Rose Rocketry

Project Silverstein
Flight Readiness Review

Rose-Hulman Institute of Technology

March 7, 2022

500 Wabash Ave, Terre Haute, IN 47803

Table of Acronyms

Acronym	Definition
3D	Three Dimensional
ADC	Analog-To-Digital Converter
AGL	Above Ground Level
APCP	Ammonium Perchlorate Composite Propellant
BIC	Branam Innovation Center
CAD	Computer Aided Design
CDR	Critical Design Review
CG	Center of Gravity
COTS	Commercial Off-The-Shelf
CP	Center of Pressure
DOF	Degree of Freedom
FAA	Federal Aviation Administration
FIRST	For Inspiration and Recognition of Science and Technology
FMEA	Failure Modes and Effects Analysis
FRC	FIRST Robotics Competition
FRR	Flight Readiness Review
GPIO	General-Purpose Input/Output
GPS	Global Positioning System
GUI	Graphical User Interface
HPR	High Powered Rocketry
I2C	Inter-Integrated Circuit
IMU	Inertial Measurement Unit
KIC	Kremer Innovation Center
LRR	Launch Readiness Review
MDF	Medium-density fiberboard
NAR	National Association of Rocketry
NASA	National Aeronautics and Space Administration
OTFR	One Time Funding Request
PDR	Preliminary Design Review
PLAR	Post-Launch Assessment Review
PPE	Personal Protection Equipment
RF	Radio Frequency
RHIT	Rose-Hulman Institute of Technology
RR-SL	Rose Rocketry - Student Launch
RSO	Range Safety Officer
SDR	Software Defined Radio
SGA	Student Government Association
SL	Student Launch
SPI	Serial Peripheral Interface
STEM	Science Technology Engineering and Math
TRA	Tripoli Rocket Association
USB	Universal Serial Bus
USLI	University Student Launch Initiative

1. Summary of FRR Report

1.1. Team Summary

Table 1.1: Team Summary and Mentor Contact Information

Team Name	Rose Rocketry - Student Launch (RR-SL)
Mailing Address	5500 Wabash Ave, Terre Haute, IN 47803
Mentor Name	Gary Kawabata
Mentor Contact	rocketguy9914@gmail.com
Mentor Certifications	NAR 89092; TRA 3019; level 3
NAR/TRA Sections	Indiana Rocketry Group Tripoli #132 NAR Section #711
Hours Spent on FRR	250
Primary Location and Date	SL Launch Field at Bragg Farm Toney, Alabama April 23, 2022
Secondary Location and Date	SL Launch Field at Bragg Farm Toney, Alabama April 24, 2022

1.2. Launch Vehicle Summary

Table 1.2: Launch Vehicle Summary

Official Target Apogee	5000 ft.
Final Motor Choice	Cesaroni Technology Inc. L2375WT-P
Recovery System	Main: SkyAngle Cert3 XXL Drogue: SkyAngle Cert3 Drogue
Rail Size	12' 1515 Rail

Table 1.3: Vehicle Size and Mass Summary

Vehicle Length	165.38 in.
Vehicle Airframe Nominal Diameter	5.5 in.
Vehicle Wet Mass	49.3 lbm
Vehicle Dry Mass	40.1 lbm

Vehicle Subsystem	Mass (lbm)	Length (in)
Payload	4.7	31
Recovery	15.9	59.75
Altitude Assurance	13.3	42.75
Booster	15.3	31.88

1.2.1. Payload Experiment

The payload experiment's goal is to autonomously locate the rocket. The objective is to be robust enough for the simulation of interplanetary travel, thus we will use two methods with minimal required hardware. The RF system uses directional transmissions from the ground station to determine the position of the rocket. The IMU System uses two accelerometers to continuously measure acceleration starting from a reference position. All computation will be done using a flight computer. Both techniques will be used to calculate a most probable flight path. Additionally, GPS and a separate altimeter will be used and will have their data transmitted to the ground station. A GUI on the ground station will display all the data and the final location determination. A successful criteria of the payload is to locate the rocket with an error of ±125 ft.

2. Changes Made Since CDR Report

2.1. Vehicle Criteria

The following changes have been made to the vehicle, as detailed in Section 3.1.1.

- A port was added to the tank airframe to allow easier filling and valve access.
- The small 3D-printed shims previously used to fill the space between the aluminum spars and the airframe have been removed for ease of assembly.
- The 10-32 Phillips screws used on the spar section have been replaced with Torx to minimize likelihood of stripping.
- An additional loop has been added to the main parachute harness to allow for better protection when packed.
- A pilot chute has been added to the main parachute, and charge amounts have been increased by 1 gram each, to minimize deployment delay.

2.2. Payload Criteria

All changes are explained in more detail and justified in Section 4.1.1

- A custom PCB was designed to sit on top of the Pi that will contain all the sensors on the payload
- The Raspberry Pi case located on the rocket has been eliminated from the design
- The payload ground station now contains custom 3D printed parts to add in the rotating antenna and a detailed design.
- Tests for the Xbee have been added
- The battery holder has been updated from knowledge gained after manufacturing

2.3. Project Plan

- Several new derived requirements were added for all systems

3. Vehicle Criteria

3.1. Design and Construction of Vehicle

3.1.1. Changes from CDR

- Payload Bay
  - Threaded inserts for side mounted holes

In post-flight analysis of the full scale vehicle, it was determined that the payload bay bulkhead that mounts to the nose cone had shown signs of yielding at the edge of the side mounting holes.

Figure 3.1: Side Mounting Hole Yielding from Bearing Load

The bulkhead is a 3D printed part made from Nylon 66 filament. Since yielding was only shown to be a bearing failure (the bulkhead itself is warped from printing), the team determined that a design change to strengthen only the side mounting holes is necessary. The bulkhead will now utilize 10-32 threaded inserts for these holes. From this change, we can expect a stronger design in preventing yielding at any point of this part.

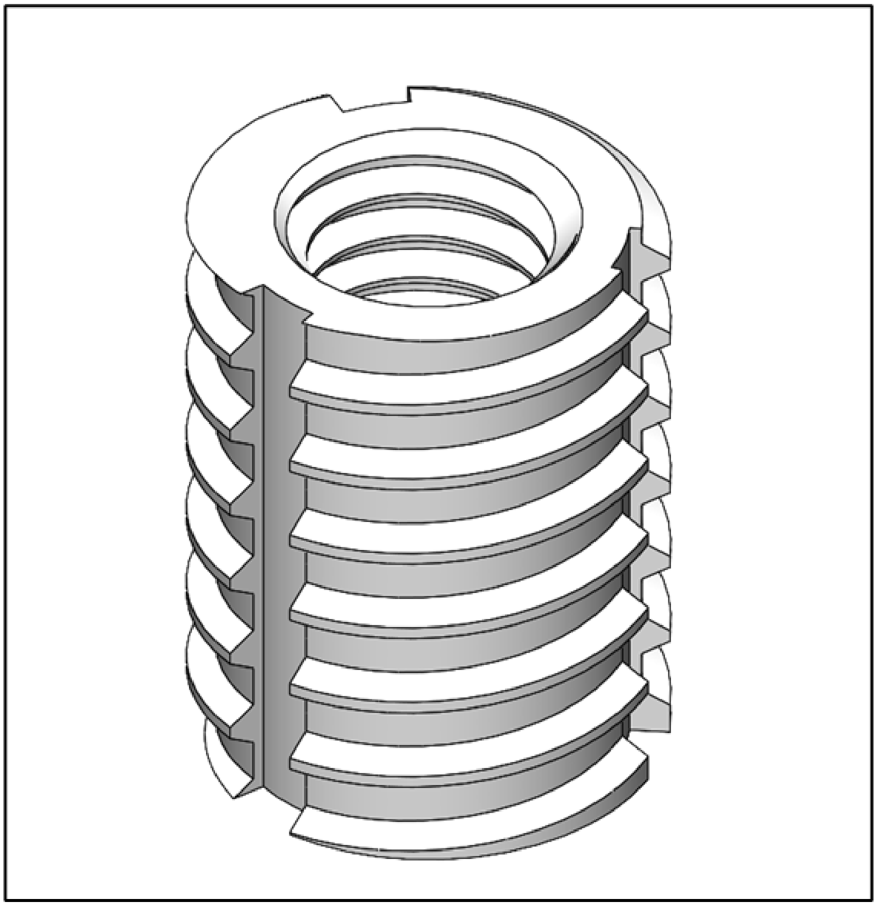

Figure 3.2: 10-32 Threaded Insert

- Recovery
    - Two 2mm distributor plates in place of one 4 mm

The design of the Recovery subsystem called for the addition of 4mm thick aluminum distributor plates at the interface of the coupler bulkheads and their U-bolts.

