind settings of the simulation software being unable to account for different wind velocities at different altitudes and the simulation overestimating how far into the wind the vehicle would turn. As drift distance is directly proportional to the descent rate, the mitigations for ensuring drift distance is under 2,500ft are described in section 3.2.8.

###### 3.2.6.1.5. Time to Apogee

The simulation highly overestimated the time to the apogee of the subscale launch vehicle, being 3.1 seconds higher than the actual value of 15.3 seconds. The team determined that the value from the vehicle's data is a product of an average calculation. As the altimeters on the vehicle give readings over seven seconds off the average value, the team determined that the time to apogee is within the margin of error in calculation and that no corrective action is required to be taken on this front.

###### 3.2.6.1.6. Flight Time

Total predicted flight time is lower than the actual subscale flight time. The team determined that the majority of this extra time comes from the descent, with the same errors in the drogue parachute calculation, and mitigations to ensure a more accurate prediction of flight time are described in section 3.2.8.

###### 3.2.6.1.7. Bearing

To ensure the full-scale vehicle implements the rotating airframe design, the team elected to fly a prototype of the bearings (component of the Rotation Control ME Payload system) that would enable the tube to rotate to ensure the bearing was a sound design and the 3D-printed material would be able to withstand the forces involved in flight. The bearing was locked in place during the flight but performed excellently as a structural element, successfully remaining intact and functional after flight despite a much higher touchdown velocity than the planned full-scale design.

##### 3.2.6.1.8. Simulation Accuracy

The simulation, after being refined as described in section 3.2.5, was very accurate on the most important factors to the team. The team has also increased the level of understanding and expertise in the simulation software, and is much more aware of how the simulation software functions.

### 3.2.7. Landed Configuration

**Figure 3.27: Subscale booster section with attached harness as landed**

**Figure 3.28: Subscale avionics section with attached shock cable and drogue parachute as landed**

**Figure 3.29: Payload and nose cone section with attached shock cord and main parachute as landed. Bearing seen here as a white stripe**

### 3.2.8. Full-Scale Impact

#### 3.2.8.1. Altitude

While the subscale overperformed in terms of altitude, the overperformance was due to the lack of a full ballast and payload mass. Simulations accounting for the lack of ballast and payload accurately reflect the measured altitude of our subscale flight. Before the flight of the full-scale vehicle, the team will adjust the simulation to account for the skin's smoothness, exact launch day conditions, and exact launch weight when simulating the full-scale vehicle. The group plans to fly the full-scale vehicle multiple times with the payload to fine-tune further simulations and ballast to ensure a flight as close as possible to the targeted altitude and stay within competition limits. However, the team did change the motor due to the overperformance of the subscale.

#### 3.2.8.2. Descent Time

The descent time of the subscale vehicle was significantly higher than the competition limit, and the descent time of under 80 seconds the team was targeting. However, the team believes the full-scale vehicle does not require changes to the design, as mitigations are already built-in into the full-scale vehicle. First, the team only plans to fly to 5,000ft, an altitude approximately 20% lower than the subscale achieved during testing. The reduced altitude will result in a reduced descent time. Second, the full-scale design uses a significantly smaller drogue parachute of 12 inches compared to the subscale's 18-inch parachute, despite the full-scale being a more extensive and heavier launch vehicle with an expected descent rate of 100.75 ft/s under drogue parachute.

#### 3.2.8.3. Descent Rates

The descent rates of the subscale vehicle needed to be more accurate for the simulation to be the sole source of information on descent rates. The team will be extrapolating this to the full-scale vehicle. The drogue and main parachutes will be test-flown on the full-scale before the competition flight in the VDF and the PDF. The test flights, parachute tests, and simulations will provide the team with a comprehensive understanding of the descent rates of the vehicle.

#### 3.2.8.4. Drift Distance

The descent rate, altitude, and wind velocity determine the drift distance of the vehicle. At a maximum, the launch will take place in winds of 20mph. As handbook section III describes, the drift distance is calculated by multiplying the descent time by 20mph. Using advanced full-scale simulation, the team has determined the descent time of the full-scale vehicle will be 76.5 seconds.

#### 3.2.8.5. Time to Apogee

As described in section 3.2.6.1.5, the time to apogee difference lies within the margin of error of the altimeters. As the time to apogee is within an expected margin of error, the team has determined that as long as the vehicle performs as expected in other properties, no design changes to the full scale will need to be made from the measured time to apogee.

#### 3.2.8.6. Flight Time

As flight time depends on descent time and time to apogee, the team can only directly impact the flight time of the vehicle if changing the time to apogee and descent time. As such, the team plans to decrease the flight time by implementing the mitigations described in sections 3.2.8.1 and 3.2.8.3.

#### 3.2.8.7. Bearing

The subscale launch, while not performing as expected in the scope of the preliminary simulations, performed flawlessly in proving that the bearing that allows for rotation of the payload tube, even when 3D printed, is capable of surviving the forces of flight and landing, allowing the team to continue with the planned design of the vehicle and bearing.

#### 3.2.8.8. Simulation

The team learned a great deal about the proper simulation of the launch vehicle from the subscale flight. The team plans to leverage the knowledge gained regarding component finish and weather conditions to increase the accuracy of simulations of full-scale flights, allowing for more precise ballast loading and flying closer to the targeted altitude.

### 3.2.9. Drag Coefficient Calculations

The drag coefficient is estimated as a verification of our flight profiles as well as for use in future mission performance predictions of the full-scale. The drag coefficient is calculated according to the equation below.

$$C_d = 2\,D/\rho V^2 A$$

Where D is the drag force, rho is the air density, V is the velocity and A is the reference area. The reference area is the frontal area of the vehicle which is equivalent to the cross-sectional area of the airframe. To relate this to the flying of the vehicle Values for all these are known and explained in subsequent paragraphs. After motor burnout, the only forces on the vehicle are the drag force and the force of gravity, and both act in the same direction. The force equilibrium equation then becomes

$$ma = -D - F_G$$

Where D is drag force, Fg is force of gravity, m is mass, and a is acceleration. From data gathered during the subscale flight, these values are

**Table 3.17: Values for drag force and drag coefficient**

| | |
|---|---|
| A | 7.07 $in^2$ (.0491 $ft^2$) |
| ρ | 0.0023769 slug/$ft^2$ |
| V | 637 ft/s |
| a | -20.8 ft/$s^2$ |
| $F_g$ | 10.25lbs (total) - 1.27lbs (propellent weight) = 8.98 |
| m | 0.279 slugs |

For the subscale, since the diameter is 3in, the reference area is 7.07 in^2. The air density we used is the average sea level for simplicity. The average acceleration after motor burnout was determined using position data between the burnout and the peak. This average over about 10 secs accounts for some of the noise in the data due to derivation from the position. Solving for D we find that D = 14.78 lbs. Then plugging all values into Equation 1, we find the Cd to be .623.

Since the aspect ratios of the subscale were designed to be very close to ¾ the size of the full scale, the Cd should be the same at .623.

## 3.3. Recovery Subsystem

### 3.3.1. Component Choices

The component choices are outlined in the table below. Further and more comprehensive justification is provided in the sections below.

**Table 3.18: Component-Level Design of the Full-Scale Recovery System**

| Component | Choice | Justification |
|---|---|---|
| Main Parachute | Rocketman 60” Toroidal | • Low packing volume<br>• High drag coefficient<br>• High stability<br>• Significantly lower descent rate than required |
| Drogue Parachute | Rocketman 1’ Hemispherical | • Easily available<br>• Good stability<br>• Easy to simulate |
| Parachute Protection | Nomex Blankets | • Low litter<br>• Reliable<br>• Significant team experience |
| Recovery Harness | OneBadHawk Kevlar Harness | • Highly regarded<br>• Significant team experience<br>• Worked very well on Subscale vehicle |
| U-bolt | 425lb McMaster-Carr | • Low probability of failure<br>• High strength<br>• Multiple attachment options<br>• Vehicle longevity |
| Quick Link | ¼” 1800lb National Hardware | • Low probability of failure<br>• Very high strength<br>• Vehicle longevity |
| Quick Release | 330lb Kong | • Separate parachute from payload |

| | | |
|---|---|---|
| | | section<br>● Avoid dragging of payload after landing |
| Quick Release Harness | Custom component made using 7075 aluminum | ● Prevents quick release from accidentally triggering<br>● Reduces unpredictable motion of quick release<br>● Ensures quick release does not lose contact with attachment hardpoint |
| Primary Altimeter | MissileWorks RRC3 | ● Reliable<br>● Precise<br>● Team experience |
| Secondary Altimeter | Altus Metrum EasyMini | ● Reliable<br>● Team experience |
| Shear Pins | #2-56 Nylon | ● Team experience<br>● Availability in workspace |
| Black Powder Charges | 1.75g to 3.75 g | ● Main and Drogue primary and secondary deployments |
| E-matches | MJG FireWire | ● Reliable<br>● No requirement for hazmat shipping |

### 3.3.2. System Design

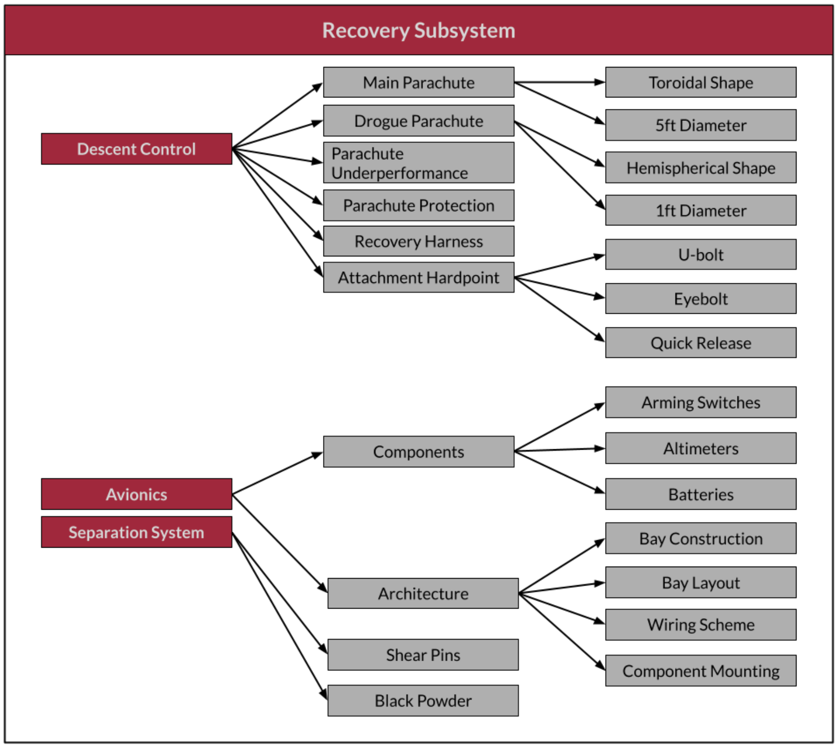


**Figure 3.30: System design for recovery subsystem**

### 3.3.3. Descent Control

The expected descent rates are listed below.

**Table 3.19: Descent Rates Under Parachutes**

| Parachute | Descent Rate |
|---|---|
| Main | 18.5 ft/s |
| Drogue | 102.75 ft/s |

#### 3.3.3.1. Main Parachute

The purpose of the main parachute is to slow the vehicle to a safe touchdown velocity that ensures the vehicle satisfies the kinetic energy requirements as described in handbook requirement 3.3, the payload tube remains intact and operational, and to avoid physical damage to the vehicle to ensure it is recovered in a reusable condition.

#### 3.3.3.1.1. Shape

Given the purpose of the main parachute, the shape must be optimized for the slowest descent rates possible. Based on research done for the Preliminary Design Review, the shapes with the highest drag coefficients are hemispherical and toroidal parachutes, with toroidal parachutes having a drag coefficient of 2.2. Additionally, the toroidal design incorporates a spill hole while the hemispherical parachute does not, giving the toroidal parachute a greater stability in the final stages of the descent. Due to the high drag coefficient and high stability, the team has chosen a toroidal design.

#### 3.3.3.1.2. Size

The size of the parachute is very important, as it is the only factor in the design of a parachute that significantly impacts the descent rate once the shape is chosen. To decide the final size of the parachute, the team considered the maximum allowable descent rate for the vehicle at touchdown, derived from the kinetic energy requirements in the handbook.

The team set a requirement to be under 60 ft*lbf of kinetic energy in each section to ensure the vehicle satisfies both the maximum kinetic energy requirement of 75 ft lbf of kinetic energy per section; and that it achieves the bonus points from touching down with less than 65 ft lbf of kinetic energy in each section. As the heaviest section of the vehicle is 7.75 pounds, the team used this mass to calculate the maximum allowable descent rate of the vehicle; with the resulting maximum descent rate being 22.3 ft/s.

The team then used both simulations and a parachute sizing equation to choose the final size of the parachute. Similarly to the subscale vehicle, the simulations were conducted using OpenRocket; the team inputted the correct parachute information and experimented with the size until the descent rate of 22.3ft/s was reached at a diameter of 48.3 inches.

The parachute sizing equation, $D = \sqrt{\frac{8mg}{\pi\rho C_d v^2}}$, where D is the diameter in meters, m is the mass of the rocket in kilograms, g is the acceleration due to gravity in meters per second squared, ρ is the density of air, 1.22 kilograms per cubic meter, $C_d$ is the coefficient of drag of the parachute, and v is the ground impact speed in meters per second, yielding a slightly larger minimum parachute diameter of 49.61 inches.

The closest size of toroidal parachute that satisfies both of the calculations that is also a common size is 60 inches; and the team has decided to use a 60 inch diameter parachute.

Toroidal parachutes are only sold by a few manufacturers. On the basis of cost and team experience, the team chose the Rocketman's 60 inch toroidal parachute, which has been received and inflated, with tests to follow.

### 3.3.3.2. Drogue Parachute

A drogue parachute is a small parachute designed to slow down and stabilize a descending vehicle. In industry, they are typically found on any vehicle designed to carry crew, such as SpaceX's Dragon or the Orion capsule. In model rocketry, they are typically found on dual-deploy designs, which employ a drogue to have a faster descent and a main to have a soft touchdown while not drifting too far from the launch site.

#### 3.3.3.2.1. Shape

The leading designs for the drogue parachute outlined in the preliminary design review were a hemispherical shape due to its stability and decent drag coefficient; and an X-form shape due to its very high strength in the relevant speed range. Thus, the difference in drogue parachute shape for the team was dependent on availability, cost, and simulation accuracy. When searching for parachutes and running flight simulations, the team concluded that hemispherical parachutes are better in all three parameters than X-form parachutes. Combined with the team's previous experience with hemispherical parachutes on both the subscale and other vehicles, the group decided to use a hemispherical drogue parachute.

Based on the expected descent time of the vehicle and simulations, the team does not expect the slightly lower stability of the hemispherical parachute to significantly impact the recovery of the vehicle.

#### 3.3.3.2.2. Size

Equally as important as the shape of the parachute, the size of a drogue parachute is a significant factor in the descent rate of the full-scale vehicle. With the shape decided, it is the single biggest factor in determining descent rate and time, drift distance, and ensuring a safe deployment of the main parachute.

The maximum size of the drogue parachute is determined by the team's goal for descent time. In order to achieve bonus points in the competition, the vehicle must descend from apogee in under 80 seconds. Simulations showed that the maximum diameter of the drogue parachute to achieve this goal is 13 inches.

With commonly available parachute sizes, the parachute size of choice was a 12-inch parachute; and the team decided to use a Rocketman 12-inch hemispherical model.

### 3.3.4. Parachute Underperformance

In the preliminary design review, the team did not account for possible underperformance of the main parachute. Based on team experience and the difficulty of parachutes in real-world situations, the team ran simulations in OpenRocket to determine how much the coefficient of drag ($C_d$), effective diameter (D), and air density (ρ) could change before the kinetic energy of the largest section upon landing exceeds a) the derived requirement of 60 ft lbf, b) the bonus point threshold of 65 ft lbf, and c) the competition limit of 75 ft lbf.

**Table 3.20: Required Parachute Properties to Achieve Kinetic Energy Requirements**

| | Parachute Manufacturer Data | Minimum under 60 ft lbf | Minimum under 65 ft lbf | Minimum under 75 ft lbf |
|---|---|---|---|---|
| $C_d$ | 2.2 | 1.5 | 1.4 | 1.2 |
| D | 59.06in (including spill hole) | 49 in | 47 in | 43 in |
| ρ | 14.7 psi (Sea Level) | 10.0 psi | 9.4 psi | 8.0 psi |

**Table 3.21: Underperformance of Each Property Required to Exceed KE Requirements**

| | Underperformance for 60 lbf | Underperformance for 65 lbf | Underperformance for 75 lbf |
|---|---|---|---|
| $C_d$ | 0.7 | 0.8 | 1.0 |
| D | 10.06 in | 12.06 in | 16.06 in |
| ρ | 4.7 | 5.3 | 6.7 |

The team has also combined the different factors, using an underperformance of the parachute and effective diameter of 5%, 10%, and 15%, and the average air pressure in Huntsville during April of 14.7 psi.

**Table 3.32: Results of Combination of Underperformance Factors at 14.7 psi**

| | 5% | 10% | 15% |
|---|---|---|---|

| | | | |
|---|---|---|---|
| **$C_d$** | 2.09 | 1.98 | 1.87 |
| **D** | 56.1 in | 53.1 in | 50.2 in |
| **Descent rate** | 19.9 ft/s | 21.4 ft/s | 23.2 ft/s |
| **Touchdown KE** | 47.7 ft lbf | 55.2 ft lbf | 64.8 ft lbf |

Based on the team's simulations, the team has concluded that in the event the main parachute underperforms, the vehicle will remain under the threshold for kinetic energy bonus points and significantly under the threshold of disqualification. As such, the team believes the current selection of parachute is applicable to the full-scale vehicle with ample margin.

### 3.3.5. Parachute Protection

As the vehicle uses black powder to separate the stages, the parachutes require protection from the energetics. In the preliminary design review, the team determined that the two leading options for parachute protection were wadding and fireproof blankets.

In previous vehicles belonging to the team, including the subscale vehicle, a fireproof blanket was used for parachute protection. Given this experience, the use of a blanket on the subscale, extensive wadding required to protect parachutes of the relevant size, and the excessive litter wadding would cause, the team determined fireproof blankets would be the best solution for parachute protection, and will incorporate them on the full-scale design.

For the size and manufacturer, the team has chosen a 18 inch x 18 inch Nomex blanket from Recon Recovery to protect the main parachute, and a 12 inch x 12 inch Nomex blanket from Recon Recovery to protect the drogue parachute.

### 3.3.6. Recovery Harness

The purpose of the recovery harness is to ensure all sections of the vehicle remain connected after deployment, and to provide a secure location to attach recovery hardware. As such, they must be strong, able to tolerate a sudden spike in force at deployment and inflation, and fireproof.

As discussed in the Preliminary Design Review, the team considered Kevlar, Nylon, and a combination of the two. The team will be using a Kevlar harness, as it is strong, fireproof, and contains the fewest points of failure, with ample team experience, including the flight of the subscale.

The team has chosen a $^{7}/_{16}$” set of Kevlar harnesses from OneBadHawk, as the team has experience with them previous vehicles and OneBadHawk harnesses are regarded as the best in the world.

### 3.3.7. Attachment Hardpoint

The team plans to use three types of attachment hardpoints: U-bolts, quick links, and quick releases. U-bolts will be used to connect quick links to the vehicle. A custom-designed eye bolt, which the team calls a quick release harness, will serve as the attachment point for the quick release. A quick release rated at 330 lb will connect the rest of the vehicle to the payload tube.

**Table 3.33: Attachment hardpoint type**

| Hardpoint Type | Reasons for Choice | Usage | Final Decision |
|---|---|---|---|
| U-bolt | • High strength<br>• Two attachment points spread force across bulkhead and reduce chance of failure | Hardpoints for quick link connections of the launch vehicle. | McMaster-Carr 1/4"-20 Galvanized Steel U-bolt with mounting plate rated at 425 lb |
| Quick Link | • Very high strength<br>• Allows for easy non-permanent mounting of recovery hardware | Connection of parachutes and harnesses to the launch vehicle. | National Hardware 3167BC Series N262-493 Stainless Steel Quick Link rated at 1800 lb |
| Quick Release | • Allows for detachment of main parachute from payload section after landing, avoiding damage and dragging of the payload | Post-landing separation of the payload section from the rest of the vehicle. | KONG Quick Release 525 Stainless Steel is rated at 330 lb |

| | | | |
|---|---|---|---|
| Quick Release Bracket | - Reduces length of exposed string compared to eye bolt or u-bolt | Secures the quick release to the bulkhead | Custom machined part |

### 3.3.7.1. U-Bolt

U-bolts are used for all connections in the vehicle aside from the payload-side attachment between the payload and main section. They were chosen due to their high strength and attachment to the bulkhead in two locations. Combined with a plate, the forces are spread across a far larger area than in a single eye bolt, which would significantly reduce the probability of shearing at a point, which impacted a non-competition launch of the team in November 2022.

### 3.3.7.2. Quick Link

Quick links have widespread use in the vehicle, and are used to attach the kevlar harness to the different sections of the vehicle, and are used to attach the parachutes to the harnesses. The quick link system of attachment allows for quick setup and replacement of parts, ensuring longevity of the vehicle. Rated at 1,800 lb, the team is not concerned about any attachment, as the parachute deployment force at its maximum is 523.1 lbf, 3.44 times less than the rated capacity.

### 3.3.7.3. Quick Release and Quick Release Harness

The payload portion of the vehicle will be attached to the recovery system by a KONG Quick Release 525 with a rated load of 330 lb. This part is expected to endure a maximum load of 221.6 lbf as calculated in 3.5.7, and will be operating within rated limits.

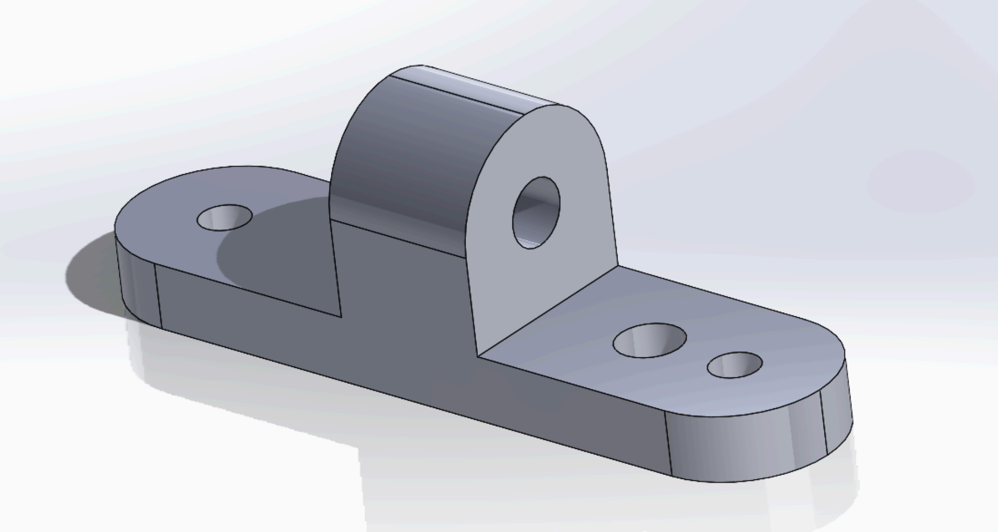


**Figure 3.31: Custom U-bolt**

In addition to physical failure, a possible failure mode for the quick release mechanism is that lateral movement will place tension on the release cord and cause it to release early. To mitigate this issue, the quick release will be mounted to an aluminum bracket that restricts it from rotating in that direction. To verify that the bracket would be sufficiently strong, by-hand calculations were performed to determine the factors of safety for both axial and lateral loads on this part.

The total deployment force on the parachute was calculated in section 3.3.8.1 at 523.1 lbf. This results in a force of 232.5 lbf on the payload section, which, due to the chaotic nature of parachute deployment may be considered to occur in a random direction. We assume that the two worst cases for deployment forces are directly in line with the axis of the vehicle and parallel to the quick-release pin.

For loads in line with the vehicle, strength may be modeled as the minimum of tear-out and ovalization force. For the following parameters:

- Ultimate tensile strength: 85000 psi (7075 T651 Temper Aluminum)
- Thickness: 0.6”
- Pin diameter: ¼”
- Center-to-edge length: ⅜”

Hand calculations predict that this part will fail in tear-out first, with a maximum load of 22950 lbf. This yields a safety factor of 98.7, well in excess of the required safety factor of 3 for critical components.

For lateral loads, failure is modeled by ovalization in bending, with the neutral axis at the center of the rod and bearing stress proportional to distance from this axis. This yields a maximum moment before ovalization of 918 lbf*in, which corresponds to a load of 502 lbf at the maximum possible radius of 1.83 inches (the far end of the quick link). This yields a safety factor of 2.2 for this scenario. This is an allowable safety factor, as ovalization in bending results in distortion of the mounting bracket rather than complete tear-out.; after the initial shock, the integrity of the mount will not be greatly affected.

### 3.3.8. Maximum descent velocity

The main parachute determines the maximum descent rate, as its deployment and inflation is the most significant force that will act on the vehicle during descent, and the largest single force that will act on the vehicle during flight.

### 3.3.8.1. Force of Parachute Deployment

Using the drag formula $F_d = \frac{1}{2}\rho v^2 C_d A$, where ρ is the density of air in kg/m$^3$, v is the velocity in m/s, $C_d$ is the coefficient of drag, and A is the area in square meters, and $F_d$ is the force of drag in Newtons, and with appropriate unit conversions, the estimated deployment force is 523.1 pounds. Using the relationship of force, mass, and acceleration, the acceleration at main parachute deployment is 965.2 ft/s$^2$.

Using the acceleration data and mass of the sections, the forces on the sections of the vehicle can be determined, and are listed below.

**Table 3.34: Estimated Forces on Attachment Hardpoints at Main Parachute Deployment**

| Section | Force |
|---|---|
| Payload | 232.5 lbf |
| Main | 292.1 lbf |
| Booster | 161.8 lbf |

### 3.3.8.2. Component Limits

The component strengths are described below:

**Table 3.35: Components and Strengths**

| Component | Rated Capacity | Sections of Vehicle |
|---|---|---|
| U-bolt | 425 lb | • Booster<br>• Main |
| Custom Quick Link Harness | 501 lb | • Payload |
| Quick Link | 1800 lb | • Booster<br>• Main<br>• Payload |
| Quick Release | 330 lb | • Payload |

### 3.3.9. Avionics

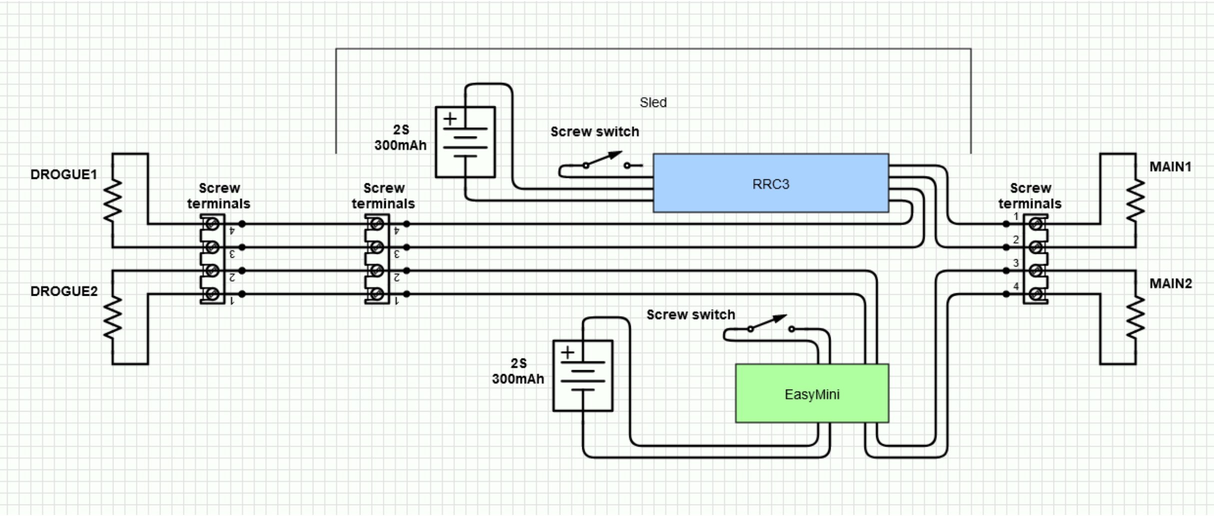


**Figure 3.32: Avionics schematic**

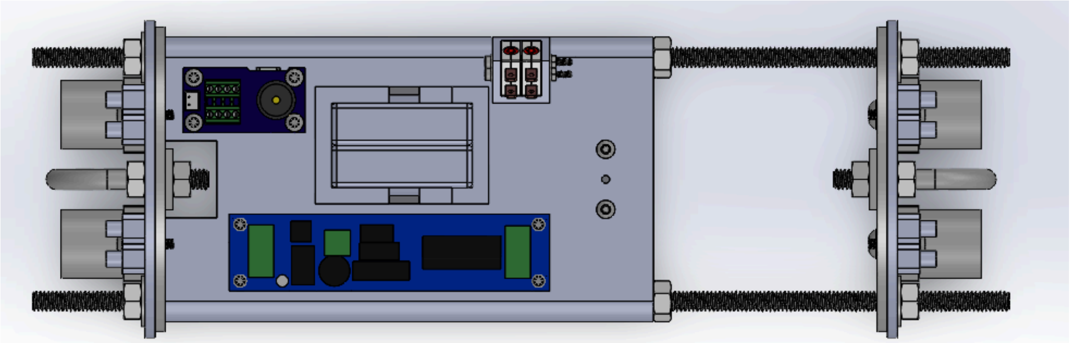


**Figure 3.33: Avionics bay**

#### 3.3.9.1. Altimeters

The primary altimeter for this vehicle is a Missileworks RRC3 (blue components at bottom of Figure 3.31), with an Altus Metrum EasyMini (blue components at top of Figure 3.31 as a backup).

#### 3.3.9.2. Batteries

The batteries used for flight are Tattu 2S 300mAh lithium-polymer batteries. These batteries have been used on several past team projects and are designed for high-current-draw drones, so they do not contain current-limiting circuits that could cause brownout when firing charges.

The highest expected current draw of either altimeter is 35 mA when the RRC3 is producing a beep tone. At this current draw, the rated 300mAh capacity of the batteries yields a maximum pad life of 8.5 hours, significantly more than the 4 hours specified by requirement AV.2.

#### 3.3.9.3. Switches

Both altimeters are switched on via independent Fingertech Robotics screw switches. These switches were selected based on their extreme vibration resistance and overall ruggedness based on their rated application as power switches for combat robots; in past projects, the team has encountered issues with PCB-style screw switches failing under impact and vibration, which this switch type should mitigate. Additionally, the switches are mounted to the avionics sled in order to minimize stress on the switch wires.

#### 3.3.9.4. Wiring

The e-matches for each charge are connected via screw terminal blocks located on each end cap of the avionics bay. From here, the main charges directly connect through the forward bulkhead to the main terminals of the altimeter via 18 AWG stranded wire. The drogue terminal blocks, however, are wired through the aft bulkhead to a second set of screw terminals on the sled before being attached to the altimeter terminals. Because the drogue side of the avionics bay is the side from which it is assembled, this minimizes stress on the altimeter terminals from the assembly process.

### 3.3.10. Separation System

The separation system of the launch vehicle is made up of two sets of shear pins, one set for each parachute, and two sets of deployment charges, one set for each parachute.

#### 3.3.10.1. Shear Pins

##### 3.3.10.1.1. Drogue Shear Pins

The drogue shear pins are sized under the assumption that the primary risk of early drogue separation is from pressurization of the lower airframe. Note that while the drogue section is vented to reduce this risk, all calculations are done under the assumption that no venting occurs to ensure that the flight is safe even if the vent port is compromised by debris or other obstacles.

Based on the Standard Atmosphere Model [1], an altitude increase from sea level to the maximum allowable competition altitude of 6000 feet represents a decrease in air pressure from 14.7 to 11.8 psi. This yields a total differential force of 36.44 lbf based on a 4-inch-diameter circular bulkhead. Apogee Rockets quotes a shear strength of 64.24 lb per #2-56 nylon shear pin [2], so two shear pins are required to provide a safety factor of 3 for this application per requirement V.5.

#### 3.3.10.1.2. Main Shear Pins

The main shear pins are sized under the assumption that the primary risk of early main separation is from the deceleration of the parachute section after drogue deployment. Note that while the drogue shock cord will be bundled to provide shock absorption, the shear pins will be sized to ensure safe deployment even if this mitigation does not function.

To calculate the force experienced by the main shear pins, the kinetic energy of deployment is first calculated by assuming that the maximum ejection pressure of 15 psi is applied over the full 4-inch travel of the coupler. This results in a total energy of 85.2 joules.

To calculate the force required to stop the bay at the end of the cord, we assume that the shock cord will act as an ideal spring, with the rated 3% stretch at the final breaking strength of 3600 lb. This yields a spring constant of 58376 N/m. If the entire deployment energy of 85.2 J is absorbed by the cord, it will stretch by 5.4 cm, applying a force of 3153 N.

By conservation of momentum, this results in an acceleration of 292 $m/s^2$ on the forward section and 1033 $m/s^2$ on the aft section, which places a force of 249 lbf on the shear pins. As in the previous section, each shear pin represents 64.24 lb of force; however, unlike for the drogue section, a safety factor of 3 is not observed for this joint, as early main deployment is considered less of a safety risk than failure to deploy the main parachute due to oversized shear pins. Therefore, 4 shear pins are used to retain this section.

### 3.3.10.2. Separation Charges

The separation charges are black powder charges that push the parachutes and sections of the vehicle apart when separation times and/or altitudes are reached. The charges are sized using online charge calculators, with the secondary charge set at 1 gram higher than the primary to ensure successful deployment should the secondary system be necessary.

#### 3.3.10.2.1. Drogue Separation Charges

The drogue parachute uses the following charge amounts:

**Table 3.36: Drogue Parachute Charge Amounts**

| Primary | Secondary |
|---|---|
| 1.75g | 2.75g |

##### 3.3.10.2.2. Main Separation Charges

The main parachute uses the following charge amounts:

**Table 3.37: Main Parachute Charge Amounts**

| Primary | Secondary |
|---|---|
| 2.5g | 3.5g |

### 3.3.11. Concept of Operations

#### 3.3.11.1. Introduction

The purpose of a recovery subsystem is to provide a safe recovery of the launch vehicle in a reusable condition (reusable defined as ready to fly again the same day with no repairs). As the USLI necessitates a new vehicle every year, a new recovery subsystem is required.

The development of the recovery subsystem has the following assumptions and constraints: the subsystem will be dissimilarly redundant; the subsystem will use COTS parachutes; the subsystem will keep the subsections of th
e vehicle under a certain kinetic energy; the subsystem will be ready for usage by February 2023 at the latest; the subsystem will use a dual-deploy mechanism; the subsystem will allow the payload to be detached after touchdown.

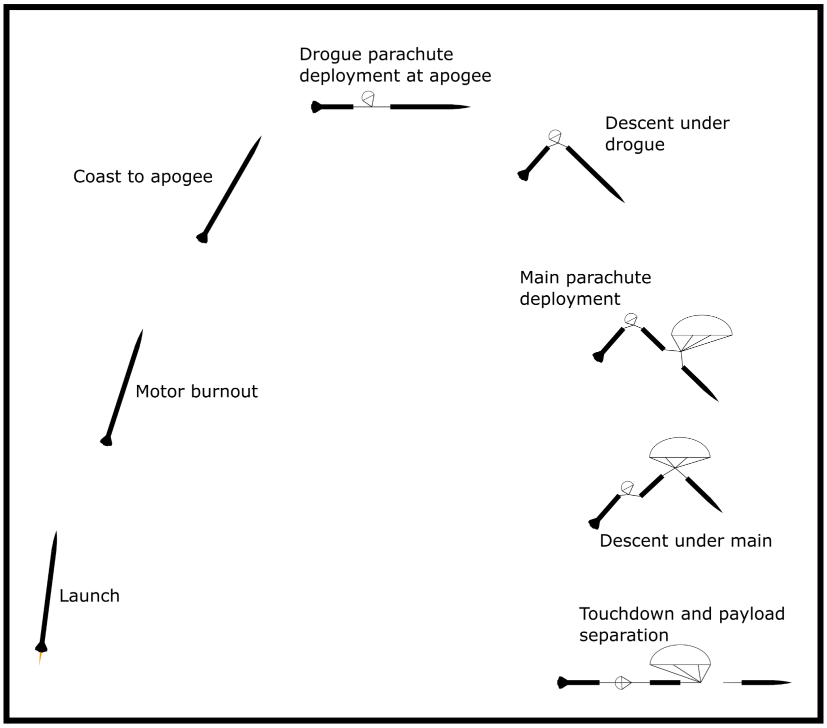


**Figure 3.34: Launch and Recovery Conceptual Illustration**

The recovery subsystem is a key part to mission success, and takes up an entire section of the vehicle, with elements of the system in all sections.

The subsystem has one external interface made up of two screw switches, allowing the system to be armed and disarmed before and after launch, and in the event of a scrub.

The recovery subsystem consists of a main parachute and protector, a drogue parachute and protector, two 3-loop harnesses, two sets of shear pins, two sets of two black powder charges, four e-matches, two dissimilar altimeters, a quick release, U-bolts, and a custom-designed quick release bracket.

The system must be able to be in a ready-to-fly state for at least 2 hours. At any point in that time period, it must be able to survive the forces of flight, and autonomously deploy both parachutes at specified times or altitudes in flight, before detecting touchdown and separating the payload section from the rest of the vehicle.

#### 3.3.11.2. References

The main references used in designing the recovery subsystem are as follows:

OpenRocket, a free rocketry simulation software, was used to design and simulate the vehicle's ascent and descent phases of flight.

The Rocketry Forum, an online discussion platform about model rocketry, was used for general advice and data that others have gathered.

RocketMime, a website with many equations about model rocketry, was used for an equation to determine the size of the parachutes.

Apogee Rockets, a model rocketry vendor, was used for calculations regarding the drag produced by the airframe of the vehicle during descent.

Insane Rocketry, a video and tracking website for model rocketry, was used to size the black powder charges.

#### 3.3.11.3. Envisioned System

As discussed in 3.3.10.1 and the NASA USLI handbook, the subsystem must recover the vehicle in a reusable condition, keep it under a certain kinetic energy, and be autonomous once enabled.

The most important part in the recovery subsystem are the parachutes, as they do the work to stabilize and slow the vehicle for a safe touchdown. The vehicle uses two parachutes, a small drogue parachute, and a much larger main parachute.

The drogue parachute serves two main purposes; slowing down the vehicle to a safe speed for deployment of the main parachute and stabilizing the descent of the vehicle.

The drogue parachute chosen for the task is a 1-foot hemispherical drogue parachute from The Rocketman. Combined with the airframe drag, it is expected to reduce velocity at deployment to 102.75 ft/s.

The purpose of the main parachute is to slow the vehicle to a touchdown speed that ensures the survival of the payload and ensuring each section of the vehicle is under a team-derived requirement of 60 ft lbf of kinetic energy.

The parachute chosen as the main parachute is a 5-foot toroidal parachute from The Rocketman, with a high performance for its mass. After its deployment at 700 feet, it is expected that the vehicle will descend at 18.4 ft/s, and the heaviest section of the vehicle is expected to not exceed 42 ft lbf of kinetic energy. The team does believe the size is excessive, as it leaves margin for ballast and underperformance, should either arise.

Each parachute must be protected from the explosive separation event. The team accomplishes by placing the packed parachutes inside of a fireproof Nomex blanket. The drogue parachute uses a 12-inch protector and the main parachute uses an 18-inch protector.