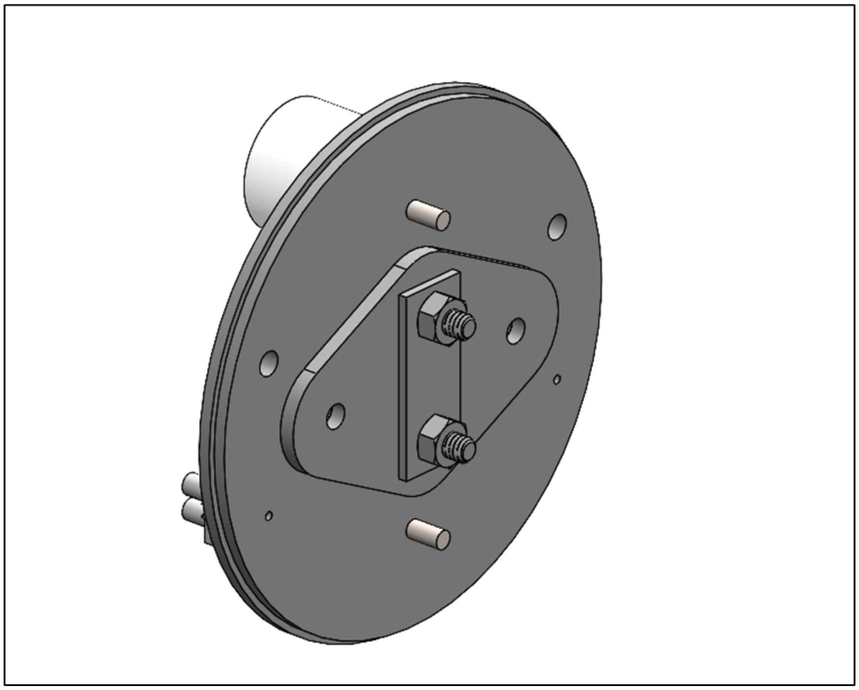

Figure 3.3: 4mm Aluminum plate with bulkhead and U-bolts

To reduce the cost of construction, the team wanted to use materials that our workspace had on hand. Unfortunately, the sheet-metal aluminum that was on-hand was limited in selection. The particular sheet metal used in construction of the distributor plates was 2mm thick. Our construction of the vehicle varied from the design in that two 2mm thick aluminum distributor plates were used in place of one 4mm thick plate..

- Additional loop in main shock cord

During final assembly, it was found that the main parachute could not be packed while attached directly to the nose cone as originally planned without creating a risk of damage to the fabric from ejection gasses. As a result, an alpine butterfly knot was used to create an attachment loop approximately 3 feet from the nose cone and the parachute attached to this instead.

- Pilot chute

The long delay between chute deployment and observed chute inflation caused some concern that the main parachute was not being ejected from the tube quickly enough. As a result, both the primary and backup black powder charges have been increased by 1 gram, and an additional 24” pilot chute has been added to the apex of the main parachute to help encourage deployment if the chute becomes stuck partway out of the tube.

- AA
  - Scrapped the 3d-printed spacers between spars and airframe

The original design of the Altitude Assurance vehicle subsystem called for 3D printed spacers at the interface between the aluminum stiffening spars and the airframe of the rocket. This was done to remove the gap between the flat surface of the spar and the curved surface of the airframe.

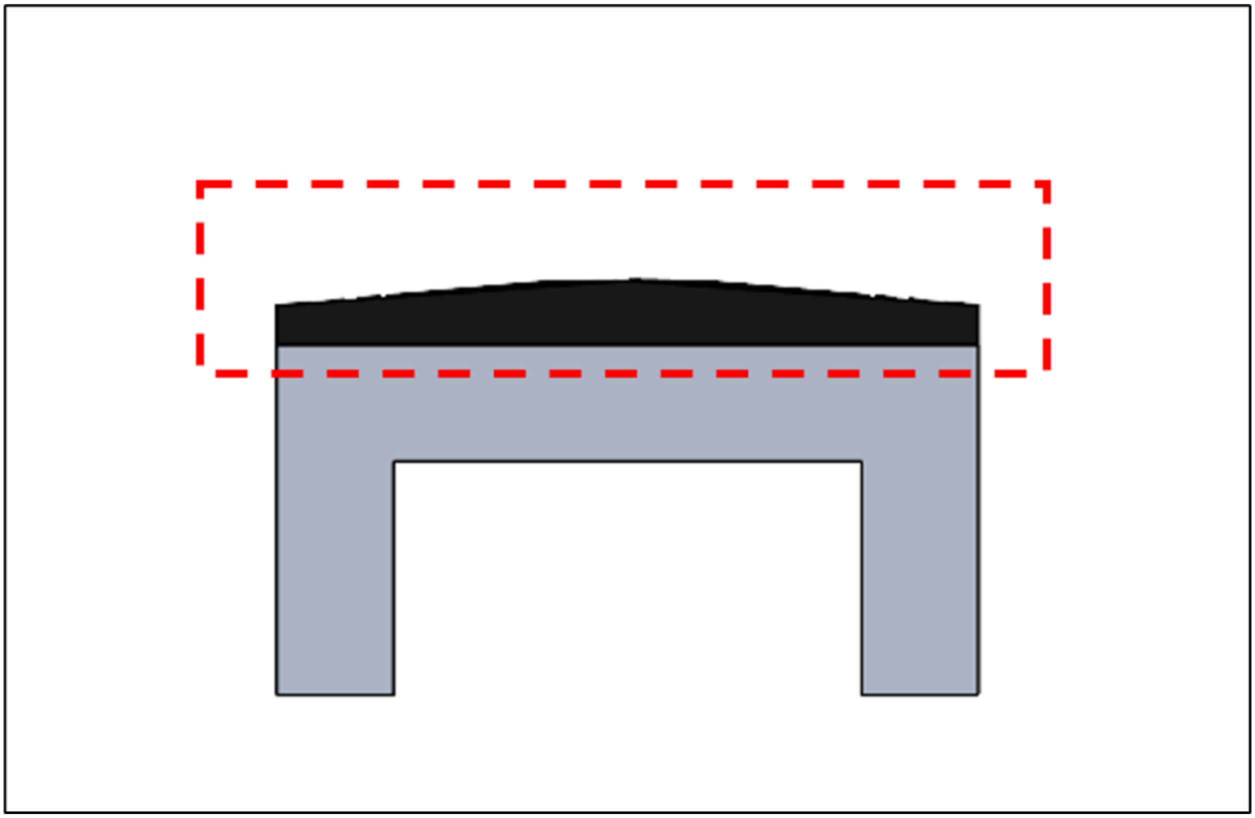

Figure 3.4: The spacers that were used to close the gap between the body tube and the c-channel (in red)

Since the spacers were designed to be 3D printed, they had to be reduced into sections that could fit on our 3D printer beds. Working with these individualized spacers was troublesome in practice. In assembly of the vehicle, the tolerance at the interface of the spars and the airframe was found to be minimal and so these spacers were excluded from the design.

- External fill port

As discussed in Section 5 of this report, one major failure of the Vehicle Demonstration Flight was the malfunction of the Altitude Assurance subsystem. As designed, it was not possible to access the valve leading to the pneumatics system or connect to the tank fill port without disassembling the rocket. Just before launch during the VDF, it was discovered that the pneumatics system was not receiving air, and since the team was behind schedule for the launch, there was no time to disassemble the rocket to check tank pressure and valve states. This is an issue that necessitates a redesign of the tank-segment airframe to include an external fill-port. This will take the form of a 1.25 in. hole in the airframe for fill-port access.

- Vehicle
    - 10-32 phillips to 10-32 torx

The vehicle was originally designed to use 10-32 phillips screws to assemble the airframe. During construction, stripping of these screws became a major issue that slowed down construction time. Because of this, it is necessary to change the design of the vehicle to use 10-32 torx screws instead of 10-32 phillips screws in assembly of the airframe as their design minimizes stripping at the head of the screw.

Figure 3.5: Example of a stripped phillips screw

3.1.2. Final Locations of Separation and Energetic Devices

In Figure 3.1.4, the points of separation and locations of energetic devices are shown. The vehicle uses 6 grams of black powder for the main chute's primary charge and 7 grams of black powder for the main chute's secondary charge. The drogue chute ejection charges are 2.5 grams for the primary and 3.5 grams for the secondary.

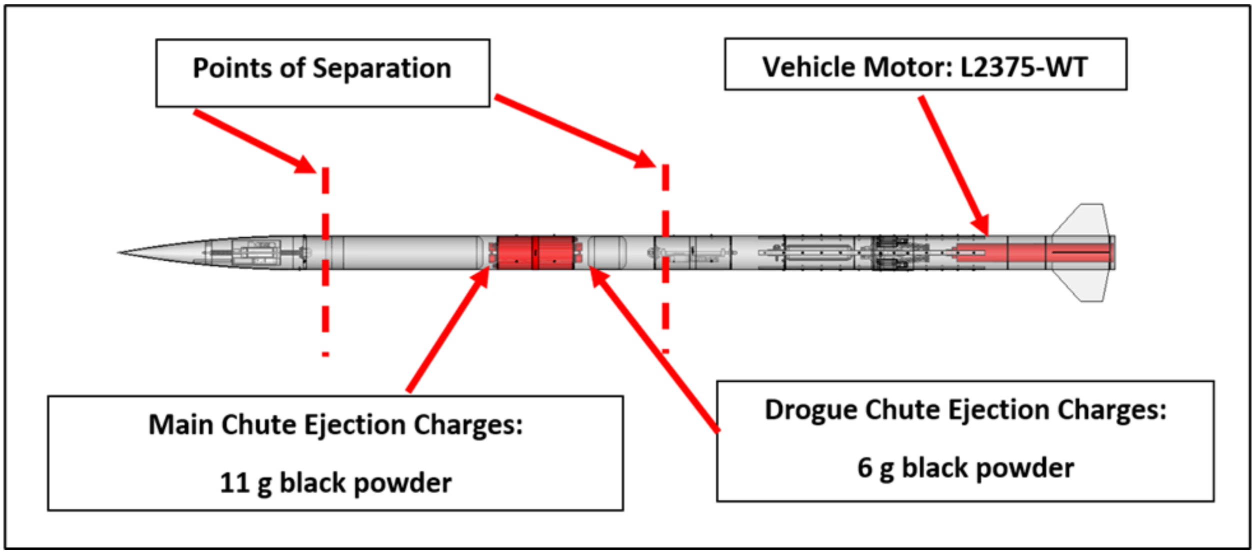

Figure 3.6: Points of Separation

3.1.3. Construction Process

The rocket fuselage is constructed from four primary tubes, a nose cone, and two internal couplers, all made of fiberglass. The final section of the body is the short housing compartment for the Altitude Assurance assembly, which will be discussed later, and was 3D printed with Nylon filament.

The first fiberglass tube is the roughly 32-in Booster section and houses the internal motor tube, fins, and half the supports for the rose petals. The motor tube which sits flush against the base of the rocket was epoxied with three fiberglass discs the width of the internal diameter of the rocket. The first disc was epoxied very close to the end of the motor tube, the second was roughly 10 inches up, and the third was roughly 17 inches up. The main priority was maintaining perpendicularity, which was achieved by repeated hand adjustments as the epoxy settled and the tube was suspended by its ends. Once epoxied, the motor tube assembly was slid into the base of the Booster section and epoxied in place. The final disk was set just behind the end of the aft tube and the motor tube was approximately flush.

The fin slots were cut into the aft airframe section with a fin slotting jig, which was constructed according to the specifications of a similar product developed by Apogee Components [1]. The four fin slots were measured with a paper wraparound template to ensure level and evenly spaced lines. It should be noted that this same technique was applied to all rotary measurements for screw holes on the vehicle body. The fin slots were cut with a ⅛ inch rotary bit one inch from the base and nine inches long. The guide rail was a nailed piece of wood which led to some difficulty with alignment. All of the fin slots were acceptably accurate. Further fine-tuning was completed with sandpaper and a powered rotary tool with a sanding bit.

Figure 3.7: Fabricated Fin Slotting Jig

The fins were inserted into the slots until equally pushed in, using the motor tube as a stopper. An initial epoxy layer was applied to all contact points before a secondary fillet coat was applied to the outside of the tube against the fins for structural support. The final modification for the Booster section was the screw holes for the C-channel supports. The following method was repeated for all external screws, except for shear pins. Initially, the holes were cut to a smaller diameter to allow for a 10-32 tap, but the fiberglass proved to be too soft for fine-threaded taps so the holes were later expanded to a diameter of 5/32" and the C-channel was drilled and tapped for support. Four sets of four holes were drilled into the aft tube spaces 2.5 inches apart and two inches from the top.

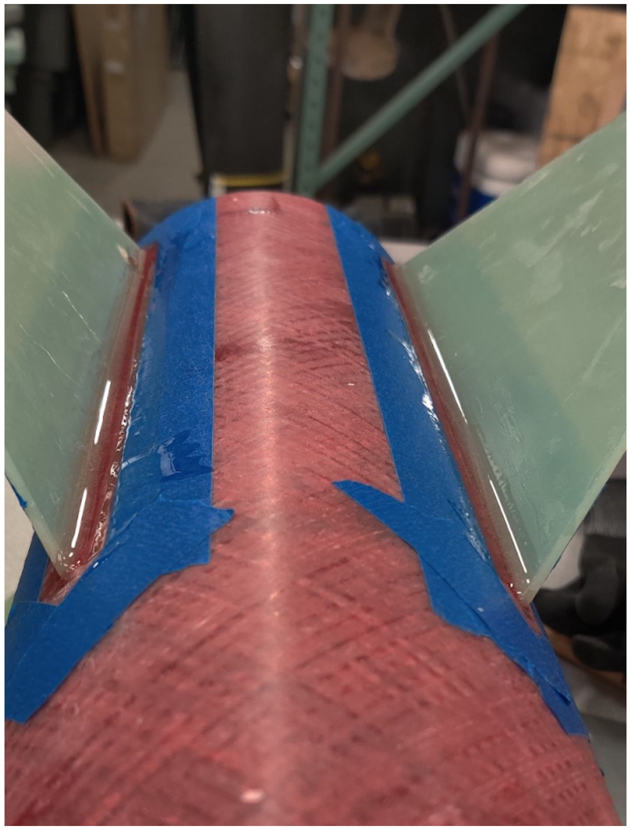

Figure 3.8: Fin Fillets on Booster Section Airframe

The air tank segment of the airframe was initially 28 inches long, but was cut to 27 inches. The last inch is compensated with a one inch switchband epoxied to the middle of the first coupler. The only modifications made to the tube are six 10-32 holes for the C-channel assembly and one for the AA coupler. The four sets of six were similarly cut 2.5 inches apart and two inches from the base of the tube. The four top screw holes were cut 2.5 inches from the top. When drilling the coupler screw holes, the thickness of the fiberglass was enough to allow for thread tapping so for each subsequent attachment to a coupler, the holes are smaller and threaded.

The Altitude Assurance bay coupler outer diameter matches the rocket's internal diameter of 5.375 inches so that it slides snugly into the body tubes. Each end is covered by fiberglass coupler caps held together with ¼ inch threaded rods spaced 2.5 inches apart from the center. These rods also hold together the pressboard sled used to hold the Altitude Assurance components. The aft cap originally had large cuts to allow for wires to pass through, but this design was unnecessary and time consuming to cut, so appropriately sized holes were drilled in to achieve the same goal. This cap is unique in that it allows for air to pass through. All other caps must be sealed since they undergo pressure during separation. It is also unique because it does not have a U-bolt attached, as it is not connected to a parachute and does not act as a point of security when the rocket separates. The electronics sled itself is a 10x4 in. wooden board with brackets on both ends for ¼ in holes spaced 2.5 inches apart to accommodate the threaded rods. All of the electronic components on the sled were screwed down with M3 screws. At each point the threaded rods go through, bolts are attached to each side with washers on the caps. The forward coupler cap used two distributor plates to spread the shock load of recovery forces across the bulkhead. This differs from the original design since the only on-hand aluminum sheet metal was only half the thickness that was required and the team wanted to use on-hand building materials (including the aluminum sheet metal for the distributor plates) as much as possible. The distributor plates were manufactured using a water jet owned by the BIC. The U-bolt for the bay is perpendicular to the threaded rod holes and sticks out to be attached to one end of the drogue chute. The U-bolts used were of the designed specifications: ¼-20 thread size and 1 inch internal spacing.