To allow for the separation of the vehicle into its sections at deployments, special nylon screws called shear pins are used. #2-56 shear pins are the pins of choice, with two pins being used for the drogue parachute and four pins for the main parachute. These pins shear before the parachute deploy.

The deployment itself is accomplished by usage of black powder charges. Each parachute uses two charges, a primary charge, and a secondary charge. To ensure deployment of the parachute, the primary deployment system and secondary deployment system are completely independent from each other, and the secondary charges are 1 gram larger than the primary to further ensure deployment. The charge amounts for the drogue and main parachute are listed below:

**Table 3.38: Black Powder Charge Amounts**

| Parachute | Primary Charge | Secondary Charge |
|---|---|---|
| Drogue | 1.75g | 2.75g |
| Main | 2.5g | 3.5g |

The charges are ignited by e-matches. E-matches burn after a known current passes through them. Due to being the cheapest, having very good reliability, and not requiring hazmat shipping, the team uses MJG Firewire e-matches to ignite the black powder charges.

The matches are controlled by altimeters, where the primary charges are wired to one altimeter and the secondary charges are wired to another altimeter, and each altimeter is powered by a separate Tattu 2S 300mah battery. The altimeters being used are the MissileWorks RRC3 and Altus Metrum EasyMini. This is how the team achieves dissimilar redundancy for deployment of parachutes.

The primary altimeter is the RRC3, due to its better computing power and team-determined better reliability. The EasyMini is the secondary altimeter, as it is less powerful and has generally had a larger error in deployment altitudes based on the team's experience.

To transfer the force from the parachutes to the vehicle, Kevlar recovery harnesses, because of their high strength, fireproof qualities, and good reputation, are used. Each harness is made of 3 loops; the end loops attach to the two sections of the vehicle being connected, and the central loop attaches to the parachute. These harnesses are purchased from OneBadHawk, are 35 ft long, and ¼" wide.

The harnesses connect to quick links, which are rated at 1,800 pounds. The team's predicted loads are far less than the estimated forces on the sections of the vehicle, which are estimated to be under 280 pounds. The use of quick links allows for easier maintenance and switching of the harnesses if required.

The quick links attach to two kinds of hardpoints, a quick release and a U-bolt. The U-bolts are found in all connections but that to payload. The U-bolts have two points that they attach to the bulkhead with, and as such, have a much lower chance of ripping from the bulkheads than eyebolts; an event which impacted the flight of a non-competition vehicle in November 2022.

The payload section requires stability after touchdown, which cannot be achieved in windy conditions with a parachute still attached. As a result, the team decided to separate the payload section from the main section. To accomplish this task, a 330 lb-rated quick release is used to connect the main and booster sections of the vehicle to the payload section. This quick release is triggered when the payload detects landing.

The quick release is attached to the airframe via a custom-designed quick release bracket, with a calculated factor of safety of 2. The bracket restricts the motion of the quick release, reducing the chance that the release would be triggered by forces experienced during tumble.

#### 3.3.11.4. Physical Environment

The system will have to withstand a total of 8 different physical environments, which are described with the appropriate concerns below.

**Table 3.39: Expected Environments of the Recovery Subsystem**

| Environment | Concerns |
|---|---|
| Storage | • Overcompression of parachutes |
| Transit | • Damage to system from unexpected movements |
| Home Launch Pad | • Wind<br>• Pad Installation<br>• Cold weather |
| Home Flight | • Launch forces<br>• Aerodynamic forces<br>• Cold weather |
| Home Field | • Touchdown forces<br>• Cold weather<br>• Moisture<br>• Mud |
| Competition Launch Pad | • Wind<br>• Pad Installation |
| Competition Flight | • Launch forces<br>• Aerodynamic forces |
| Competition Field | • Touchdown forces<br>• Moisture |

| | |
|---|---|
| | Mud<br>People |

The team designed the recovery subsystem to sustain the conditions at both the home field and competition field. Forces of flight are expected to be far larger than during transit or storage, of which neither non-launch case will contain a fully-assembled and armed system.

### 3.3.11.5. Risks and Points of Failure

The points of failure of the recovery subsystem are listed below. The impacts, severity, and mitigations of the failures are further described in section 5.3.1.

**Table 3.40: Risks and points of failure of the Recovery Subsystem**

| Point of Failure | Component(s) |
|---|---|
| Attachment to Booster | U-bolt<br>Quick Link<br>Bulkheads<br>Epoxy |
| Drogue Protector Attachment | Quick Link<br>Kevlar |
| Drogue Attachment | Quick Link<br>Kevlar |
| Drogue Deploy | Black Powder Charges<br>E-Matches<br>Altimeters<br>Wiring |
| Avbay Attachment (Bottom) | U-bolt<br>Quick Link |
| Avbay Attachment (Top) | U-bolt<br>Quick Link |
| Main Protector Attachment | Quick Link |
| Main Parachute Attachment | Quick Link<br>Included Parachute Swivel<br>Kevlar |

| | |
|---|---|
| Main Parachute Deploy | - Black Powder Charges<br>- E-Matches<br>- Altimeters<br>- Wiring |
| Attachment to Payload | - Quick Link<br>- Quick Release<br>- Quick Release Harness<br>- Kevlar |
| Payload Separation | - Quick Link<br>- Quick Release |

## 3.4. Mission Performance Predictions

### 3.4.1. Expected Kinetic Energies

**Table 3.41: Expected Kinetic Energy of Vehicle Sections**

| Section | Drogue Kinetic Energy | Main Kinetic Energy |
|---|---|---|
| Booster | 1,597 ft lbf | 28.7 ft lbf |
| Main | N/A | 23.1 ft lbf |
| Payload | 1,272 | 41.2 ft lbf |

### 3.4.2. Expected Descent Properties

The descent of the vehicle contains two phases, drogue and main parachutes. Through simulations, the descent rates under each parachute are shown below.

**Table 3.42: Vehicle Descent Rates Under Parachutes**

| Phase | Rate |
|---|---|
| Main | 18.5 ft/s |
| Drogue | 102.75 ft/s |

The descent time of the vehicle is calculated from the total flight time and time to apogee, for which our calculations show 81.5 seconds.

### 3.4.3. Simulation Methodology

Flight profile simulations for this mission were performed in the vehicle's default configuration, with a payload mass of 4.5 pounds and a Cesaroni Technology, Inc. 2130K600-17A motor. The thrust curve of that motor is included below.

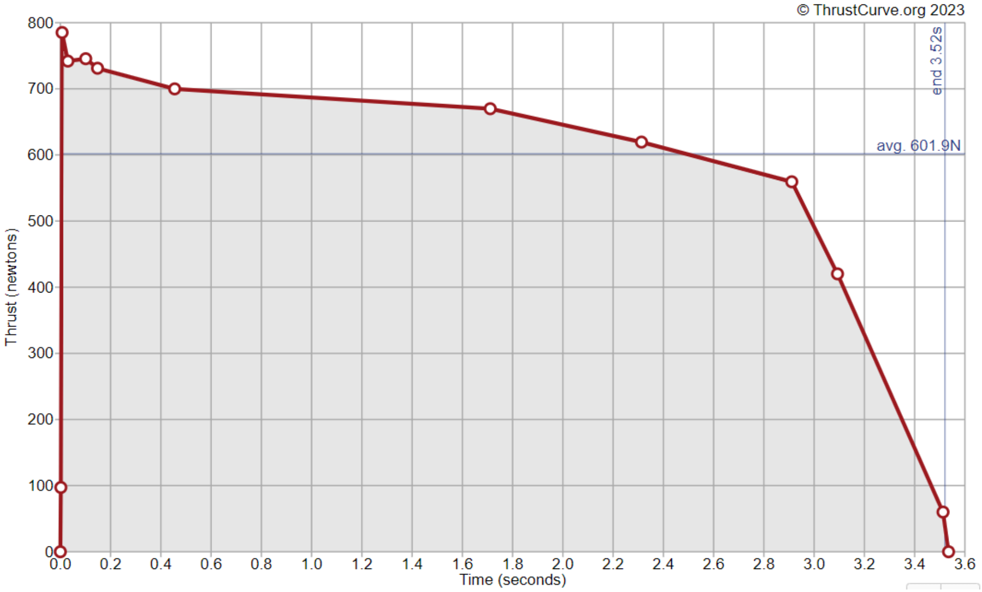


**Figure 3.35: Thrust curve for a Cesaroni 2130K600-17A (Source: thrustcurve.org)**

OpenRocket and RASAero were used to simulate the rocket's flight profile. In the same way as the PDR, for each piece of software, a primary simulation was conducted at the median rail angle of 7.5 degrees and median allowable wind speed of 10 mph, which was recorded in full. Additionally, 8 further simulations were conducted by varying the launch angle of the rocket by 2.5 degrees and wind speed by to 10 mph to ensure that the vehicle's performance would remain within mission constraints for all possible flight conditions.

### 3.4.4. OpenRocket Simulation

The team conducted simulations with two softwares. The following section is based on OpenRocket. The mission performance predictions are based on a payload mass of 4.5 pounds; accounting for a heavier than expected vehicle and/or payload, or the usage of ballast for the difference between the payload mass and 4.5lbs.

The following table describes the best-case, mean case, and worst-case scenarios of wind speed and launch angle. Highest altitudes, velocity, and accelerations are listed in each cell.

**Table 3.34: OpenRocket Simulation Results**

| | Wind Speed | | |
|---|---|---|---|
| **Launch Angle** | 0 mph | 10 mph | 20 mph |
| 5 degrees | Altitude: 5370 ft<br>Velocity: 641 ft/s<br>Acceleration: 242 ft/s$^2$ | Altitude: 5212 ft<br>Velocity: 641 ft/s<br>Acceleration: 242 ft/s$^2$ | Altitude: 4892 ft<br>Velocity: 638 ft/s<br>Acceleration: 242 ft/s$^2$ |
| 7.5 degrees | Altitude: 5297 ft<br>Velocity: 641 ft/s<br>Acceleration: 242 ft/s$^2$ | Altitude: 5097 ft<br>Velocity: 641 ft/s<br>Acceleration: 242 ft/s$^2$ | Altitude: 4824 ft<br>Velocity: 639 ft/s<br>Acceleration: 243 ft/s$^2$ |
| 10 degrees | Altitude: 5197 ft<br>Velocity: 642 ft/s<br>Acceleration: 242 ft/s$^2$ | Altitude: 4913 ft<br>Velocity: 642 ft/s<br>Acceleration: 242 ft/s$^2$ | Altitude: 4661 ft<br>Velocity: 639 ft/s<br>Acceleration: 243 ft/s$^2$ |

The OpenRocket simulations show a flight well within competition limits in all cases. In the PDR, the team determined that a flight altitude within 500’ of the targeted altitude would provide acceptable flight performance. No flights exceed this threshold, validating the vehicle design.

The new OpenRocket simulations reflect the team’s new understanding of how to model the skin friction drag of our rockets. After the simulation of the subscale underpredicted the altitude of the vehicle, we changed the skin friction model to one that more closely simulated performance.

Below is a graph that plots the mean case, 7.5 degree launch angle and 10 mph wind.

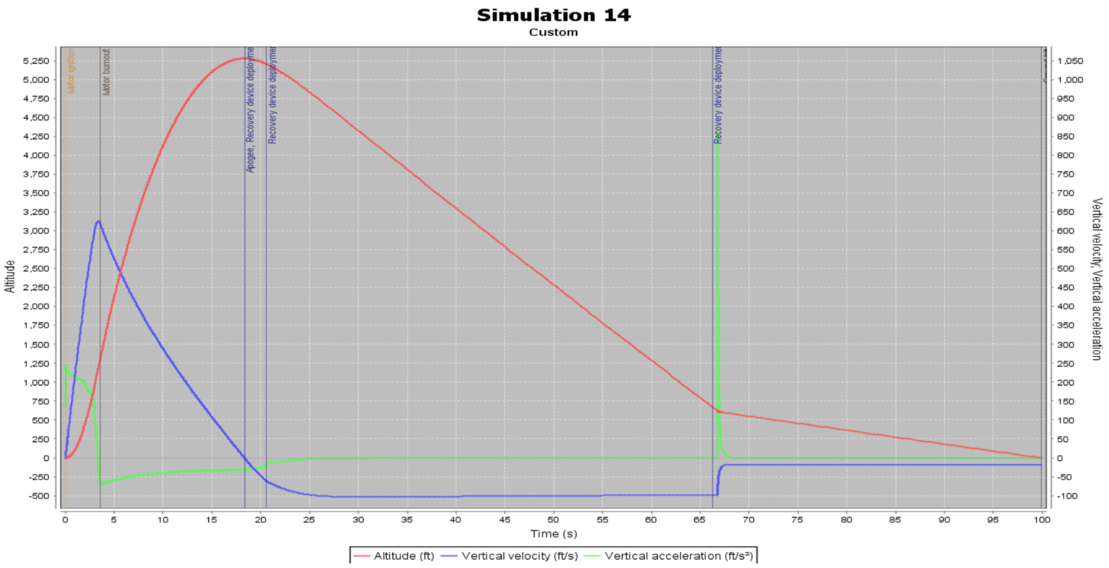


**Figure 3.36: Full-Scale Vehicle SImulation**

### 3.4.5. RASAero Simulation

Simulations were also conducted using RASAero, a software found to be very accurate through our research in the PDR. The vehicle was configured identically to how it was configured in the OpenRocket simulations. The following table summarizes simulation results using the same possible launch rod angles and wind conditions as the OpenRocket simulations to ensure the vehicle will remain within competition limits.

**Table 3.35: RASAero Simulation Data Summary**

| | **Wind Speed** | | |
|---|---|---|---|
| **Launch Angle** | 0 mph | 10 mph | 20 mph |
| 5 degrees | Altitude: 5151 ft<br>Velocity: 643 ft/s<br>Acceleration: 250 ft/s$^2$ | Altitude: 4994 ft<br>Velocity: 646 ft/s<br>Acceleration: 250 ft/s$^2$ | Altitude: 4656 ft<br>Velocity: 651 ft/s<br>Acceleration: 250 ft/s$^2$ |
| 7.5 degrees | Altitude: 5048 ft<br>Velocity: 644 ft/s<br>Acceleration: 250 ft/s$^2$ | Altitude: 4871 ft<br>Velocity: 648 ft/s<br>Acceleration: 250 ft/s$^2$ | Altitude: 4496 ft<br>Velocity: 653 ft/s<br>Acceleration: 309 ft/s$^2$ |
| 10 degrees | Altitude: 4908 ft<br>Velocity: 645 ft/s<br>Acceleration: 250 ft/s$^2$ | Altitude: 4727 ft<br>Velocity: 650 ft/s<br>Acceleration: 250 ft/s$^2$ | Altitude: 4323 ft<br>Velocity: 656 ft/s<br>Acceleration: 250 ft/s$^2$ |

The RASAero simulations are fairly similar to the OpenRocket results. Each simulated apogee results in about 300 feet less altitude than the corresponding OpenRocket result. Since the skin friction model cannot be updated in RASAero, the results are expected to be lower, similarly to original OpenRockety Sims. All altitudes, velocities, and accelerations are well inside competition rules. These results indicate that if the wind speed is lower, the launch vehicle will fly much closer to the target apogee of 5000 feet. This simulation would also indicate we have less margin for increases in mass and aerodynamic drag from rough surfaces or screw heads. The team is still confident that these simulations validate the vehicle design and motor selection.

### 3.4.6. Stability

To ensure a successful mission, the vehicle must be stable for the duration of its flight at all velocities it will encounter. The stability margin in calibers was simulated relative to velocity using an OpenRocket simulation. The graph of this simulation is shown below.

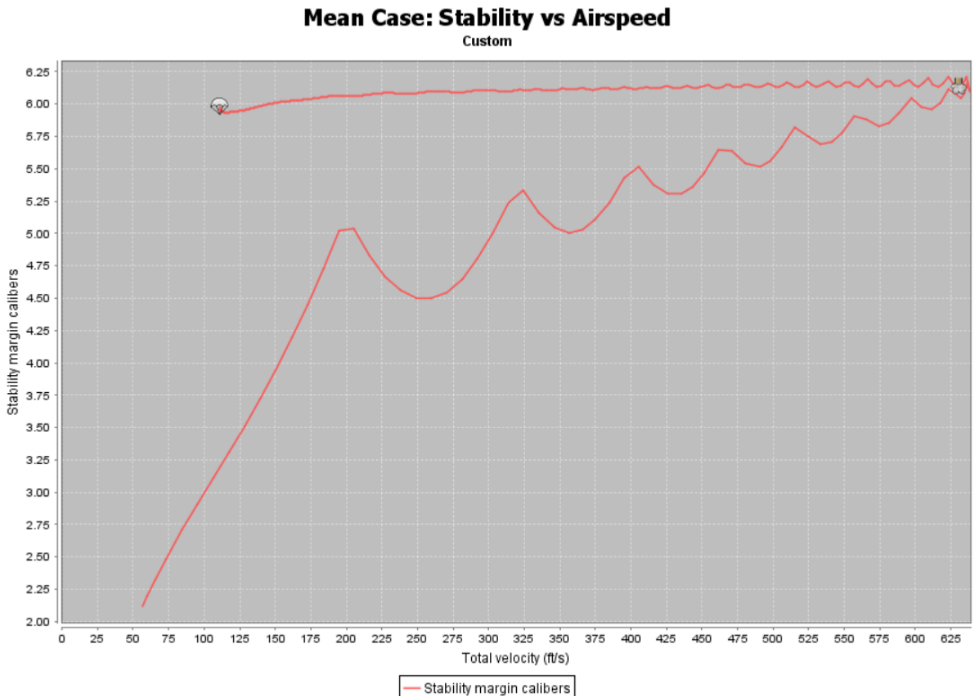


Figure 3.37: Stability Relative to Airspeed

Including the redesign of the fins, the static stability at rail exit in the mean case is 2.13 calibers, satisfying the requirements for a stable flight of the vehicle, and validating the design of the vehicle.

# 4. Payload Criteria

The payload design has been compartmentalized into two sections: the mechanical system and its electrical counterpart. This section will detail selected alternatives, an analysis of the payload at system-level design, as well as a completed design that provides a more granular display for the payload.

## 4.1. Design of Mechanical Payload Equipment

### 4.1.1. Selected Alternatives

Following rigorous testing and analysis of different proposed mechanisms, the team has selected the following alternative designs to be used.

Table 4.1: Mechanical Payload Selected Alternative

| Mechanical Payload Design | Selected Alternative | Justification | Components |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Airframe Stabilization Mechanism | Simple Rotating Legs | • Mechanically simple<br>• Easy to actuate<br>• Sturdy | • Torsion spring<br>• 3D printed legs<br>• 3D printed supporting frame<br>• Burn wire<br>• Fishing wire |
| Airframe Rotation Mechanism | 3D Printed Bearing & 360 degree servo | • Customizable<br>• Easy to replace<br>• More control | • 3D printed bearing<br>• Continuous servo |
| Bay Door Hinge and Deployment | Spring-loaded Commercial Off The Shelf (COTS) Hinges | • Known Strength<br>• Less deployment time<br>• Ease of development | • COTS Hinges<br>• Servo motor<br>• 3D printed linkage & pin release |
| Automated Camera System Deployment | Four-Bar lift | • Simple actuation<br>• Small<br>• Flexibility in top attachment | • 3D printed four-bar lift<br>• Servo motor |
| Automated Camera System Stabilization | Passive Gimbal | • No actuators needed<br>• Compact<br>• Simple and cheap to manufacture | • 3D printed gimbal |
| Automated Camera System Rotation | Direct Drive 360-degree Servo | • Space efficient<br>• Does not need gear system | • 360 degree servo |
| Payload Section Release Mechanism | Cord Quick Release | • Stronger material<br>• Less development time | • KONG quick release<br>• Servo motor<br>• 3D printed pulley system<br>• Custom eye bolt |
| Payload Electronics Sled | Custom 3D Printed Sled | • Customizable<br>• Easy access and assembly<br>• Support for deployable structures | • 3D printed sled<br>• Heatset inserts |

#### 4.1.1.1. Airframe Stabilization

The Leg Support alternative was chosen for its superior stiffness and ease of deployment. The legs will be deployed by burning a nylon retention cable (fishing line) using a current through nichrome wire.

Both the legs and the frame will be manufactured using a 3D printer because of their complex geometry. The torsion springs are necessary for them to deploy after burning through the fishing line. A test (see Section 6.1.2.13) will be performed to ensure the torsion spring has enough force to lift the airframe to reduce the force needed to rotate the section using the Rotation Section.

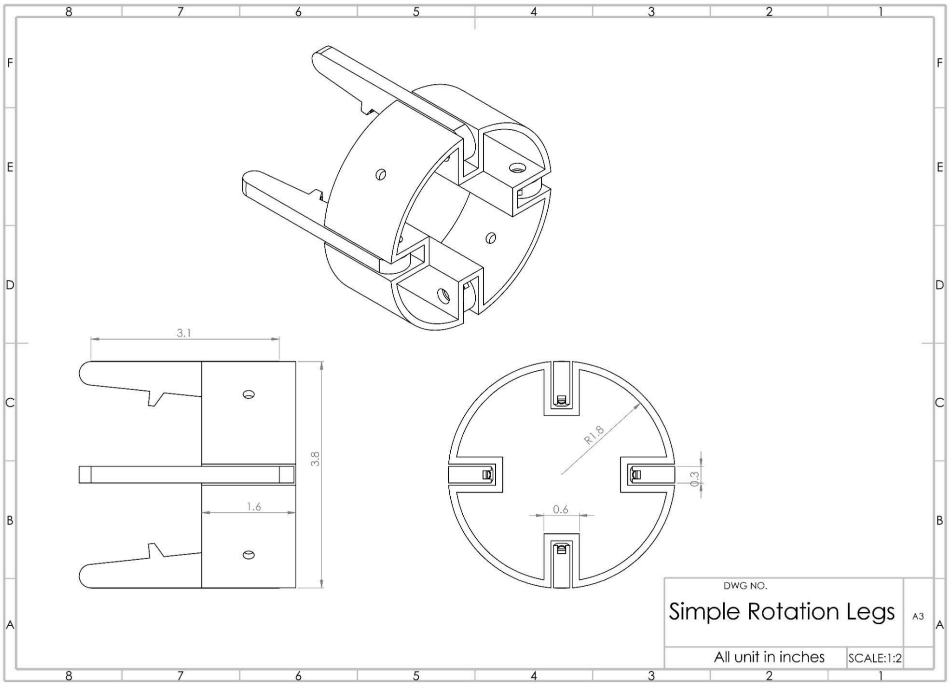


**Figure 4.1: Simple Rotation Legs Dimensional Drawing**

#### 4.1.1.2. Airframe Rotation Mechanism

The Airframe Rotation is achieved with a 3D printed custom bearing. After investigating off-the-shelf bearings, the team decided that a custom one would better suit our needs and requirements. There is concern about the strength of the bearing due to the high loads during launch and recovery, and so this system will be rigorously tested (See Test. 6.1.2.12).

A continuous servo will be used to control this system, as it is much lighter than a stepper and does not require the external gearing that a standalone DC motor would. Figure 4.2 shows the  specifications.

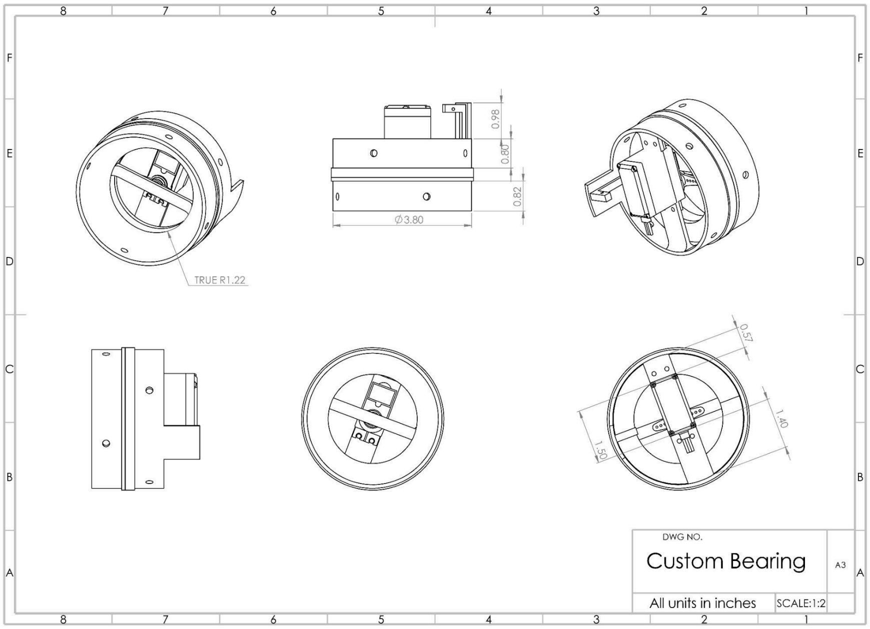


**Figure 4.2:Custom Bearing Dimensional Drawing**

#### 4.1.1.3. Bay Door Hinge and Deployment

The Bay Door deployment system is achieved through spring–loaded Commercial Off The Shelf (COTS) hinges. These were selected due to their known strength and ease of deployment and development. The hinges are attached to the wall of the airframe through a 3D printed connector and screws,  and when released allow for the hinges to actuate and deploy the bay doors to allow for the camera to deploy outside of the airframe of the vehicle.

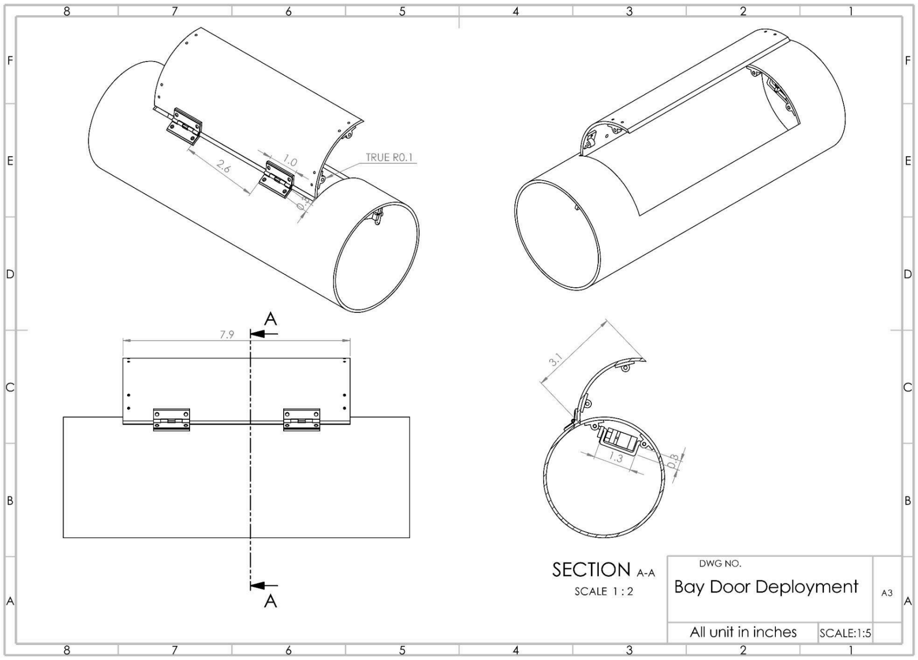


**Figure 4.3: Bay Door Deployment Dimensional Drawing**

### 4.1.1.4. Camera Deployment

The Camera Deployment is achieved through use of a 4-bar lift. This is a departure from the alternative chosen in the PDR. The 4-bar lift takes significantly less space and only requires a small servo to actuate. In addition, it is easier to mount the required systems onto this design of mechanism. It will be 3D printed for ease of fabrication and to minimize weight while maximizing stiffness (utilizing low-density infill). Figure 4.4shows the linkages and connection points.

The Camera Deployment system also deploys the APRS antenna required by Electronics Payload. The antenna leaves the airframe to point the tip towards the sky since it receives the least radiation in that direction and cannot fit upright in the airframe. The size of the antenna additionally drives the size of the bay door.

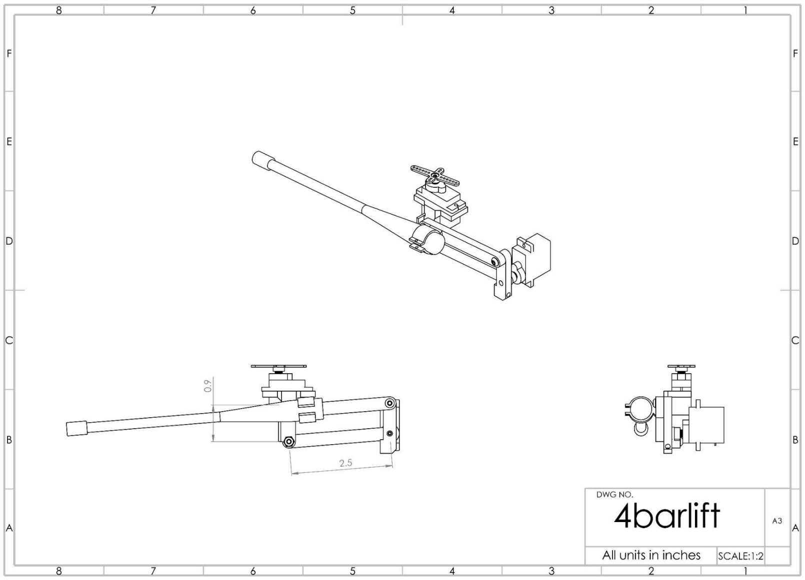


**Figure 4.4: 4-Bar Lift Dimensional Drawing**

#### 4.1.1.5. Camera Stabilization

Camera Stabilization is required to ensure that the camera stays parallel with the z-axis (defined in Section 4.2.1.1 in the Handbook) regardless of whether the airframe lands perpendicular to the z-axis. The chosen alternative for this system is a passive gimbal. Since this system needs to be light and carries little load, it will also be 3D printed. Figure 4.5 shows the Camera Stabilization system.

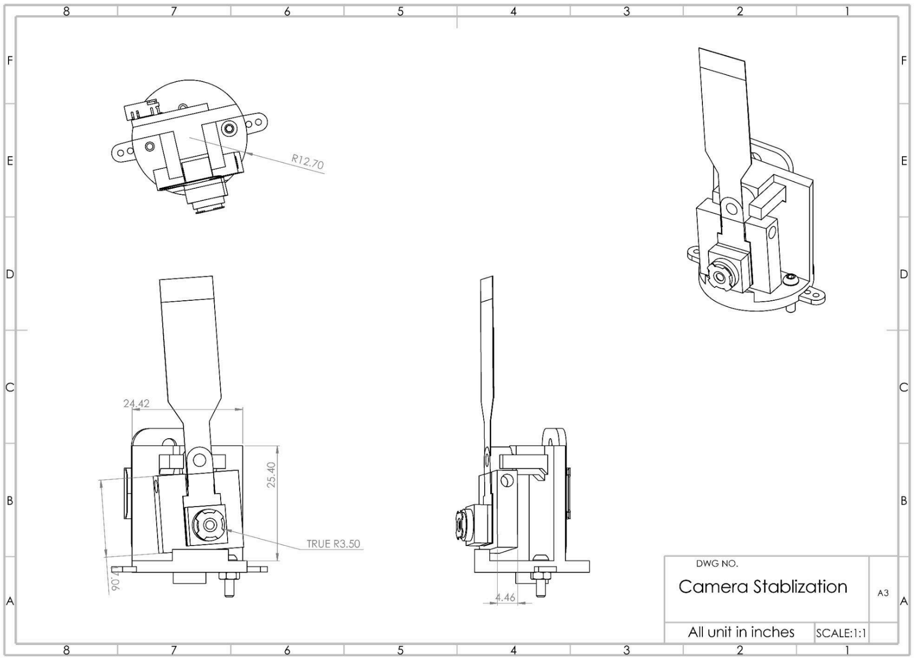


**Figure 4.5: Camera Stabilization Dimensional Drawing**

### 4.1.1.6. Camera Rotation

The camera rotation fulfills Handbook requirement 4.2.1 and is achieved through the use of a 360-degree servo. Design studies determined that gearing a motor would take up too much space, and a small 360 servo will be of adequate torque to rotate the Camera Stabilization and the Camera. See Figure 4.6 (camera deployment figure ) for its illustration.

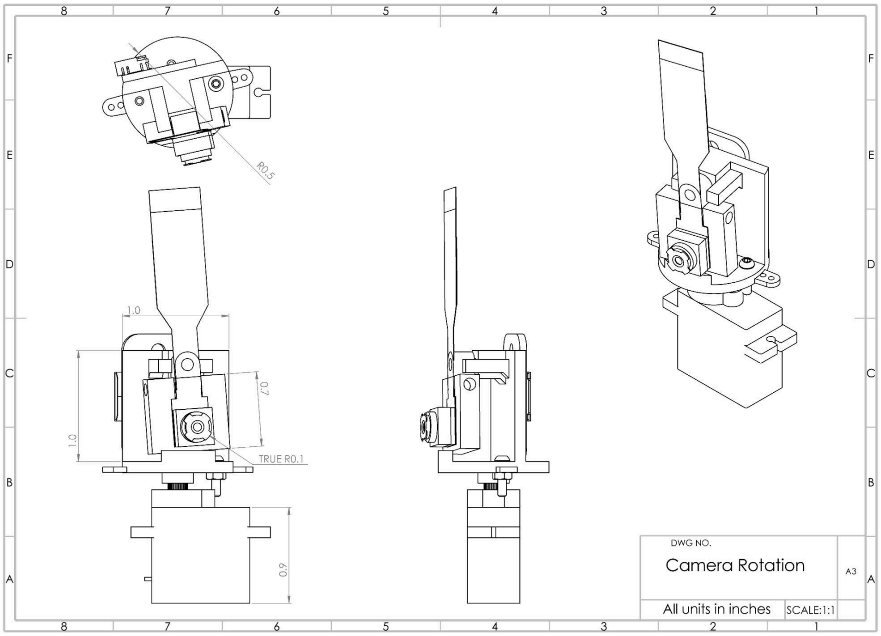


**Figure 4.6: Camera Rotation Dimensional Drawing**

#### 4.1.1.7. Quick Release

After landing, the quick release is used to separate the payload section of the vehicle. The separation is to ensure that wind catching the parachutes does not interfere with the payload mission. The quick release is made up of a KONG quick release, a servo motor, and a pulley system. The servo and the pulley is used to pull the release cord once the payload lands.

The KONG quick release is being chosen due to its easiness to quickly open the closing lever even under load. The design is compact to fit into the airframe meanwhile has enough integrity to withstand significant load. Due to the connection geometry between the eye bolt and quick release, the landing position of the quick release is unpredictable, which may cause the release being pulled but not enough to open the lever. Therefore, a 3D printed supporting suture will be mounted between the eye bolt and quick release to provide extra structure integrity.

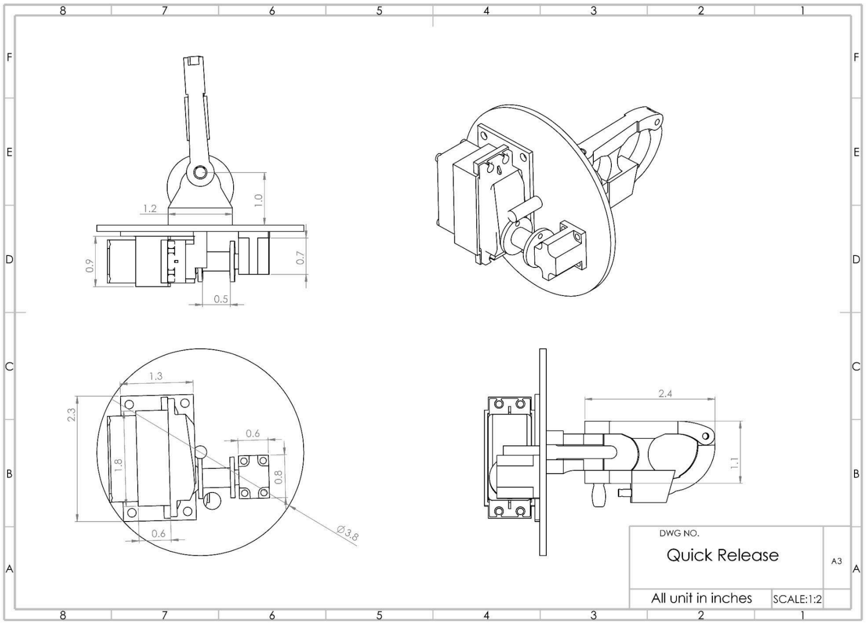


**Figure 4.7: Quick Release Dimensional Drawing**

### 4.1.1.8. Electronics Sled

The electronics sled has been custom designed for the components needed to mount on it. Figure 4.8 shows the electronics sled.

The sled is a unique design as required by the awkward geometries of the components. It meets certain requirements enforced by the systems of Mechanical and Electronic Payload. These include: keeping the CSI to HDMI board near the HDMI port on the Pi, putting the motherboard's component side near the airframe for the screw switch, putting the battery on the back side of the motherboard, and keeping the Camera Deployment mechanism near the center of the airframe. Finally, the sled should easily slide into the airframe with all the components mounted. As per these requirements and space constraints, the sled could not simply be flat, so more complex geometry was utilized. This geometry offers a huge benefit in the form of adaptability. Its structure can be expanded to include pieces for Camera Deployment retention and Camera Stabilization retention.

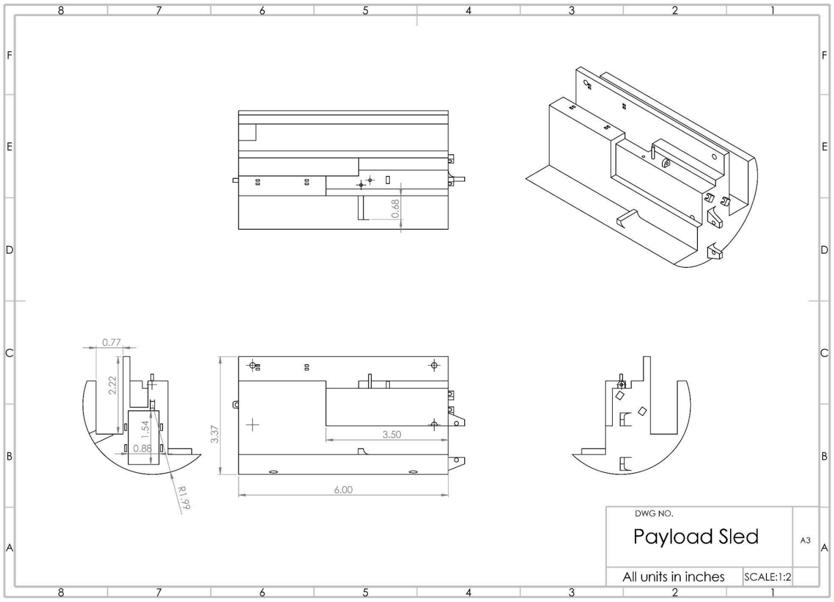
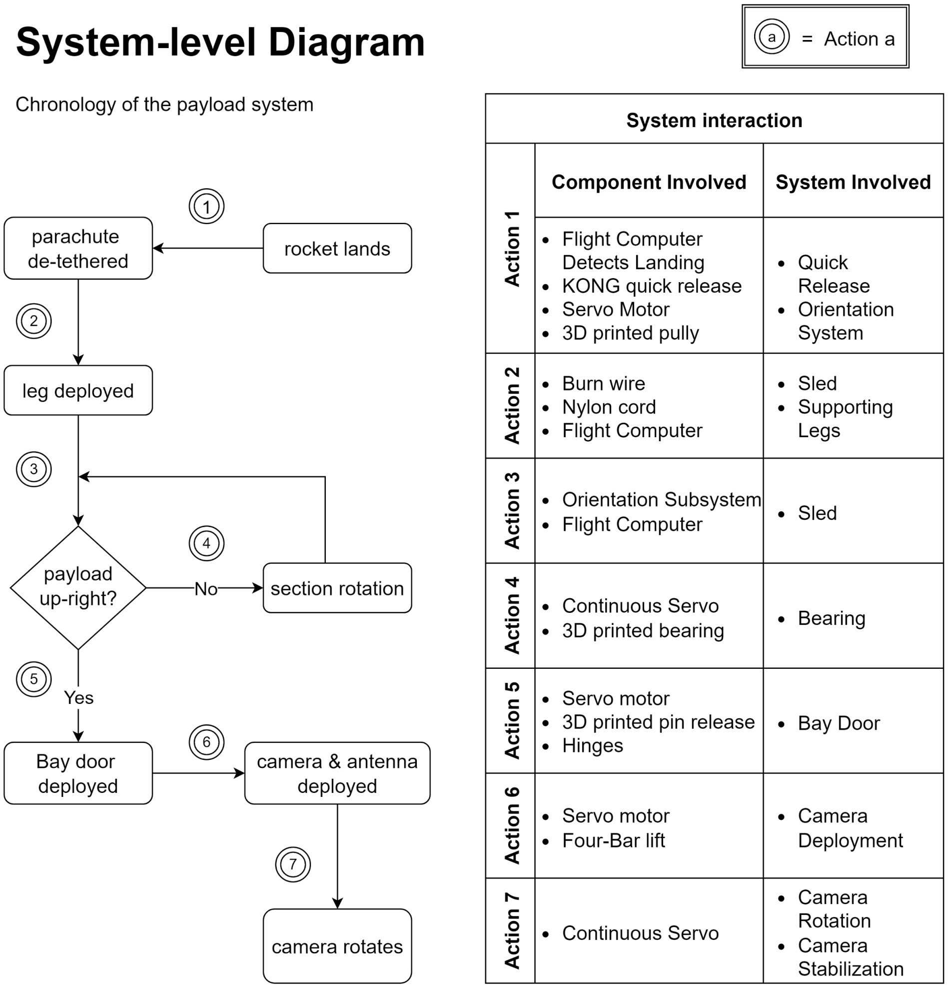


**Figure 4.8: Payload Sled Dimensional Drawing**

### 4.1.2. System-Level Design

The components and systems in Section 4.1.1 work together to accomplish the payload challenge. Figure 4.9 shows a flow diagram of the payload's functionality in terms of the actions the payload will take at each step of the mission.



**System interaction**

| | Component Involved | System Involved |
|---|---|---|
| **Action 1** | • Flight Computer Detects Landing<br>• KONG quick release<br>• Servo Motor<br>• 3D printed pully | • Quick Release<br>• Orientation System |
| **Action 2** | • Burn wire<br>• Nylon cord<br>• Flight Computer | • Sled<br>• Supporting Legs |
| **Action 3** | • Orientation Subsystem<br>• Flight Computer | • Sled |
| **Action 4** | • Continuous Servo<br>• 3D printed bearing | • Bearing |
| **Action 5** | • Servo motor<br>• 3D printed pin release<br>• Hinges | • Bay Door |
| **Action 6** | • Servo motor<br>• Four-Bar lift | • Camera Deployment |
| **Action 7** | • Continuous Servo | • Camera Rotation<br>• Camera Stabilization |

Figure 4.9: System level design for payload system

#### 4.1.2.1. Full Payload Assembly

The full assembly is shown in Figure 4.10 below.

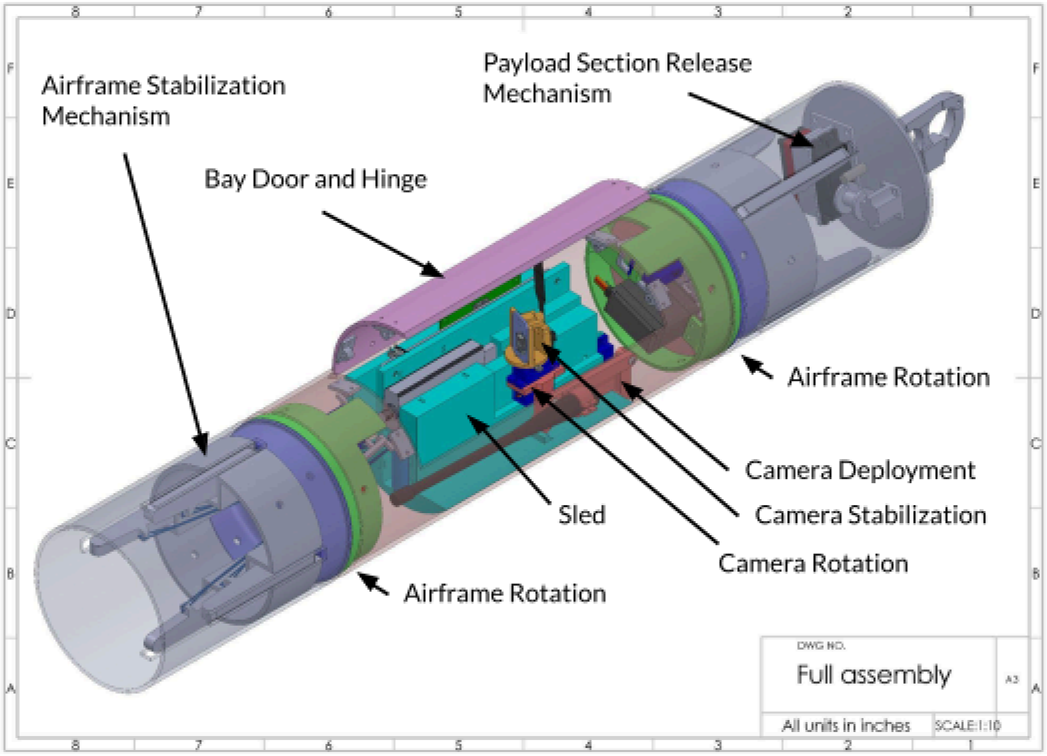


**Figure 4.10: Payload full assembly**

#### 4.1.2.2. Intrasystem Interactions

Most of the payload mechanical systems are sequential in design and operation - they depend on the previous one to function rather than functioning in tandem. Thus, systems were designed mostly independently. This section will go through the system-level diagram in Figure 4.9 with an emphasis on interactions between payload systems and components.

In Action 1, the only mechanical payload system is the quick release. Action 2 only contains the leg support system, but the burn wire is mounted on the sled. Action 3 only contains Electronics Payload data collection and calculation which will be covered in Section 4.2. Action 4 contains the Airframe Rotation, which includes a continuous servo and 3D printed bearing. The Airframe Rotation moves all downstream systems and components. After Action 3 is successful, the Bay Door will open using a servo removing the pin keeping it in place. Note that this servo is mounted to the bearing due to space constraints. The Camera Deployment, Rotation,  and Stabilization Systems are permanently attached as the Camera Stabilization and Rotation must leave the airframe to take photos. They all deploy together and afterwards the servo on the Camera Rotation rotates according to APRS commands.

#### 4.1.2.3. Vehicle Integration

This year's payload design requires several systems that integrate heavily with the vehicle. These systems include the Airframe Stabilization system, Airframe Rotation system, Bay Door and Hinge system, and Payload Section Release Mechanism. All of these systems are located near the top of the rocket and in the payload section so any failure does not affect the rest of the vehicle's recovery.

Figure 4.12 shows the holes that need to be cut in the airframe to allow the legs to deploy. The stowed legs will cover most of the opening, but it will not be air-tight. This is expected to have a small amount of impact on flight performance, but testing is planned to find out how much.

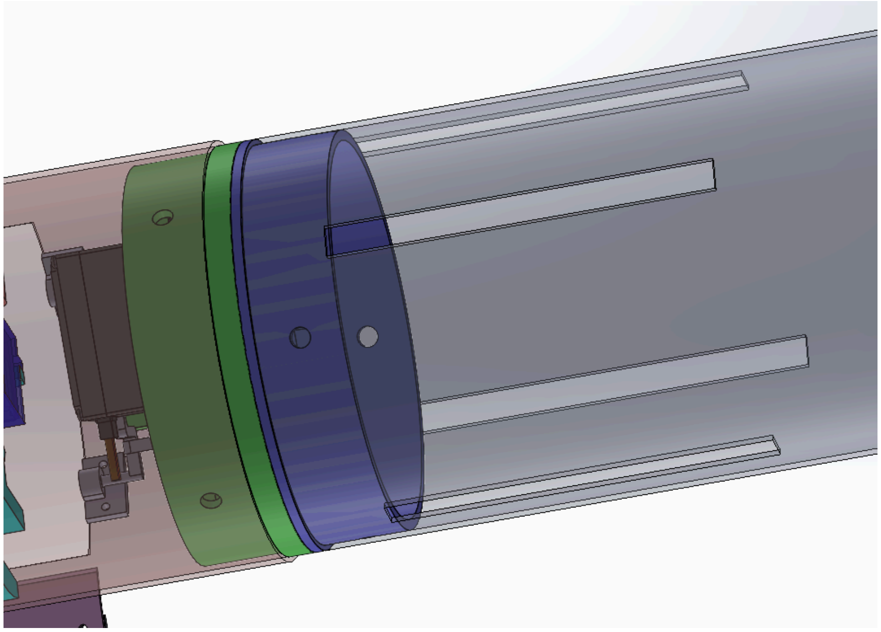


**Figure 4.12: Holes on airframe for legs to deploy**

The bearing acts as a coupler between two sections of the airframe. As such, it needs to be strong enough to handle recovery loads as well as ground impact forces. The axial and shear loads the bearing can handle without failing will be tested. Details on these tests are in Section 6.1.2.12.

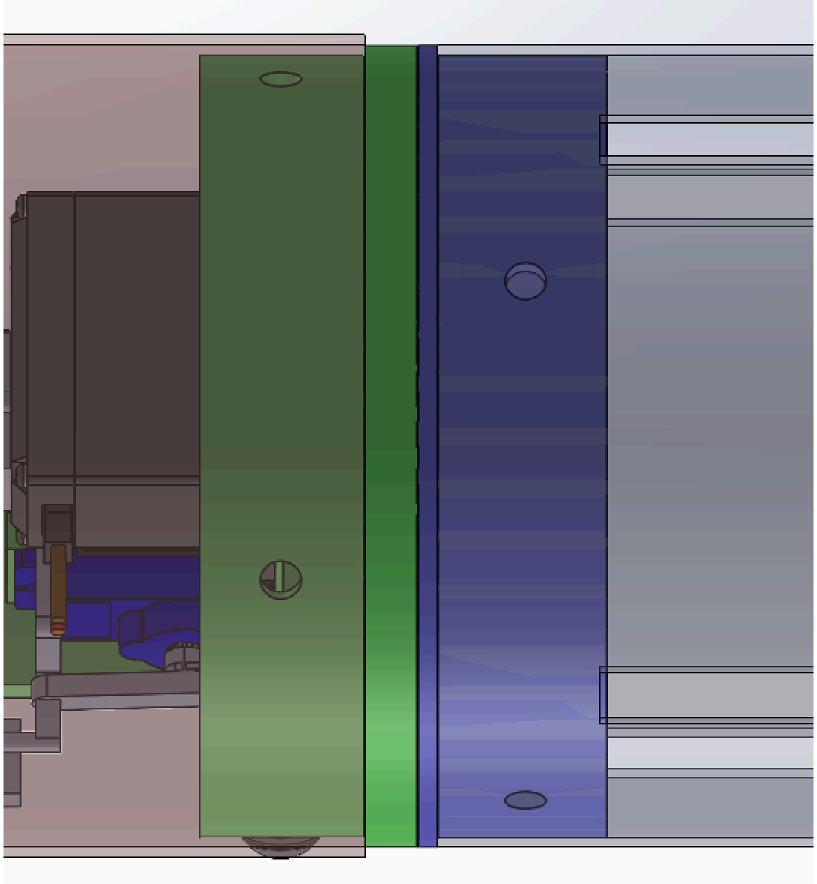


**Figure 4.13: Bearing connecting two sections of airframe**

Finally, the quick release acts as a link between the main parachute shroud lines and the eyebolt connected to the bulkhead. It must handle similar forces required of the eyebolt.

#### 4.1.2.4. Retention System

The payload retention system consists of the payload sled and the attachment points for all components not on the sled. All purely electrical components are located on the sled, including the battery and SDR, attached via zip ties, and the motherboard, attached via screws and inserts. In addition, the camera deployment, gimbal, and rotation mechanism are directly or indirectly linked to it. The sled itself is attached via heat-set inserts sunk into the sled. Figure 4.14 shows a view of the Electronics Sled with all attachment points highlighted.

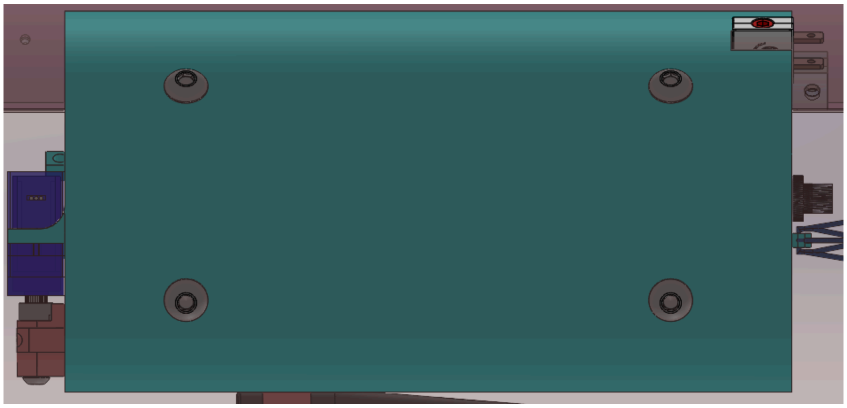


**Figure 4.14: Heat-set inserts sunk on sled**

The camera rotation mechanism will be retained during flight using a pin on the sled. Since the Camera Deployment system will deploy before the Camera Rotation system is actuated, the pin will only secure it in a stowed state.

The camera stabilization system has hard stops on it to limit its movement during flight. The movement allowed is small enough to not interfere with other components or to allow the system to vibrate significantly. See Figure 4.15

During flight, the rotating bearing will be held in place using the static torque capacity of the geared servo. This system also functions passively, due to the drag of the servo when unpowered. Both ends of the bearing will connect to the airframe via metal screws.

The Airframe Stabilization Mechanism is held in place via the base of the system attached via screws and nuts to the airframe. The legs themselves are attached via screws. These attachment points are highlighted in Figure 4.15 below.

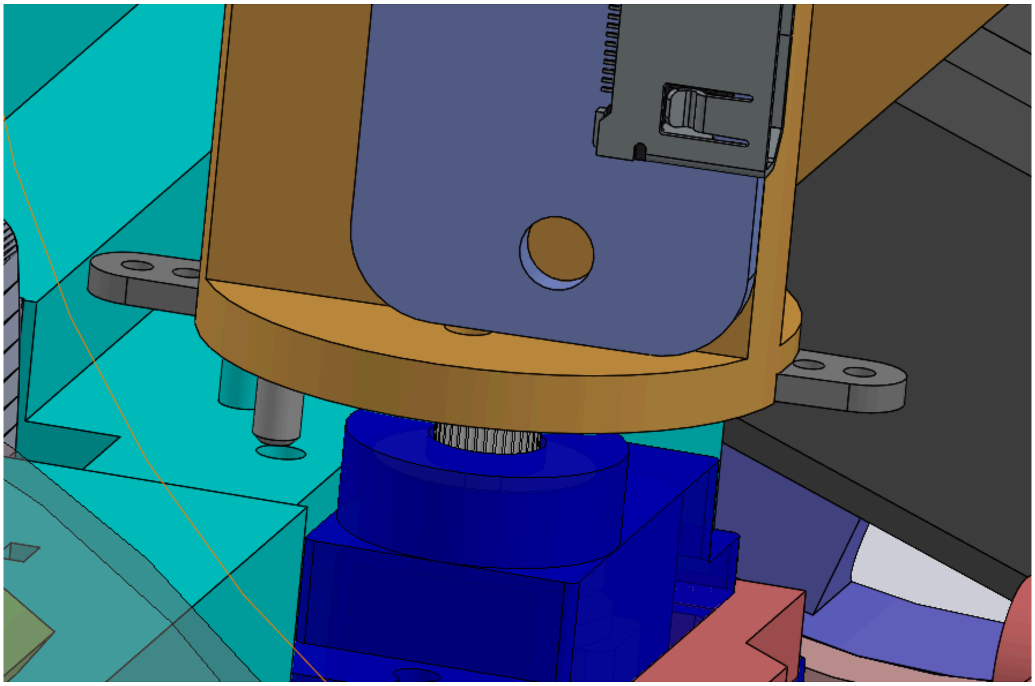


**Figure 4.15: Pin hole on sled to secure the camera**

### 4.1.3. Unique Aspects

One sentence description of each unique aspect (can just reference system sections under alternative design tables). Just here to give opinions on what we think is unique to draw attention to it

## 4.2. Design of Electrical Payload Equipment

The payload electronics consist of a custom-designed motherboard, of which has the single-board computer (SBC), IMU, altimeter, GPS module, and power supply that are either a daughter board or soldered on. Figure 4.16 below is the schematic for the motherboard. There are three hierarchical diagrams as part of the motherboard: the power supply, Figure 4.17; the high-current output control, Figure 4.19; and a CSI-to-HDMI converter, Figure 4.18. Finally, the external control signals, such as pulse width modulation (PWM) output, U.S.B., and digital input/output are described in Figure 4.20.Figure 4.21 shows how all the alternative payload software components work together.

### 4.2.1. Selected Alternatives

Tables 4.2.1, 4.2.2, and 4.2.3 describes and justifies the individual choices for system-level, software, and hardware designs.

**Table 4.2: Table of Selected System Choices**

| Component | Choice | Justification |
|---|---|---|
| APRS Antenna System | Deployed “Rubber Ducky” antenna | • Relatively easy to deploy<br>• Sufficient performance in testing<br>• Balance of mechanical complexity and RF performance |
| APRS Radio System | RTL-SDR | • Easy to use<br>• Widely available<br>• Prior team experience<br>• Extensive documentation and community support |
| APRS Decoder System | Dire Wolf | • Best performance in our testing<br>• Official Raspberry Pi Support<br>• Easy to integrate into payload software stack<br>• Easy to isolate program execution and reduce risk of payload software failure |
| Camera Filtering Library | OpenCV | • Cross-platform support<br>• Wide range of filters<br>• Prior team experience<br>• Extensive documentation and community support |
| Orientation Subsystem | Integrated Payload Computer | • Provides the information needed for the camera system to be deployed in the correct orientation. |

#### 4.2.1.1 Deployed “Rubber Ducky Antenna” (APRS Antenna System)

We chose the deployed “Rubber Ducky” antenna because of its compact package, its resonance on the 145MHz band. It is a well-balanced compromise based on radio and mechanical performance.

#### 4.2.1.2 RTL-SDR (APRS Radio System)

The RTL-SDR is a commercial-off-the-shelf SDR which makes it widely available and well documented. Based on our previous team experience with SDR’s it was easy to use and was part of our team’s previous history. It uses USB to send information to the host computer, which in this use case is the SBC. The SDR receives signals from the antenna through a coaxial cable to mitigate electrical noise disrupting the APRS transmissions.

#### 4.2.1.3 Dire Wolf (APRS Decoder System)

The payload uses Dire Wolf as an APRS Decoder System. Dire Wolf has a Keep It Simple, Stupid (KISS) interface commonly used for TNC applications making it a drop-in piece of software for decoding the RAFCO commands. We can then use KISS to communicate these commands to the rest of the system through our sensor daemon.

#### 4.2.1.4 OpenCV(Camera Filtering Library)

As per the competition rules, we must be able to take pictures and apply filters based on the RAFCO commands. OpenCV is a library that is able to both capture and process images programmatically and is easily accessible through several different language APIs. Several team members also have previous experience with this library.

#### 4.2.1.5 Integrated Payload Computer (Orientation Subsystem)

Using an integrated payload computer for part of the orientation subsystem was selected due to the design's simplicity and cost effectiveness. Our team has the most experience with a monolithic computer design where a single host computer controls a given system. While we could have used several microcontrollers for each specified system, we avoided this route due to the complexity of keeping the codebase for each system up-to-date.

**Table 4.3: Table of Selected Software Choices**

| Choice | Justification |
|---|---|
| RTL_FM | - Well supported by Dire Wolf and Raspberry Pi<br>- Sufficient performance in preliminary testing<br>- Very simple design |
| Dire Wolf | - A well documented and robust APRS decoder.<br>- Demonstrated to handle noise in data.<br>- Demonstrated to process APRS quickly and efficiently. |
| MQTT | - An industry standard for subscribing to different data streams.<br>- Used in IoT applications for sensors<br>- Enables different software components to be fully independent |
| RSMB | - Support for MQTT and MQTT-SN<br>- Robust MQTT-SN bridging support, enabling quality telemetry without reliance on the ground station |
| XBLink | - Allows IP communication over XBee<br>- Support for any internet protocol, including MQTT or MQTT-SN for data transfer, and SSH for debugging |

#### 4.2.2.1 RTL_FM

As stated in the table, RTL_FM is well supported for use with the RTL SDR, Dire Wolf, and Raspberry Pis. RTL_FM also performed satisfactorily with the rest of the system in our preliminary demonstrations for radio communications and was part of our preliminary APRS communications demonstration system.

#### 4.2.2.2 Dire Wolf

As explained in the previous section, Dire Wolf demonstrated that it was capable of handling APRS decoding well. We have used it extensively in preliminary testing and as part of our scale radio communications test.

#### 4.2.2.3 MQTT (Protocol)

MQTT is an industry standard publish-subscribe data protocol that has many use cases in IoT devices. For the payload's purposes, it manages every piece of data that must be communicated between subsystems including the APRS commands, vehicle orientation, and altitude. Figure DIAG_DATA best describes how data will be communicated between different portions of the payload.

#### 4.2.2.4 RSMB

RSMB is used as an implementation of MQTT as a data broker, so it handles all the data between subsystems. We chose an externally developed broker because we depend on the reliability of this portion of the payload subsystem.

#### 4.2.2.5 XBLink

XBLink is the data link connection for RSMB and the XBee transmitter to send telemetry data to our debugging ground station. XBlink does not affect anything in the rest of the payload. XBLink has been demonstrated for use in hobby projects for transmitting data from an MQTT broker through an XBee.

**Table 4.4: Table of Selected Electronics Hardware**

| Choice | Justification |
|---|---|
| RTL SDR | • Compact<br>• Commonly used, widely supported by existing software |
| Raspberry Pi Zero 2 W | • Appropriate compute power<br>• Wifi Interface for easy debugging<br>• CSI Camera interface<br>• I2C, SPI, and UART interfaces<br>• In stock<br>• Well documented |

| | |
|---|---|
| Custom PCB | ● Less spatial volume<br>● Built-to-specification<br>● Easier to manage design complexity than alternatives<br>● Lower mass budget compared to perma-proto board. |
| SAM-M8Q | ● Commonly used hobby GPS module. |
| TPS56424X | ● Part of TI's recommended design<br>● Compact design<br>● Inexpensive |
| MPL3115A2 | ● Previous experience<br>● Already in the team's stock |
| MPU-6050 | ● Experience using sensor before<br>● Commonly used<br>● Already in the team's stock |
| MCP3004 | ● Easy to source<br>● Low-cost |
| PCA9685 | ● Commonly used for this case<br>● Previous Team Experience |
| Mini HDMI to CSI Converter | ● Compact connector<br>● High-quality COTS cables available<br>● Both HDMI and CSI use 50-ohm impedance, so no impedance matching is needed<br>● Sufficient twisted pairs and individual signals for the entirely of the 22-pin CSI connector |
| XBee | ● Previous team experience<br>● Support in existing software<br>● Well documented |

#### 4.2.3.1 RTL SDR

The RTL-SDR acts as the RF frontend for the APRS radio system, taking the radio signals from the antenna and sampling them into a digital format that can be processed by the single board computer.

#### 4.2.3.2 Raspberry Pi Zero 2 W

The Raspberry Pi is the center of the payload, connecting to almost all other components. It uses a variety of interfaces including I2C, SPI, UART, CSI, and GPIO. It is also performant enough to run all of the payload's software.

#### 4.2.3.3 Custom PCB

Using a custom PCB greatly simplifies the assembly of the payload compared to using many breakout boards or a perf-board. It also comes with many other benefits including increased design flexibility for part selection and reduced size at a cost of additional design effort.

#### 4.2.3.4 SAM-M8Q

The SAM-M8Q is a compact, self-contained GPS module. It fulfills two roles: first, it synchronizes the time of the system to the true time to make log files easier to correlate with outside events. Secondly, along with the XBee telemetry system, it acts as a redundant secondary recovery location system in case the primary system fails. It connects to the raspberry pi using UART.

#### 4.2.3.5 TPS56424X

The TPS56424X is a buck converter chip that, along with a few passive components, can regulate the battery voltage down to 5V with high efficiency and little board space. The main reason we chose this chip was because of its excellent documentation, giving us the confidence to design our board around it even though we don't have much experience designing power supply circuits.

#### 4.2.3.6 MPU-6050

The MPU-6050 is a 6-axis accelerometer/gyroscope that the team has experience using. Its precision and range are sufficient for our usage.

#### 4.2.3.7 MCP3004

This is a commonly used ADC that is used for measuring the battery voltage. It's not flight critical, it's just used so that we can monitor the battery's voltage before and throughout flight. It connects to the raspberry pi using SPI.

#### 4.2.3.8 PCA9685

The PCA9685 is a I2C PWM/GPIO expander that allows us to control many PWM devices without using the raspberry pi's limited GPIO. It is used for controlling the servo motors and nichrome burn wire.

#### 4.2.3.9 Mini HDMI to CSI Converter

Due to the motion of the design of the camera deployment mechanism, the cable(s) connecting the raspberry pi to the camera must be relatively long, longer than any commonly available individual ribbon cable. This would require us to use multiple “adapters” to combine multiple cables, or search for super long cables. We were concerned about the signal integrity of such an unshielded, untwisted design given the high bandwidth requirements of CSI. In addition, ribbon cables are not designed to be repeatedly twisted or bent, both of which occur in the deployment and rotation of the camera. The cable is also fairly bulky, raising questions about how we would prevent the cable from tangling or kinking. For these reasons, we decided to design a custom adapter that would allow us to use a robust, round COTS cable. We decided to use Micro HDMI since it is commonly available, compact, and has sufficient twisted pairs and individual wires to carry all of the signals needed to interface in the camera. HDMI and CSI are very similar, both using shielded, twisted pairs with 50-ohm impedance, so using HDMI cables to carry CSI signals is a natural choice. There are similar commercial solutions available for converting the 15-pin connector to HDMI, but none for the 22 pin connector our raspberry pi and camera use.

#### 4.2.3.10 XBee

The XBee is the team’s telemetry radio to send data back from the rocket to the ground station. It uses the UART protocol and has supported software. It isn’t
Debugging, monitoring everything on the flight is going well.

### 4.2.4 Indicators

The payload has two types of indicators: visual and audio. The SBC has built-in visual indicators for power and activity. On the motherboard, we have a piezo buzzer for giving system-level alerts as to the health of the payload during integration and launch readiness procedures.

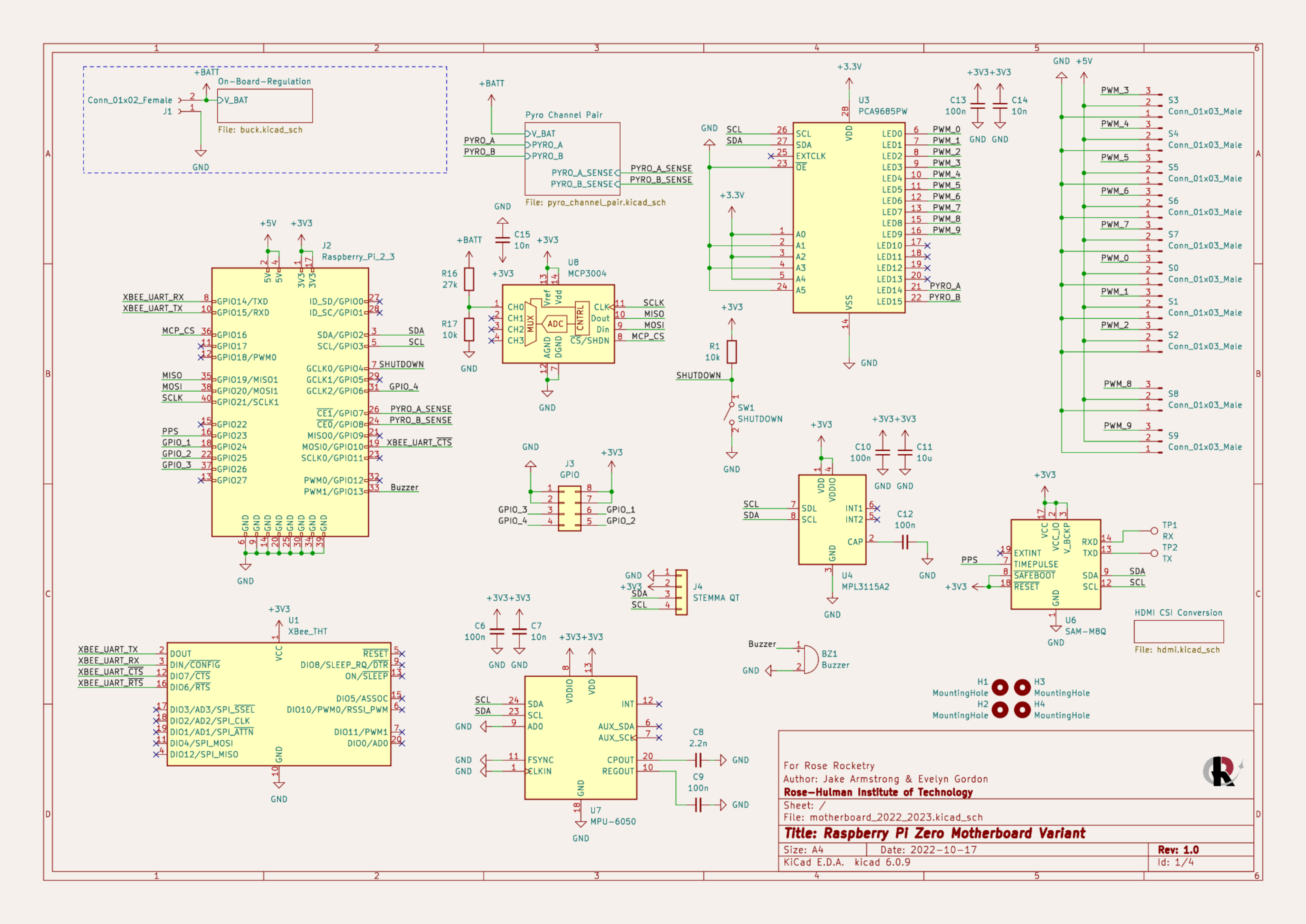


Figure 4.16: Schematic for the payload's motherboard.

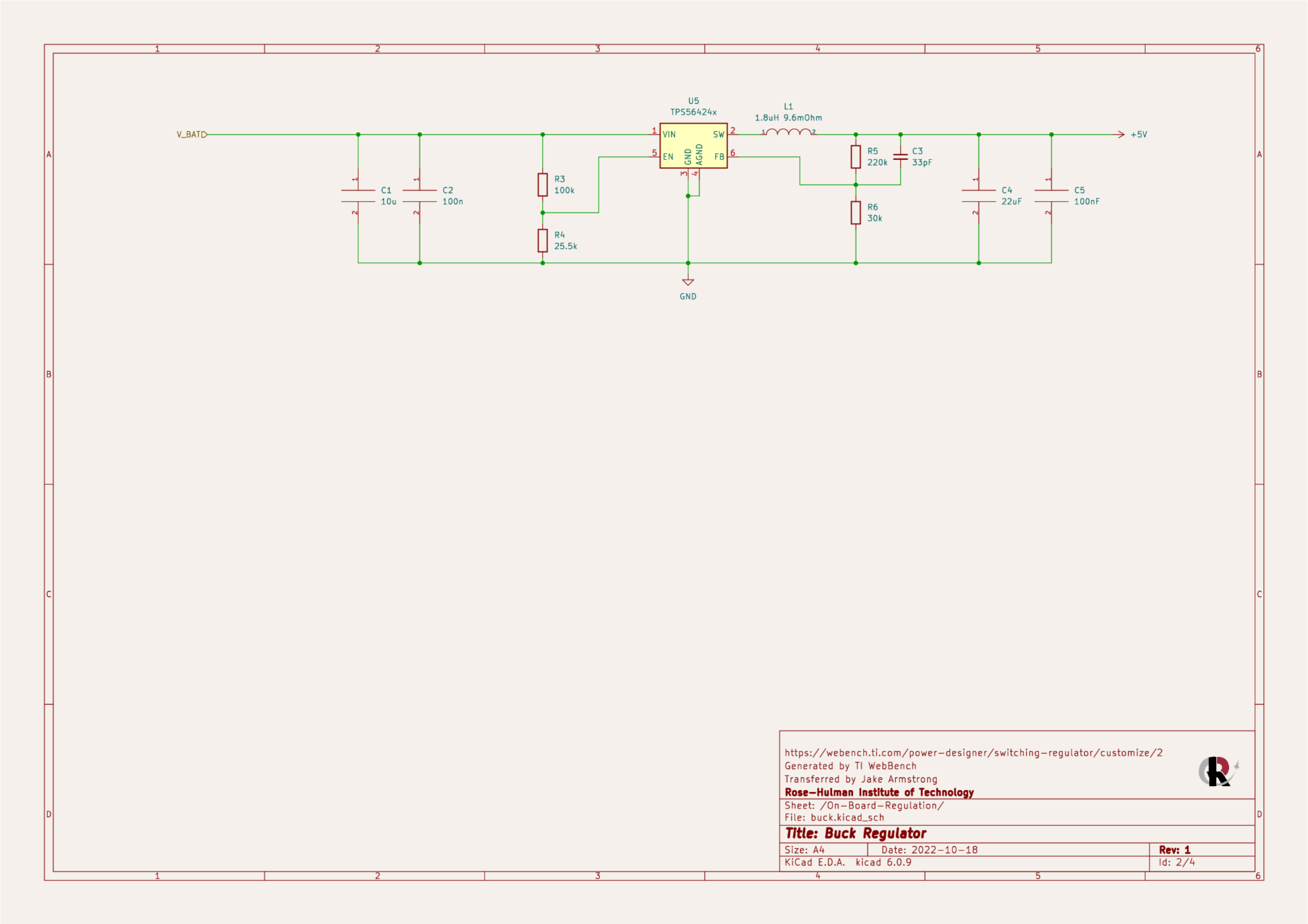


Figure 4.17: Electrical diagram for the Motherboard's power supply generated by TI WebBench.

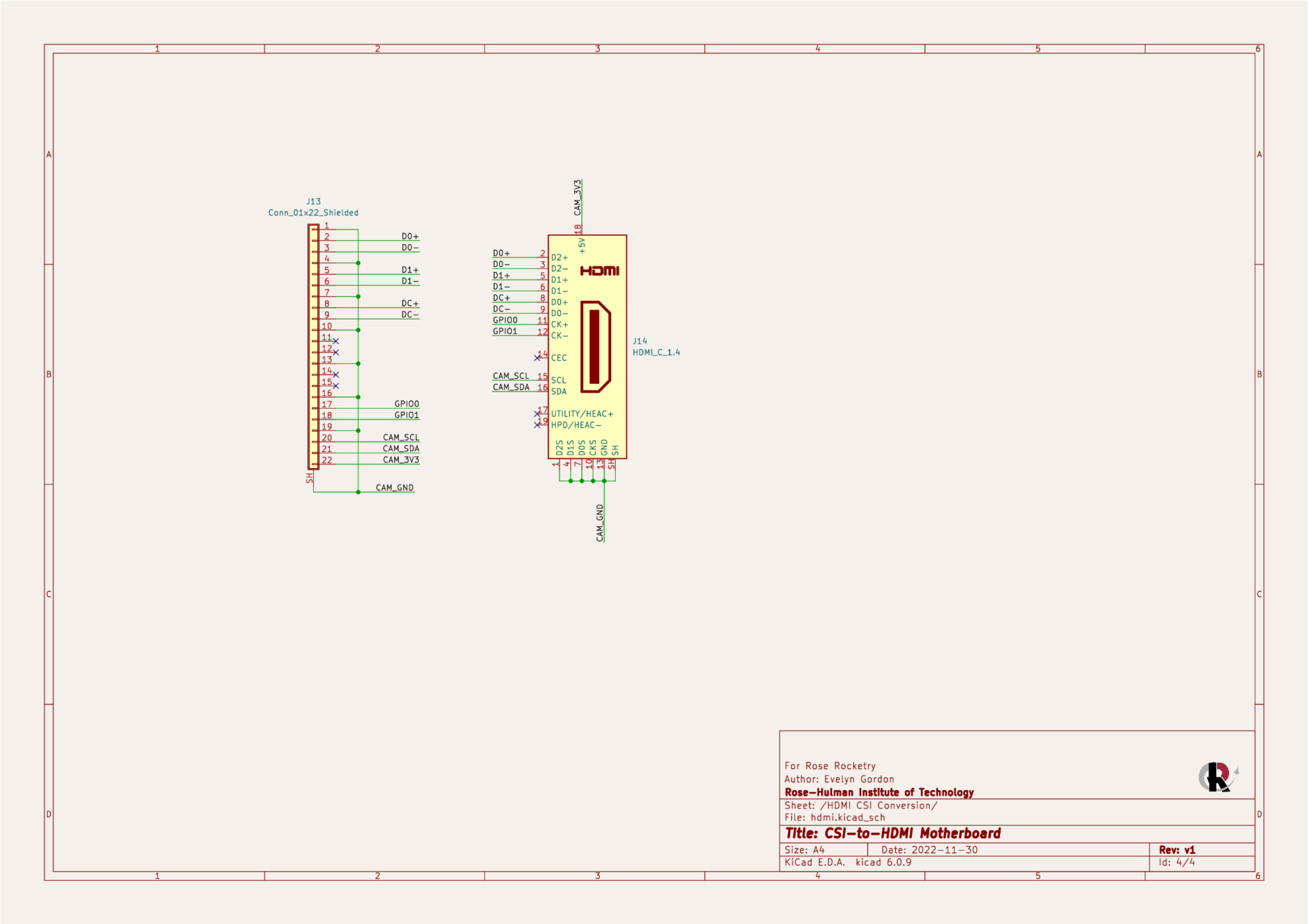


Figure 4.18: HDMI to CSI converter for data into the SBC from the motherboard.