Three holes are drilled into the side of each switchband for arm the electronics. The center hole is drilled a ¼ in wide with two ⅛ in mounting holes. This process was repeated for the Avionics coupler, but instead allows access for the arming switch to the black powder charges.

The other end of the AA coupler attaches to the second mid tube, measuring 24 inches. This is the first separation point for the rocket that houses the drogue chute, so the screw hole 2.5 inches from the base of the tube is 0.89 inches for the smaller nylon shear pins. This hole was drilled intentionally too large for the pins to allow for easy removal after deployment. The holes into the coupler were appropriately sized and threaded. Similarly, the other end of the mid tube attaches to the Avionics coupler with 10-32 screws located 2.5 inches from the top.

The Avionics coupler strongly resembles the AA coupler with the same wooden sled for internal components, fiberglass caps, and threaded rods. Both fiberglass caps have the additional brackets and U-bolts sticking out from each end. The main difference are the PVC pipe cups for the black powder charges for separation. Two 1.3-in. cups are attached on each end for drouge and primary parachute separation respectively. Their fixed holes are spaced 3.25 inches apart in line with the U-bolt holes, with terminal blocks screwed in nearby with M3 Screws.

Again, the other end of the coupler has 10-32 screws 2.5 inches from the base of the front body tube.

The front body tube has the 10-32 holes for the coupler on one end and four shear pins drilled into the top three inches from the edge. These were drilled inline with the internal coupler attached to the nose cone. The 6-inch coupler was epoxied first into the nose cone to assume the expected design and was later drilled in place with the shear pin holes on the front body tube. Since the nose cone was from a different source as the other fiberglass parts, there were some sizing issues that required heavy sanding to fit the coupler inside the cone. These issues were not as evident when fitting the payload integration in the cone.

The method for drilling all the screw holes of any size varied as multiple people worked on this process. Most holes were drilled manually over measured marks with the tube in question clamped to the edge of a worktable. Some of the holes were drilled with a drill press, which yielded more accurate results but was significantly more difficult to secure to the work surface. Structurally, the priority was internal consistency over linear accuracy.

The Rose Petal assembly was 3D printed entirely with Nylon 66 with the exception of the pneumatics, screws, and the aluminum C-channel. For the linkages and the actual Petals, the main difficulty was clearing out all the printing supports. This was mitigated by manually editing the slicing software's preferences and heavy tooling to file down excess. The Petal mount and the linkage mount that held the brake assembly together were also printed and suffered from an even greater support issue. Clearing these pieces out took significant effort. The largest and most technically challenging print was the cylindrical petal housing component, which would form the only external body part of the rocket not made from fiberglass. The original design assumed a single solid part, but had to be cut in half for several reasons. First, team experience with printing with Nylon was extremely limited, so the parameters for such a large print to avoid buckling or warping were relatively unknown. Second, it was judged that the risks of the part failing were too great and there was not enough time or spare nylon filament to make too many attempts. This solution did not change any structural elements because the aluminum C-channel that ran through the housing would provide enough support. These holes were printed to match the same 10-32 screws throughout the rest of the body.

The holes for the C-channel were drilled by using the holes in the fiberglass as a guide. This was achieved by first drilling the last holes in the C-channel externally and using them as a guide to insert the entire C-channel/housing assembly. Here, human error was most evident as the crooked holes and C-channel attachments created visible propagation. However, all angles were within margins and well within the constraints of the C-channel, so final drilling had no effect on the structure or assembly.

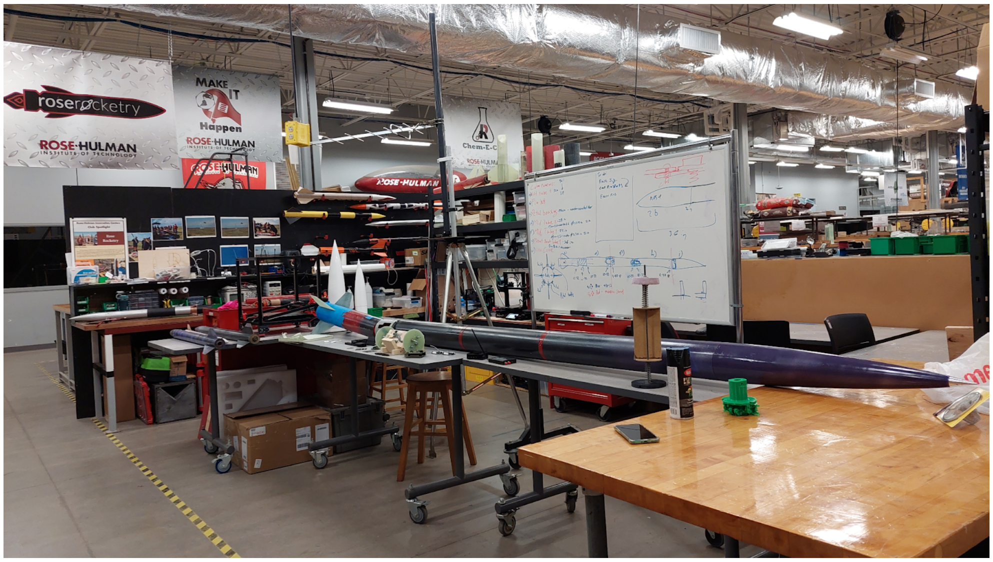

Figure 3.9: Partially Constructed Vehicle

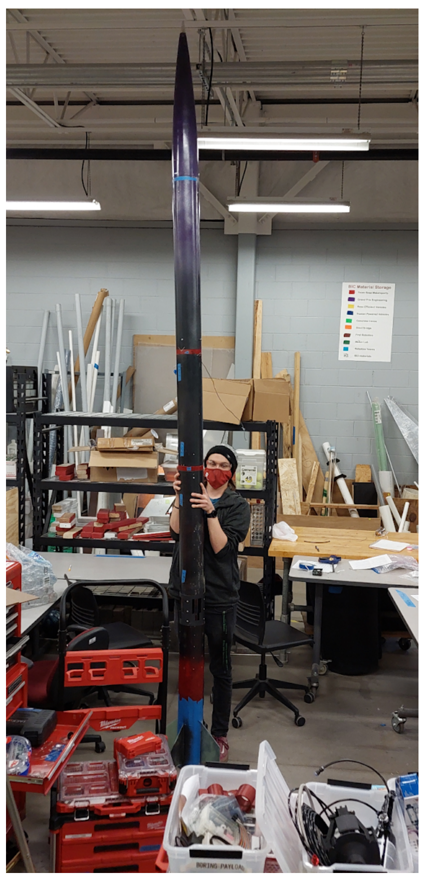

Figure 3.10: Fully Constructed Vehicle

3.1.4. Schematics

This is a drawing of the fully assembled avionics bay inside the coupler

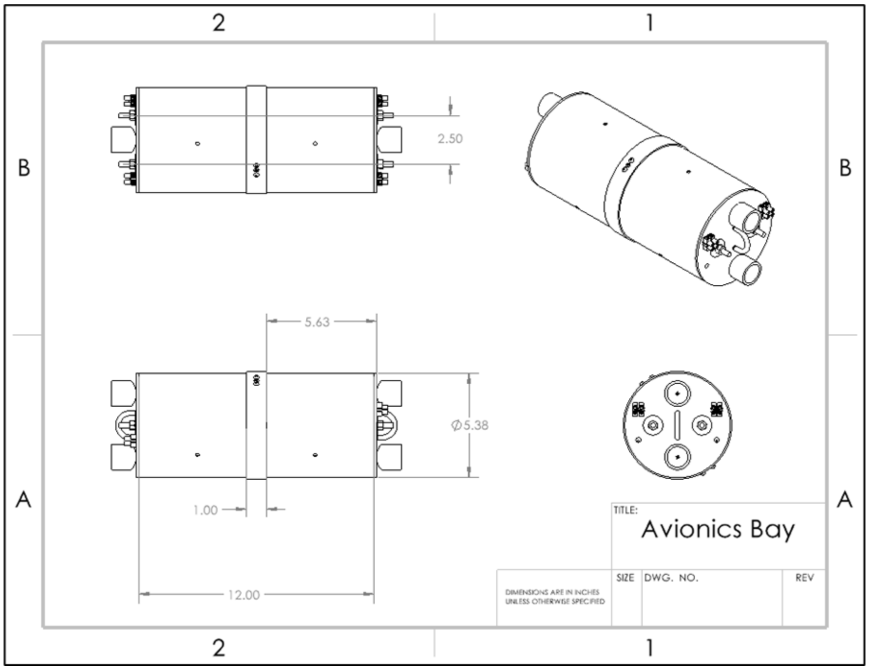

Figure 3.11: Avionics Bay Schematics

This is a drawing of the fully assembled Payload Sled outside of the Nosecone housing

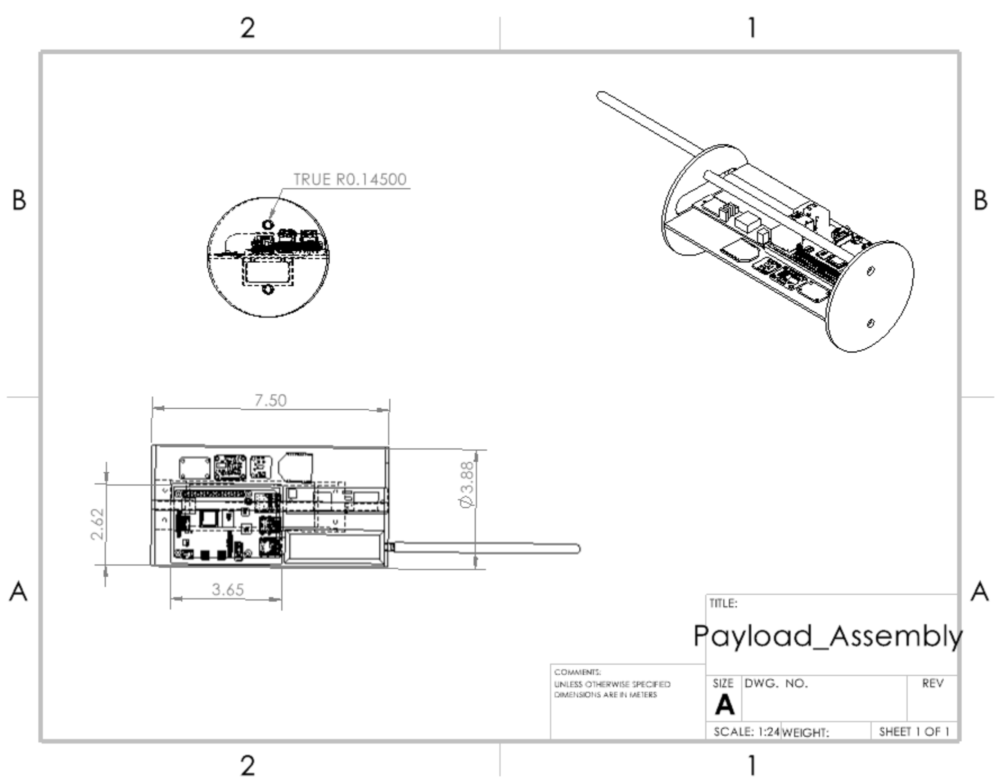

Figure 3.12: Payload Sled Schematics

This is a drawing of the Payload Bulkhead, the component used on the end of the electronics sled in Figure 3.1.6

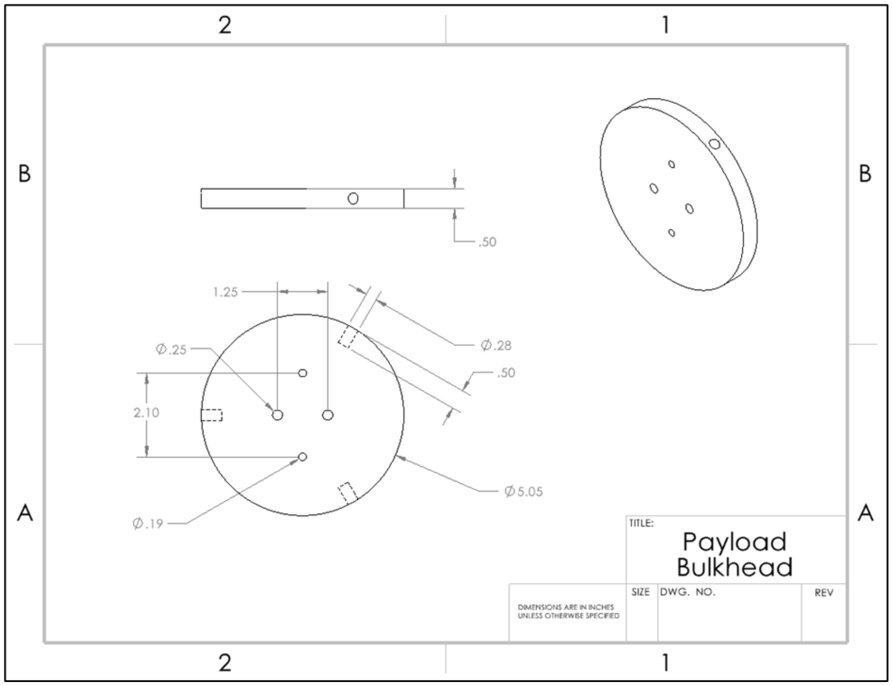

Figure 3.13: Payload Bulkhead

This is a drawing of a Distributor Plate, a component used to secure the U-bolts to the Avionics and AA couplers, as well as the Payload bay.

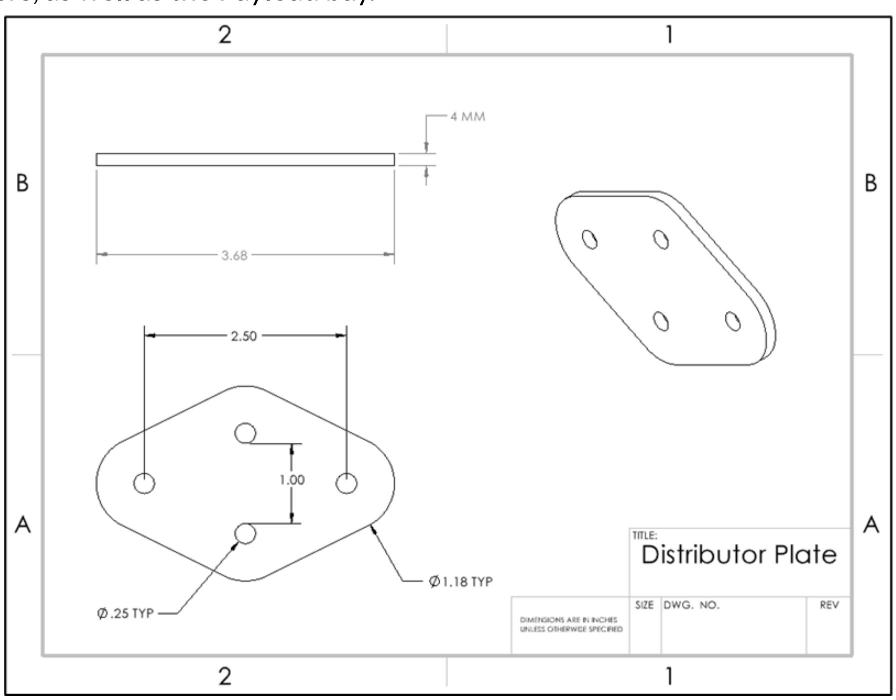

Figure 3.14: Distributor Plate

This is a drawing of the body parts housing the recovery systems, including switchband.