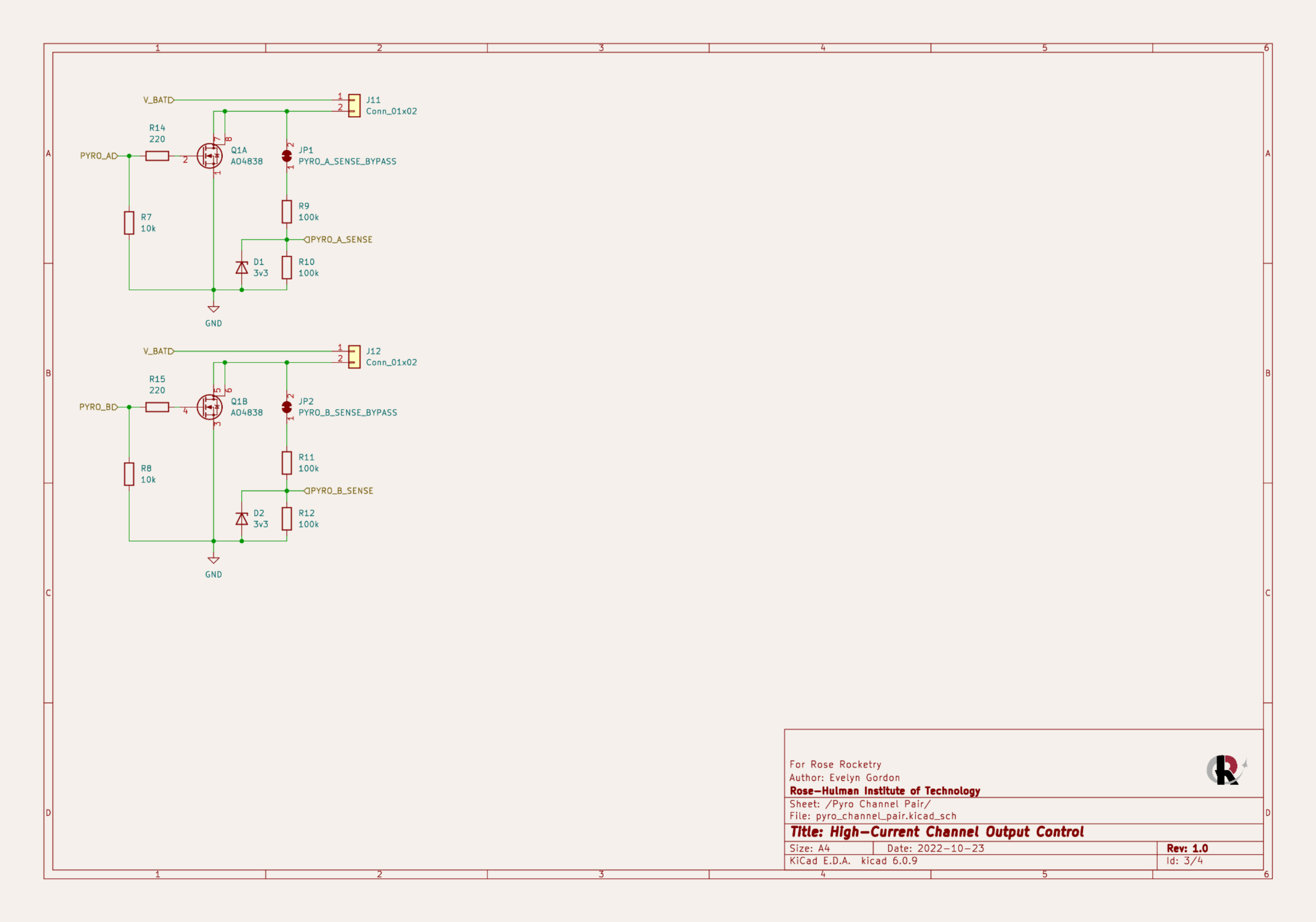


Figure 4.19: An electrical diagram for controlling the high-current output.

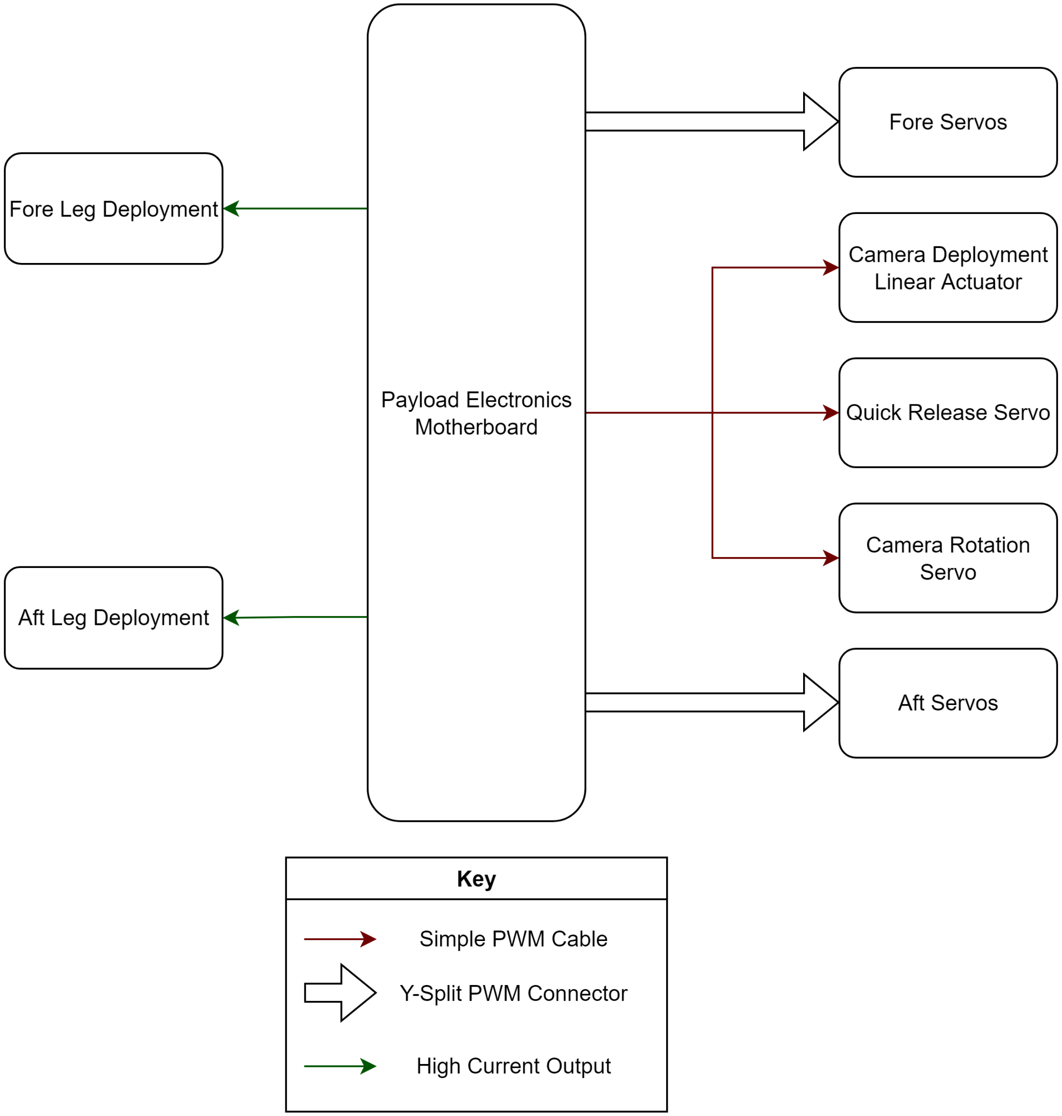


Figure 4.20: Wiring diagram for ECE payload

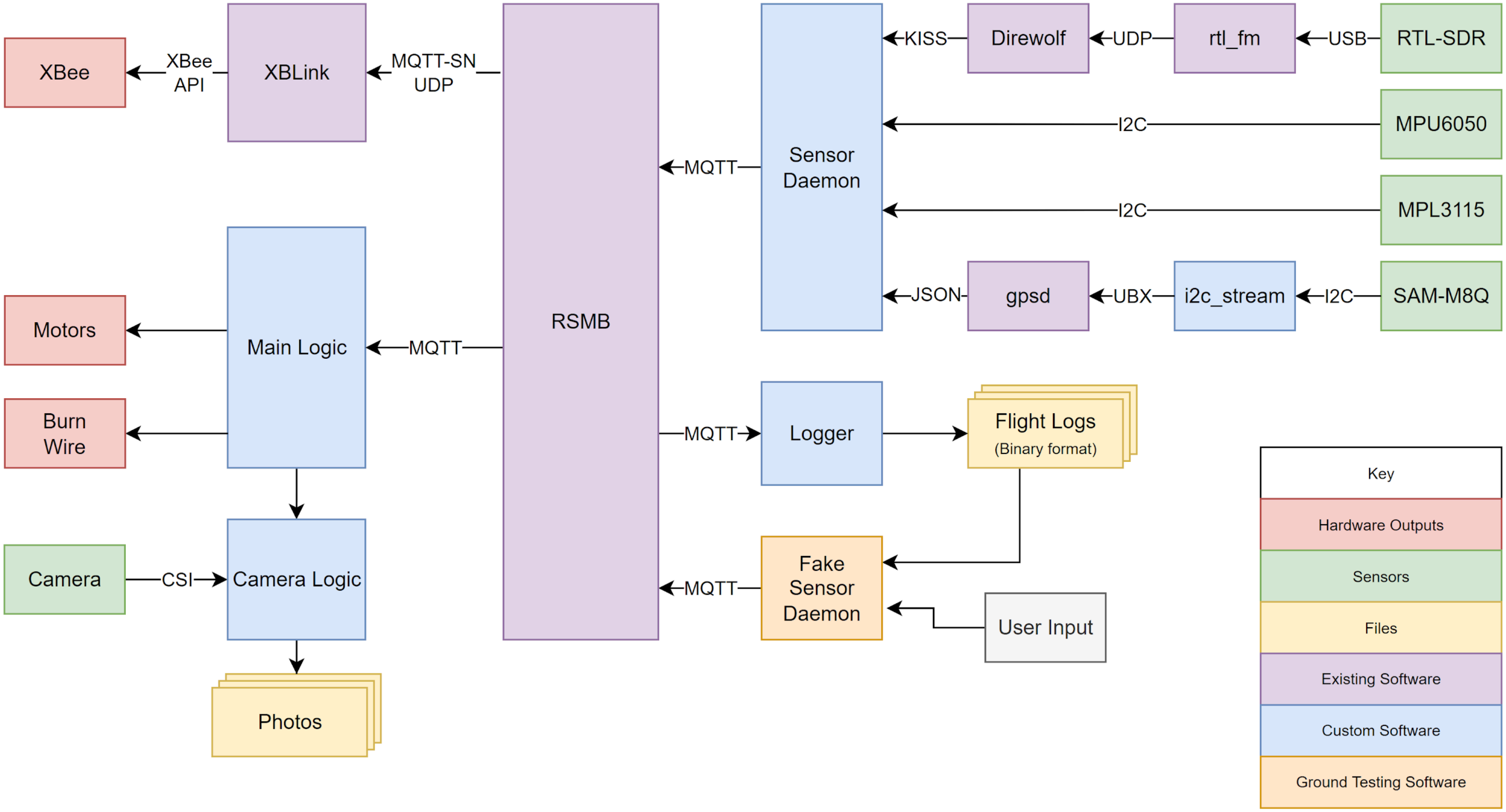


Figure 4.21: System diagram for ECE payload

## 4.3. System Integration

### 4.3.1. Integration of ECE and ME payload

The integration of the two systems in the payload system interact through control of electromechanical components like servos and power switching through the nichrome wire. When the electronics of the payload are completed, the electronics team will then deliver to the mechanical team, who can then determine which IO ports will be designated to the electro-mechanical systems. The mechanical team will design and manufacture a sled that will mount the PCB to the vehicle and rest of the payload.

### 4.3.2. Integration of ECE and Vehicle

The vehicle will be outfitted with a transmitter (an eggtimer) for recovery purposes. In order to be sure the transmitter will not interfere with the payload, we used the RTL-SDR which has built-in shielding. The rest of the signals on the payload will not be affected by the transmitter.

### 4.3.3. Integration of ME and Vehicle

The payload deployment mechanism, which includes the leg deployment, will be encased within the payload portion of the vehicle. Four small symmetric cuts were made to the airframe to allow for the legs to deploy out of the vehicle frame.

# 5. Safety

Safety Officer Designation: Ben Graham

## 5.1. Launch Checklists

For the purposes of document readability, launch procedures are included in Appendix A in section 7.

## 5.2. Personnel Hazard Analysis

The goal of this section is to highlight hazards to personnel, determine mitigations for these hazards, and develop a plan for implementing and verifying these mitigations. A hazard is an event or object which can cause injury (human impact), loss (equipment impact), or mission delay (mission impact). These are categorized by the type of impact and the probability described in Tables 5.1 and 5.2. These tables also include initial mitigations. These mitigations will be evaluated in detail and finalized for the FRR. Note that the checklists listed are created as part of the mitigations. They are to be implemented as the mitigation according to the wording of the mitigation.

**Table 5.1: Definitions of severity of hazards**

| Category | Value | Human Impact | Equipment Impact | Mission Impact |
|---|---|---|---|---|
| Negligible | 1 | Minor or none | Minor or none | No disruption |
| Marginal | 2 | Minor injury | Minor damage | Proceed with caution |
| Moderate | 3 | Moderate injury | Repairable equipment failure | Flight delayed until event resolved |
| Critical | 4 | Serious injury | Partially irreparable equipment failure | Flight does not proceed until system removed |
| Catastrophic | 5 | Life threatening or debilitating injuries | Failure resulting in total loss of system or equipment | Flight canceled or destroyed |

**Table 5.2: Mapped Risk Assessment Matrix**

| Category | Negligible | Marginal | Moderate | Critical | Catastrophic |
|---|---|---|---|---|---|
| Improbable | 1 | 2 | 3 | 4 | 5 |
| Unlikely | 2 | 4 | 6 | 8 | 10 |
| Possible | 3 | 6 | 9 | 12 | 15 |
| Likely | 4 | 8 | 12 | 16 | 20 |
| Probable | 5 | 10 | 15 | 20 | 25 |

**Table 5.3: Hazards and preliminary mitigations**

| Hazard | Causes | Effects | Mitigations | Preliminary Verifications |
|---|---|---|---|---|
| Fire in workspace | Mishandling of energetics and motors | -Severe burns<br>-Loss of part or project | Energetics and motors are stored in a locked flammable cabinet and only handled with the supervision of the RHIT Office of Public Safety and Team Safety Officer. | RHIT Office of Public Safety shall maintain custody of the key to the flammable cabinet at all times and will be contacted by the Team Safety Officer when these materials are needed. |
|  | Improper wiring | -Loss of part or project<br>-injury to personnel | Wiring shall be double-checked before powering on any electronics. | The safety officer shall inspect all components before flight and may request further verification for any component deemed suspect. |
| Fire on the launch field | -Motor misfire | -Loss of part or all of vehicle | -Adhere to NAR guidelines for minimum distance | The safety officer will inspect the behavior of all members on the launch field to ensure RSO |

| | | | | |
|---|---|---|---|---|
| | -Accidental black powder ignition | -Injury to personnel ranging from minor burns | -Follow all RSO directions | directions and NAR guidelines are followed. |
| Airborne particle exposure | -Sanding dust<br>-Metal shavings<br>-Paint<br>-Aerosols<br>-Machining composites | -Skin laceration or irritation<br>-Eye damage<br>-Respiratory distress | -Use dust booths when engaging in activities which generate dust<br>-Use appropriate PPE (safety glasses, dust masks, gloves, etc.) | All members must paint and sand in the dedicated booths in the BIC. All sanding and painting materials are located there. |
| Pinching | -Rapid spring movement | -Temporary pain<br>-Bleeding | -Mark actuation areas with bright colors for easy identification | The safety officer shall maintain a list of all actuation areas and verify that they are marked |
| | -Rapid assembly of airframe sections | | -Deburr all part edges to minimize risk of laceration | The safety officer will be present at all build sessions |
| Parachute Deployment failure | -Failure to arm altimeters<br>-Parachute packed incorrectly | -Severe injury or damage to person or object struck<br>-Loss of vehicle | -Following proper procedures to rig recovery system<br>-Follow all NAR safety guidelines for safe distances | The checklists in Appendix A, Sections 4-6 will be used during flight and managed by the VP during launch day. |
| Improper use of power tools | -Negligence<br>-Improper Power Tool Usage<br>-Lack of Training | -Mild to severe injury to appendages or person | -Team members shall be properly trained to use power tools<br>-Team members must maintain a safe distance from all powered machinery | -All members shall attend a mandatory university training course before using tools, either inside or outside the workspace<br>-PPE requirements for safe materials fabrication shall be posted in the workspace |

| | | | | |
|---|---|---|---|---|
| | | | -Wear proper PPE, including safety glasses, long pants, and close-toed shoes | |
| Chemical Irritation | -Improper handling of epoxy and its resulting fumes | -Local skin irritation | -Utilize proper Personal Protective Equipment, including long pants, closed-toed shoes, safety glasses, and gloves | -PPE requirements for materials used shall be posted in the workspace<br>-Members shall be trained on safe use of epoxy |
| Improper use of Burn wire | -Carelesshandling of burn wire | -Burns<br>-Lacerations | -Wear proper PPE, including safety glasses, long pants, and close-toed shoes<br>-Use manufacturer recommendations for how to handle burn wire | -PPE requirements for materials used shall be posted in the workspace |
| Battery electrical fire | -Improper handling of battery<br>-Short-circuit wiring | -Burns to Personnel<br>-Destruction of components | -Batteries shall be kept in a fireproof container when not in use<br>-The safety officer shall inspect batteries for physical integrity before and after each launch<br>-Team members shall supervise batteries while charging | The team has a fireproof container where all batteries are stored. Appendix A lists procedures |

| | | | | |
|---|---|---|---|---|
| | | | -Inspect wiring before installing battery | |
| Tripping | -Blocked walkways<br>-Cluttered workspace | -Minor Injury<br>-Broken bones<br>-Team activities halted | -Adhere to 5S principles | The team is required to participate in 5S principles to learn about proper organization and workspace usage habits. The BIC hosts external reviews to rate our adherence. |
| Splinters from composite materials | -Handling of composites machining debris<br>-Handling of freshly cut composite stock | -Laceration or skin irritation | -Wear work gloves when handling non-deburred parts<br>-Paint or otherwise condition surfaces for flight-ready vehicles | Safety Handling Procedures demonstrates steps to complete this verification. These checklists will be reviewed as a team before manufacturing and posted in the workspace. |
| Activated Energetics | -Members working with open flame near energetics<br>-Accidental energization of igniter while handling | -Severe burns<br>-Kinetic impact with personnel<br>-Destruction of vehicle and/or work environment | -All energetics shall be stored in a fireproof cabinet with controlled access.<br>-Energetics shall not be removed from storage in the presence of open flame.<br>-Igniters shall be installed only when vertical on pad | Checklists in Appendix B will be used during flight preparation and managed by the VP during launch day. |
| 120V Electrocution | -Misuse of power extension cables | -Severe Burns<br>-Death | -Proper use of electrical equipment | -All power tools are inspected prior to use for damage to the wires |

| | | | | |
|---|---|---|---|---|
| | -Misuse of power connection<br>-Exposed mains voltage on manufacturing equipment such as 3D printers | | -Maintenance of manufacturing equipment via periodic inspections to ensure sustained reliability | -All accessible power is run through voltage-protected power extension cables. |
| Epoxy Allergy | -Repeated skin exposure to epoxy | -Sensitivity, rash, burn around epoxy | -Correct PPE usage, limit exposure to epoxy | The Safety Officer shall instruct all members on the proper use and handling of epoxy before manufacturing using a presentation and examples. |
| Soldering burns | -Misuse of tools<br>-Carelessness | -Minor Burns | -Properly train members on use of a soldering iron | Only members who are trained in soldering are given access to soldering equipment. |
| Premature firing of separation charges | -Electronics misfire<br>-Incorrect altimeter reading<br>-Accidental ignition of black powder<br>-Faulty e-matches | -Severe injury<br>-Severe damage to vehicle and systems | -Design fully dissimilarly redundant systems<br>-Test recovery systems and altimeters | Checklist in Appendix A section 4 will be used during flight and managed by the VP during launch day. |
| Black Powder accidental ignition | -Heat near black powder<br>-Black powder spillage | - Burns<br>- Minor injury | -All energetics shall be stored in a fireproof cabinet with controlled access | See Appendix E for BP handling and preparation procedure. The procedure will be used during flight |

| | | | | |
|---|---|---|---|---|
| | | | -Black Powder should only be handled by the team mentor<br>-Proper PPE and caution should be used around black powder | preparation and managed by the VP during launch day. |
| Personal Injury from Terrain | -Uneven ground from clods of dirt, ditches, or puddles | -Sprained or broken ankles or hands | -Traveling in groups<br>-Communication of seen hazards<br>-Awareness of surroundings | Inform all members recovering flight vehicles of the mitigations and risks. Appendix B Section 2 assigns roles to ensure people traveling in groups. The VP is in charge of ensuring people are assigned to these roles during launch day. |
| Untrained personnel in workspace | -Students allowing friends into restricted areas<br>-Campus tours pass near work areas | -Chemical irritations<br>-Injury due to power tools<br>-Burns<br>-Damage to vehicle | -Locking up irritants after use<br>-Putting tools away after use<br>-Delineate workspace via tape line to discourage unauthorized entry into work area | The safety officer enforces a clean workspace by investigation 3 times a week. In addition, the BIC hosts organization audits every other month. |

**Table 5.4: Risk assessment of all hazards in 7.8**

| Identified Hazard | Risk (Probability/Severity/Total) | | |
|---|---|---|---|
| Parachute Deployment failure | 4 | 5 | 20 |
| Improper use of power tools | 3 | 4 | 12 |
| Fire in workspace | 2 | 5 | 10 |
| Fire on the launch field | 2 | 4 | 8 |
| Airborne particle exposure | 2 | 4 | 8 |
| Tripping | 4 | 2 | 8 |
| Premature firing of separation charges | 2 | 4 | 8 |
| Personal Injury from Terrain | 4 | 2 | 8 |
| Pinching | 3 | 2 | 6 |
| Improper use of Burn wire | 2 | 3 | 6 |
| Epoxy Allergy | 2 | 3 | 6 |
| Black Powder accidental ignition | 2 | 3 | 6 |
| Untrained personnel in workspace | 2 | 3 | 6 |
| Activated Energetics | 1 | 5 | 5 |
| 120V Electrocution | 1 | 5 | 5 |
| Chemical Irritation | 2 | 2 | 4 |

| | | | |
|---|---|---|---|
| Compressed air injuries | 2 | 2 | 4or |
| Splinters from composite materials | 2 | 2 | 4 |
| Battery electrical fire | 1 | 3 | 3 |
| Soldering burns | 3 | 1 | 3 |

## 5.3. Failure Modes and Effects

In contrast to Section 7.2, Section 7.3 reports failure modes from one of the systems. These are hazards that specifically impact the project due to some source within a main system.

### 5.3.1. Vehicle

**Table 5.5: Vehicle Failure Modes and Effect Analysis**

| Hazard | Causes | Effects | Mitigations | Preliminary Verifications |
|---|---|---|---|---|
| Failure of recovery system deployment | -Avionics failure<br>-Recovery entanglement<br>-Battery depletion<br>-Broken screw switches | -Severe damage to or loss of vehicle<br>Risk to personnel and equipment on ground | -Fully dissimilar redundancy for both drogue and main deployment<br>-A strictly-delineated process will be developed for arming the vehicle safely during launch. | Recovery avionic section 3.3.9 |
| Motor ignition failure | -Ground equipment failure<br>-Igniter failure | -Delay in launch of vehicle | -Follow consistent procedures for igniter installation<br>-Have spare igniters available at all launches | Appendix B Sections points 8 and 9 are in place to ensure the mitigation is implemented. The checklists are verified during the VP during launch day. |

| | | | | |
|---|---|---|---|---|
| Failure of fin joints | -Weak epoxy bond<br>-Disturbance of epoxy while curing | -Severe damage to or loss of vehicle<br>-Risk to personnel and bystanders due to unstable flight | -Follow consistent and safe procedures for use of epoxy<br>-Use fin jig to hold fins stable while epoxy sets | Safety and Handling 5.2 for proper procedures for use of epoxy. The Safety Officer oversees all epoxy use and enforces following of procedures. |
| Failure of airframe joints | - Use of airframe materials lacking adequate strength<br>-Improper simulation | -Rapid unscheduled disassembly of launch vehicle | - Use COTS materials and equipment wherever possible.<br>- Use simulation techniques to model the stresses and strength of nonstandard airframe joints. | See section 3.1.3 for dimensional CAD drawings. |
| Tangling of parachute | -Improper packing of parachute<br>-Improperly implemented recovery rigging | -Severe damage to or loss of vehicle<br>-Risk to personnel and equipment on ground | -Ground-test all packing techniques used in flight<br>-Minimize unnecessary components attached to recovery system<br>-Follow consistent procedures in recovery preparation | See Appendix D for proper parachute folding techniques. These techniques are followed during every launch or ground test as verified by the VP. There are no unnecessary components in the design that would be a candidate for tangling. |
| Loss of aerodynamic stability during flight | -Errors in simulation<br>-Incorrect weight balance<br>-Damag e to control surfaces<br>-High winds | -Incorrect trajectory<br>-Payload or vehicle damage to to impact or | -Inspect vehicle prior to launch to ensure weight is balanced<br>- Inspect components during construction to verify mass budgets<br>-Perform test flights with accurate weight distribution | See Appendix A for checklist inspection guidelines. These checklists will be implemented and verified by the VP during launch day. |

| | | | | |
|---|---|---|---|---|
| Failure of airframe structure | -Improper motor class for frame<br>- Poorly-designed airframe components<br>-Inaccurate simulation<br>-Damage during construction | -Loss of vehicle section(s)<br>-Loss of components within damaged selection(s)<br>- Injury to personnel or bystanders | -Inspect vehicle prior to launch to ensure structural integrity<br>-Perform mechanical testing to ensure custom components are of sufficient strength.<br>-Cross-check simulations to manufacturer specifications | See Bearing Test in 9.1.1.7 and custom eye-bolt test 6.1.1.2 for plans for ensuring the components have sufficient strength. The test results will be given in the FRR. |
| Early detection of payload landing | -Sensor failure<br>-Software failure<br>-Improper programming | -Violating of NASA guidelines<br>-Damage to deployed payload on impact<br>-Failure to complete mission | -Perform software in the loop and hardware in the loop testing<br>-Use different, redundant sensors to determining landing | See section 6.1.2.4 for testing of the orientation sensor. Results will be given in the FRR. |
| Shear pin fails to shear | -Incorrect calculation of shear pin strength or black powder amount | -Vehicle segment(s) fail to separate<br>-Loss or severe damage to vehicle on impact<br>-Danger to personnel and property | -Ground test separation systems<br>-Perform shear pin calculations | Calculations for shear pins are shown in section 3.3.10.1. These calculations inform our design of the recovery separation systems. |
| Excessive Vehicle Drift | -Early deployment of main parachute<br>-Improper or inaccurate simulation | -Failure to meet NASA requirements | -Use redundant and dissimilar simulation techniques to assess mission performance<br>-Test full-scale vehicle performance with adequate time allotted for design adjustment and retest | See Mission Performance Predictions for predicted drift. Tests will be in the form of additional subscale tests and the VDF. |

**Table 5.6: Vehicle failure modes risk assessment**

| Identified Hazard | Risk (Probability/Severity/Total) | | |
|---|---|---|---|
| Failure of recovery system deployment | 3 | 5 | 15 |
| Shear pin fails to shear | 3 | 5 | 15 |
| Early detection of payload landing | 3 | 4 | 12 |
| Tangling of parachute | 3 | 3 | 9 |
| Excessive Vehicle Drift | 3 | 3 | 9 |
| Loss of aerodynamic stability during flight | 2 | 4 | 8 |
| Motor ignition failure | 1 | 5 | 5 |
| Failure of fin joints | 1 | 5 | 5 |
| Failure of airframe joints | 1 | 5 | 5 |
| Failure of airframe structure | 1 | 5 | 5 |

### 5.3.2. Payload

**Table 5.7: Payload Failure Modes and Effect Analysis**

| Hazard | Causes | Effects | Preliminary Mitigations | Preliminary Verification |
|---|---|---|---|---|
| Electrical Short | -Human Error<br>-In-flight error/movement | -Loss of power to electronics<br>-Electrical Fire | -Soldering shall be performed by experienced members<br>- Solder joints will be inspected for integrity<br>-All electronics will be ground-tested for functionality | See checklist Appendix A Section 1.1 for procedure for inspection of solder joints. |
| Short Circuit on Battery | -User unaware of hardware design<br>-Mishandling of batteries or charger<br>-Plugging in a battery backwards | -Failure resulting in total loss of system or equipment<br>-Flight canceled or destroyed | -Label polarity of the battery connector (if not present)<br>-Only use keyed connectors<br>-Check polarity before connecting | Checklist Appendix A Section 1.2 lists a procedure to check battery polarity. All checklists are verified by the VP. All battery designs use XT-30s or XT-60s which only connect in the correct polarity. |
| Flight Computer Resource Exhaustion | -CPU overloading<br>-Memory swapping<br>-Lack of disk space | -Software crash or freeze<br>-Inability to process incoming signals or images | -Measure CPU, memory, and disk usage while testing to ensure proper headroom<br>-Use memory-safe languages when feasible | Section 6.1.2.8 describes testing for resource exhaustion. Results from the test will be present in the FRR. |
| Software crash or freeze | -Bug in software<br>-Temporary hardware | -Failure to perform payload tasks | -Perform ground-testing of software prior to launch | Test Plan 6.1.2.9 describes the procedure for ensuring payload |

| | | | | |
|---|---|---|---|---|
| | disconnect leading to software freeze | | using both simulated and real-world inputs<br>-Use proper exception handling<br>-Use a system of watchdog timers to detect and restart failed units | functionality during vehicle edge-cases to test coded exception handling and watchdog timers. The results of this test will be present in the FRR. |
| RF signal received is too weak | -Insufficient antenna gain<br>-Bad antenna connection<br>-Interference with signal from terrain or launch vehicle parts | -Unable to decode APRS<br>-Failure of payload mission<br>-Poor competition performance | -Antenna placement should be near top of launch vehicle to limit other electronic signal interference<br>-Test antenna for data rate and packet loss | See section 4.1.1.4 for antenna placement outside the airframe and, see 6.1.2.2 for the test to verify data rate and packet loss. The test results will be included with the FRR. |
| Gimbal Failure | -Breakage of supports<br>-Breakage of gimbal | -Camera obscured by supports<br>-Camera falls off the gimbal<br>-Camera skew instead of horizontal view | -Provide enough support and gimbal material to prevent breakage | See section 4.1.2.4 for gimbal retention during flight |
| Camera rotational failure | -Servo failure<br>-Disconnected wires<br>-Breakage of servo Supports | -Camera Rotation does not function<br>-Camera unable to deploy | -Provide enough support material to prevent breakage<br>-Make sure servo wires remain connected<br>-Make sure servo supports are connected properly | Appendix A Section 2.1 details checks for full range of motion and proper wire connections. All checklists are managed and verified by the VP during launch preparation. |

| | | | | |
|---|---|---|---|---|
| Electrical Connection Broken | -Loosely fitting connectors slipping<br>-G-Forces pulling wire off | -Actuation of servos may not occur<br>-Power may not be delivered to electronics | -Secure wires using one of the following: hot glue, bundling, or clamp<br>-Check all connections before integration | All wired connections will be secured with hot glue after testing, see checklist Appendix A Section 1.1 for inspection |
| Failure of springed hinge deployment | -Servo release mechanism not activating<br>-Disconnected wires<br>-Improper payload assembly | -Camera would not be able to deploy<br>-Potential damage to camera | -Proper and extensive testing prior to flight<br>-Preflight checks of wiring and range of motion | Appendix A Section 2.1 details checks for full range of motion and proper wire connections. All checklists are managed and verified by the VP. |
| Damage to rotation bearings | -Stress of launch and flight<br>-Improper simulation<br>-Misuse of the vehicle prior to flight | -Airframe could not rotate leading to no camera deployment<br>-Airframe breaks in two during any part during launch | -Proper handling and caretaking of the launch vehicle<br>-Bearing testing under various loads | Bearing Stress Test in 6.1.2.11 and 6.1.2.14 show test procedures to ensure the breaking can take unpredictable launch loads. |
| Burn wire failure | -Electrical failure<br>-Incorrect rigging<br>-Not enough heat to burn nylon wire | -Failure of leg deployment<br>-Burning of other components in the payload | -Proper handling and caretaking of the launch vehicle<br>-Proper wiring | See Nichrome Wire Testing in Section 6.1.2.11 for procedures to test proper rigging and power through the wire. |
| Servo motor failure | -Backwards wiring<br>-Higher-than-rated voltage across wiring | -Camera deployment will be unsuccessful | -Testing of the servo motor prior to flight | See checklist in Appendix A Section 2.1 for inspection procedure. All checklists are managed and verified by the VP. |
| Camera deployment failure | -Part breaks under load from launch, flight or landing | -Camera deployment unsuccessful | -Properly secure lift for launch<br>-Constrain properly | See checklist in Appendix A Section 2.1 for inspection procedure. All |

| | | | | |
|---|---|---|---|---|
| | -Pin comes loose | | -Inspect before flight | checklists are managed and verified by the VP. The lift is constrained to the sled and using the servo powered during flight. |
| Stability leg deployment malfunction | -Incorrect wiring of fishing line and nichrome wire<br>-Binding between parts of mechanism<br>-Torsion springs are not strong enough | -Payload will lack ability to effectively self-right | -Assemble legs to reduce friction and binding points<br>-Design legs to reduce binding points<br>-Test legs in adverse conditions to confirm ruggedness | See leg support test in Section 6.1.2.12. The test ensures the legs can lift the weight of the payload. The results of the test will be reported in FRR. |

**Table 5.8: Payload failure modes risk assessment**

| Identified Hazard | Risk (Probability/Severity/Total) | | |
|---|---|---|---|
| Damage to rotation bearings | 3 | 5 | 15 |
| Electrical Short | 3 | 4 | 12 |
| Software crash or freeze | 3 | 4 | 12 |
| RF signal received is too weak | 2 | 6 | 12 |
| Failure of springed hinge deployment | 3 | 4 | 12 |
| Camera Deployment failure | 3 | 4 | 12 |
| Camera rotational failure | 3 | 3 | 9 |
| Electrical Connection Broken | 3 | 3 | 9 |
| Short Circuit on Battery | 2 | 4 | 8 |
| Gimbal Failure | 3 | 2 | 6 |
| Burn wire failure | 2 | 3 | 6 |
| Servo motor failure | 2 | 3 | 6 |
| Stability leg deployment malfunction | 2 | 3 | 6 |
| Flight Computer Resource Exhaustion | 1 | 5 | 5 |

### 5.3.3. Payload Integration

**Table 5.9: Payload Integration Failure Modes and Effect Analysis**

| Hazard | Causes | Effects | Mitigations | Preliminary Verification |
|---|---|---|---|---|
| Leg mechanism damage | -Spring lock mechanism deploys unexpectedly during flight<br>-Spring lock mechanisms are unable to deploy | -Damage to and possible failure of legs<br>-Failure of camera to orient upwards | -Mechanical and audio feedback for when payload legs are properly stowed | ME Payload Preparation Checklist Section 2.2 |
| Failure of screws | -Improper simulation<br>-Failure of materials | -Partial or total loss of the vehicle | –Testing of materials<br>-Redundant simulation | Testing during VDF |
| Failure of bulkhead | -Improper simulation<br>-Improper manufacturing or testing | -Partial or total loss of the vehicle | -Testing<br>-Redundant simulation | See Vehicle section 3.1.6 |

**Table 5.10: Payload failure modes risk assessment**

| Identified Hazard | Risk (Probability/Severity/Total) | | |
|---|---|---|---|
| Leg mechanism injury | 2 | 3 | 6 |
| Failure of screws | 2 | 5 | 10 |
| Failure of bulkhead | 2 | 5 | 10 |

### 5.3.4. Launch Support Equipment

**Table 5.11: Launch Support Failure Modes and Effect Analysis**

| Hazard | Causes | Effects | Mitigations | Preliminary Verification |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Launch pad tipping or flexure | -Insufficient rail size<br>-Insufficient pad counterweight<br>-Pad placed on unsafe ground<br>-Pad not secure | -Reduced margin of stability due to low launch speed<br>-Reduced altitude due to launch angle<br>-Increased downrange distance | -Inspect pad before launch<br>-Ensure ground around pad is firm before mounting vehicle<br>-"Shake test" vehicle on pad to ensure sufficient strength with installed rail | See checklist in Appendix B Section 1 for written mitigations. VP will manage and enforce all checklists during launch preparation |
| Ignition Control Failure | -Poor wiring to ignition control<br>-Misinput to launch control | -Early or late motor ignition<br>-Failure to ignite motor | -Check appropriate and accessible wiring | See point 14 in checklist in Appendix B Section 1 for written mitigations. VP will manage and enforce all checklists during launch preparation |

**Table 5.12: Launch Support failure mode risk assessment**

| Identified Hazard | Risk (Probability/Severity/Total) | | |
|---|---|---|---|
| Ignition Control Failure | 3 | 3 | 9 |
| Launch pad tipping or flexure | 2 | 3 | 6 |

### 5.3.5. Launch Operations

**Table 5.13: Launch Operations Failure Modes and Effect Analysis**

| Hazard | Causes | Effects | Mitigations | Preliminary Verification |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Launch vehicle caught on rail | -Rail button(s) broken<br>-Damage to rail | -Reduced launch velocity<br>-Launch failure | -Inspect all rails and rail buttons before launch<br>-Ensure sufficient liftoff speed margin to account for minor rail drag | See Vehicle section 3.1.2.6 |
| Insufficient personnel at launch | -Launch date conflicts with school deadlines<br>-Lack of communication | -Failure to meet prep-time requirements<br>-Expiration of launch waiver | -Early communication<br>-Early planning of launches | Plan launches far ahead of time (see timeline section 6.8) |

**Table 5.14: Launch operations failure mode risk assessment**

| Identified Hazard | Risk (Probability/Severity/Total) | | |
|---|---|---|---|
| Insufficient personnel at launch | 4 | 3 | 12 |
| Launch vehicle caught on rail | 1 | 3 | 3 |

## 5.4. Environmental Hazard Analysis

**Table 5.15: Environmental Hazards**

| Hazard | Causes | Effects | Mitigations | Preliminary Verification |
|---|---|---|---|---|
| Transmission of harmful RF interference to atmosphere | -Improper shielding | -May interfere with other radio communications or vehicles | -Do not transmit on or near 145Mhz | Transmission only occurs shortly during flight and the dead zone of the antenna is pointed upwards. |

| | | | | |
|---|---|---|---|---|
| | -Excessive transmit power or duty cycle | -Legal action from FCC | -Use COTS radio hardware with build-in shielding<br>-Limit power and duty cycle in software | |
| Damage to launch field terrain | -High kinetic energy impact with launch field | -Property damage to launch field owner | -Follow launch day procedures to ensure successful launch and recovery<br>-Simulate and calculate kinetic energy to assume a healthy margin | See Appendix A for launch procedures to be followed to ensure proper recovery of the vehicle. Section 3.3.3 for parachute and kinetic energy calculations |
| Water damage | -Condensation on cold surfaces on/in components<br>-Weather / dew | -Short circuits<br>-Corrosion of mechanical parts | -Visual inspection of electronic components / housings / seals<br>-Use waterproof housings / components | See checklist in Appendix A Section 1.2 for procedures to ensure water is kept away from electronics. The VP is responsible for the verifications of all checklists during launch preparation. |
| Wildfire | -Hot launch vehicle landing in flammable materials<br>-Exhaust plume igniting flammable grasses | -Potential death<br>-Potential property and infrastructure damage<br>-Air Pollution<br>-Use of government money to put fire out | -Launch in a clear safe area where fire danger is low | Check the launch site before launch for fire danger. The President is in charge of ensuring the team is a go for launch day. |
| Airspace misuse | -Improper Simulation<br>-Failure to check air for obstacles | -Collision causing damage to other vehicles or aircraft<br>-Potential death | -Check airspace before launch<br>-Proper motor selection and simulation<br>-Vehicle inspection prior to launch | Follow RSO rules during launch day. Even at the highest we could fly in USLI, we would be well within the waiver of the field we launch at. |

| | | | | |
|---|---|---|---|---|
| Low visibility weather | -Weather patterns<br>-Time of Day<br>-Poor visibility of launch vehicle | -Failure to recover | -Have vehicle ready in time for multiple back-up launches<br>-High visibility decals and/or reflectors on launch vehicle | See section 6.4.1 for backup launches to ensure there is good weather to launch the vehicle safely and with the highest chance of success. The President is in charge of planning launches. |
| Dirt contamination | -Vehicle impacting ground at high rate of speed<br>-Parachute dragging vehicle after landing | -Potential damage to mechanical and electrical components | -Limit holes in the airframe<br>-Separate payload section after landing | The Airframe Stabilization Mechanism include holes, but are intentionally located far away from electronics. Other than vent holes, there are no other holes in the airframe. |
| Battery Failure | -Physical damage to battery<br>-Overcurrent or other electrical fault | -Can start wildfire<br>-Can release corrosive acids | -Structurally protect batteries from impact<br>-Simulate and test power draw of all components | See Section 4.1.2.4 for battery retention to ensure the battery is protected from impact. Data from the PDF and VDF will prove that these retention methods are adequate. |
| 3D Printed Parts Waste | -Not recycling the plastic parts<br>-Being wasteful<br>-Printing out unnecessary parts | -Waste ends up in landfills or oceans<br>-Microplastics pose a danger to wildlife | -Printing out parts with discretion | Dispose of litter in 3D printed parts waste bin located in the KIC. |
| Electronic Waste | -Broken Boards<br>-Ordering boards we don’t use | -Release of lead solder to environment<br>-Release of long lasting, man-made materials into environment | -Mount boards securely<br>-Prototyping circuits prior to ordering | See Section 4.1.2.4 for electronics retention to ensure the boards stay within the airframe. Data from the PDF and VDF will prove that these retention methods are adequate. |

**Table 5.16: Environmental hazards risk assessment**

| Identified Hazard | Risk<br>(Probability/Severity/Total) | | |
|---|---|---|---|
| Non-recovery of vehicle | 3 | 4 | 12 |
| Water damage | 3 | 3 | 9 |
| Low visibility weather | 3 | 3 | 9 |
| Electronic waste | 3 | 3 | 9 |
| Battery failure | 2 | 4 | 8 |
| Dirt contamination | 3 | 2 | 6 |
| Wildfire | 1 | 5 | 5 |
| Airspace misuse | 1 | 5 | 5 |
| 3D printed parts litter | 4 | 1 | 4 |
| Damage to launch field terrain | 3 | 1 | 3 |
| Harm to wildlife | 1 | 3 | 3 |
| Transmission of harmful RF interference | 1 | 1 | 1 |

# 6. Project Plan

## 6.1. Testing

### 6.1.1. Vehicle

#### 6.1.1.1. Fin Flutter Test

| | |
|---|---|
| **Test Objective** | **Verify that the fin flutter on the full scale vehicle's fins does not significantly impact flight performance** |
| **Success Criteria** | The fins on the vehicle will have minimal fin flutter |
| **Variable to be tested** | Deflection under perpendicular load |
| **Methodology** | . |
| **Justification** | Substantial fin flutter will drastically affect the flight performance of the vehicle. |
| **Result Impact** | Current fin design is effective and will suffice against fin flutter during flight. |
| **Test Results** | Not yet completed. |

#### 6.1.1.2. Custom Eye-Bolt Test

| | |
|---|---|
| **Test Objective** | **Verify that the custom eye-bolt will be able to withstand full-scale stresses** |
| **Success Criteria** | The custom eye-bolt will not break under stress |
| **Variable to be tested** | Yield strength of the bolt |
| **Methodology** | Attach to bulkhead<br>Test to destruction using a tensile tester |

| | |
|---|---|
| **Justification** | To ensure the payload section remains attached to the vehicle until separation is commanded after touchdown |
| **Result Impact** | The eye-bolt is able to withstand flight stresses, Vehicle and payload are deemed safe for flight and able to fly at competition |
| **Test Results** | Not yet completed |

#### 6.1.1.3. Kinetic Energy Test

| | |
|---|---|
| **Test Objective** | Verify that the vehicle will fall within the kinetic energy bounds as prescribed by derived requirement DC.9 |
| **Success Criteria** | The kinetic energy of the vehicle does not exceed 60 ft-lbs |
| **Variable to be tested** | Kinetic energy of the vehicle |
| **Methodology** | ● Measure the weight of all sections after launch<br>● Measure the mean landing speed from both altimeters following launch using the EasyMini and RRC3 altimeters<br>● Make sure that the Kinetic Energy requirements comply with derived requirement DC.9 |
| **Justification** | To comply with the team and NASA’s kinetic energy requirements, as seen in requirement DC.9. |
| **Result Impact** | The vehicle falls within the allowable range of kinetic energy, and can fly at competition. |
| **Test Results** | Not yet completed, planned for first full-scale launch. |

#### 6.1.1.4. Black Powder Quantity Test

| | |
|---|---|
| **Test Objective** | Verify the correct amounts of black powder used for separation |
| **Success Criteria** | Quick and smooth ground-based deployment of the main and drogue parachutes |
| **Variable to be tested** | Quantity of black powder |
| **Methodology** | ● Pack black powder charges<br>● Connect unpowered and disarmed testing system<br>● Assemble vehicle without motor<br>● Move away from the vehicle<br>● Power on and arm the tester<br>● Trigger each deployment |
| **Justification** | To ensure successful deployment of the recovery subsystem |
| **Result Impact** | The vehicle is assured to have a safe descent |
| **Test Results** | Not yet completed |

#### 6.1.1.5. Shear Pin Quantity Test

| | |
|---|---|
| **Test Objective** | Verify the correct amounts of shear pins are used |
| **Success Criteria** | Successful separation of the vehicle when commanded and not before |
| **Variable to be tested** | Amount of shear pins |
| **Methodology** | ● Assemble vehicle<br>● Fly vehicle<br>● Observe successful separation at specified times and altitudes |

| | |
|---|---|
| **Justification** | Ensure the vehicle is structurally sound during the burn and coast phases of flight |
| **Result Impact** | The vehicle is determined to be structurally sound and can fly at competition. |
| **Test Results** | Not yet completed |

#### 6.1.1.6. Quick Release Structural Test

| | |
|---|---|
| **Test Objective** | Verify the quick release can withstand the forces of recovery |
| **Success Criteria** | Successful recovery of the vehicle with no visible damage of the quick release. |
| **Variable to be tested** | Quick release tolerance |
| **Methodology** | • Launch and recover the full-scale vehicle |
| **Justification** | Ensure the quick release may be used in the vehicle without posing a danger to the mission and surrounding environment. |
| **Result Impact** | The vehicle may separate the payload section after touchdown and ensure a successful mission. |
| **Test Results** | Not yet completed |

#### 6.1.1.7. U-bolt Structural Test

| | |
|---|---|
| **Test Objective** | Verify the U-bolt can withstand the forces of recovery |
| **Success Criteria** | Successful recovery of the vehicle with no visible damage of the U-bolts. |
| **Variable to be tested** | U-bolt tolerance |

| | |
|---|---|
| **Methodology** | - Launch and recover the full-scale vehicle |
| **Justification** | Ensure the U-bolt may be used in the vehicle without posing a danger to the mission and surrounding environment. |
| **Result Impact** | The vehicle will be able to safely deploy the recovery devices. |
| **Test Results** | Not yet completed |

### 6.1.2. Payload

#### 6.1.2.1. APRS Loss Measurement Scale Test

| | |
|---|---|
| **Test Objective** | Measure, with a mathematically to-scale setup, the packet loss of different antennae with orientations. |
| **Success Criteria** | The to-scale model is able to exceed 2500 ft. in real scale distance with all packets received. |
| **Variable to be tested** | Packet loss for similar APRS commands. |
| **Methodology** | 1. Find the power rating of the power of the SDR<br>2. Calculate the scale of the setup through the inverse square law and geometry.<br>3. Find the maximum distance for each different orientation & type of antenna.<br>4. Recalculate the equivalent distance for each orientation.<br>5. Verify that the orientation+antenna pair meet the minimum specification. |
| **Justification** | Since the landing area is limited to 2,500 ft (Handbook 3.10), the scale model must be able to exceed the distance of a real model in order to account for un-ideal conditions on the field. |

| | |
|---|---|
| | This test is critical for determining if the design is capable of receiving commands from NASA. |
| **Result Impact** | The results of this test impacted whether our design was able to receive the real-world RAFCO commands. This dictated whether we should be able to |
| **Test Results** | The signal stick antennas had a slightly lower success rate compared to the rubber ducky antenna in most orientations. However, the only orientation that was able to meet our success criteria was the vertical orientation. |

#### 6.1.2.2. Payload Pad Battery Life Test

| | |
|---|---|
| **Test Objective** | Determine the length of time the payload computer and associated electronics are capable of continuously being powered on in launch configuration. |
| **Success Criteria** | The payload computer stays powered for at least 4 hours with every component powered and software configured in launch-ready configuration. |
| **Variable to be tested** | Length of time the payload computer stays powered on, maximum 8 hours. |
| **Methodology** | • Prepare payload electronics subsystem in launch-ready configuration by following the pre-launch procedures in Appendix A section 1.<br>• Connect a 2S 2200mAh to the test payload, utilizing polarized XT60 connectors to eliminate the risk of damaging the battery or electronics.<br>• Energize the payload and begin time tracking.<br>• Continuously monitor the payload for battery failure or unintentional voltage drop.<br>• Record the battery voltage every 15 minutes as measured by the payload onboard voltage monitoring.<br>• De-energize the payload once the battery voltage drops below 3.2v or the test has been run for 8 hours, whichever occurs first. |

| | |
|---|---|
| **Justification** | Per requirement 2.6, the vehicle must be capable of remaining on the pad in launch ready configuration for 2 hours. To allow for the payload battery to be utilized during launch preparation and post flight during recovery, a battery life time of 4 hours was chosen.<br>This test is limited by the practical length of time for which a discharging battery can be continuously monitored. An additional 2x factor of safety was determined to be a practical limit of testing which would ensure performance could be met in unfavorable conditions such as partial discharge or cold weather. |
| **Result Impact** | Elapsed time of >8 hours will result in an unconditional pass of the battery. Elapsed times from 4-8 hours will result in additional checks to ensure batteries are fully charged. An elapsed time of less than 4 hours will result in the team selecting a proportionally larger battery to yield 6 hours of run time. |
| **Test Results** | To be completed. |

### 6.1.2.3. Image Fidelity Test for sending CSI signals over an HDMI cable

| | |
|---|---|
| **Test Objective** | To verify the system is able to detect when the vehicle has launched and landed. |
| **Success Criteria** | Are images with a 99% match of the expected image returned from the camera system. |
| **Variable to be tested** | Fidelity of image returned |

| | |
|---|---|
| **Methodology** | Test Methodology 1:<br>1. Connect the camera directly to the SBC with the ribbon cable.<br>2. Send a command to the image sensor on the camera to return a reference image for fidelity testing.<br>3. Connect the camera with the CSI-HDMI-CSI conversion<br>4. Send the same command and receive the image returned.<br>5. Subtract the two images and quantify the artifacts.<br>Test Methodology 2:<br>1. Mount the camera to a stationary position.<br>2. Connect the camera directly to the host computer with the ribbon cable<br>3. Take the picture. (Control)<br>4. Connect the camera to the host using the CSI-HDMI-CSI cable.<br>5. Take a picture. (Test)<br>6. Subtract the two images and quantify the artifacts |
| **Justification** | Transmitting video/image data over HDMI is standard practice for everyday consumers, but instead of following the HDMI standard due to difficulty of implementation, we use the differential pairs and send CSI signals through the HDMI cable. |
| **Result Impact** | The results of this test tell us that we have a continuity issue with our conversion equipment and therefore tells us whether we need to adjust the PCB design. |
| **Test Results** | Not yet completed |

#### 6.1.2.4. Payload Custom Circuit Board Power Supply Test

| | |
|---|---|
| **Test Objective** | Characterize the performance of the power supply subsystems |
| **Success Criteria** | The voltage output from the power supply is within ±5% of the target voltage when idle and under a simulated load. |

| | |
|---|---|
| **Variable to be tested** | Voltage of 5V buck converter when idle and under load<br>Idle current draw of 5V buck converter<br>Voltage of raspberry pi 3.3V line under load |
| **Methodology** | 5V buck converter test methodology:<br>1. Assemble only the buck converter portion of the PCB (See Figure 4.17), including the xt-30 power connector<br>2. Set a variable lab bench power supply to output 12V, at a maximum current of 50 mA to prevent any shorts from causing damage. Disable the output.<br>3. Connect the variable power supply to the xt-30 input on the PCB. Ensure that the polarity is correct.<br>4. Enable the output of the variable power supply. Verify that the power supply doesn’t go into constant current mode. Observe the idle current draw of the buck converter.<br>5. Measure the 5V output voltage on the expansion port with a multimeter.<br>6. Connect a 1kΩ ¼-W resistor to the expansion port. Ensure that there is no change to the output<br>7. Ensure that the output voltage remains stable<br>3.3V raspberry pi test methodology:<br>1. Attach the raspberry pi to the PCB<br>2. Connect power to the PCB the same way as above, but with a 1A current limit<br>3. Measure the 3.3V output voltage on the expansion port with a multimeter |
| **Justification** | Ensure the power supply can supply sufficient power and will not damage any other parts before assembling the entire PCB. This will catch any design or manufacture errors early and prevent unnecessary damage to other components. |
| **Result Impact** | Current design of the PCB power supply subsystem is usable for the rest of the payload. |
| **Test Results** | 5V Buck converter test: |

| | |
|---|---|
| | 1. Idle: 5.00V output voltage, 12.00V and 10mA input<br>2. 1kΩ load: 5.01V output voltage, 12.00V and 14mA input<br>3. 3.3V raspberry pi test: completed |

#### 6.1.2.5. Orientation Sensor Performance Test and Calibration

| | |
|---|---|
| **Test Objective** | Measure different sensors during flight and recovery. |
| **Success Criteria** | Are we able to clearly determine flight events, with a suite of different sensors for redundancy. |
| **Variable to be tested** | Sensor precision. |
| **Methodology** | 1. Build a subscale payload with the suite of sensors to be tested.<br>2. Record the data throughout the flight<br>3. Review the data by hand with a graphing tool |
| **Justification** | Since the payload is forbidden from receiving RAFCO commands until after it has landed, we need to make sure that the payload has several redundant ways to determine if the vehicle has landed. |
| **Result Impact** | If these sensors are not able to make a consensus, the payload will not be able to determine if it has landed and will not be able to continue to deploy the antenna. |
| **Test Results** | Based on subscale results, we have been able to visually determine if the vehicle has landed successfully. |

#### 6.1.2.6. Payload Circuit Board High Current Output

| | |
|---|---|
| **Test Objective** | Verify the high-current mosfets will handle the load from the Nichrome wire. |

| | |
|---|---|
| **Success Criteria** | The MOSFETs switch and do not exceed 100 degrees celsius for a sustained load of 5 seconds. |
| **Variable to be tested** | Junction temperature of mosfets. |
| **Methodology** | Using a finished demonstration of the motherboard PCB<br>Use an external power supply (not a battery)<br>1. Use a microcontroller to send a command over i2c to set the PWM output for the MOSFET.<br>2. Using a thermal camera, the temperatures of the MOSFETS will be measured |
| **Justification** | According to the datasheet of the AO4838 MOSFET, the Junction ($T_J$) and Storage Temperature Range ($T_{STG}$) are -55 to 150 °C. The team has decided to make nominal temperature readings not exceed the conservative average of 100 °C (approximately 102.5 °C. |
| **Result Impact** | When operating the circuit board, the temperature of the components should be made sure to not overheat causing small explosions and destructive failures to the rest of the board. |
| **Test Results** | To be tested |

#### 6.1.2.7. Payload Circuit Board High Current Output

| | |
|---|---|
| **Test Objective** | Verify that the continuity detection circuits work properly |
| **Success Criteria** | The sense pins respond correctly to the outputs being connected or disconnected<br>The sense pins never go above 3.3V |
| **Variable to be tested** | Voltage of each sense pin when the output is disconnected<br>Voltage of each sense pin when their output is |

| | |
|---|---|
| **Methodology** | 1. Ensure that nothing is connected to either high-current output.<br>2. Connect the board to power<br>3. Use a multimeter to probe the sense pins on the raspberry pi header. Ensure that both pins are at 0V.<br>4. Connect a jumper wire between the outputs of high current output A<br>5. Ensure that sense pin A is at 3.0V-3.3V, and sense pin B is at 0V. Neither pin can go above 3.3V without risking damage to the single board computer.<br>6. Disconnect the jumper wire<br>7. Repeat steps 4-6 for output B |
| **Justification** | If the sense pins are improperly wired or assembled, they have the possibility of directly connecting the battery-voltage high-current section to the single board computer, damaging it. |
| **Result Impact** | If these tests do not pass, we will disconnect the sense-enable solder bridges, losing the ability to check the continuity automatically. We will need to verify continuity manually as part of our pre-flight procedures. |
| **Test Results** | Not yet completed |

#### 6.1.2.8. Battery Voltage Test

| | |
|---|---|
| **Test Objective** | Measure the life of a 2200mAh battery during load on the pad |
| **Success Criteria** | The battery lasts over 4 hours on idle. |
| **Variable to be tested** | Duration which battery will last while idle. |
| **Methodology** | Load the Raspberry Pi to it's "Ready-on-Pad" status |

| | |
|---|---|
| **Justification** | According to the provided requirement of allowing the “on-pad time” to be 2 hours the team has decided to create this test to make sure the batteries can output voltage and current for an extended period of time in the case of waiting for other teams to launch and preliminary launch setup procedures. The team has decided to use 4 hours as a metric to allow for a higher margin of error in case of extreme wait times. |
| **Result Impact** | Without passing the test, the team risks the chance of not being able to fix last-minute launch pad procedures and possible disqualification. |
| **Test Results** | To be tested |

#### 6.1.2.9. Flight Computer Resource Exhaustion Tests

| | |
|---|---|
| **Test Objective** | Determine the resource utilization for the flight computer upon startup and throughout the flight |
| **Success Criteria** | No more than 75% of the processor shall be utilized throughout the flight |
| **Variable to be tested** | Processor Utilization Percentage |
| **Methodology** | The team plans on utilizing Hardware-in-the-Loop testing to run a simulated flight (refer to DIAG_DATA). Fake flight files are created with reasonably random telemetry data and the flight computer will be exhaustively tested to a point of maximum processor usage (75%). |
| **Justification** | This test is necessary to ensure that some processor resources remain for important tasks that the flight computer executes and the team needs. |
| **Result Impact** | Without this test passing, the problem could cause the team to experience overloaded memory and processor usage and repurposing the processor for optimizing certain tasks. |

| | |
|---|---|
| **Test Results** | To be tested |

### 6.1.2.10. Flight Data Log Tests

| | |
|---|---|
| **Test Objective** | Determine how the flight computer software will handle several different edge cases for different vehicle flight profiles |
| **Success Criteria** | Payload performs all expected tasks in simulation. |
| **Variable to be tested** | File mentions graceful shutdown |
| **Methodology** | Several tests may be conducted to ensure that the edge cases are able to be registered and understood by the flight computer. One of these tests could be rolling the launch vehicle down hill. These tests can be tested with the resource monitoring tests. |
| **Justification** | These tests determine whether the payload is resilient to edge cases and scenarios. |
| **Result Impact** | Verify that payload meets competition rules that forbid the payload from performing an action during flight. |
| **Test Results** | To be tested. |

### 6.1.2.11. Nichrome Wire Testing

| | |
|---|---|
| **Test Objective** | Determine the current needed to heat the wire up to burn fishing line(/rubber band etc) in under 5 seconds assuming the voltage supplied is 5 Volts. |
| **Success Criteria** | The nichrome is able to melt the line in under 5 seconds, using at most 12 volts and at most 10A. |

| | |
|---|---|
| **Variable to be tested** | Time to melt line<br>Voltage supplied<br>Current supplied |
| **Methodology** | ● Use the rigging in Figure 6.1 to mount 2in (tolerance of .1in) of nichrome wire wrapped around the screws<br><br>**Figure 6.1: Nichrome wire testing stand**<br>○ Note: actual test case should find the fishing line with more contact with the wire<br>● Attach a positive and negative terminal connected to a power supply to either end of the nichrome wire (do not turn supply on)<br>● Wrap the fishing line two times around the wire.<br>● Supply 5V from the power supply at the same time as starting a timer<br>● Stop the timer and power supply when the fishing line breaks<br>● Repeat experiment in while increasing voltage in 1 volt intervals |
| **Justification** | The test will validate the design by solidifying our burn material choice to ensure consistent deployment of the legs. |

| | |
|---|---|
| **Result Impact** | If the fishing line will not burn within our current and time limit, we need to select another material to burn or determine a new deployment method. |
| **Test Results** | At 5V, the test bench reported a load of approximately 2A which burned the nylon string in about 1.5 seconds. This far exceeded our expectations for deploying the legs because the test procedure recommended increasing the voltage, which did not seem necessary. |

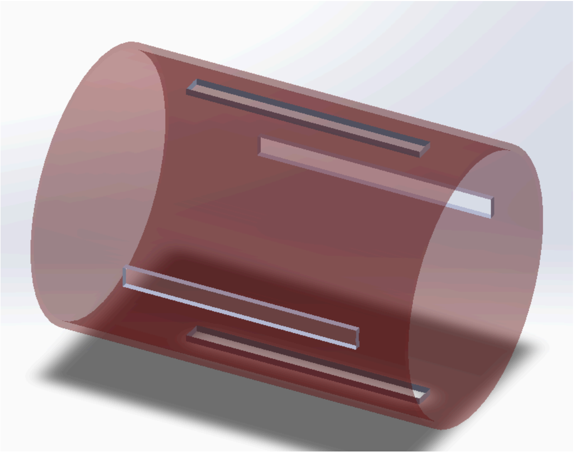
### 6.1.2.12. Bearing Stress Test

| | |
|---|---|
| **Test Objective** | Ensure the 3D-printed bearings have enough strength to withstand full-scale vehicle loads |
| **Success Criteria** | The bearing has no visual damage after 5 tests. |
| **Variable to be tested** | Strength of 3D-Printed Bearings |
| **Methodology** | Using the 3D printed bearing as a coupler to connect two parts of the airframe, then apply load at one one end. The other end will be secured at a fix hanging connected with a pull scale. Slowly increase the load and record the weight. |
| **Justification** | This test is needed to validate the design of the 3D-printed bearings. If the bearings fail under full-scale vehicle loads, then a redesign of the bearing must be completed in order to ensure proper functionality of the bearing system. |
| **Result Impact** | The result will highlight if any changes need to be made to the bearing design to allow for it to have sufficient structural rigidity. |
| **Test Results** | Not yet completed |

### 6.1.2.13. Leg Deployment Test

| | |
|---|---|
| **Test Objective** | Determine the load the legs can lift during deployment before failure |
| **Success Criteria** | The load lifted is at least 6lbs |
| **Variable to be tested** | Weight of airframe |
| **Methodology** | The test will be conducted on a hard flat surface with the legs fully-installed into a full scale-sized tube. The legs will be fully wired to ensure that the legs will be fully retracted within the confines of the vehicle's airframe. The nichrome wire will be hooked up to a power supply supplying the same voltage and current as the Pi would.<br>The test will begin with only the airframe as weight. The legs will be deployed by turning on the power supply and burning the nichrome wire. As the nichrome wire burns, the legs will no longer be wired to the vehicle and will be free to protract and extend outside of the airframe of the vehicle. If successful, the legs will be set up again with 500g added to the airframe. The weight is in the form of cylindrical test weights placed in the center of the tube. The test will repeat until the legs can no longer lift the weights and airframe. |
| **Justification** | This test is needed to validate the design of the legs for their intended purpose. If they do not lift the weight of the payload, then a redesign is necessary in order to ensure they will function properly. If they do lift the weight, then we know the design functions as intended in ideal conditions. |
| **Result Impact** | The result will drive design changes in the legs in the form of construction material, springs used, leg location, and payload weight. |
| **Test Results** | Not yet completed |

### 6.1.2.14. Leg Support Airframe Hole Test

| | |
|---|---|
| **Test Objective** | Ensure that the holes in the airframe necessary for the leg deployment system do not significantly affect vehicle performance. |
| **Success Criteria** | The altitude of the subscale does not change within 150 ft of simulations |
| **Variable to be tested** | Altitude |
| **Methodology** | The subscale will be launched according to all checklists with the hole in the airframe proportional to the full scale holes. See figure below.<br><br>After flight, the data from the altimeters will be recorded and compared vs. a simulation as well as the actual subscale data from the subscale launch. |
| **Justification** | The holes change the geometry of the airframe, so may change the way the vehicle flies. This is a variable that should be accounted for to ensure that simulations still predict the vehicle accurately. |

| | |
|---|---|
| **Result Impact** | If they do significantly affect the flight, then the holes will need to be sealed or made to be smaller. |
| **Test Results** | Not yet completed. |

### 6.1.2.15. Bearing Transverse Load Test

| | |
|---|---|
| **Test Objective** | Ensure the bearing and servo can handle transverse loads similar to the ground impact by measuring the maximum force the bearing can take. |
| **Success Criteria** | The bearing can handle double the force expected during recovery in the transverse direction |
| **Variable to be tested** | Height of bearing transverse failure and bending failure |
| **Methodology** | **The bearing should be fully assembled with the servo attached and connected to a piece of airframe on either side, from now on referred to as the bearing section<br>● Weigh the bearing section of the vehicle<br>● Using expected landing kinetic energies, calculate the height needed to simulate decent speed (using gravitational potential energy equation)<br>● Clear a space at least 5ft x 5ft to perform the test<br>● Use a ladder to achieve the necessary height<br>● Drop the bearing section such that the airframe is parallel with the ground and so that the force lands on the center of the bearing (transverse loading failure)<br>● Repeat test so that the height mimics double the landing kinetic energy<br>● Repat above two steps but drop the bearing section so it lands initall around 3 ft away from the center of the bearing (bending failure) |

| | |
|---|---|
| Justification | The airframe will most likely land in one of the two configurations mentioned. The bearing needs to survive these loads in order to function as intended during payload deployment. |
| Result Impact | If the success criteria is not met, the bearing walls may need to be thicker, the material may need to be changed, or the 3D printing settings will need to be optimized for strength. Regardless, the design would need to be reviewed and retested in order to pass this test. |
| Test Results | Not yet completed |

## 6.2. Handbook Requirements

In order to ensure the proposed launch vehicle design fulfills all the requirements set forth by the competition handbook, the team has individually reviewed each requirement and ensured it is addressed throughout Project Kirkpatrick. For each requirement, a type of verification and a plan for verification is chosen. Definitions for types of verification that the team used are below.

- **Test:** Rigorous and systematic method of determining an unknown specific parameter or characteristic
- **Analysis:** Methodic and detailed examination of a system to explain and interpret results without testing. Can rely on previous data and case studies to draw conclusions.
- **Demonstration**: Verification is achieved through showing the requirement outcome either in documentation or on launch day
- **Inspection:** Thorough investigation of a system for certain criteria used when the result can be easily determined from simple observation without need for further investigation

The status for every general requirement is also provided. A completed requirement is one that has been fulfilled in the CDR or in a previous document. An ongoing requirement is one that requires work throughout the competition and is only completed upon completion of the competition. An in progress requirement is currently being fulfilled but is not complete. Planned is defined as a requirement that will be fulfilled at a date such as the FRR or VDF.

The status of all requirements is summarized in Figure 6.1.

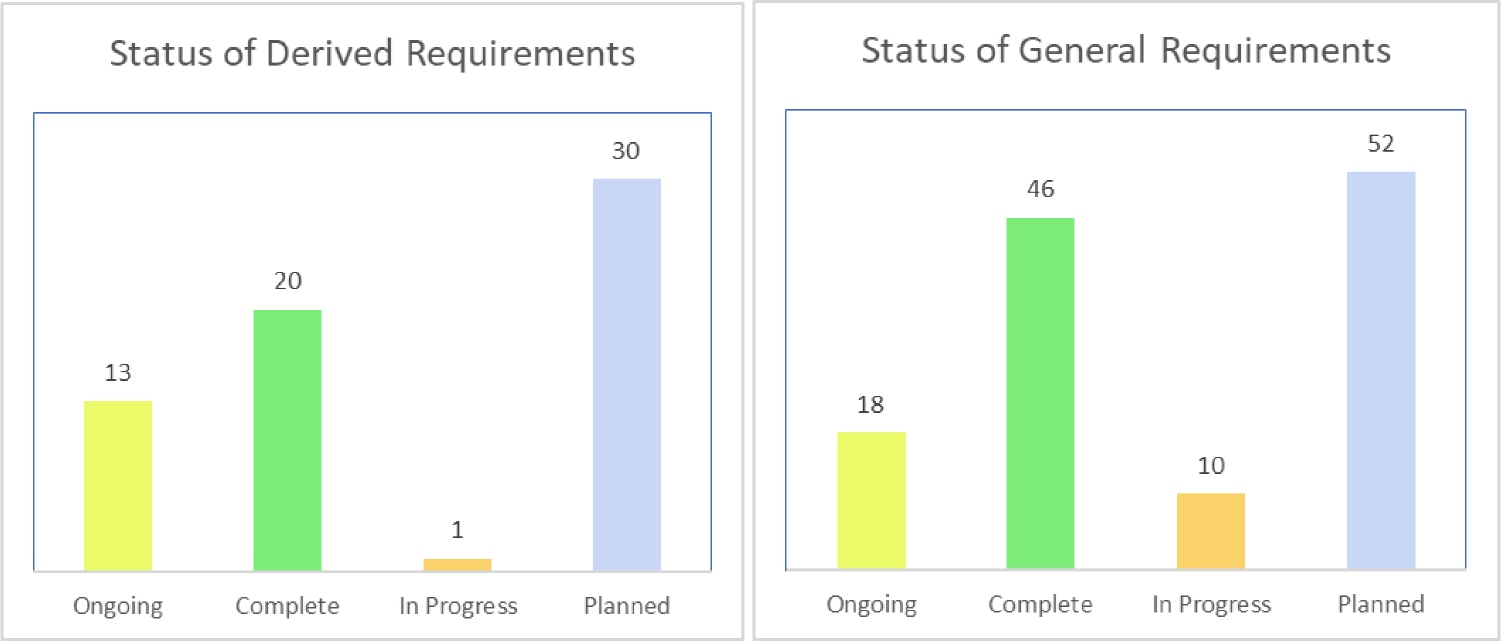


**Figure 6.1: Status of Requirements Verification**

**Table 6.1 Status Legend**

| Color | Status |
|---|---|
| 🟥 | Incomplete |
| 🟧 | In progress |
| 🟨 | Ongoing |
| 🟩 | Complete |

| | |
|---|---|
| 🟦 | Planned |

Table 6.2: Individual Verification of General Requirements

| No. | Requirement Description | Type of Verification | Plan | Status |
|---|---|---|---|---|
| 1.1 | Students on the team will do 100% of the project. Teams will submit new work. | Demonstration | Project work will be regularly documented and validated by the Vice President to ensure work integrity. Project Leads will ensure all new work is submitted promptly. | Ongoing |
| 1.2 | The team will provide and maintain a project plan including project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations | Demonstration | The project plan work is divided among the officers depending on their expertise is updated for every milestone | Ongoing |
| 1.3 | The team will identify participating members in launch week by CDR | Demonstration | A survey will be sent out in December to gauge interest for launch week with confirmation shortly thereafter | Complete |
| 1.4 | STEM engagement will engage 250 participates to be considered for relevant awards | Demonstration | The lead of engagement will plan to engage 250 participants and log all necessary information to be considered for awards. This will be demonstrated with the FRR package. | In progress |
| 1.5 | The team will maintain social media presence | Demonstration | The team's instagram will be updated every week with progress updates. The social media officer of the club is responsible for the social media's maintenance, and the demonstration | Ongoing |
| 1.6-1.10 | The team will submit all deliverables by email by the deadline in PDF format with the necessary sections | Demonstration and Inspection | The team will review deliverables before submission to ensure required sections are present, and will submit on time and adhere to all NASA action items. This plan will be demonstrated by completion of the requirement for each milestone, and the Vice President will inspect the document before submission | Ongoing |

| | | | | |
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| 1.11 | The team will provide computer equipment necessary to host the video teleconference | Demonstration | The team will test and obtain all equipment including a camera, microphone, and quiet room, prior to the conference. This plan will be demonstrated during video teleconferences | In progress |
| 1.12 | The team will use launch pads provided by NASA SL | Demonstration | The vehicle will be designed to 1515 or 1010 specification, and this requirement will be demonstrated during launch day. | In progress |
| 1.13 | The team will identify a mentor for liability reasons | Demonstration | The team has and will continue to communicate with our mentor about launch vehicle design and will continue to include his contact information in deliverables | Complete |
| 1.14 | The team will track hours worked on each milestone | Demonstration | The team has created a “hours worked” form that every member fills out after working on a given deliverable. It will be included in the deliverables for every milestone which will be verified by the Vice President | In progress |

**Table 6.3: Individual Verification of Vehicle Requirements**

| No. | Requirement Description | Type of Verification | Plan | Status |
|---|---|---|---|---|
| 2.1 | The vehicle shall deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). | Analysis | The vehicle has a target altitude of 5000 ft. Simulations will be performed using OpenRocket and RASAero software to verify this, and will be recalculated as the design is iterated. | Ongoing |
| | | Testing | Subscale flight testing will verify the accuracy of the analysis. Data was collected via redundant altimeters. The results of this test are in section | Complete |
| | | | Full-scale flight testing with the payload or a mass simulator will further validate target compliance. | Planned |
| 2.2 | Teams shall declare their target altitude goal at the PDR milestone. | Demonstration | Extensive simulation will be performed before PDR completion; flexibility for adjustments in payload mass | Complete |

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| | | | or geometry will be maintained in vehicle design. | |
| 2.3 | The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications. | Analysis | Simulations of recovery system deployment in flight will be run to determine forces on the vehicle, kinetic energies, and drift. The vehicle will be designed to handle stresses of flight and remain within NASA kinetic energy and drift requirements to ensure a recoverable and reusable launch vehicle. | Ongoing |
| | | Testing | Full-scale flight testing with the payload or a mass simulator on the competition recovery hardware will further validate launch vehicle recoverability and reusability. | Planned |
| | | Demonstration | The team will fly the subscale launch vehicle with a partially-complete payload twice in one day. | Planned |
| 2.4 | The launch vehicle shall have a maximum of four (4) independent sections. | Demonstration | The team has designed a launch vehicle with three independent sections. | Complete |
| 2.4.1 | Coupler/airframe shoulders which are located at in-flight separation points shall be at least 2 airframe diameters in length. | Demonstration | The team has designed a launch vehicle with couplers 8 inches long in order that they are double the diameter of the airframe (4 inches). | Planned |
| 2.4.2 | Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length. | Demonstration | The team has selected an off-the-shelf nosecone which fulfills these requirements. | Complete |
| 2.5 | The launch vehicle can be prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens | Inspection | The team will track the preparation time throughout the season for different systems and schedule accordingly on the launch day. This inspection will be performed at every full-scale launch and a pre-launch day dry run to ensure this requirement is met. | Planned |
| | | Demonstration | During launch day, the team will completely prepare the vehicle for launch within 2 hours of the time that the flight waiver opens to fulfill this requirement | Planned |

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| 2.6 | The vehicle and payload can maintain launch-ready configuration on the pad for a minimum of 2 hours. | Analysis | Materials, components, and power sources have been selected with the appropriate efficiency and capacity. | Complete |
| | | Testing | Tests will be conducted by configuring electronics as they will be configured in the launch vehicle and measuring how long the batteries can power the electronics. This test is detailed in section 7.1.2.1 and derived requirement AV.2 under section 7.3.2, and is included to ensure the pad time is quantifiably longer than 2 hours. | Planned |
| 2.7-2.8 | The launch vehicle must be launched using only a NASA-designated 12v launch system, with commercial igniters. | Demonstration | The team will only use a NASA-designated 12v launch system with commercial igniters and design a launch vehicle that is capable of being launched on them. | Planned |
| 2.9 | The launch vehicle will use COTS solid motors approved by NAR | Demonstration | The team will only buy motors approved by the NAR and are solid motors. The K600-WH, a COTS motor, has been selected as the vehicle's motor. | Complete |
| 2.10 | The launch vehicle will be a single motor propulsion system | Demonstration | The launch vehicle will be a single-motor, single-stage design. | Complete |
| 2.12 | The total impulse will not exceed L-class | Demonstration | The K600-WH, a motor not exceeding L-class impulse, has been selected as the vehicle's motor. | Complete |
| 2.13 | Pressure Vessels will be approved by the RSO and will meet criteria including relief valves and a minimum factor of safety | Analysis | The vehicle and payload will not use pressure vessels. The complete design, which does not include pressure vessels, will be included in section 3.1.2. | Complete |
| 2.14 | The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail. | Analysis | The vehicle has been designed with a stability margin of significantly higher than 2.0 and verified with OpenRocket and RASAero simulation software and the safety officer. The results of this analysis are in section 3.4.6. | Complete |
| | | Testing | The full-scale vehicle will be test-flown at least once before Launch Week to validate stability. | Planned |

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| 2.15 | The launch vehicle will have a minimum thrust to weight ratio of 5.0 : 1.0. | Analysis | The weight of the vehicle and payload will be predicted from the sum of the weight of components. Thrust specifications from the chosen motor will be used to find the ratio, which is 11.1 : 1.0. | Complete |
| | | Demonstration | The team will conduct mass audits of the vehicle and payload to verify the weight is 20.625 pounds as designed. | Planned |
| 2.16 | Any structural protuberance on the vehicle will 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 vehicle stability. | Demonstration | While the in-flight configuration of the vehicle and payload does not contain protuberances, the payload will deploy protuberances after flight. Shock testing will be conducted to verify any payload mechanisms do not deploy during flight. | Planned |
| 2.17 | The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit. | Analysis | Simulations will be performed using OpenRocket software to simulate expected rail exit velocity. | Complete |
| | | Demonstration | The team will conduct a vehicle demonstration flight and will use OpenRocket to determine the velocity off the rail. | Planned |
| 2.18 | All teams will successfully launch and recover a subscale model of their launch vehicle prior to CDR. Success of the subscale is at the sole discretion of the NASA review panel. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data shall be reported in the CDR report and presentation at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor). | Analysis | This requirement is considered complete if the requirements 2.18.1 through 2.18.4 are complete, in addition to the motor choice for the subscale vehicle being a J-class impulse motor. | Complete |
| 2.18.1 | The subscale model should resemble and | Analysis | The subscale will be designed to reach the competition | Complete |

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| | perform as similarly as possible to the full-scale model; however, the full-scale model will not be used as the subscale model. | | targeted apogee of 5,000ft using the same materials and construction techniques as the full scale launch vehicle where possible, along with a partially-complete payload. | |
| | | Demonstration | The subscale will be flown to an altitude within competition limits with a partially complete payload onboard. | Complete |
| 2.18.2 | The subscale model will carry an altimeter capable of recording the model's apogee altitude. | Demonstration | The subscale vehicle is equipped with two dissimilar altimeters. The avionics bay is designed to have vent holes which will allow the altimeter's barometer to measure air pressure. See section 3.3.9 for details on the team's altimeters. | Complete |
| 2.18.3 | The subscale vehicle shall be newly constructed, designed and built specifically for this year's project. | Demonstration | The team designed and manufactured a new launch vehicle to serve as the subscale based on the design of the full-scale launch vehicle. | Complete |
| 2.18.4 | Proof of a successful flight shall be supplied in the CDR report. | Inspection | Flight data, including apogee, drift and visuals of launch and landing are provided in section 3.2 | Complete |
| 2.18.4.1 | Altimeter flight profile graph(s) OR a quality video showing successful launch, recovery events, and landing as deemed by the NASA management panel are acceptable methods of proof. Altimeter flight profile graph(s) that are not complete (liftoff through landing) shall not be accepted. | Demonstration | Altimeter graphs as well as payload data are included in section 3.2.1. | Complete |
| 2.18.4.2 | Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the CDR report. This includes but not limited to nosecone, recovery system, airframe, and booster. | Demonstration | Pictures of all landed sections of the vehicle are provided in section 3.2.7. | Complete |
| 2.18.5 | The subscale rocket shall not exceed 75% | Inspection | The subscale is 73.7% the height of the full-scale | Complete |