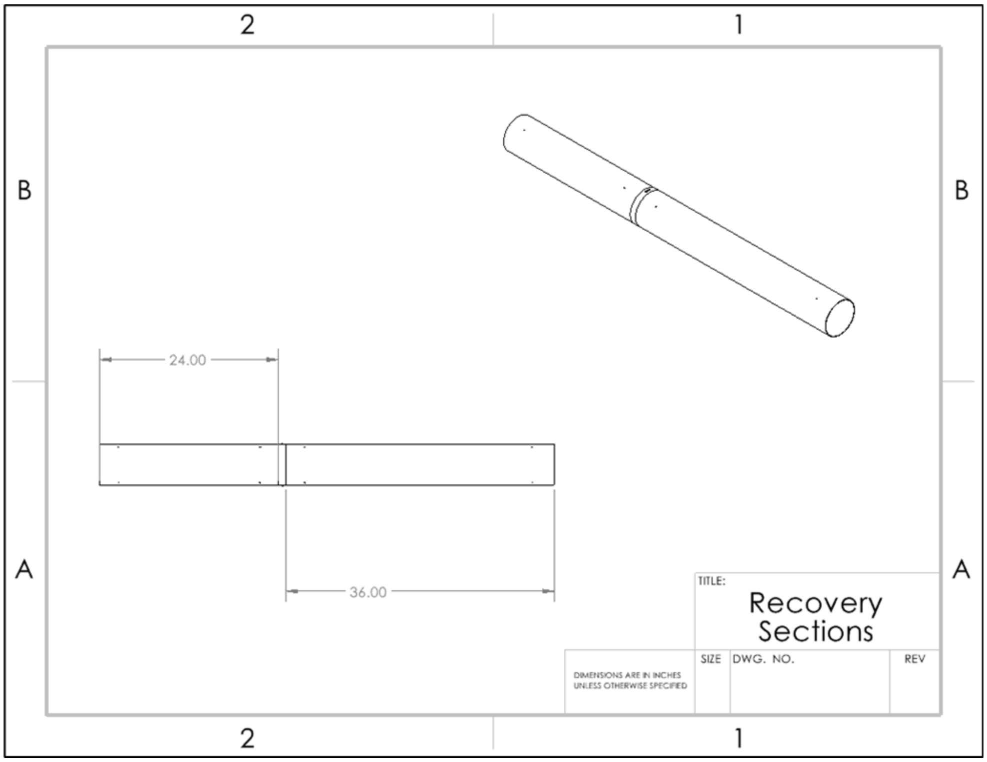

Figure 3.15: Recovery Body

This is a drawing of one of the C-channels used to secure the Rose Petal Assembly

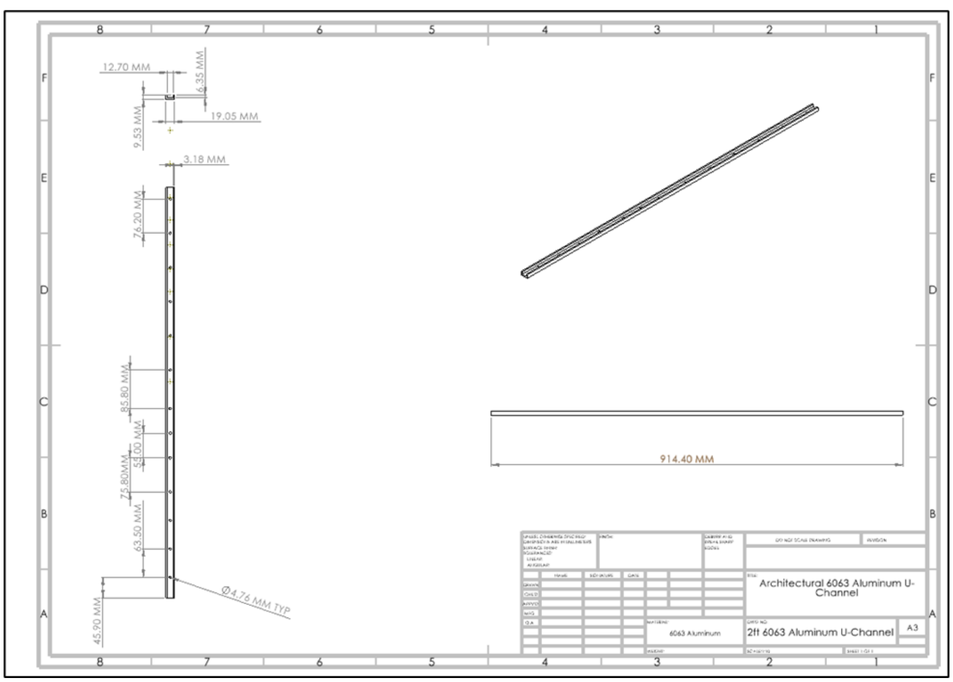

Figure 3.16: C-channel Rod

This is a drawing of one of the Linkage arms used to push up the Rose Petals.

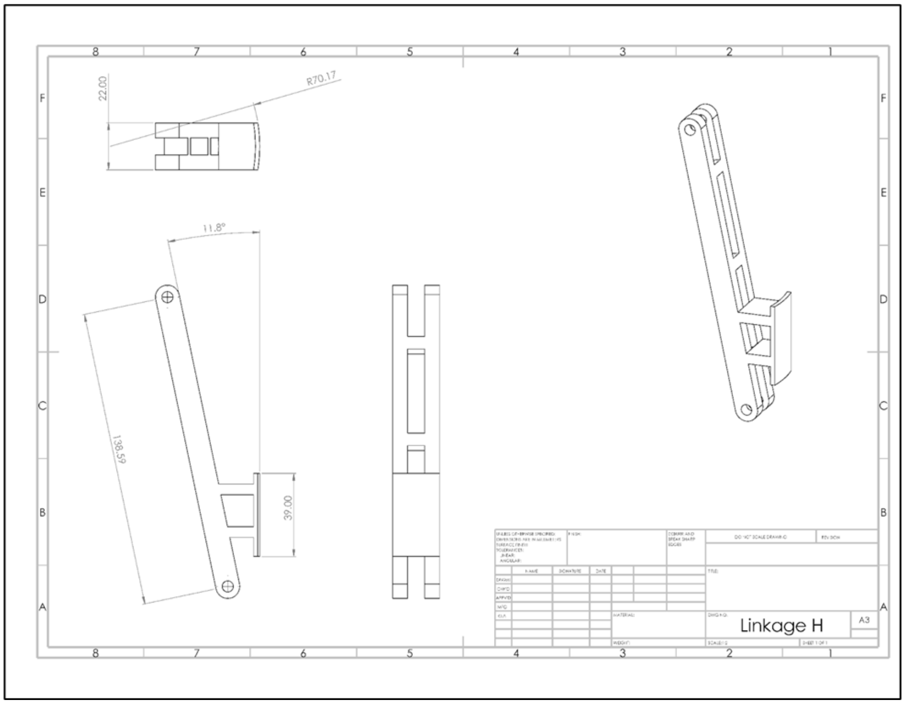

Figure 3.17: Linkage Arms

These three drawings are of the different position rings used for the air tank in the body.