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| | 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. | | vehicle and 75% of the diameter. Dimensional drawings are located in section 3.2.2. | |
| 2.19.1 | Vehicle Demonstration Flight—All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. | Demonstration | The team will fly the full-scale vehicle twice before the competition launch, with each flight achieving the criteria for mission success as described in section 3.1.1. These flights will be documented in the FRR. | Planned |
| 2.19.1.1 | The vehicle and recovery system will have functioned as designed. | Testing | Ground tests shall be conducted with the vehicle in its complete flight configuration using varying amounts of black powder to determine how much is needed to deploy recovery hardware. | Ongoing |
| | | Demonstration | A vehicle demonstration flight shall be conducted as described in requirement 2.19.1. | Planned |
| 2.19.1.2 | The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year's project. | Demonstration | Dimensional drawings and new design of the full-scale launch vehicle shall be included in section 3.1.3. The vehicle shall be built in January per the timeline in Section 6.8. | Ongoing |
| 2.19.1.3 | If the payload is not flown during the vehicle demonstration flight, mass simulators must be used. | Demonstration | The current timeline in section 6.8 does not plan to fly the finalized payload at the VDF. Thus a mass simulator will be used. | Planned |
| 2.19.1.4 | If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight. | Demonstration | The payload will not change the external surface of the launch vehicle during flight. Payload deployment mechanisms will be operational during the Vehicle Demonstration Flight. | Planned |
| 2.19.1.5 | Teams shall fly the competition launch motor for the Vehicle Demonstration | Demonstration | The team will decide a reliable motor ahead of time and acquire multiple motors of the type before | Ongoing |

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| | Flight. | | full-scale testing begins. Correct motor and installation will be verified by multiple people and the safety officer before each test fight. | |
| 2.19.1.6 | The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. | Demonstration | By following the pre-launch procedure checklists, the vehicle will be correctly ballasted and in configuration before every test flight. This will be confirmed by the safety officer. | Planned |
| 2.19.1.7 | After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO). | Demonstration | The team will post visual reminders and announcements in communications channels to not modify the launch vehicle without NASA concurrence. | Planned |
| 2.19.1.8 | Proof of a successful flight shall be supplied in the FRR report. | Inspection | Altimeter logs will be supplied in the FRR report. Images of the flight and its major events will be supplied where possible. | Planned |
| 2.19.1.8.1 | Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement. | Inspection | The team will recover altimeter, time, and velocity data with the launch vehicle, insert the data into plots, and provide the plot to NASA in the FRR report. | Planned |
| 2.19.1.8.2 | Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the FRR report. | Inspection | The team will take quality pictures of the landed configurations of all sections of the launch vehicle and include them in the FRR. | Planned |
| 2.19.1.9 | Vehicle Demonstration flights shall be completed by the FRR submission deadline. | Demonstration | The team will complete all Vehicle Demonstration flights by the FRR submission deadline and ensure there is enough time for backup opportunities to launch should the planned launch be scrubbed. See the timeline in section 6.8 for these dates. | Planned |
| 2.19.2 | Payload Demonstration Flight—All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload | Demonstration | The team will perform at least one demonstration flight with the payload integrated into the vehicle. The mission is planned for March 11, (see section 6.8) | Planned |

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| | Demonstration Flight deadline. | | | |
| 2.19.2.1 | The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair. | Demonstration | The team will conduct a demonstration flight of a subscale vehicle which will include a scaled version of the payload rotation bearing. This flight will be documented in section 3.2. | Planned |
| 2.19.2.2 | The payload flown shall be the final, active version. | Demonstration | The payload used in the payload demonstration flight will be the same payload flown at competition. | Planned |
| 2.19.2.3 | If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required. | Inspection | The complete payload will be flown in the Vehicle Demonstration Flight and the results of the flight and the payload performance will be documented in the FRR, as shown in the payload development timeline in section 6.8. If circumstances arise preventing the payload from functioning for this flight, the team will complete a payload demonstration flight]. | Planned |
| 2.19.2.4 | Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED. | Inspection | Payload demonstration flights will be completed either on the vehicle demonstration flight as verified in requirement 2.19.1 or in a separate payload demonstration flight as verified in requirement 2.19.2.4. | Planned |
| 2.20 | An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report. | Inspection | The team will complete an FRR Addendum if our Vehicle Demonstration flight is not accepted by the NASA team. | Planned |
| 2.20.1 | Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly a final competition launch. | Demonstration | The team will listen to the NASA team whether we are allowed to launch at the final competition launch. | Planned |

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| 2.20.2 | Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly a final competition launch. | Demonstration | The team will listen and adhere to guidelines from the NASA team on whether their Payload Demonstration Flight is satisfactory. | Planned |
| 2.20.3 | Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. | Demonstration | In the event of an unsuccessful payload demonstration flight, the team will implement corrective actions and petition the RSO for permission to fly the payload at Launch Week. | Planned |
| 2.21 | The team's name and Launch Day contact information shall be readily accessible from the rocket systems. | Demonstration | The team will mark all separable systems with the team name and Launch Day contact information. | Planned |
| 2.22 | All Lithium Polymer batteries will 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. | Demonstration | Brightly colored labels marking LiPo batteries as fire hazard will be made and used according to the vehicle launch procedure in Appendix A. In addition, the batteries will be protected. See avionics and electronics sled sections to how batteries are mounted. | Planned |
| 2.23.1 | The launch vehicle will not utilize forward firing motors. | Demonstration | Forward firing motors are not present in the design of the vehicle which is located in section 3.1.2. | Complete |
| 2.23.2 | The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.) | Demonstration | The motor selected for the final launch vehicle is the K600-WH, which does not include titanium sponges. | Complete |
| 2.23.3 | The launch vehicle will not utilize hybrid motors. | Demonstration | The motor selected for the final launch vehicle is the K600-WH, which is not a hybrid motor. | Complete |
| 2.23.4 | The launch vehicle will not utilize a cluster of motors. | Demonstration | The vehicle shall be designed to only require a single K600-WH motor to achieve the target apogee of 5000 feet. Simulations using this single motor are present in section 3.4. | Planned |

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| 2.23.5 | The launch vehicle will not utilize friction fitting for motors. | Demonstration | The launch vehicle shall use a standard motor retainer. This design is present in CAD drawings in section 3.1.3. | Planned |
| 2.23.6 | The launch vehicle will not exceed Mach 1 at any point during flight. | Analysis | Simulations shall be conducted using OpenRocket and RASAero and velocity graphs shall be examined to ensure the vehicle does not exceed Mach 1 at any point during flight. | Complete |
| 2.23.7 | Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast). | Demonstration | The team will weigh all components to ensure that the vehicle ballast will not exceed 10% of the total unballasted weight of the launch vehicle. | Planned |
| 2.23.8 | Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter). | Demonstration | The team will measure the power supply to ensure that any individual transmitter does not exceed 250 mW of power. | Planned |
| 2.23.9 | Transmitters will not create excessive interference. Teams will utilize unique frequencies, hand shake/passcode systems, or other means to mitigate interference caused to or received from other teams. | Demonstration | The team will use unique frequencies, hand shake/passcode systems, or other means to mitigate interference. | Planned |
| 2.23.10 | Excessive and/or dense metal will not be utilized in the construction of the vehicle. | Demonstration | Structural airframe elements are not manufactured from metal. See section 3.1.2.1 for construction of the launch vehicle materials. The construction for the launch vehicle reported in the FRR will reflect the completion of this requirement. | In progress |

**Table 6.4: Individual Verification of Recovery System Requirements**

| No. | Requirement Description | Type of Verification | Plan | Status |
|---|---|---|---|---|
| 3.1 | The full scale launch vehicle will 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. | Demonstration | The recovery subsystem utilizes a dual-deployment recovery system as shown in section 3.3.11. The full scale recovery system will be demonstrated additionally during the Vehicle Demonstration Flight. | Ongoing |
| 3.1.1 | The main parachute shall be deployed no lower than 500 feet. | Inspection | Flight data regarding parachute deployment is included in 3.2. | Ongoing |
| | | Demonstration | SubScale fights will display parachute deployment at 700 feet for primary charges and 600 feet for secondary. Altimeter and charge integrity will be confirmed as part of the pre-flight checklist. | Complete |
| | | | Full scale fights will display parachute deployment at 700 feet for primary charges and 600 feet for secondary. Altimeter and charge integrity will be confirmed as part of the pre-flight checklist. | Planned |
| 3.1.2 | The apogee event may contain a delay of no more than 2 seconds. | Inspection | Flight data regarding parachute deployment of the VDF will be included in the FRR. | Planned |
| | | Demonstration | SubScale flights will display compliance with [DC.11]. Altimeter and charge integrity will be confirmed as part of the pre-flight checklist. | |

| | | | | |
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| | | | Fullscale flights will display compliance with [DC.11]. Altimeter and charge integrity will be confirmed as part of the pre-flight checklist. | |
| 3.1.3 | Motor ejection is not a permissible form of primary or secondary deployment. | Demonstration | The vehicle will retain its motor with a screw on collar in compliance with [M.4] | Complete |
| 3.2 | Each team will perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale vehicles. | Demonstration | The team will perform ground ejection test according to the test plan in section 6.1.1.4 | Planned |
| 3.3 | Each independent section of the launch vehicle will 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. | Analysis | The team simulated the kinetic energy of all independent sections to ensure they are less than 75 ft-lbfs. | In progress |
| | | Testing | After the VDF, the team will calculate and report the landing kinetic energies of all independent sections. | Planned |
| | | Demonstration | The launch vehicle will take the analysis and testing results to alter the design of the vehicle if the requirement is not yet met. The team will demonstrate the results of this work and completion of this requirement at Launch Week. | Planned |
| 3.4 | The recovery system will 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. | Demonstration | The team uses COTS altimeters designed for recovery events, the RRC3 and the EasyMini. See section 3.3.9 | Complete |
| 3.5 | Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries. | Demonstration | Both altimeters are independently powered by Lipo batteries (see section 3.3.9) | Complete |
| 3.6 | Each altimeter will be armed by a dedicated | Demonstration | The mechanical switch that the team uses is a | Complete |

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| | 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. | | screw switch that is turned on via a screw from the outside of the vehicle. | |
| 3.7 | Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces). | Demonstration | These screw switches were locked ON for subscale flight. The same screw switches will be used on the full-scale vehicle. | Complete |
| 3.8 | The recovery system, GPS and altimeters, electrical circuits will be completely independent of any payload electrical circuits. | Demonstration | The team has vehicle plans that have the recovery system, GPS, and altimeters independent of all payload electronics. See section 3.3.9 for details on payload electrical circuits. | Complete |
| 3.9 | Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment. | Demonstration | The team will design the vehicle so that removable shear pins will separate the main and drogue compartments. See section 3.3.10.1 on details on the recovery design with shear pins. | Complete |
| 3.10 | The recovery area will be limited to a 2,500 ft. radius from the launch pads. | Analysis | The team simulated the vehicle to ensure that the recovery radius is less than 2,500 ft. See section X for details on the simulations. | In progress |
| | | Testing | The tests for the subscale reflect completion of this requirement (see section 3.4)<br>The full-scale test of this requirement will be tested via the Eggtimer TX GPS flight path feature. | In progress |
| 3.11 | Descent time of the launch vehicle will 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. | Analysis | The team's mission performance predictions show the launch vehicle descending in less than 90 seconds. See section 3.2.6 for simulation details. | In progress |
| | | Inspection | The tests for the subscale reflect completion of this requirement (see section 3.4)<br>The full-scale test of this requirement will be tested via a video from launch to takeoff relaying | In progress |

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| | | | and recording flight events. | |
| 3.12 | An electronic GPS tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver. | Demonstration | The team will use an Eggtimer TX in the launch vehicle that transmits the coordinates to a receiver that connects to a Bluetooth phone to display location. See section 3.1 for location and installation plans. It is planned to be present on the full-scale vehicle. | Planned |
| 3.12.1 | Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic GPS tracking device. | Demonstration | The team has no section or payload component that lands untethered to the launch vehicle | Complete |
| 3.12.2 | The electronic GPS tracking device(s) will be fully functional during the official competition launch. | Testing | During the VDF, the team will test the GPS tracking device for functionality. | Planned |
| | | Demonstration | The GPS tracking device planned (see section 4.2.2) will be fully functional during the competition launch. | Planned |
| 3.13 | The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing). | Testing | The recovery system electronics will be tested during the VDF to ensure they are not adversely affected by other on-board electronics. During the subscale launch, this was already not the case. | Planned |
| 3.13.1 | The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device. | Demonstration | The team's altimeters are located in a separate compartment termed the avionics bay. See section 3.1.3 for the layout of the launch vehicle. | Complete |
| 3.13.2 | The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics. | Demonstration | The recovery system electronics will not receive interference from all other onboard transmitting devices. | In progress |
| 3.13.3 | The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid | Demonstration | | In progress |

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| | valves, and Tesla coils) to avoid inadvertent excitation of the recovery system. | | | |
| 3.13.4 | The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics. | Demonstration | | In progress |

**Table 6.5: Individual Verification of Payload Experiment Requirements**

| No. | Requirement Description | Type of Verification | Plan | Status |
|---|---|---|---|---|
| 4.1 | Design a payload that will autonomously upon landing receive RF commands and perform tasks based using an onboard camera system. If there is an extra payload experiment it must be included in all reports for flight safety review. | Demonstration | A payload system with an antenna, camera and supporting mechatronics will be flown. We will not be flying an extra payload. | Ongoing |
| 4.2.1 | Launch Vehicle shall contain an automated camera system capable of swiveling 360° to take images of the entire surrounding area of the launch vehicle | Demonstration | A payload bay door will open up to allow the antenna to access the Z axis. A motorized camera rotation system will allow the camera to rotate. | Ongoing |
| | | Testing | See Test Plan 7.1.2.2 for the planned demonstration of this. | Ongoing |
| 4.2.1.1 | The camera shall have the capability of rotating about the z axis. The z axis is perpendicular to the ground plane | Demonstration | An orientation sensor and a passive gimbal on the payload will allow it to have a system that can account for the rocket's orientation to allow the camera to be relatively perpendicular to the ground. | Complete |
| 4.2.1.2 | The camera shall have a FOV of at least 100° and a maximum FOV of 180° | Demonstration | The camera the team has decided to use has an FOV of 120°. This is present in the line-item budget in 6.7. | Complete |
| 4.2.1.3 | The camera shall time stamp each photo taken. The | Demonstration | The payload electronics system will have software | Planned |

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| | time stamp shall be visible on all photos submitted to NASA in the PLAR. | | onboard to timestamp each picture immediately after it is taken. See section 4.2 for demonstration of how the payload will accomplish this. This requirement will be demonstrated with the photos submitted in the PLAR. | |
| 4.2.1.4 | The camera system shall execute the string of transmitted commands quickly, with a maximum of 30 seconds between photos taken. | Demonstration | The mechatronics on board will be performed enough to quickly move the camera. See Test Plan 6.1.2.3 for the planned demonstration of this. | Planned |
| 4.2.3.3 | The payload system shall not initiate and begin accepting RAFCO until AFTER the launch vehicle has landed on the planetary surface. | Demonstration | The electronics on the payload will measure the altitude and the payload will only begin accepting RAFCO when the electronics have detected a consistent altitude change of zero feet. The code is being written to reflect this, and its completion will be demonstrated during the VDF. | Planned |
| 4.2.4 | The payload shall not be jettisoned. | Demonstration | The payload will not leave the airframe during the duration of flight. See section 4.9 for the complete payload flowchart. | Complete |
| 4.2.5 | The sequence of time-stamped photos taken need not be transmitted back to the ground station and shall be presented in the correct order in our PLAR. | Demonstration | The payload receiving hardware will only have the capability to receive data. (See section 4.2.1 on the receiver on the payload).<br>The photos will be present in the FRR. It is the payload lead's responsibility to include them. | Planned |
| 4.3.1 | Black Powder and/or other similar energetics are only permitted for deployment of in-flight recovery systems, not for any surface operations. | Demonstration | The payload system will not use any energetics similar to black powder, and black powder is only used in the recovery system see section 3.3.10 for details on our usage of black powder. | Complete |
| 4.3.2 | Teams shall abide by all FAA and NAR rules and regulations | Demonstration | The team will follow the Guidelines provided by the FAA by keeping communication lines open with NAR club members on the status of waivers, as well as not designing or launching a vehicle that violates Chapter 31 Section 2 of FAA Order JO 7400.2. | Ongoing |

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| | | | The Vice President and Safety Officer communicate with the RSO and senior members of the launch club to understand all their guidance and rules. They will then communicate the information with the rest of the club. See section 7 for the item in the checklists | |
| 4.3.3 | Any secondary payload experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement the CDR milestone by NASA | Inspection | The team is not flying an additional payload experiment | Complete |
| 4.3.4 | Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS | Inspection | The team does not plan on using unmanned aircraft systems (UAS) for our payload. | Complete |
| 4.3.5 | Teams flying UASs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112–95 Section 336; see https://www.faa.gov/uas/faqs). 4.3.6. Any UAS weighing more than .55 lbs. shall be registered with the FAA and the registration number marked on the vehicle. | Inspection | The team does not plan on using unmanned aircraft systems (UAS) for our payload. | Complete |
| 4.3.6 | Any UAS weighing more than 0.55 lbs. Shall be registered with the FAA and the registration number marked on the vehicle. | Inspection | The team does not plan on using unmanned aircraft systems (UAS) for our payload. | Complete |

**Table 6.6: Individual Verification of Safety Requirements**

| No. | Requirement Description | Type of Verification | Plan | Status |
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| 5.1 | The team will use a launch and safety checklist | Demonstration | The team designates a day planner that presides over the master checklists during launch day. The day planner also designates a person in charge of each section of the launch prep checklists (payload, avionics, etc).<br>The safety checklist is maintained by the Safety Officer during launch prep and construction. See section 7for these checklists. | Ongoing |
| 5.2 | The team will identify a Safety Officer | Inspection | The team has and will continue to report who the safety officer is in every deliverable and maintain the position as part of the officers of the club according to the university.<br>See section 6 for this identification. | Complete |
| 5.4 | The team will abide by the RSO and the NAR or TRA club at any launch they attend | Demonstration | See General Requirement 4.3.2 | Ongoing |
| 5.5 | Teams will abide by all rules set forth by the FAA | Demonstration | See General Requirement 4.3.2 | Ongoing |

## 6.3. Derived Requirements

### 6.3.1. Vehicle

**Table 6.7: Vehicle requirements verification**

| No. | Requirement Description | Justification | Type of Verification | Verification Plan | Status |
|---|---|---|---|---|---|
| Vehicle | | | | | |
| V.1 | The team shall only launch at club launch sites our mentor has | -Easy presence of club members and mentor | Demonstration | The safety officer will only allow launches to proceed if the assigned mentor is capable of accessing the | Planned |

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| | access to. | | | site. | |
| V.3 | The launch vehicle shall have three sections | -(HB 2.4) The vehicle will have no more than four sections<br>-Complexity and risk is reduced<br>-Team already has experience with 3-section vehicles<br>-Team sees no reason for fourth section to achieve goals | Demonstration | The vehicle will consist of payload, main parachute, and booster sections. These are evident in the design drawings included in section 3.1.3. | Complete |
| V.4 | The order of sections from aft to fore is booster, followed by avionics and main tube, followed by payload. | -Booster section is the aft-most section due to the motor<br>-Mounting the avionics bay adjacent to the booster section allows the motor ejection charge to act as a failsafe in case both ejection charge systems fail. Drogue parachute is stored inside the booster tube, so the ejection charge would push out the drogue.<br>-Payload tube is at the fore of the vehicle so it can quickly release from the recovery harness on the ground | Inspection | Design drawings show the vehicle design and stack layout in section 3.1.3. | Complete |
| V.5 | All critical structural components shall be either manufacturer-specified to the full expected load or determined to meet load requirements with a safety factor of 3. | -(HB 2.3) Vehicle must be recovered in reflyable condition A safety factor of 3 is commonly used in industry for strength-critical components. | Analysis, Test, Inspection | Exact verification methodology of this requirement is specified per-component, and may be performed via either inspection of part specifications, test of components under simulated loads, or analysis of forces encountered. | Ongoing |

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| V.6 | All components which are only critical to usability and will not affect vehicle operation will be determined to meet the full expected load. | -(HB 2.3) Vehicle must be recovered in reflyable condition As usability failure modes do not affect the safety of the vehicle, they are not subject to requirement V.5, but damage to these parts would affect the reusability of the vehicle, so they must still be robust enough for all expected flight loads. | Analysis, Test, Inspection | Exact verification methodology of this requirement is specified per-component, and may be performed via either inspection of part specifications, test of components under simulated loads, or analysis of forces encountered. | Ongoing |
| Airframe |  |  |  |  |  |
| AF.1 | Vehicle will be constructed from 4-inch tube | -(M.3) Vehicle will be sized to reach the target altitude on a K-class motor<br>-(HB 2.15) The launch vehicle will have a minimum thrust to weight ratio of 5:1<br>-4-inch tubes are commercially available and at reasonable cost | Inspection | The vehicle will be constructed with fiberglass tubing of 4 inch diameter to account for the payload size and to endure the forces of flight. This is displayed in the design drawings and CAD in 3.1.3. | Ongoing |
| AF.2 | Vehicle will be constructed from fiberglass tubing | -(AF.1) Vehicle will be constructed from 4-inch tube<br>-(V.2) Vehicle must be built to withstand all forces of flight with significant margin<br>-Fiberglass is strong and commercially available | Demonstration | Fiberglass tubing is described as the airframe material of choice in section 3.1.2.1. | Ongoing |
| AF.3 | Main vehicle tubing will have a wall thickness of 0.05 inch | -(1.7) The vehicle must be built to withstand all forces of flight. | Inspection | The fiberglass tube will be measured with a caliper upon arrival to ensure wall thickness. | Ongoing |
| Aerodynamics |  |  |  |  |  |

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| AD.1 | The target altitude for the launch vehicle will be 5,000 feet | -(HB 2.1) The vehicle will deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground Level<br>-Provides as much margin in each direction as possible<br>-(M.3) Reachable on a K-Class motor | Test | The subscale will launch and collect altitude data to compare to simulated apogee. Simulations will be adjusted to more effectively estimate apogee. The data can be viewed in section 3.2. | Complete |
| | | | Analysis | Simulations are run to confirm the launch vehicle's ability to reliably achieve the target altitude of 5,000 feet. | |
| AD.2 | The launch vehicle will use fins to provide aerodynamic stability | -(HB 2.14) The launch vehicle must have a static stability margin of at least 2.0 at rail exit | Inspection | The vehicle's use of fins for aerodynamic stability is displayed in the CAD drawings at 3.1.3. | Complete |
| AD.3 | The launch vehicle will use a trapezoidal fin design | -(AD.2) The launch vehicle will use fins to provide aerodynamic stability<br>-(HB 2.3) Vehicle must be recovered in reflyable condition | Inspection | The vehicle's utilization of trapezoidal fin design is displayed in the CAD drawings at 3.1.3. | Complete |
| AD.4 | The fins will be constructed from fiberglass. | -(HB 2.3) Vehicle must be recovered in reflyable condition<br>-(AV.4) The launch vehicle shall be recoverable in a state sufficient to allow failure analysis in the event of a complete loss of electrical power<br>-Fiberglass is commercially available at a reasonable cost and has proven in past flights to survive failed landings without significant damage | Inspection | The use of fiberglass in the construction of fins will be observed by visually verifying the sheet the fins are cut out of is fiberglass. | Ongoing |
| AD.5 | The vehicle will use 4 | -(AD.2) The launch vehicle will | Inspection | As seen in CAD section 3.1.3 | Planned |

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| | fins mounted at the booster section. | use fins to provide aerodynamic stability<br>-(HB 2.16) Any structural protuberance on the rocket will be located aft of the burnout center of gravity<br>-(V.4) The order of sections from aft to fore is booster, followed by avionics and main tube, followed by payload.<br>- 4 fin design provides more stability than 3. | | | |
| AD.6 | Fins shall be mounted such that two pairs of collinear fins are perpendicular to each other and the airframe. | -(AD.2) The launch vehicle will use fins to provide aerodynamic stability<br>-(AD.5) The vehicle will use 4 fins mounted at the booster section<br>- Perpendicular arrangement of fins provides the most stability in a 4 fin design. | Inspection | A fin jig shall be used during the construction process to ensure components are mounted in the correct orientation.<br><br>Actual angles may be measured and confirmed prior to launch day to ensure compliance. | Planned |
| AD.7 | Vehicle will use a nose cone to provide aerodynamic stability | -(HB 2.14) The launch vehicle must have a static stability margin of at least 2.0 at rail exit | Inspection | See CAD drawings at 3.1.3. | Complete |
| AD.8 | The nose cone shall be a long ogive | -Long ogive provides high aerodynamic efficiency at subsonic speeds<br>-Shape provides more internal room for mounting electronic components | Demonstration | The vehicle's utilization of a long ogive shaped nose cone can be determined when viewing the CAD drawings at 3.1.3. | Complete |
| | | | Inspection | The vehicle's utilization of long ogive shaped nose cone can be easily determined via a simple observation. | |
| AD.9 | The exterior of the rocket shall be smooth | -(HB 2.16) Any structural protuberance on the rocket will | Inspection | The vehicle's painted exterior can easily be determined via a simple | Planned |

| | | | | | |
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| | and finished. | be located aft of the burnout center of gravity<br>-(HB 2.14) The launch vehicle must have a static stability margin of at least 2.0 at rail exit | | observation. | |
| Motor | | | | | |
| M.1 | The launch vehicle will use a common and reliable igniter | -(HB 2.7) The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system.<br>-(HB 2.9) Each team shall use commercially available ematches or igniters.<br>-Reduce chance of motor failure or off-nominal ignition sequence | Demonstration | The vehicle’s K600-WH motor comes with an igniter that will be used for the launch. | Planned |
| M.2 | The motor will use an ejection charge | - In the event of a total failure of avionics, the motor ejection charge will ensure the vehicle is recovered using at least a drogue | Inspection | The vehicle's utilization of a K600-WH motor is described | Planned |
| M.3 | Vehicle will not fly on a motor larger than a K-class | -(HB 2.12) total impulse will not exceed 5,120N s<br>-(M.2) The motor will use an ejection charge (L-class motors have no ejection charges) | Inspection | The vehicle's utilization of a K600-WH motor shown in 3.4.3. | Planned |
| M.4 | The Vehicle will use a K600-WH motor. | - (AD.1) The target altitude for the launch vehicle will be 5,000 feet<br>- (M.2) The motor will use an ejection charge<br>- (M.3) The motor will use an ejection charge | Inspection | The vehicle's utilization of a K600-WH motor is shown in 3.4.3.d | Planned |

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| M.5 | The motor will be retained by a screw-on collar retainer | -(HB 2.23.5) The launch vehicle will not utilize friction fitting for motors. | Inspection | The vehicle’s utilization of a screw-on collar retainer is described in 3.1.6.3. | Planned |

### 6.3.2. Recovery

**Table 6.8: Recovery requirements verification**

| No. | Requirement | Justification | Type of Verification | Verification Plan | Status |
|---|---|---|---|---|---|
| Descent Control | | | | | |
| DC.1 | The parachute will be of toroidal design | -Highest drag coefficient of parachute options<br>-Lightest for the required performance | Inspection | Upon delivery of the parachute, the shape will be observed. | Complete |
| DC.2 | The parachute diameter will be a maximum of 72in | -The next size up will exceed the descent time and/or drift requirements depending on wind at the launch site. | Inspection | Upon delivery of the parachute, the diameter will be measured | Complete |
| DC.3 | The parachute diameter will be a minimum of 49.2 in | -Calculations show that minimum diameter to achieve less than 55 ft lbf on the heaviest section is 49.2 in | Inspection | Upon delivery of the parachute, the diameter will be measured | Complete |
| DC.4 | The vehicle will not descend faster than 22.3ft/s under the main parachute. | (DC.9) Each section of the vehicle will not exceed 55 ft lbf of kinetic energy on landing<br>(HB 2.3) Vehicle must be recovered in a reusable condition | Analysis | Two separate performance simulations shall be performed using manufacturer-provided data to ensure that descent rate under main does not exceed the maximum safe speed | Complete |
| DC.6 | The vehicle will not descend faster than | -Ensures integrity of main parachute at deploy | Analysis | Two separate performance simulations shall be performed | Complete |

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| | 140 ft/s under drogue | -Reduces jerk on payload | | using manufacturer-provided data to ensure that descent rate under drogue does not exceed the maximum safe speed | |
| DC.7 | The drogue parachute will be no smaller than 10in | (DC.6) Vehicle will not descend faster than 170 ft/s under drogue | Inspection | Upon delivery of the parachute, the diameter will be measured | Planned |
| DC.8 | The drogue parachute will be no larger than 24in | (DC.5) Vehicle will have a descent time of less than 80 seconds | Inspection | Upon delivery of the parachute, the diameter will be measured | In progress |
| DC.9 | Each section of the vehicle will not exceed 60 ft lbf of kinetic energy on landing | (HB 3.3) 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.<br>-Gives ample margin to achieve bonus points<br>-Ensures that an unexpected reduction in parachute performance will still result in landing under the kinetic energy limit of 75 ft lbf | Analysis | Calculations of kinetic energy as a function of descent rate shall be performed and the maximum descent rate will be used to inform requirement DC.4 | Ongoing |
| DC.10 | The vehicle will utilize a kevlar recovery harness. | -(HB 2.3) The launch vehicle must me recoverable and reusable<br>Kevlar is nearly immune to damage from heat and has proven reliable in multiple past team projects. | Inspection | The harness is stored in a labeled bag between launches denoting size and material. Previous launches involving black powder did not damage the harness. | Complete |
| DC.11 | The vehicle will have no greater than a one second apogee event delay | -(HB 3.1.2) | Demonstration | Before the vehicle is launched, a black powder test shall be conducted according to the checklist in section 7. | Planned |
| Avionics | | | | | |

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| AV.1 | The avionics sled shall be 3D printed | -(HB 3.3) To minimize the total weight of the vehicle, which will ensure the kinetic energy of the vehicle will not exceed 75 ft-lbf.<br>-Team had trouble with a wooden bay in previous competitions<br>-Electronics locations can be integrated much more easily<br>-Will be printed as one piece, increasing structural strength<br>-Ease of manufacturing | Inspection | The avionics sled shall be verified as viable for 3D printing by two team members before manufacturing. | Complete |
| AV.2 | The launch vehicle will have batteries capable of supporting flight for 4 hours | -(HB 2.6) The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components<br>-Gives extra time<br>-Accounts for any battery decay that may appear | Analysis | Battery life of avionics components shall be estimated based on quoted maximum current draw. | Ongoing |
| | | | Test | A battery endurance test shall be conducted according to section 6.1.2.8 in which the vehicle's electronics are prepared in the launch configuration and left on until the batteries are drained. | Planned |
| AV.3 | The launch vehicle will use lithium-ion batteries. | (HB 2.5) The launch vehicle will have batteries capable of supporting flight for at least a two-hour delay<br>-Li-Po batteries are commercially available<br>-Li-Po batteries will fit our size constraints | Inspection | The safety officer shall inspect the avionics bay before flight to ensure that the correct batteries are installed. | Planned |
| AV.4 | The launch vehicle shall be recoverable in a state sufficient to allow failure analysis in the event of a complete loss of | -Complete-power-off failure in a past flight caused complete destruction of the vehicle and electronics, making analysis of the cause of the failure difficult. | Inspection | According to M.4, a K600 motor shall be used which contains a motor ejection charge. With the vehicle layout shown in section 3.1, the motor ejection charge will deploy the drogue parachute | Planned |

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| | electrical power. | | | should the avionics fail. | |
| AV.5 | A hard plastic shell will shield all LiPos from impact | (HB 2.22) LiPos will be protected from impact with the ground | Inspection | Present in CAD drawings in section 3.3.9 for the avionics bay and section 4.8 for the payload. | Complete |
| AV.6 | All major avionics bay components shall be mounted on a single planar face of the sled | -Wiring shall be double-checked before powering<br>-Mounting components on a single side greatly increases ease of component inspection | Inspection | Two team members shall independently verify that all components are accessible before the part is manufactured. | Ongoing |
| AV.7 | The avionics sled shall be mounted on a pair of threaded rods at a spacing of 3 inches center-to-center | (AV.6) All major avionics bay components shall be mounted on a single planar face of the sled<br>Past projects have shown a 3-inch center-to-center distance to be sufficient space for electronics to be mounted on a single face | Inspection | Two team members shall independently verify that the center-to-center distance is correct before part is manufactured. | Ongoing |
| Separation System | | | | | |
| SS.1 | The separation system will use black powder for actuation | (HB 2.3) Vehicle must be recovered in reflyable condition<br>-Black powder has proven to be reliable<br>-Black powder is commercially available<br>-The team has experience with black powder separation | Inspection | Locations for black powder charges are shown in section 3.1.4. The construction and preparation of the vehicle will be documented in the FRR. | Planned |
| SS.2 | The separation system will use nylon shear pins sized sufficiently to prevent adverse separation | (HB 3.9) Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment<br>-Nylon shear pins are easily obtainable and have significant heritage in past team designs and throughout high-power rocketry | Inspection, Analysis | Present in CAD drawings in section 3.1.3.<br>Shear pin sizing verified in section 3.3.10.1 | Planned |

### 6.3.3. Payload

**Table 6.9: Payload Requirements Verification**

| No. | Requirement Description | Justification | Type of Verification | Plan | Status |
|---|---|---|---|---|---|
| APRS Antenna | | | | | |
| AA.1 | The antenna must be deployed so that it is angled less than 40 degrees from the positive Z direction. | In testing, leaving the antenna stowed within the launch vehicle, parallel to its length, leads to poor reception if the vehicle lands aimed toward the transmitter. Angling the antenna up ensures that this is not possible. | Demonstration | Once deployed, the antenna's angle from the positive Z direction will be measured to ensure it is less than 40 degrees. | Planned |
| AA.2 | The antenna must be securely attached to the servo designated for its deployment. | If the antenna detaches from the deployment servo, it will not be deployed properly out of the vehicle body and will fail to receive adequate reception. | Demonstration | The antenna will be shaken to ensure that it is not loose and will remain securely attached to the servo designated for its deployment. | Planned |
| APRS Radio | | | | | |
| AR.1 | The APRS radio packet loss rate must be less than twenty five percent. | If packet loss occurs, there will be a loss of transmission data vital to the reception of commands. | Analysis | The APRS will be tested for packet loss by observing the signal for any loss of transmission data. | Ongoing |
| AR.2 | All cable interconnections between the SBC, SDR, and antenna are secure. | If any of these cables fail during flight, the payload will not be able to receive RAFCO commands. | Inspection | When integrating the payload, we apply zip ties on all connections that do not screw on. For screw connections, we will tighten until the connection no longer freely moves. | Planned |
| Single | | | | | |

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| Board Computer |  |  |  |  |  |
| SC.1 | A flight computer's software must be able to be set up from scratch within 30 minutes. | If any part of the flight computer breaks, like an SD card, EMMC flash, or SBC, we need to be able to easily set up a new flight computer quickly and ensure that we know precisely how to do it. We also want to create multiple, identical flight computers easily. | Demonstration | From boot, the software on the flight computer will be timed to ensure that it can be set up within 30 minutes. | Planned |
| SC.2 | All software components must be able to be automatically restarted in case it freezes or becomes unresponsive. | In some of our testing, various components froze during exceptional conditions  and did not recover unless manually restarted. | Analysis | Software components will have a failsafe watchdog mechanism to ensure that the software will be automatically restarted to continue processing data. | Planned |
| SC.3 | System resources must not be exhausted by the software, and there must be sufficient headroom to account for variance without lag. | If the SBC runs out of CPU or memory, the software could lag significantly, causing us to lose radio packets or fail to meet the 30 second cutoff. If we run out of disk space, the photos taken by the camera could fail to be saved. | Testing<br>Demonstration | During simulated and actual flights, real-time statistics will be logged including memory usage, CPU usage, and disk usage. We can use this data to ensure that there is proper headroom on all system resources | Planned |
| Camera Payload |  |  |  |  |  |
| CP.1 | The main avionics sled plate will have a maximum width of 95% of the total airframe diameter. | To prevent any component damage that may arise and ensure a snug fit with the airframe. This prevention also allows for vertical space along the length of the vehicle for daughter boards. | Demonstration | The avionics bay will be fitted on a full-scale tube and measured to ensure that it falls below the maximum width of 95% of the total airframe diameter. | Complete |

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| CP.2 | Maximum runtime of 20 seconds between picture capture commands. | To ensure that there is plenty of time to meet the handbook’s 30-second limit, the team will achieve a runtime of 20 seconds. This will necessitate a safety factor in case of any unexpected interference or lag. | Analysis | The software | Planned |
| CP.4 | The camera’s lens must be clean. | A clean lens is required to ensure that it can take clear images. | Inspection | The lens will be cleaned, if needed, prior to flight. | Planned |
| Bay Door Deployment | | | | | |
| DD.1 | The bay door must open to at least 100 degrees. | This is to ensure the camera can pass through the airframe unimpeded. This would also ensure the bay door would stay open after the actuation has been completed. | Demonstration | The mounting position and the hinges will have enough rotational freedom to ensure the camera can deploy out of the air frame. | Complete |
| Camera Deployment | | | | | |
| CD.1 | The payload shall be separated from the airframe after landing. | From previous experience, the parachute often catches the wind and drags the vehicle after landing. The camera should also stay in the same orientation (per HB 4.2.1.1), so any additional wind forces would jeopardize this. | Demonstration | A quick release will be attached to a customized U bolt on the end of payload. A pulley system with a servo will pull the quick release cord to untether the parachute. | Planned |
| CD.2 | All deployable mechanisms shall be mechanically secured during flight. | This ensures that the payload can make it to its deployment phase in its proper orientation. Improper securing could result in unpredictable aerodynamics. | Demonstration | The gimbal mechanism will be attached to a supporting structure that is secured within the inside of the airframe. | Planned |
| CD.3 | Ejecting a tethered payload from the | If the payload is ejected (while still tethered to fulfill HB 4.2.4), we | Inspection | Ejecting the payload will require force either eliminated from black | Complete |

| | | | | | |
|---|---|---|---|---|---|
| | launch vehicle shall not be an option. | determined that the risk of interfering with recovery was too significant. | | powder or preloaded string, and both of them has the potential of damaging the payload | |
| CD.4 | All burn wire must be mounted within one inch of the airframe | To ensure that it is kept away from electronics and sensitive hardware near the center of the vehicle. | Demonstration | The burn wire will be mounted outside of the sled plate, which means there is a physical separation between burn wire and electronics. | Planned |
| Camera Stabilization | | | | | |
| CS.1 | The camera must come to rest within 10 degrees of the horizon (in all axes). Zero degrees is defined as the horizon in the center of the camera frame. | NASA requires the images to be “close to level showing a good balance of sky and ground using the horizon as a center line,” so the team set a qualitative limit based on what we could count as level. | Demonstration | A set of customized bearings connected to continuous servos will rotate the payload upon landing  so that the camera is pointing upright. In addition, the 4-bar lift is designed such that the first and last links are parallel. With the bearing to ensure the links are parallel with the gravity vector, this requirement is accounted for with the exception of the x/y axes. These are accounted for in CS.3. | Ongoing |
| CS.2 | Derived requirement CS.1 shall be met for every point within the 360 degrees of rotation. | A level camera is defined as the horizon line that will be within 450 pixels on the Y-axis of the camera. | Analysis<br>Testing | The camera will be on a passive gimbal that is 3D printed, which will allow the camera to see at least 60 degrees in the yaw direction and pitch direction. | Complete |
| CS.3 | The camera shall be mounted on a gimbal stabilization platform to allow | This is to ensure the camera will be level with the horizon according to CS.1. | Demonstration | The gimbal platform is labeled the Camera Stabilization System and is passive on two axes. See Section 4.1.1.5. | Ongoing |

| | | | | | |
|---|---|---|---|---|---|
| | for rotational control along the x and y axis parallel to the ground. | | | | |
| Quick Link | | | | | |
| CL.1 | The servo attached to the mechanism must have a minimum of 120 degrees of rotation. | This is to ensure that there is enough rotation in the servo to actuate the pulley-quick link mechanism successfully. | Demonstration | The quick link will be actuated utilizing a servo attached to a pulley mechanism. | Complete |
| Bay Legs | | | | | |
| BL.1 | The leg mechanism must deploy to a minimum angle of 90 degrees or greater perpendicular to the body tube. | In testing, we determined that such an angle of deployment would ensure an effective and successful support mechanism. | Demonstration | A 3d printed prototype will be fitted onto a bay frame and its deployment mechanism will be tested using torsion screws. | Complete |
| BL.3 | The burn wire must not melt. | Melting the burn wire would cause there to be hot, loose, conductive debris within the payload. This could interfere with many systems within the vehicle, including the camera deployment mechanism. | Demonstration | Instead of melting the wire, the team will burn a nylon fishing wire connecting the legs to the payload sled to release the legs.. Nylon is not conductive, so will cause no damage to surrounding components. | Planned |

## 6.4. Funding Plan

The Rose Rocketry USLI Team currently has budgeted $16,936.16, down from $17,368.09 reported in the PDR, for the 2023 competition season. The team currently has secured $20,400.00 from our school's Student Government Association, innovation centers, and outside donations. Of the project's 159 line items, including travel purchases, 120 have been ordered and received. 20 items have been ordered but not received. And, 19 items have yet to be ordered. Currently, funding provides minimal risk to the successful completion of the project. Notably from the PDR, the team has secured additional funding from our Student Government Association to bring our entire roster to competition. A summary of anticipated expenses by category is included below.

Although the final budget is lower, there are notable differences in the budget since the PDR. The team has decreased travel cost from $12,042.50 to $8,223.34 by utilizing an airbnb rental, as opposed to a hotel, and by reducing the number of vehicles rented to reflect our final travel roster. The team has spent more than initially budgeted in consumable supplies. Many of these items were not initially included in the budget due to being shared amongst all of Rose Rocketry, not just the USLI team. However, it was decided that the inclusion of these consumables better reflects the costs which would be spent if USLI did not share a budget. The full scale motors category has almost doubled in price due to ordering 4 k780 motors on Dec. 4th to ensure adequate stock for mission success. However, the team later decided to switch to the k600 to better meet mission altitude specifications. Lastly, the prototyping and materials for the payload electronics cost more than initially estimated but the mechanical components cost significantly less.

**Table 6.10: Team Budget**

| | |
|---|---|
| **Consumable Supplies:** | **$1,992.75** |
| **General Tools:** | **$871.24** |
| **Full Scale Vehicle:** | **$1,234.56** |
| **Full Scale Motors:** | **$1,979.45** |
| **Subscale Vehicle:** | **$749.72** |
| **Subscale Motors:** | **$154.73** |
| **Payload Mechanical:** | **$441.96** |

| | |
|---|---|
| **Payload Electrical:** | **$1,224.02** |
| **Travel and Lodging:** | **$8,223.34** |
| **Total:** | **$16,936.16** |

## 6.5. Funding Acquisition Plan

The team receives a baseline level of yearly funding through a university program which supports various competition teams, as well as the Student Government Association (SGA). These are requested during the prior academic year, and take effect September of the following year. The team also applied for travel funding via a “one-time funding request” process, which allots additional SGA funds on a case-by-case basis. In addition, we have been raising outside funds through alumni donations, social media donations, and grants. A summary of the funding sources is provided below.

**Table 6.11: Team Funding Sources**

| | |
|---|---|
| **Student Government Association Baseline Budget:** | **$8,500.00** |
| **Student Government Association Travel Funding Request:** | **$8,000.00** |
| **Branam Innovation Center Baseline Budget:** | **$1,500.00** |
| **Outside Donations:** | **$2,400.00** |
| **Total:** | **$20,400.00** |

Rose Rocketry USLI is a sub-team of the Rose Rocketry university club. The club shares a budget amongst all sub-teams and projects. Since the PDR other Rose Rocketry teams have also secured additional funding in the form of grants. This has in turn increased the amount of funding available to our USLI competition team. All figures included in this document reflect funding designated specifically to the Rose Rocketry USLI team.

**Table 6.12: Team Budget and Funding Sources**

| | | | | | |
|---|---|---|---|---|---|
| **Budget Total:** | **$16,936.16** | **Future Spending:** | **$9,648.07** | **Funding Secured Total:** | **$20,400.00** |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| To-date Spent: | $7,288.10 | Future spending without Travel: | $1,424.73 | Remaining Funds to Secure: | $0.00 |

## 6.6. Material Acquisition Plan

Rose-Hulman Institute of Technology has specific workflows to follow, depending on the source of funding being used to acquire materials. All material orders, regardless of funding source, start by placing the desired item, link to purchase, price, quantity, and other related information into a spreadsheet which is maintained by our treasurer. To ensure parts are ordered in a reasonable time for mission success, the treasurer compiles purchase requests from the master spreadsheet every Monday and Wednesday. It is the responsibility of the treasurer to set intermediate purchasing deadlines for internal deadlines, e.g subscale vehicle materials. The subteam leads are responsible for final decisions on component choices and their entry into the master spreadsheet.

After the team treasurer compiles a purchase request it is sent to the innovation center office where the funds are pulled from the specified account and the order is placed. When a manufacturer sends the team material it is first delivered to the university mailroom, then the innovation center, and finally the team workspace. The compiling of purchase orders from the treasurer, communication with the innovation center, and shipping through campus mail, can add multiple days of overhead to material acquisition.

The twice weekly purchase request and enforcement of ordering deadlines by the team treasurer ensure the team will always have the materials necessary for project success. For example, all subscale vehicle parts were ordered on October 4th. Upon checking on the order status October 19th, the team learned a miscommunication within the innovation center resulted in the order never being placed. However, the subscale vehicle materials were ordered the following day on October 20th, with confirmation, and will still arrive within the allotted time frame to construct and launch on November 12th.

The team has implemented two procedures since the PDR to address parts arriving at our workbay or being lost once arriving at our workbay and supply chain issues. First, packages which arrive in our workbay are to be immediately opened and the contents placed into the appropriately labeled clear bin, shown in the figure 8.1 below. Only the team member who ordered the item, or a delegated replacement, is to sort and organize an item away into team storage. This is to address a growing issue of losing parts from different team areas which are shipped together. Due to the frequency at which we order parts, sharing an address with other competition teams, and all competition team order's being placed by the innovation center office, items from multiple teams often are placed on the same order and occasionally are lost. For example, if we place a McMaster Carr order on the same day as one of the robotics teams, they will likely be placed on the same order by the innovation office and it is up to the innovation office to open and currently sort the package contents once they arrive. Since the implementation of the procedures for arriving packages on November 28th, no items have been lost.

**Figure 8.1: Clear, Labeled Bins for Received Packages**

The second issue the team has addressed is supply chain issues regarding airframe components, including the added internal ordering complications mentioned above. Following the incident ordering subscale vehicle parts, described above, and other Rose Rocketry teams requiring 3 and 4 inch air frames, the team has decided to always keep two 5 foot sections of 3 inch fiberglass airframe, two 5 foot 4 in fiberglass airframe, two feet of 3 inch fiberglass coupler, and two feet of 4 inch fiberglass coupler. Due to the projects built by Rose Rocketry, most project's utilized a majority, if not all, of a 5 foot airframe. Any team member who uses a 5 foot airframe or coupler notifies the treasurer immediately to replace the used stock. The team has decided the one-time, upfront cost of material is outweighed by the reduced project risks of missing launch deadlines due to inadequate stock.

## 6.7. Line Item Budget

**Table 6.13: Status Legend**

| Color | Status | Quantity |
|---|---|---|
| 🟥 | Not Ordered | 19 |
| 🟨 | Ordered | 20 |
| 🟩 | Received | 120 |
| | **Total** | **159** |

**Table 6.14: Line item budget**

| Item | Unit Cost | Quantity | Tax % | Shipping and other fees (e.g hazmat) | Total Cost | Vendor | Area of use | Status |
|---|---|---|---|---|---|---|---|---|
| 4 X AA battery holder | $10.00 | 1 | 8.00% | $0.00 | $10.80 | Amazon | Consumable Supplies | Ordered |
| Blue Tape (3-pack) | $9.99 | 1 | 8.00% | $0.00 | $10.79 | Amazon | Consumable Supplies | Ordered |
| white spray paint | $7.00 | 1 | 8.00% | $0.00 | $7.56 | Amazon | Consumable Supplies | Ordered |
| M3 screws of different sizes | $11.00 | 1 | 8.00% | $0.00 | $11.88 | Amazon | Consumable Supplies | Ordered |
| XT30 | $12.00 | 2 | 8.00% | $0.00 | $25.92 | Amazon | Consumable Supplies | Received |
| velco wire tires | $7.00 | 1 | 8.00% | $0.00 | $7.56 | Amazon | Consumable Supplies | Received |
| purple spray paint | $6.00 | 1 | 8.00% | $0.00 | $6.48 | Amazon | Consumable Supplies | Received |
| Rose-red PETG | $27.99 | 1 | 8.00% | $0.00 | $30.23 | Amazon | Consumable Supplies | Received |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spool of velcro wire ties | $6.00 | 1 | 8.00% | $0.00 | $6.48 | Amazon | Consumable Supplies | Received |
| orange paint | $7.00 | 1 | 8.00% | $0.00 | $7.56 | Amazon | Consumable Supplies | Received |
| red paint | $7.00 | 1 | 8.00% | $0.00 | $7.56 | Amazon | Consumable Supplies | Received |
| blue paint | $7.00 | 1 | 8.00% | $0.00 | $7.56 | Amazon | Consumable Supplies | Received |
| red spray paint | $7.00 | 1 | 8.00% | $0.00 | $7.56 | Amazon | Consumable Supplies | Received |
| Screw switch | $7.00 | 10 | 8.00% | $3.00 | $78.60 | Chris' Rocketry | Consumable Supplies | Received |
| 36" X 48" fiberglass sheet | $185.00 | 1 | 8.00% | $15.00 | $214.80 | Composite Wharehouse | Consumable Supplies | Received |
| White 18AWG wire 100' | $34.06 | 1 | 8.00% | $20.00 | $56.78 | Digikey | Consumable Supplies | Received |
| Yellow 18AWG wire 100' | $34.06 | 1 | 8.00% | $0.00 | $36.78 | Digikey | Consumable Supplies | Received |
| Red 18AWG wire 100' | $34.06 | 1 | 8.00% | $0.00 | $36.78 | Digikey | Consumable Supplies | Received |
| Blue 18AWG wire 100' | $34.06 | 1 | 8.00% | $0.00 | $36.78 | Digikey | Consumable Supplies | Received |
| Green 18AWG wire 100' | $34.06 | 1 | 8.00% | $0.00 | $36.78 | Digikey | Consumable Supplies | Received |
| Orange 18AWG wire 100' | $34.06 | 1 | 8.00% | $0.00 | $36.78 | Digikey | Consumable Supplies | Received |
| Black wire 100' | $21.46 | 1 | 8.00% | $0.00 | $23.18 | Digikey | Consumable Supplies | Received |
| Yellow wire 100' | $21.46 | 1 | 8.00% | $0.00 | $23.18 | Digikey | Consumable Supplies | Received |
| Blue wire 100' | $21.46 | 1 | 8.00% | $0.00 | $23.18 | Digikey | Consumable Supplies | Received |
| Green wire 100' | $21.46 | 1 | 8.00% | $0.00 | $23.18 | Digikey | Consumable Supplies | Received |
| Orange wire 100' | $21.46 | 1 | 8.00% | $0.00 | $23.18 | Digikey | Consumable Supplies | Received |
| Whilte wire 100' | $25.38 | 1 | 8.00% | $0.00 | $27.41 | Digikey | Consumable Supplies | Received |
| Red wire 100' | $25.38 | 1 | 8.00% | $0.00 | $27.41 | Digikey | Consumable Supplies | Received |
| Black 18AWG wire 100' | $34.06 | 1 | 8.00% | $0.00 | $36.78 | Digikey | Consumable Supplies | Received |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| g-14 fiberglass 12x12 sheet | $35.00 | 1 | 8.00% | $15.00 | $52.80 | McMaster Carr | Consumable Supplies | Received |
| g10/cr fiberglass sheet | $25.00 | 1 | 8.00% | $0.00 | $27.00 | McMaster Carr | Consumable Supplies | Received |
| gp03 sheet | $13.00 | 1 | 8.00% | $0.00 | $14.04 | McMaster Carr | Consumable Supplies | Received |
| Wildman 3" tube | $112.81 | 2 | 8.00% | $25.00 | $268.67 | Wildman Rocketry | Consumable Supplies | Received |
| Wildman 4" tube | $128.43 | 2 | 8.00% | $0.00 | $277.41 | Wildman Rocketry | Consumable Supplies | Received |
| Wildman 1/8" G10 sheet | $19.80 | 10 | 8.00% | $0.00 | $213.84 | Wildman Rocketry | Consumable Supplies | Received |
| I600R motor | $115.49 | 2 | 8.00% | $0.00 | $249.46 | Wildman Rocketry | Consumable Supplies | Received |
| K600 source 2 | $172.90 | 3 | 8.00% | $30.00 | $590.20 | Animal Motor Works | Full Scale Motors | Not Ordered |
| K600 source 1 | $165.19 | 3 | 8.00% | $30.00 | $565.22 | Animal Motor Works | Full Scale Motors | Not Ordered |
| Fullscale motor | $172.90 | 4 | 8.00% | $30.00 | $776.93 | Animal Motor Works | Full Scale Motors | Ordered |
| Fullscale motor mount | $15.84 | 1 | 8.00% | $30.00 | $47.11 | Wildman Rocketry | Full Scale Motors | Received |
| Eggfinder antenna kit | $12.00 | 2 | 8.00% | $0.00 | $25.92 | Eggtimer | Full Scale Vehicle | Received |
| Eggfinder Kit | $80.78 | 2 | 8.00% | $0.00 | $174.48 | Eggtimer | Full Scale Vehicle | Received |
| U-bolts | $1.31 | 4 | 8.00% | $0.00 | $5.66 | McMaster Carr | Full Scale Vehicle | Received |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Charge caps (fullscale) | $1.23 | 4 | 8.00% | $0.00 | $5.31 | McMaster Carr | Full Scale Vehicle | Received |
| g-10 fr4 fiberglass sheet | $25.00 | 1 | 8.00% | $15.00 | $42.00 | McMaster Carr | Full Scale Vehicle | Received |
| Drogue chute | $28.50 | 1 | 8.00% | $8.00 | $38.78 | The RocketMan | Full Scale Vehicle | Not Ordered |
| Wildman 3" coupler | $2.54 | 24 | 8.00% | $25.00 | $90.84 | Wildman Rocketry | Full Scale Vehicle | Received |
| Coupler tube | $2.86 | 36 | 8.00% | $0.00 | $111.20 | Wildman Rocketry | Full Scale Vehicle | Received |
| Wildman 4" coupler | $2.86 | 24 | 8.00% | $0.00 | $74.13 | Wildman Rocketry | Full Scale Vehicle | Received |
| Wildman 38mm tube | $72.00 | 1 | 8.00% | $0.00 | $77.76 | Wildman Rocketry | Full Scale Vehicle | Received |
| Wildman 54mm tube | $79.20 | 1 | 8.00% | $0.00 | $85.54 | Wildman Rocketry | Full Scale Vehicle | Received |
| Airframe tube | $128.43 | 3 | 8.00% | $0.00 | $416.11 | Wildman Rocketry | Full Scale Vehicle | Received |
| Kevlar strap | $4.50 | 1 | 8.00% | $0.00 | $4.86 | Wildman Rocketry | Full Scale Vehicle | Received |
| Nose cone | $75.90 | 1 | 8.00% | $0.00 | $81.97 | Wildman Rocketry | Full Scale Vehicle | Received |
| safety cones | $12.00 | 1 | 8.00% | $0.00 | $12.96 | Amazon | General Tools | Ordered |
| box cutters | $13.00 | 1 | 8.00% | $0.00 | $14.04 | Amazon | General Tools | Ordered |
| 5 X 1ft ethernet cable | $13.00 | 1 | 8.00% | $0.00 | $14.04 | Amazon | General Tools | Ordered |
| 30mm linear rail for voxelab | $36.00 | 1 | 8.00% | $0.00 | $38.88 | Amazon | General Tools | Ordered |
| 128GB SD Card | $17.49 | 1 | 8.00% | $0.00 | $18.89 | Amazon | General Tools | Ordered |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ethernet adapter | $13.00 | 1 | 8.00% | $0.00 | $14.04 | Amazon | General Tools | Ordered |
| 3 X 3 foot usb micro cable | $15.00 | 1 | 8.00% | $0.00 | $16.20 | Amazon | General Tools | Received |
| 2 X usb wall charger | $10.00 | 1 | 8.00% | $0.00 | $10.80 | Amazon | General Tools | Received |
| Noisemakers | $26.99 | 1 | 8.00% | $0.00 | $29.15 | Amazon | General Tools | Received |
| 12 qt totes | $46.00 | 1 | 8.00% | $0.00 | $49.68 | Amazon | General Tools | Received |
| Soldering magnifier | $45.99 | 1 | 8.00% | $0.00 | $49.67 | Amazon | General Tools | Received |
| SD cards x5 | $17.00 | 2 | 8.00% | $0.00 | $36.72 | Amazon | General Tools | Received |
| 128gb sd card (2 pack) | $26.00 | 1 | 8.00% | $0.00 | $28.08 | Amazon | General Tools | Received |
| 2 rechargable battery packs | $25.00 | 1 | 8.00% | $0.00 | $27.00 | Amazon | General Tools | Received |
| Tweezers | $10.25 | 1 | 8.00% | $0.00 | $11.07 | Amazon | General Tools | Received |
| 2 X 6ft usb C cable | $11.00 | 1 | 8.00% | $0.00 | $11.88 | Amazon | General Tools | Received |
| 2 X 6ft usb C cable | $11.00 | 1 | 8.00% | $0.00 | $11.88 | Amazon | General Tools | Received |
| 128GB Micro SD Card | $17.00 | 1 | 8.00% | $0.00 | $18.36 | Amazon | General Tools | Received |
| rrc3 data cable | $25.00 | 1 | 8.00% | $0.00 | $27.00 | Animal Motor Works | General Tools | Received |
| eevblog multimeter | $130.00 | 1 | 8.00% | $15.00 | $155.40 | EEV Blog | General Tools | Received |
| Eggfinder Mini Kit | $59.50 | 1 | 8.00% | $8.00 | $72.26 | Eggtimer | General Tools | Received |
| Eggtimer Proton | $80.78 | 1 | 8.00% | $0.00 | $87.24 | Eggtimer | General Tools | Received |
| ESD Mat | $80.00 | 1 | 8.00% | $8.00 | $94.40 | ESD Mat | General Tools | Received |
| 2 X 25ft milwaukee tape measure | $20.00 | 1 | 8.00% | $0.00 | $21.60 | Home Depot | General Tools | Received |
| rubber ducky antenna | $12.00 | 1 | 8.00% | $0.00 | $12.96 | Amazon | Payload Electrical | Not Ordered |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| sma adapters | $13.00 | 1 | 8.00% | $0.00 | $14.04 | Amazon | Payload Electrical | Not Ordered |
| Screw Terminal Block | $6.88 | 1 | 8.00% | $0.00 | $7.43 | Amazon | Payload Electrical | Not Ordered |
| long sma cable (2 pack) | $10.00 | 1 | 8.00% | $0.00 | $10.80 | Amazon | Payload Electrical | Not Ordered |
| short sma cable (4 pack) | $13.00 | 1 | 8.00% | $0.00 | $14.04 | Amazon | Payload Electrical | Not Ordered |
| PWM Extension (LED Driver) | $2.94 | 5 | 8.00% | $0.00 | $15.88 | Amazon | Payload Electrical | Not Ordered |
| XBee®-PRO 900HP/XSC RF Modules | $65.44 | 2 | 8.00% | $0.00 | $141.35 | Amazon | Payload Electrical | Not Ordered |
| raspberry pi zero 2w | $80.00 | 2 | 8.00% | $0.00 | $172.80 | Amazon | Payload Electrical | Ordered |
| SMD291AXT5 Solder Paste | $21.99 | 1 | 8.00% | $0.00 | $23.75 | Amazon | Payload Electrical | Ordered |
| More flat jumper wires | $9.00 | 2 | 8.00% | $0.00 | $19.44 | Amazon | Payload Electrical | Ordered |
| SAM-M8Q | $31.50 | 1 | 8.00% | $0.00 | $34.02 | Amazon | Payload Electrical | Ordered |
| AideTek BOXALL96 96 Lids Enclosure SMD SMT Parts Organizer | $23.00 | 1 | 8.00% | $0.00 | $24.84 | Amazon | Payload Electrical | Received |
| 10 foot usb micro cable | $7.00 | 1 | 8.00% | $0.00 | $7.56 | Amazon | Payload Electrical | Received |
| Left, Right, and Straight Micro USB OTG Cables | $7.59 | 1 | 8.00% | $0.00 | $8.20 | Amazon | Payload Electrical | Received |
| Header pins | $6.00 | 1 | 8.00% | $0.00 | $6.48 | Amazon | Payload Electrical | Received |
| RTL-SDR Blog R820T2 RTL2832U 1PPM TCXO SMA Software Defined Radio | $29.95 | 2 | 8.00% | $0.00 | $64.69 | Amazon | Payload Electrical | Received |
| 5 qt plastic totes | $45.00 | 1 | 8.00% | $0.00 | $48.60 | Amazon | Payload Electrical | Received |
| 25x Female SMA connector | $10.99 | 1 | 8.00% | $0.00 | $11.87 | Amazon | Payload Electrical | Received |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| Mini HDMI Cable 1m | $16.44 | 2 | 8.00% | $0.00 | $35.51 | Amazon | Payload Electrical | Received |
| 22 pin Molex FPC cable | $2.53 | 3 | 8.00% | $0.00 | $8.20 | Amazon | Payload Electrical | Received |
| 22 pin Molex FPC cable flipped | $3.35 | 3 | 8.00% | $0.00 | $10.85 | Amazon | Payload Electrical | Received |
| 22 pin Molex FPC connector | $2.60 | 5 | 8.00% | $0.00 | $14.04 | Amazon | Payload Electrical | Received |
| RPi Pico | $4.00 | 1 | 8.00% | $0.00 | $4.32 | Amazon | Payload Electrical | Received |
| Digikey parts for motherboard | $89.65 | 1 | 8.00% | $0.00 | $96.82 | Amazon | Payload Electrical | Received |
| Wide Angle Pi Camera | $19.99 | 2 | 8.00% | $5.00 | $48.18 | ArduCam | Payload Electrical | Received |
| MPL3115A2 | $4.00 | 4 | 8.00% | $5.00 | $22.28 | Arrow | Payload Electrical | Received |
| 22 pin FPC breakout | $10.94 | 1 | 8.00% | $0.00 | $11.82 | Ebay | Payload Electrical | Ordered |
| Mini HDMI Socket breakout | $2.95 | 2 | 8.00% | $5.00 | $11.37 | Ebay | Payload Electrical | Ordered |
| Motherboard PCB | $66.20 | 1 | 8.00% | $10.00 | $81.50 | Oshpark | Payload Electrical | Received |
| Motherboard Paste Stencil | $22.51 | 1 | 8.00% | $5.00 | $29.31 | Oshpark | Payload Electrical | Received |
| 2 X pi zero 2w (from pihut) | $76.00 | 1 | 8.00% | $70.00 | $152.08 | PiHut | Payload Electrical | Received |
| Super-elastic Signal Stick: SMA male | $25.00 | 2 | 8.00% | $5.00 | $59.00 | Signal Stuff | Payload Electrical | Received |
| 360 degree micro servo (5 pack) | $13.00 | 1 | 8.00% | $0.00 | $14.04 | Amazon | Payload Mechanical | Not Ordered |
| Nylon cord | $5.26 | 1 | 8.00% | $0.00 | $5.68 | Amazon | Payload Mechanical | Ordered |
| Aidetek 28 transparent compartment | $9.00 | 1 | 8.00% | $0.00 | $9.72 | Amazon | Payload Mechanical | Ordered |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 48 pack double A battery | $17.00 | 1 | 8.00% | $0.00 | $18.36 | Amazon | Payload Mechanical | Received |
| Servo 5V | $10.00 | 1 | 8.00% | $0.00 | $10.80 | Amazon | Payload Mechanical | Received |
| 3 X servo tester | $7.00 | 2 | 8.00% | $0.00 | $15.12 | Amazon | Payload Mechanical | Received |
| Cord quick release | $25.04 | 2 | 8.00% | $0.00 | $54.09 | Amazon | Payload Mechanical | Received |
| 25 kg*cm Servo | $16.00 | 2 | 8.00% | $0.00 | $34.56 | Amazon | Payload Mechanical | Received |
| Overture White PETG | $20.99 | 2 | 8.00% | $0.00 | $45.34 | Amazon | Payload Mechanical | Received |
| Overture Red PETG | $21.99 | 1 | 8.00% | $0.00 | $23.75 | Amazon | Payload Mechanical | Received |
| Overture Black PETG | $21.99 | 1 | 8.00% | $0.00 | $23.75 | Amazon | Payload Mechanical | Received |
| Servo (bigger) | $14.00 | 1 | 8.00% | $0.00 | $15.12 | Amazon | Payload Mechanical | Received |
| 5mm Steel Rod | $6.00 | 1 | 8.00% | $0.00 | $6.48 | Amazon | Payload Mechanical | Received |
| Linear Servo (4in stroke) | $32.99 | 1 | 8.00% | $0.00 | $35.63 | Amazon | Payload Mechanical | Received |
| Spring Loaded Hinges | $2.50 | 4 | 8.00% | $18.00 | $28.80 | McMaster Carr | Payload Mechanical | Received |
| m3 lock nuts | $5.00 | 1 | 8.00% | $0.00 | $5.40 | McMaster Carr | Payload Mechanical | Received |
| m3 nuts | $3.00 | 3 | 8.00% | $0.00 | $9.72 | McMaster Carr | Payload Mechanical | Received |
| 8 mm m3 nuts | $8.00 | 1 | 8.00% | $0.00 | $8.64 | McMaster Carr | Payload Mechanical | Received |
| 12 mm m3 nuts | $7.00 | 1 | 8.00% | $0.00 | $7.56 | McMaster Carr | Payload Mechanical | Received |
| 16 mm m3 nuts | $10.00 | 1 | 8.00% | $0.00 | $10.80 | McMaster Carr | Payload Mechanical | Received |
| 20 mm m3 nuts | $6.00 | 1 | 8.00% | $0.00 | $6.48 | McMaster Carr | Payload Mechanical | Received |
| Torsional Springs | $6.00 | 1 | 8.00% | $0.00 | $6.48 | McMaster Carr | Payload Mechanical | Received |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Nuts | $8.95 | 1 | 8.00% | $0.00 | $9.67 | McMaster Carr | Payload Mechanical | Received |
| Thrust bearing | $12.76 | 1 | 8.00% | $0.00 | $13.78 | McMaster Carr | Payload Mechanical | Received |
| Springs | $7.85 | 1 | 8.00% | $0.00 | $8.48 | McMaster Carr | Payload Mechanical | Received |
| Nichrome Wire | $9.00 | 1 | 8.00% | $4.00 | $13.72 | Temcoindustrial | Payload Mechanical | Received |
| Gloves XL | $15.29 | 1 | 8.00% | $0.00 | $16.51 | Amazon | Safety | Received |
| Gloves Medium | $15.29 | 1 | 8.00% | $0.00 | $16.51 | Amazon | Safety | Received |
| Key switch | $14.52 | 2 | 8.00% | $0.00 | $31.36 | Digikey | Safety | Received |
| J760WT | $115.49 | 1 | 8.00% | $30.00 | $154.73 | Wildman Rocketry | Subscale Motors | Ordered |
| White spray paint primer | $6.00 | 2 | 8.00% | $0.00 | $12.96 | Amazon | Subscale Vehicle | Received |
| Black gloss spray paint | $6.19 | 1 | 8.00% | $0.00 | $6.69 | Amazon | Subscale Vehicle | Received |
| 1/4" eyebolts | $5.37 | 10 | 8.00% | $0.00 | $58.00 | McMaster Carr | Subscale Vehicle | Received |
| The Rocketman 60" toroidal parachute | $150.00 | 1 | 8.00% | $10.00 | $172.00 | The Rocket Man | Subscale Vehicle | Received |
| Aeropack retainer | $31.00 | 2 | 8.00% | $20.00 | $86.96 | Wildman Rocketry | Subscale Vehicle | Received |
| 3.0 13" Fiberglass Coupler | $2.54 | 13 | 8.00% | $0.00 | $35.66 | Wildman Rocketry | Subscale Vehicle | Received |
| 2.1 1ft Fiberglass Motor Tube | $15.84 | 1 | 8.00% | $0.00 | $17.11 | Wildman Rocketry | Subscale Vehicle | Received |
| 3.0OD 5ft Fiberglass Airframe | $112.81 | 1 | 8.00% | $0.00 | $121.83 | Wildman Rocketry | Subscale Vehicle | Received |

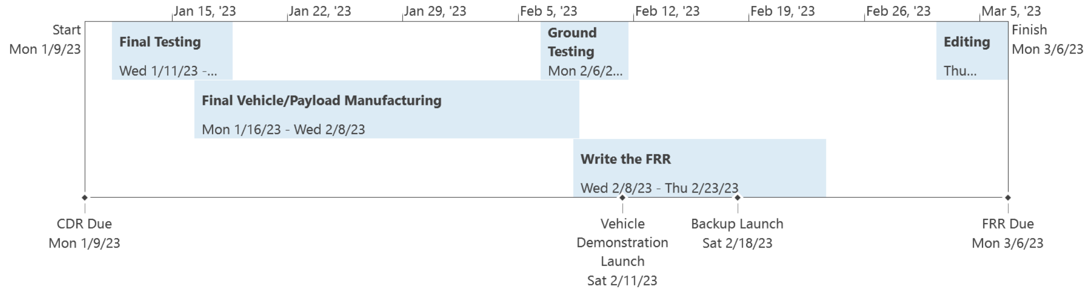
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Wildman Nosecone 3.0 5-1 | $64.90 | 1 | 8.00% | $0.00 | $70.09 | Wildman Rocketry | Subscale Vehicle | Received |
| Harness set for 3" rockets | $64.00 | 1 | 8.00% | $0.00 | $69.12 | Wildman Rocketry | Subscale Vehicle | Received |
| Recon Recovery 60" Parachute | $91.95 | 1 | 8.00% | $0.00 | $99.31 | Wildman Rocketry | Subscale Vehicle | Received |
| Airbnb for 5 nights (max price of 4 current booking options,tax and fees included) | $3,016.16 | 1 | 0.00% | $0.00 | $3,016.16 | AirBnb | Travel and Lodging | Not Ordered |
| Air Matress Pump | $18.00 | 3 | 8.00% | $0.00 | $58.32 | Amazon | Travel and Lodging | Not Ordered |
| Air Matress | $22.00 | 11 | 8.00% | $0.00 | $261.36 | Amazon | Travel and Lodging | Not Ordered |
| Van Rental (Per 5 Days. Based on previous rental orders from within the university and using university discounts) | $600.00 | 4 | 0.00% | $0.00 | $2,400.00 | Enterprise | Travel and Lodging | Not Ordered |
| Mentor Van Rental (Per 5 Days) | $600.00 | 1 | 0.00% | $0.00 | $600.00 | Enterprise | Travel and Lodging | Not Ordered |
| Mileage Reimburement (1000 mile trip at 20 MPG and $3.95 per gallon) | $197.50 | 4 | 0.00% | $0.00 | $790.00 | | Travel and Lodging | Not Ordered |
| Mentor Mileage Reimburement (1000 mile trip at 20 MPG and $3.95 per gallon) | $197.50 | 1 | 0.00% | $0.00 | $197.50 | | Travel and Lodging | Not Ordered |
| Meals (Per Person Per Meal) | $15.00 | 60 | 0.00% | $0.00 | $900.00 | | Travel and Lodging | Not Ordered |

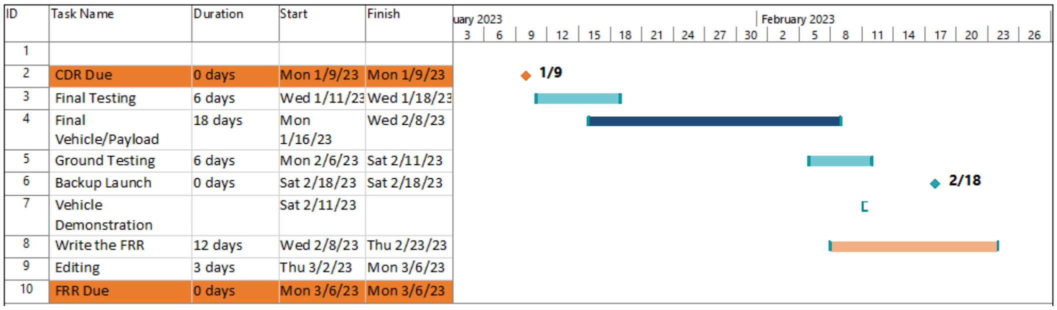
# 6.8. Timeline

The timeline is broken into a Gantt chart that details what activities are being worked on during those meetings and schedules with all meeting dates and durations.

## 6.8.1. Gantt Chart

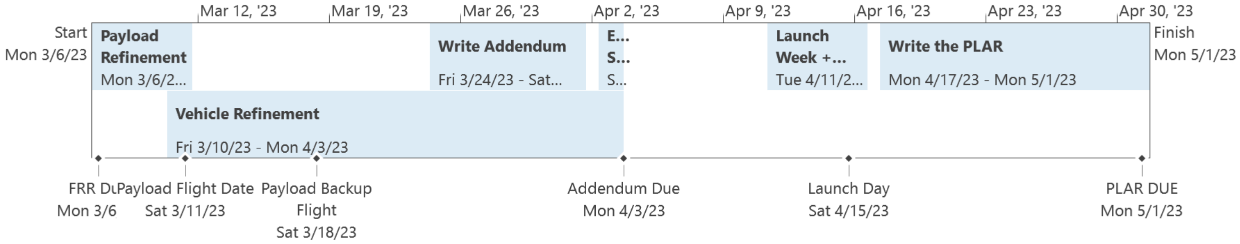
The Gantt Chart is a high-level overview of the project the team is working on. The main goal of these is to know what we should be doing and when in order to stay on track for NASA Handbook deadlines. Launches as well as backup launches are listed as well as milestones.

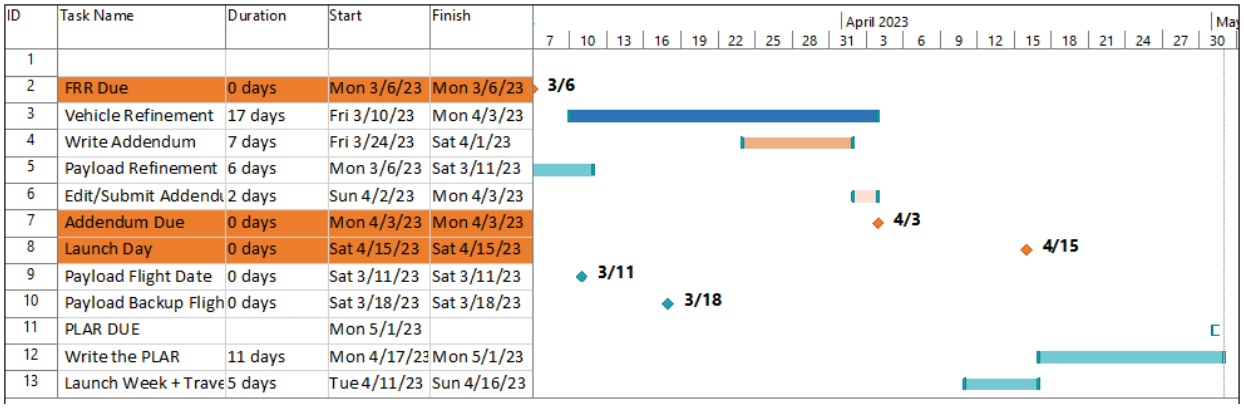




| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | | | | |
| 2 | CDR Due | 0 days | Mon 1/9/23 | Mon 1/9/23 |
| 3 | Final Testing | 6 days | Wed 1/11/23 | Wed 1/18/23 |
| 4 | Final Vehicle/Payload | 18 days | Mon 1/16/23 | Wed 2/8/23 |
| 5 | Ground Testing | 6 days | Mon 2/6/23 | Sat 2/11/23 |
| 6 | Backup Launch | 0 days | Sat 2/18/23 | Sat 2/18/23 |
| 7 | Vehicle Demonstration | | Sat 2/11/23 | |
| 8 | Write the FRR | 12 days | Wed 2/8/23 | Thu 2/23/23 |
| 9 | Editing | 3 days | Thu 3/2/23 | Mon 3/6/23 |
| 10 | FRR Due | 0 days | Mon 3/6/23 | Mon 3/6/23 |

Figure 6.15: Timeline and Gantt Chart for the period from CDR to FRR





| ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | | | | |
| 2 | FRR Due | 0 days | Mon 3/6/23 | Mon 3/6/23 |
| 3 | Vehicle Refinement | 17 days | Fri 3/10/23 | Mon 4/3/23 |
| 4 | Write Addendum | 7 days | Fri 3/24/23 | Sat 4/1/23 |
| 5 | Payload Refinement | 6 days | Mon 3/6/23 | Sat 3/11/23 |
| 6 | Edit/Submit Addendu | 2 days | Sun 4/2/23 | Mon 4/3/23 |
| 7 | Addendum Due | 0 days | Mon 4/3/23 | Mon 4/3/23 |
| 8 | Launch Day | 0 days | Sat 4/15/23 | Sat 4/15/23 |
| 9 | Payload Flight Date | 0 days | Sat 3/11/23 | Sat 3/11/23 |
| 10 | Payload Backup Fligh | 0 days | Sat 3/18/23 | Sat 3/18/23 |
| 11 | PLAR DUE | | Mon 5/1/23 | |
| 12 | Write the PLAR | 11 days | Mon 4/17/23 | Mon 5/1/23 |
| 13 | Launch Week + Trave | 5 days | Tue 4/11/23 | Sun 4/16/23 |

Figure 6.16 Timeline and Gantt Chart for the period from FRR to PLAR.