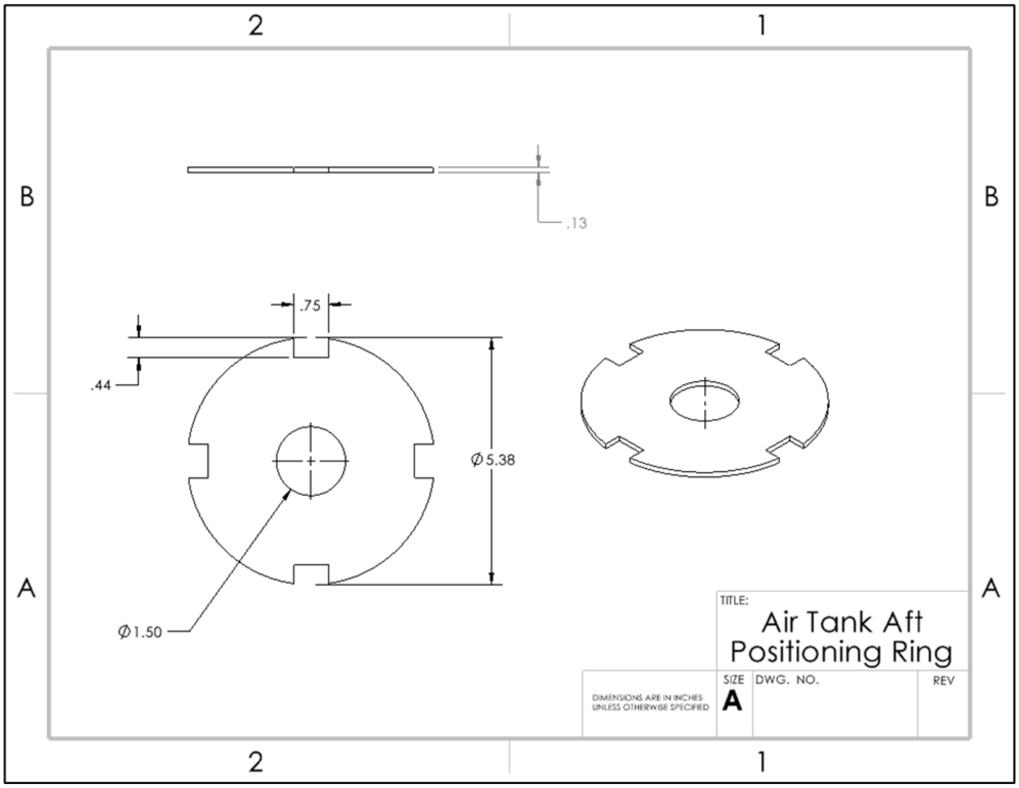

Figure 3.18: Air Tank Position Ring No.1

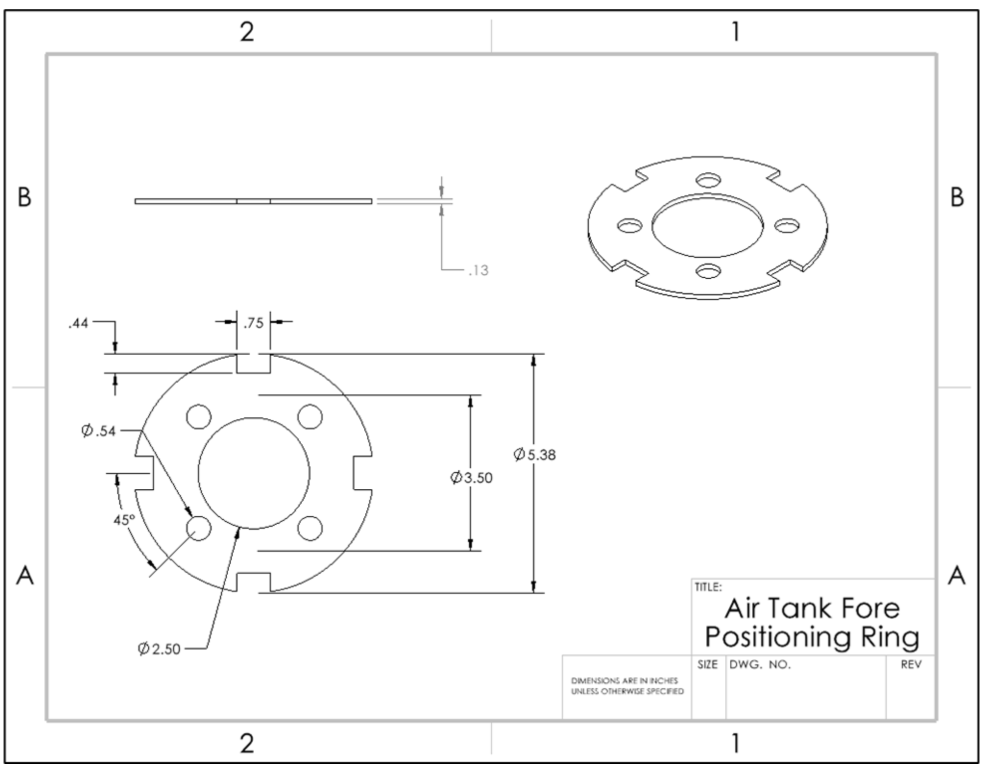

Figure 3.19: Air Tank Position Ring No.2

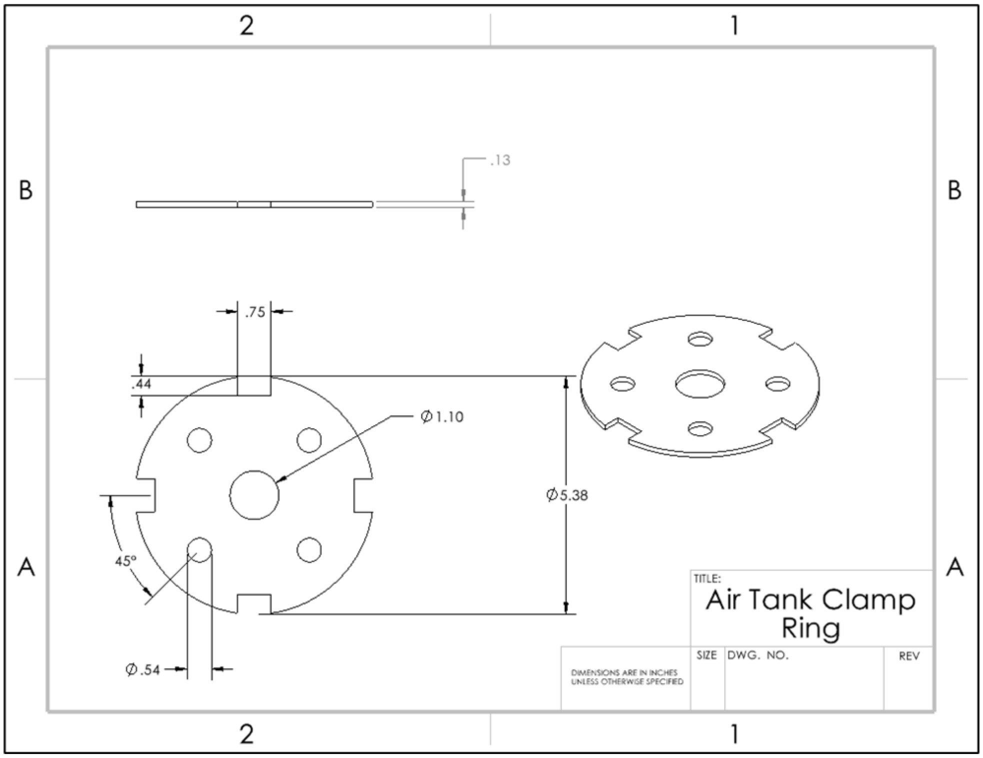

Figure 3.20: Air Tank Position Ring No.3

This is a drawing of one of the Rocket Fins inserted into the body.

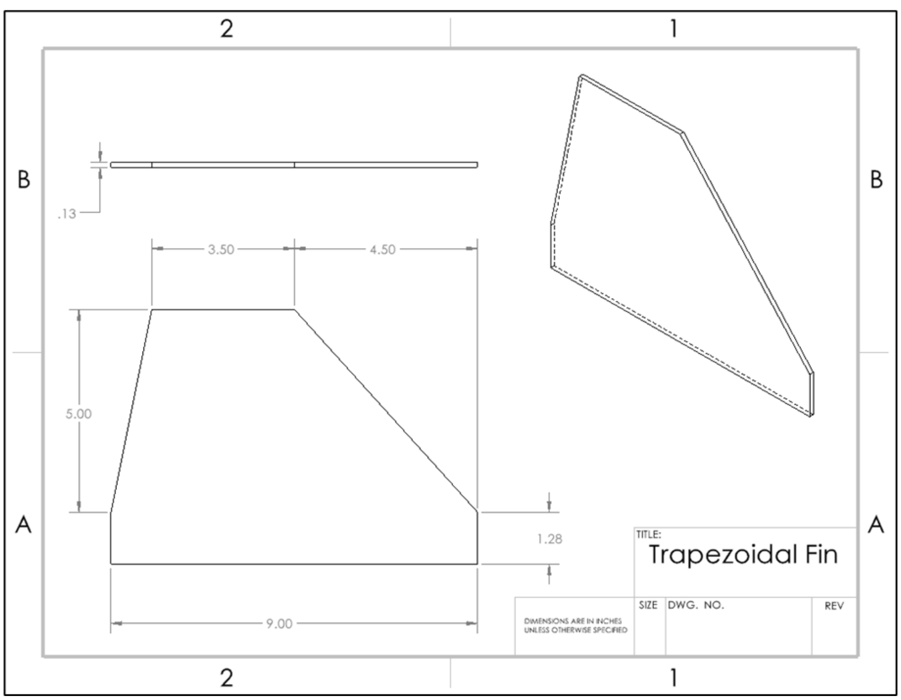

Figure 3.21: Rocket Fin

This is a drawing of the Vehicle Motor Case attached inside the base of the rocket.