### 6.8.2. Events Schedule

The numbered weeks correspond to Rose-Hulman's quarter calendar (10-week quarters) as well as finals and break weeks. All red activities are NASA Handbook events or milestones. Read the first column, second column.

| Date | Activity |
|---|---|
| **Week 4** | |
| 9-Jan | 6-7pm: System Integration Meeting<br>7-8pm: General Meeting<br>8-9pm: Mechanical/Electrical Payload Meeting |
| 10-Jan | 7:30-9pm: Electrical Payload Meeting |
| 11-Jan | 7-9pm: Mechanical Payload Meeting, Vehicle Meeting |
| 12-Jan | |
| 13-Jan | 7:30-10pm: Milestone Meeting |
| 14-Jan | 8am-6pm: Indiana Rocketry Launch |
| 15-Jan | 3-4pm: Officer Meeting<br>4-6pm: FRR Writing Session |
| **Week 5** | |
| 16-Jan | 6-7pm: System Integration Meeting<br>7-8pm: General Meeting<br>8-9pm: Mechanical Payload Meeting |
| 17-Jan | 7:30-9pm: Electrical Payload Meeting |
| 18-Jan | **10:30-11:30: CDR Milestone Presentation**<br>7-9pm: Mechanical Payload Meeting, Vehicle Meeting |

| | |
|---|---|
| 19-Jan | |
| 20-Jan | |
| 21-Jan | 10am-12pm: Vehicle Meeting |
| 22-Jan | 3-4pm: Officer Meeting<br>4-6pm: FRR Writing Session |
| **Week 6** | |
| 23-Jan | 6-7pm: System Integration Meeting<br>7-8pm: General Meeting<br>8-9pm: Mechanical Payload Meeting |
| 24-Jan | 7:30-9pm: Electrical Payload Meeting |
| 25-Jan | 7-9pm: Mechanical Payload Meeting, Vehicle Meeting |
| 26-Jan | |
| 27-Jan | |
| 28-Jan | 10am-12pm: Vehicle Meeting |
| 29-Jan | 3-4pm: Officer Meeting<br>4-6pm: FRR Writing Session |
| **Week 7** | |
| 30-Jan | 6-7pm: System Integration Meeting<br>7-8pm: General Meeting<br>8-9pm: Mechanical Payload Meeting |

| | |
|---|---|
| 31-Jan | 7:30-9pm: Electrical Payload Meeting |
| 1-Feb | 7-9pm: Mechanical Payload Meeting, Vehicle Meeting |
| 2-Feb | |
| 3-Feb | |
| 4-Feb | 10am-12pm: Vehicle Meeting |
| 5-Feb | 3-4pm: Officer Meeting<br>4-6pm: FRR Writing Session |
| **Week 8** | |
| 6-Feb | 6-7pm: System Integration Meeting<br>7-8pm: General Meeting<br>8-9pm: Mechanical Payload Meeting |
| 7-Feb | 7:30-9pm: Electrical Payload Meeting |
| 8-Feb | 7-9pm: Mechanical Payload Meeting, Vehicle Meeting |
| 9-Feb | **TBA: FRR Q&A** |
| 10-Feb | |
| 11-Feb | 8am-6pm: Indiana Rocketry Launch, Full scale attempt |
| 12-Feb | 3-4pm: Officer Meeting<br>4-6pm: FRR Writing Session |
| **Week 10** | |

| | |
|---|---|
| 13-Feb | 6-7pm: System Integration Meeting<br>7-8pm: General Meeting<br>8-9pm: Mechanical Payload Meeting |
| 14-Feb | 7:30-9pm: Electrical Payload Meeting |
| 15-Feb | 7-9pm: Mechanical Payload Meeting, Vehicle Meeting |
| 16-Feb | |
| 17-Feb | |
| 18-Feb | 10am-12pm: Vehicle Meeting |
| 19-Feb | 3-4pm: Officer Meeting<br>4-6pm: FRR Writing Session |
| **Finals Week** | |
| 20-Feb | |
| 21-Feb | |
| 22-Feb | |
| 23-Feb | |
| 24-Feb | |
| 25-Feb | 10am-12pm: Vehicle Meeting |
| 26-Feb | 3-4pm: Officer Meeting<br>4-6pm: FRR Writing Session |
| **Break Week** | |

| | |
|---|---|
| 27-Feb | |
| 28-Feb | |
| 1-Mar | |
| 2-Mar | |
| 3-Mar | 6pm-10pm: FRR Writing Session |
| 4-Mar | 6pm-10pm: FRR Writing Session |
| 5-Mar | 3-4pm: Officer Meeting<br>4-12am: FRR Writing Session |
| **Week 1** | |
| 6-Mar | **FRR DUE** |
| 7-Mar | |
| 8-Mar | |
| 9-Mar | |
| 10-Mar | |
| 11-Mar | 8am-6pm: Indiana Rocketry Launch |
| 12-Mar | |
| **Week 2** | |
| 13-Mar | 6-7pm: System Integration Meeting<br>7-8pm: General Meeting<br>8-9pm: Mechanical Payload Meeting |

| | |
|---|---|
| 14-Mar | 7:30-9pm: Electrical Payload Meeting |
| 15-Mar | 7-9pm: Mechanical Payload Meeting,  Vehicle Meeting |
| 16-Mar | |
| 17-Mar | |
| 18-Mar | 10am-12pm: Vehicle Meeting |
| 19-Mar | 3-4pm: Officer Meeting<br>4-6pm: FRR Writing Session |
| **Week 3** | |
| 20-Mar | 6-7pm: System Integration Meeting<br>7-8pm: General Meeting<br>8-9pm: Mechanical Payload Meeting |
| 21-Mar | 7:30-9pm: Electrical Payload Meeting |
| 22-Mar | 7-9pm: Mechanical Payload Meeting,  Vehicle Meeting |
| 23-Mar | |
| 24-Mar | |
| 25-Mar | 10am-12pm: Vehicle Meeting |
| 26-Mar | 3-4pm: Officer Meeting<br>4-6pm: FRR Writing Session |
| **Week 4** | |

| | |
|---|---|
| 27-Mar | 6-7pm: System Integration Meeting<br>7-8pm: General Meeting<br>8-9pm: Mechanical Payload Meeting |
| 28-Mar | 7:30-9pm: Electrical Payload Meeting |
| 29-Mar | 7-9pm: Mechanical Payload Meeting,  Vehicle Meeting |
| 30-Mar | |
| 31-Mar | |
| 1-Apr | 10am-12pm: Vehicle Meeting |
| 2-Apr | 3-4pm: Officer Meeting<br>4-12am:: FRR Writing Session |
| **Week 5** | |
| 3-Apr | **FRR Addendum DUE**<br>7-8pm: General Meeting |
| 4-Apr | 7:30-9pm: Electrical Payload Meeting |
| 5-Apr | 7-9pm: Mechanical Payload Meeting,  Vehicle Meeting |
| 6-Apr | **TBA: Launch Week Q&A** |
| 7-Apr | |
| 8-Apr | 10am-12pm: Vehicle Meeting |
| 9-Apr | 3-4pm: Officer Meeting |

| | |
|---|---|
| **Spring Break** | |
| 10-Apr | |
| 11-Apr | |
| 12-Apr | 8am-3pm: Travel to Huntsville |
| 13-Apr | **Launch Week Activities** |
| 14-Apr | **Launch Week Activities** |
| 15-Apr | **Launch Day** |
| 16-Apr | **Back-up Launch Day** |
| **Week 6** | |
| 17-Apr | |
| 18-Apr | |
| 19-Apr | |
| 20-Apr | |
| 21-Apr | |
| 22-Apr | 10am-4pm: Clean up day |
| 23-Apr | 3-4pm: Officer Meeting<br>4-12am: PLAR Writing Session |
| **Week 7** | |
| 24-Apr | |
| 25-Apr | |
| 26-Apr | |
| 27-Apr | |
| 28-Apr | |
| 29-Apr | |
| 30-Apr | 3-4pm: Officer Meeting<br>4-10pm: PLAR Writing Session |
| **Week 8** | |
| 1-May | **PLAR DUE** |

# 7. Appendices

## Appendix A: Flight Preparation Procedure

All steps should be checked by at least two team members.

Guidelines for checklist use:

- Each section is owned by one section leader. This means that person is the SINGLE person who can check off a box.
- Section Leaders should have at least one person in their group double check a requirement before it is checked.
- One copy of this complete checklist will be held by the Launch Leader who will manage Section Leaders and verify all requirements are satisfied before initiating flight procedure.
- After the Final Vehicle Assembly is complete, the Launch Leader will conduct a GO/NO-GO Poll of section leaders to verify each leader is satisfied with the readiness of their section.

## Final Preparation GO/NO-GO

Should not be completed until Final Vehicle Assembly has been completed.

| System | NO-GO | GO |
|---|---|---|
| ECE Payload | | |
| ME Payload | | |
| GPS Bay | | |
| Avionics Bay | | |
| Drogue Parachute | | |
| Main Parachute | | |
| Rocket Motor | | |
| Vehicle Assembly | | |

### 1. ECE Payload Preparation

☐ Choose a Section Leader: ____________________

### 1.1. Night before:

- ☐ Choose a Section Leader: ____________________
- ☐ Charge 2200mAh battery to completion
- ☐ Screw in every electrical component on the Payload Sled
- ☐ Check soldered electrical connections with a multimeter and for physical condition
- ☐ Ensure FUNcube Dongle Pro+ antenna is fully screwed in and secured
- ☐ Stow payload in payload section during transport

### 1.2. At work table on launch day:

- ☐ Check battery voltage
- ☐ Inspect battery for dents, rips, or any other physical damage
- ☐ Inspect all electronic components for water, soot, or damage
- ☐ Attach the battery to the bottom of the Payload Sled (check polarity is correct)
- ☐ Make sure correct code is uploaded to the Payload Pi
- ☐ Plug in the battery
- ☐ Put the payload integration system in the nose cone and screw in
- ☐ Verify the payload is active both from status LED and by SSH & Ping.

## 2. ME Payload Preparation

- ☐ Choose a Section Leader: ____________________

### 2.1. Pre-Launch Day Checklist:

- ☐ Inspection of the following vital components:
  - ☐ Bay Door (Are the bay door hinges securely attached to the bay door?)
  - ☐ Bay Legs (Are the bay legs securely attached to its casing?)
  - ☐ Bearing (Ensure the bearing pellets are adequately secured within the encasing. Shake and drop the casing to fully ensure proper function.)
  - ☐ Quick Release (Are all components secure?)
  - ☐ Gimbal (Is movement adequate for necessary rotation requirements? Are all screws and fittings attached securely to the gimbal?)
  - ☐ Camera Deployment (ensure full range of motion is clear)
  - ☐ Camera Rotation (ensure full range of motion is clear)
  - ☐ Check all servo connections
- ☐ Test all of the aforementioned components to ensure that they are functional (test mechanisms; unpowered, or if necessary, powered and actuated)
  - ☐ Bay Door (Is there proper actuation of the system? Does it achieve full range of motion?)
  - ☐ Bay Legs (Can the bay legs be actuated and work as intended?)
  - ☐ Bearing (Ensure the bearing pellets are adequately secured within the encasing)

  - ☐ Quick Release (Does the servo mechanism effectively activate the quick link?)
  - ☐ Gimbal (Ensure there are no obstructions to the gimbal's motion)
  - ☐ Camera Deployment (Is there enough clearance for the mechanism to actuate? Once lifted, is the max height reached adequate for proper camera actuation?)
  - ☐ Camera Rotation
- ☐ Have all of the components been tested and are in fully functioning order?
  - ☐ If not, elaborate here: ____________________
- ☐ Packing
  - ☐ Ensure all parts of the payload airframe are packed with the rest of the vehicle

### 2.2. Launch Day Checklist:

- ☐ Payload section of the airframe is secured onto the vehicle
  - ☐ Ensure bay legs are within the confines of the airframe
  - ☐ Mechanical and audio feedback for when payload legs are properly stowed

## 3. GPS Bay Preparation

  - ☐ Choose a Section Leader: ____________________

### 3.1. Pack Before Launch:

- ☐ GPS Board
- ☐ GPS Antenna
- ☐ GPS Sled
- ☐ M3 screws for board
- ☐ 10/32" bolts for GPS sled
- ☐ 2S LiPo
- ☐ Zip ties

### 3.2. Pre-Launch Day Checklist:

- ☐ GPS Powers on when LiPo is connected
- ☐ Take the GPS and receiver outside - Are we receiving location from the GPS?
  *Has to be tested and used with an Android phone

### 3.3. Launch Day Checklist:

- ☐ GPS board with antenna screwed onto sled
- ☐ Lipo zip-tied into the sled and connected to GPS
- ☐ Wires from LiPo secured such that they are not near GPS module
  *Any metal parts such as wires near to the GPS module can prevent GPS lock.
- ☐ Sled bolted to the bulk plate on the fore payload coupler

- ☐ Nose cone screwed to the coupler

# 4. Recovery Electronics Preparation

- ☐ Choose a Section Leader: ____________________

## 4.1. Pack Before Launch:

Parts list:

- ☐ Avionics sled assembly (sled on rails attached to aft bulkhead)
    - ☐ Contains EasyMini Altimeter
    - ☐ Contains RRC3 Altimeter
- ☐ Avionics coupler assembly (coupler with fore coupler attached)
- ☐ 2S LiPo batteries X2
- ☐ Zip Ties (2 packages of 20)
- ☐ Washers X4
- ☐ Nuts X6
- ☐ Spare wires and wire strippers

*Failure to include any of these components will likely make repair or modification of the avionics bay configuration difficult or impossible, potentially resulting in a scrubbed launch.

Tools list:

- ☐ Crescent wrench
- ☐ Small flathead screwdriver

Bring a computer with these downloaded:

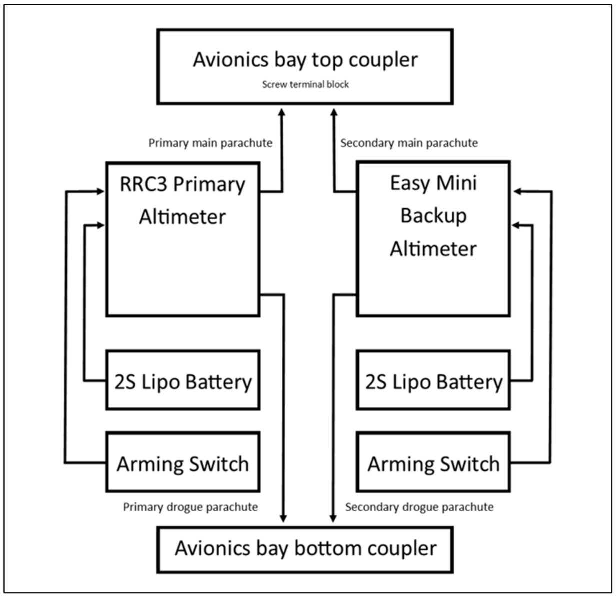
- ☐ EasyMini manual
- ☐ RRC3 manual
- ☐ Altus Metrum AltOS configuration software
- ☐ mDACS configuration software for the RRC3

*Launch locations may not have cellular signal, so all documentation must be downloaded ahead of time.

## 4.2. Pre-Launch Day Checklist:

*The following step involves the handling of lipo batteries, a known fire hazard. Lipo batteries should be treated with care, never left unattended, and stored in the team designated fire proof bag.

- ☐ Inspect lipo batteries for any signs of damage. This includes dents, swelling, broken connectors, exposed wire, etc. Notify the team safety officer of any damaged batteries before proceeding.
- ☐ Charge two 2S lipo batteries to full. There should be one battery present for each of the two altimeters.
- ☐ Ensure that no charges or ematches are connected to the avionics bay from previous flights.  
  *All pyrotechnics must be disconnected until final assembly. Even without black powder, ematches are potentially dangerous and should be treated as energetic devices.
- ☐ Verify the avionics bay wiring according to the schematic below. Be sure to match standard wire colors whenever possible.



  *Note the wire colors and confirm that brown wires in screw terminals are connected to the RRC3 and the green wires are connected to the Easy Mini
- ☐ Before plugging in batteries, verify that the polarity of the connectors matches the + and - terminals marked on the altimeter.
    - ☐ Additionally verify that the polarity of the battery and connector match. Hand-made and manufactured connectors alike may have incorrect wire coloring; any that do should be resoldered or discarded.  
      *Connecting polarity incorrectly may permanently damage the altimeters.
- ☐ Once all schematics have been checked, ensure that switches are opened.  
  Wear safety glasses and have a Class B fire extinguisher ready while initially connecting batteries, as an accidental short may result in violent sparks or, in extreme cases, fire.
- ☐ Inspect batteries for any damage. If any damage is found, dispose of batteries in a flammable waste disposal area.  
  *Damage to batteries may result in electrical fires. Therefore, damaged batteries must be disposed of safely and immediately.

☐ Connect batteries. No altimeters should power up; if any do, inspect switch contacts for debris or shorts. Do not continue until the short is cleared.
*To minimize risk in the event charges are deployed accidentally, once pyrotechnics are armed, the altimeters absolutely must not be powered on until the rocket is on the launch pad or in another designated safe area as approved by the RSO. A shortened or unreliable switch may cause avionics to become armed in an unsafe location.

☐ Close the switches associated with each altimeter, one at a time. Note the beep code for each altimeter and ensure that it is as expected based on the table of beep codes included in each altimeter's instructions. See following tables for startup and operational beep codes:

Table A.1: RRC3 Startup Sequence

| | |
|---|---|
| 5-second long tone | Startup beep, looking for a press of the program button which engages use of dip switch programming |
| 10-second silence | Enables barometric stabilization and establishes barometric history (calibrates barometer) |
| POST Mode | Performs several checks for the integrity of all sensors; if a fault is detected then it will repeatedly report the error in the following sequence. During this period, the altimeter is also looking for a host connection from a computer running the altimeter's software (mDACS). |
| 7 very quick low beeps | Occurs if fault is detected during POST mode. The code that follows should be referenced in table A.2. |
| Misc | Audio options report mode - if special audio options have been enabled, they will beep now. |
| LED flashes on/off at a 1 second rate | Launch commit test - 10 second test that conducts a trial run of launch detection mode |
| See Table A.3 | Launch Detect Mode |

Table A.2: RRC3 Fault Codes

| | |
|---|---|
| 1 | User invoked Settings Default to Factory Settings warning |
| 2 | LCD Terminal Fault / LCD is attached and a DIP Switch is ON |
| 3 | Barometric sensor Fault / No communication reply |
| 4 | Barometric sensor Fault / Prom CRC Mismatch |
| 5 | Barometric pressure Fault / Pressure < 10 mbar or > 1200 mbar |

| | |
|---|---|
| 6 | Temperature Fault / Temperature < -40 deg. C or > 85 deg. C |
| 7 | Low Battery Lockout Fault / Battery < Low Voltage Lockout Level |
| 8 | Ambient Barometric Fault / Unstable conditions during Launch Commit Test |

Table A.3: RRC3 Launch Detect Mode Beeps

| | |
|---|---|
| Long beep/flash | No continuity on drogue or main charges |
| 1 short beep | Continuity on drogue charges only |
| 2 short beeps | Continuity on main charges only |
| 3 short beeps | Continuity on drogue and main charges |

Table A.4: Easy Mini AltOS Modes

| Mode | Beep Sequence | Description |
|---|---|---|
| Startup | Battery voltage in decivolts | Calibrating sensors and detecting orientation |
| Idle | dit dit | Ready to accept commands over USB |
| Pad | dit dah dah dit | Waiting for launch; not listening for commands |
| Landed | dit dah dit dit | Stable altitude for at least 10 seconds |
| Sensor Error | dah dit dit dah | Error detected during sensor calibration |

Table A.5: Easy Mini Idle Indications

| Mode | Beep Sequence | 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. |
| Storage Full | warble | On-board data logging storage is full. This will not prevent the flight computer from safely controlling the flight or transmitting telemetry signals, but no |

| | | |
|---|---|---|
| | | record of the flight will be stored in on-board flash. |

*Diagnosing altimeter issues before launch day allows more opportunity to debug potential issues or mis-configurations while access to club equipment and internet is readily available.

☐ Before packing equipment away, ensure that all batteries are fully charged.
*A low battery may power on the computer and read continuity correctly but fail to provide enough current for deployment, resulting in a recovery failure and severe damage to the vehicle.

### 4.3. Launch Day Checklist:

☐ Re-check the wiring against the schematic and ensure that no pyrotechnics are installed.
☐ Ensure that switches are opened.
☐ Inspect, secure and plug in batteries.
*The preceding steps mirror the day-before procedure and are intended to ensure that no components have been damaged in transport.
☐ Ensure that all nuts on the sled side of the avionics bay are tightened.
A loose sled may damage itself under the acceleration of the rocket or cause wires to become disconnected in flight.
☐ Connect the wires from the avionics coupler tube and bulkhead assembly to the avionics bay sled. Ensure that brown wires are connected to the RRC3 and green wires are connected to the Easy Mini.
☐ Insert the sled assembly into the avionics bay and secure the nuts on the other bulkhead. Ensure that no wires are caught in the edges of either bulkhead.
avionics bay coupler edges have the potential to tug loose or sever altimeter wires caught in them.
☐ As before, switch on each switch one at a time and verify beep codes, then switch all switches entirely off. If beep codes differ from expected, do not proceed until the issue is resolved.
☐ Immediately after avionics bay assembly and testing, insert the two Remove Before Flight (RBF) tags into their respective locations next to the arming switches.
Failure to arm the altimeters will be catastrophic. This is an important step in the procedure checklist to ensure a successful flight.

## 5. Drogue Harness Assembly

☐ Choose a Section Leader: ____________________

### 5.1. Pack before launch:

- ☐ 12” drogue parachute
- ☐ 12” parachute protector
- ☐ ¼” 3-point kevlar harness
- ☐ 1800 lb quicklink x3

### 5.2. Launch Day Checklist:

- ☐ Quick-link the longest portion of the three-loop recovery harness to the kevlar loop from the booster section.
- ☐ Accordion-fold the portion of the cord before the middle loop in a bundle about 6” long and wrap a single loop of masking tape around the center.
  *Accordion-folding harnesses ensure that they do not become wrapped around the parachute, and the tape breaking provides damping in overly energetic deployments.
- ☐ Quick-link the drogue parachute to the middle loop of the harness.
- ☐ Quick-link the parachute protector to the middle loop of the harness.
- ☐ Put a quick-link on the empty end of the harness.
- ☐ Accordion-fold the top half of the harness as before. Note that the bundle should be smaller than the previous.
- ☐ Fold the drogue parachute in accordance with Appendix B.
- ☐ Put both cord bundles into the booster tube, but make sure the empty quick link is accessible at the entrance to the tube.
- ☐ Put the wrapped drogue chute into the tube and hold onto the empty quicklink to keep it on top and accessible at the entrance to the tube.
  *The cords must be placed below the parachute so that, in the event of a weak deployment, the tension on the cord will pull the parachute loose.

## 6. Main Harness Assembly

- ☐ Choose a Section Leader: ____________________

### 6.1. Pack before launch:

- ☐ 60” toroidal main parachute
- ☐ 18” parachute protector
- ☐ ¼” 2-point kevlar harness
- ☐ 1800 lb quicklink x2
- ☐ Shear pins

### 6.2. Launch Day Checklist:

- ☐ Connect the parachute protector, the main chute, and one end of the two-loop harness to the payload bulkhead U-bolt.

*Ensure that all parts are connected to one quicklink, rather than separate quicklinks on the u-bolt. Placing load across the u-bolt may cause unpredictable strain on the bulkhead.

- ☐ Put a quicklink on the empty loop of the harness.
- ☐ Accordion-fold the harness as before, leaving enough unfolded on the empty-quicklink end to comfortably reach the other end of the main tube.
- ☐ Fold the main chute in accordance with Appendix A.
- ☐ Slide the folded harness into the main tube, followed by the folded parachute.
- ☐ Slide the payload section into the main section.
- ☐ Rotate the tubes until the shear pin holes align and screw in all shear pins.

## 7. Rocket Motor Preparation (TO BE DONE BY MENTOR)

Note: the mentor handling the motor or reload kit components must wear safety glasses. Additionally, rubber gloves are recommended while handling grease.

### 7.1. Pack Before Launch:

- ☐ All required motor hardware (may include cases, retaining rings, spacers, and seal disks as well as tools such as specialized wrenches)
- ☐ Manufacturer instructions for the motor (2 copies); print ahead of time if possible
- ☐ Synthetic grease

### 7.2. Launch Day Checklist:

- ☐ Prepare a work surface for motor assembly. It should be clean, dry, sheltered from wind as much as possible, and away from any sources of heat or flame.
  *Motor reload kits contain many small parts and paper instruction sheets that may blow away in strong winds. Additionally, sources of heat present a risk of accidental ignition, and dirt or debris on the work surface may prevent motor components from forming a reliable seal.

- ☐ Read through the instructions in their entirety before beginning.
- ☐ Unpack the reload kit. Identify all parts as specified by the instructions and ensure that nothing is missing.
- ☐ With a partner closely following the same instructions and supervising steps, assemble the motor according to manufacturer instructions. Describe each step out loud as they are performed. Perform any “optional but recommended” steps (for example greasing the liner) unless a clear reason exists not to do so.

  *Errors in building the motor could be catastrophic. Describing steps out loud both allows the partner to verify the step and helps to prevent “autopiloting” that may lead to assembly mistakes.

- ☐ Have your partner inspect the completed motor. Verify any dimensional information given in the instructions (typical thread depths or fit tolerances).
- ☐ Ensure that no parts from the reload are unused except as specified by instructions.
- ☐ Reinstall nozzle cover to prevent dust ingress.

## 8. Final Vehicle Assembly

*Gloves should be worn while handling fiberglass to avoid splinters.

- ☐ Choose a Section Leader: ____________________

### 8.1. Pack Before Launch:

- ☐ Booster section with drogue parachute hardware prepared
- ☐ Main section with main parachute hardware prepared
- ☐ Avionics bay
- ☐ Prepare payload section
- ☐ Nose cone and GPS assembly
- ☐ Prepared motor
- ☐ Shear pins
- ☐ Bolts
- ☐ All materials for black powder charges detailed in Appendix C
- ☐ Charge tracker piece

### 8.2. Launch Day Checklist:

- ☐ Find a safe location to set up the table for vehicle preparation far from other people and point the vehicle away from cars or people.
- ☐ Lay out all parts of the vehicle on the table and verify that the quicklinks from recovery systems are accessible.
- ☐ Set up cones in a perimeter 10 feet from all sides of the vehicle and treat the vehicle as if the black powder charges could unexpectedly ignite at any time.
  *All who step inside the cones must be wearing safety glasses.
- ☐ Inspect all epoxy joints (fins, motor mount, nose cone bulkhead) for cracking or signs of wear.
  *After the following steps, the airframe will have the potential to separate violently if a separation charge is accidentally triggered. All personnel should stay clear of the area directly in front of and behind the vehicle, even outside the cones.
- ☐ Prepare the following black powder charges in accordance with Appendix F (to be done by mentor):
  - ☐ Primary drogue parachute charge
  - ☐ Secondary drogue parachute charge

  - ☐ Primary main parachute charge
  - ☐ Secondary main parachute charge
- ☐ Verify the avionics bay is in the correct orientation by looking for the arrows pointing towards the fore of the vehicle.
- ☐ Install the motor in the booster section and hand-tighten the retainer (TO BE DONE BY MENTOR).

### 8.2.1. Drogue Separation Point Assembly

- ☐ Remove the sleeves from the ends of the drogue parachute charges and place them in the charge tracker piece.
  *The charge tracker piece should hold all sleeves so it is known how many charges have been installed.
- ☐ fold the exposed leads so the lengths are about 1 cm to prevent shorting and install the charges in the drogue parachute screw terminals. The main charge should be connected to the terminal with the brown wires and the secondary charge should be connected to the terminal with the green wires.
- ☐ Connect the exposed quicklink from the drogue parachute to the avionics bay.
- ☐ Push the drogue parachute, harness, quicklink, and black powder charges into the booster tube and prepare to slide in the avionics bay.
- ☐ Slide in the avionics bay.
  *Take special care that no zip tie ends, wires, or other items are caught in between the avionics coupler tube and the body tube.
- ☐ Rotate the avionics bay until the shear pin holes align and screw in all shear pins.

### 8.2.2. Main Separation Point Assembly

- ☐ Remove the sleeves from the ends of the main parachute charges and place them in the charge tracker piece.
- ☐ fold the exposed leads so the lengths are about 1 cm to prevent shorting and install the charges in the drogue parachute screw terminals. The main charge should be connected to the terminal with the brown wires and the secondary charge should be connected to the terminal with the green wires.
- ☐ Connect the accessible quicklink from the main parachute harness to the avionics bay.
- ☐ Push the harness, quicklink, and black powder charges into the main tube.
- ☐ Slide in the avionics bay.
  *Take special care that no zip tie ends, wires, or other items are caught in between the avionics coupler tube and the body tube.
- ☐ Rotate the tubes until the bolt holes align and bolt together the avionics bay and the main tube.

The vehicle should now be completely prepared for launch. Verify all checkboxes have been checked on section checklists and the master checklist, then initiate a GO/NO-GO poll to confirm that all section leaders are ready for launch.

Record actual final mass of vehicle here: ________________

## Appendix B: Pad Setup, Pre/Post-Launch Procedure

### 1. Preflight Procedure

Safety glasses should be worn at all times while handling the rocket once charges or the motor have been installed.

☐ Obtain approval to launch from the site RSO after completing a flight card.
☐ Inspect the launch rail: is it firm? Are there cracks?
☐ Tilt the pad such that the designated "rocket side" of the rail faces upward.
☐ While one person steadies the rail, slide the rocket onto the rail until it reaches the lower stop.
☐ While steadying the rocket, rotate the pad back to vertical or the angle designated by the RSO.
☐ Instruct all non-essential personnel to return to the flight line.
*Those not involved in the readying of the rocket must be at a safe distance before charges are armed.
☐ Power on all altimeters. Check continuity beeps as before. Do not proceed unless beeps are as expected.
*There is a small chance connections may come loose on the way to the launch pad.
☐ If the configuration calls for GPS to be powered on at the pad, do so and wait for lock.
☐ Strip wires as necessary, then twist together the bare leads of the igniter.
*Ensuring that the igniter leads are shorted together reduces the risk of static discharge or other accidental energization firing the igniter.
☐ Insert the igniter into the motor until it stops. Pull the igniter out slightly and reinsert to ensure it is not caught on a grain gap.
*Motors will only ignite reliably if the igniter is installed all the way to the top of the motor.
☐ Secure the igniter with tape, a plastic cap, or as otherwise specified by the manufacturer.
☐ Tap the alligator clips together to check for voltage.
*If the controller is accidentally energized, this step will cause sparks to alert you to the issue.
☐ Connect the igniter leads to the alligator clips. Wrap any remaining leads around the outside of the clips.
*Additional wrapping of leads helps to eliminate poor connections.
☐ If the launch control system offers a continuity test, use it to ensure that the igniter is functional and connected properly.

- ☐ Return to the flight line and continue with the next procedure.

## 2. Flight Procedure

- ☐ Before flight, assign the following roles:
    - ☐ Visual tracker (groups of 2, at least 2 groups)
    - ☐ GPS operator if applicable
    - ☐ Videographer (2 if possible)
    - ☐ Flight Event Recorder (2 if possible)
- ☐ Visual trackers: Spread out on the flight line. Ensure that you have a means of communication with the team. Stay is groups of 2.
  *Multiple visual lines on the rocket will allow triangulation in the event of a GPS failure.
- ☐ Videographer: Ensure you have an unobstructed view of the rocket.
  *In the event of a catastrophic failure, video may be the only concrete evidence of the flight. Prioritize capturing the entire flight over "detail shots."
- ☐ GPS operator: Ensure that the tracking setup is ready and transmitting coordinates.
- ☐ Flight Event Recorders: Ready the flight event checklist as well as a writing implement.
  Note: Some items on this checklist refer to "without airframe failure". In the event of a mechanical failure of the airframe in flight, these checkboxes help pinpoint the exact moment of failure.
- ☐ Signal to the RSO that the team is ready.
- ☐ During the flight:
    - ☐ Visual trackers identify landmarks on the horizon as the rocket descends to aid in triangulation.
    - ☐ GPS operators call out altitude figures as they are available. This helps to identify flight events. (Note that GPS units do not always yield reliable altitude numbers.)
    - ☐ Video recorders film the rocket. Sighting over your camera or phone may yield better results than looking at the viewfinder or screen.
    - ☐ Event recorders record the flight in accordance with their checklists.
- ☐ Wait until given a range-clear signal from the RSO to begin searching.
- ☐ During recovery:
    - ☐ Visual trackers stay where they are and direct searchers via radio.
    - ☐ Depending on personnel availability, videographers may either act as visual trackers using a frame of video as reference or join the search.
    - ☐ Visual Trackers, Event recorders, and GPS operators call important events throughout the flight

# Appendix C: Recovery Ground Test Procedure

- ☐ Prepare the required items:

    - ☐ All airframe components
    - ☐ Inert motor plug
    - ☐ Shear pins
    - ☐ Screws and hardware
    - ☐ Black powder charge supplies
    - ☐ Support for the rocket
    - ☐ 12V battery
    - ☐ Launch controller
    - ☐ Test logbook
- ☐ Test the launch controller with a 12V incandescent bulb or another safe high-current load:

  Throughout these steps, be wary of short circuits. Using lead-acid batteries, short circuits can and will lead to fire if not immediately dealt with. If any component feels unexpectedly warm, disconnect power immediately.
    - ☐ Disconnect both charge wires.
        - ☐ The continuity LED should stay off regardless of switch states.
    - ☐ Connect both charge wires to the load. Ensure that the arm switch is off.
        - ☐ The green LED should light, but not the red.
    - ☐ Flip the arm switch.
        - ☐ Both LEDs should light.
    - ☐ Press the 'fire' button.
        - ☐ The red LED should go out and the load should activate.
- ☐ In the rocket's primary avionics bay, wire the charge well to be tested directly to a pair of wires leading out through a vent hole (TO BE DONE BY TEAM MENTOR).

  Important: To reduce risk of injury, do not test with more than one charge installed.
- ☐ Assemble the rocket as detailed in Appendix A, omitting internal components that are not crucial to the test and replacing with dead weight. Replace the motor with an inert dummy motor.

  All precautions from Appendix A regarding safety of black powder apply. Especially take care to ensure that no one stands along the axis of the rocket in either direction once assembled.
- ☐ Record amount of black powder used and separation point in test log.
- ☐ Set the rocket on the support in an open, non-dry area away from obstacles or human activity. Bring the test controller while performing this step but leave its battery at the viewing location.
- ☐ Ensure the controller is unarmed.
- ☐ Wire up the controller to the leads installed earlier.
- ☐ Have all participants return to the viewing location, then connect the battery to the controller. Check for the green continuity light.
- ☐ The RSO checks the area surrounding the rocket for any interruption, then clearly and loudly announces "Range is clear."

- ☐ Switch the controller to armed. Check for red continuity light.
- ☐ Provide a countdown from 5 seconds, then press and hold the fire button until firing is observed or 3 seconds have passed.
- ☐ Once the test is complete, record the following entries in a test log:
  - ☐ Payload tube separated (y/n)
  - ☐ Parachute ejected (y/n)
  - ☐ Tape loops separated (y/n/partial)
  - ☐ Significant “jerk” at end of cord (y/n)
  - ☐ Distance traveled by upper section (ft)
- ☐ Desired conditions are as follows:
  - ☐ Nose cone fully ejected
  - ☐ Parachute fully ejected
  - ☐ Some or all tape loops separated
  - ☐ Minimal jerk
  - ☐ Upper section travels nearly the full length of the cord

## Flight Event Checklist

- ☐ Liftoff (start stopwatch)
- ☐ Apogee (without airframe failure)
  - ☐ Primary charge
    - ☐ Drogue deploys with primary
  - ☐ Secondary
    - ☐ Drogue deploys with secondary
- ☐ Stable descent under drogue
  - ☐ Primary main charge: ______ feet
    - ☐ Main deploys with primary
  - ☐ Secondary main charge: ______ feet
    - ☐ Main deploys with secondary
- ☐ Touchdown under main

# Appendix D: Parachute Folding

- Draw the parachute lines together with the peak of the parachute opposite them.

- Double the lines in the center of the parachute.

- Fold the parachute in thirds vertically, covering the lines.

- Fold the parachute in thirds horizontally. The number of folds in this step may be varied for tube fitment.

- Roll the parachute vertically (along the axis of the shroud lines).

- Place the parachute in the center of the chute protector. Attach the chute protector's eyelet to the parachute's quicklink.
- Fold the top and bottom of the chute protector over the chute.
- Roll the sides of the chute protector around the parachute. The net result should be a "burrito wrap" shape.
- Ensure that the material of the parachute is not visible from the outside.
  *If nylon is exposed to ejection gasses, it will likely be damaged, resulting in a recovery failure.

# Appendix E: Charge Preparation

***Black powder is a low explosive and is very easily ignited. Safety glasses must be worn whenever handling black powder, and heat sources or flames must not be allowed within 25 feet of it.**

- ☐ Gather materials:
  - ☐ Measured black powder
  - ☐ Funnel
  - ☐ E-matches
  - ☐ Masking tape
  - ☐ Cable ties
  - ☐ Marker
  - ☐ Scissors
  - ☐ Vinyl gloves
- ☐ Prepare charge pouches:
  - ☐ Cut the vinyl glove at the base of the finger to make a charge pouch. Repeat for necessary charges.
- ☐ Prepare the igniter:
  - ☐ Pull back on the igniter element cover and remove. Pull back on the exposed wire cover and remove.
  - ☐ Stripping the wire for more exposure may be necessary.
- ☐ Insert funnel into one charge pouch and slowly pour the measured black powder. Sometimes it is necessary to gently shake the funnel if the flow of black powder is interrupted. Make sure all the black powder has escaped the funnel before removing the funnel
- ☐ Insert e-match into the now filled charge pouch until the element is completely covered with black powder.
- ☐ Twist charge pouch around e-match wire tightly and secure with a cable tie.
- ☐ Wrap the charge pouch tightly with masking tape.
- ☐ Label the black powder amount on the wire of the e-match

# Appendix F: Recovery and Reuse

- ☐ Touchdown
- ☐ Vehicle safing
  - ☐ Tumbling stopped
  - ☐ Black powder charges triggered
  - ☐ Motor burned out
  - ☐ Motor ejection charge triggered
  - ☐ Altimeters switched to landed mode

    - ☐ Batteries in good condition
- ☐ Payload Disconnect
    - ☐ Some guy goes up there and releases it
- ☐ Documentation
    - ☐ Pictures
    - ☐ Video walkaround
- ☐ Postflight inspections
    - ☐ Verify no impactful physical damage to the vehicle
        - ☐ Nose cone intact
        - ☐ Nose cone coupler ok
        - ☐ Payload tube ok
        - ☐ Payload bearing ok
        - ☐ Payload attachment tube ok
        - ☐ Payload coupler ok
        - ☐ Confirm successful main deploy
        - ☐ Ensure secure attachment of quicklinks and main parachute
            - ☐ Payload Quicklink
            - ☐ avionics bay Quicklink
            - ☐ Shock cord ok
        - ☐ Ensure the avionics bay is secured within the airframe
            - ☐ Components secure
            - ☐ Wiring secure
        - ☐ Confirm successful drogue deploy
        - ☐ Ensure secure attachment of quicklinks and drogue parachute
            - ☐ avionics bay quicklink
            - ☐ Drogue quicklink
            - ☐ Booster quicklink
            - ☐ Shock cord ok
        - ☐ Booster ok
            - ☐ Fins not broken or too damaged
                - ☐ 1
                - ☐ 2
                - ☐ 3
                - ☐ 4
            - ☐ Shock cord attachment secure
            - ☐ Motor retainer intact
            - ☐ Motor intact
            - ☐ Motor safed
            - ☐ Motor inside rocket

        - ☐ Verify no natural materials inside of the vehicle
- ☐ Recovery
    - ☐ Verify payload teams are ready to recover the vehicle
    - ☐ Wrap up parachutes to ensure they do not catch the wind
    - ☐ Assign sections of vehicle to carry
        - ☐ Booster
        - ☐ Recovery
        - ☐ Payload
    - ☐ Return vehicle to setup location
    - ☐ Clean out shear pins from inside of tubes
    - ☐ Unscrew shear pin fragments
    - ☐ Dispose of shear pins

- Assembly and Vehicle Preparation
    - ☐ Verify no shorts present in wiring
    - ☐ Verify all actuation areas are marked
    - ☐ Verify correct motor and motor installation
    - ☐ Verify correct ballast
    - ☐ Verify that mentor is capable of accessing all launch sites
- Launch Preparation
    - ☐ Verify setback distance (minimum 200 ft)
    - ☐ Verify cleared area (minimum 75 ft)

## Appendix G: References

[1] Engineering ToolBox, (2003). *Atmospheric Pressure vs. Elevation above Sea Level*. [online] Available at: https://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html [Accessed 7 Jan 2023].

[2] Apogee Rockets. *Small Nylon Shear Pins - 20 pack*. [online] Available at: https://www.apogeerockets.com/Building-Supplies/Misc-Hardware/Nylon-Shear-Pins-20-pack [Accessed 7 Jan 2023].