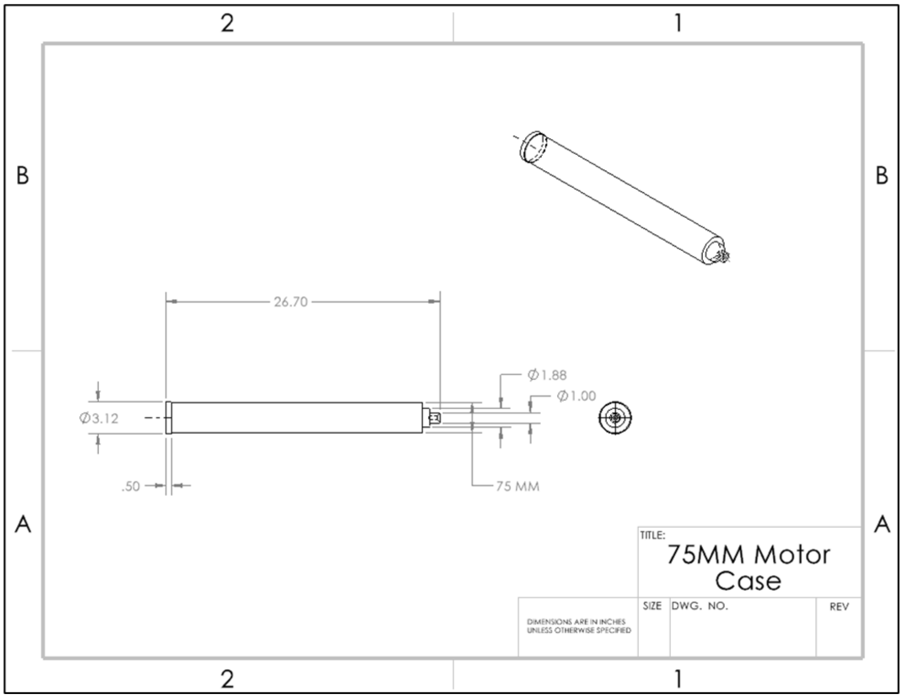

Figure 3.22: Motor Case

This is a drawing of the Brake Mount component, used to hold the Rose Petals in place.

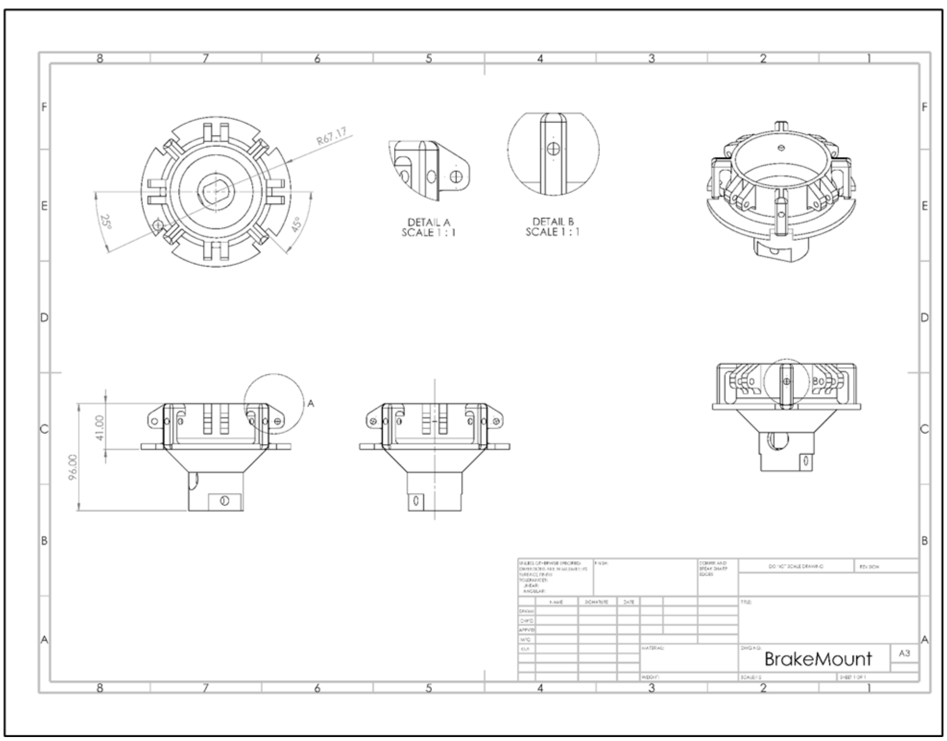

Figure 3.23: Brake Mount

This is a drawing of the Linkage mount component, used to hold the Linkage arms.

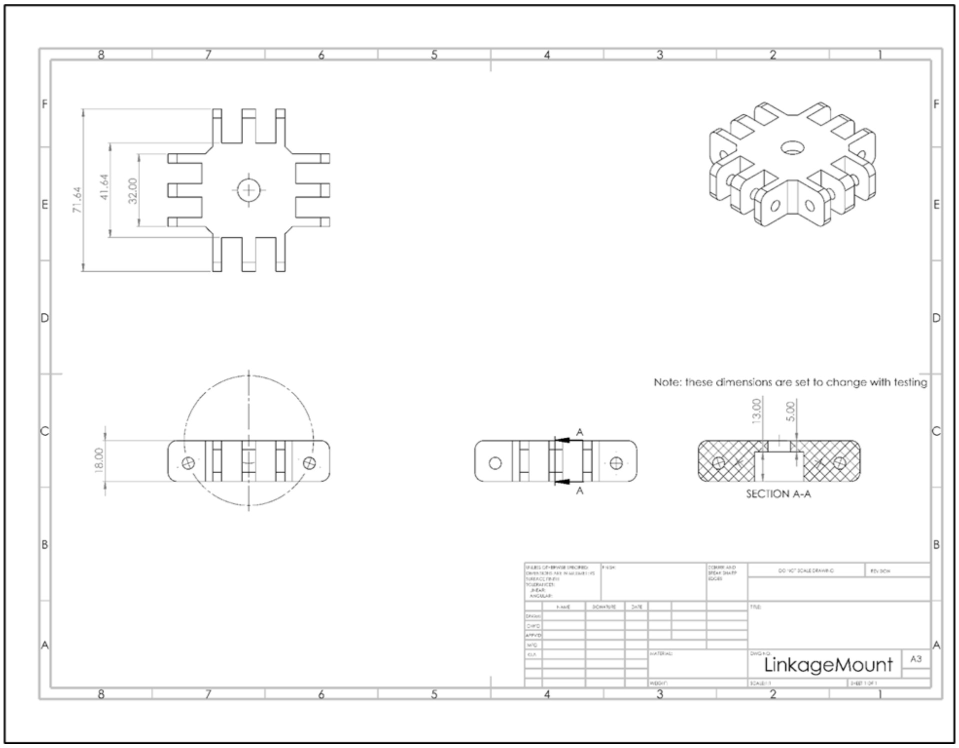

Figure 3.24: Linkage Mount

3.2. **Recovery Subsystem**

3.2.1. Overview

The recovery system for this vehicle is structured traditionally. The drogue parachute is located directly above the booster and Altitude Assurance sections. All deployment electronics are housed in a coupler above that. The main parachute is housed above that, directly below the nose cone.

3.2.2. Structural Elements

The rigging of the recovery harness system is designed to maintain a 5000 lb breaking strength at all connection points where possible. The one exception is the swivel included on the parachute, which is rated at 1500lb working load (likely representing 4500lb breaking strength) as it was not possible to modify this part without weakening the parachute overall. Removable connections are provided by quick links with a rated load of 2500 lb. Their final breaking strength was not provided, so the strength of 2500lb was selected to ensure that even a lower-than-average safety factor of 2 would not reduce the strength of the connection below 5000lb. The shock cord itself is made of 5300-lb breaking-strength tubular Kevlar webbing produced by OneBadHawk Rocketry, and is secured to 1/4-20 U-bolts at each end, whose strength is limited by their threads at 7400 lb; the plates are tied together by Grade 8 threaded rods with a total strength of 9500 lb.

During the construction of the rocket, an additional loop had to be added to the main parachute shock cord to allow the shroud lines of the parachute to be properly protected from ejection gases; this was accomplished using an alpine butterfly knot approximately 3 feet from the nose-cone end of the cord. A full schematic of the rigging of the recovery system appears in Section 3.2.6.1.

The sections are secured by 4x #4-40 nylon screws acting as shear pins each; this was found to be sufficient in the CDR and the results of the test flight did not indicate that any further adjustment was necessary. The holes for these screws were tapped on the outer tube and drilled out to their outside thread diameter on the inner coupler so that the sheared ends of the screws could be easily removed after flight.

3.2.3. Electrical Elements

The electrical component of the recovery system consists of a Missileworks RRC3 as a primary altimeter and an Altus Metrum EasyMini as a secondary altimeter. Each altimeter is powered by a 2-cell, 300mAh lithium-polymer battery manufactured by Tattu, and is powered on and off by a Featherweight screw switch mounted to the coupler switch band. The sled is wired using 18 AWG stranded wire color-coded as follows:

- EasyMini main: yellow
- RRC3 main: white
- EasyMini drogue: green
- RRC3 drogue: brown
- EasyMini switch: red
- RRC3 switch: blue
- Battery: red & black paired

At the edge of the sled, each connection is terminated by a double-sided screw terminal strip to allow configuration and repair of external wires without soldering as well as an additional set of terminal blocks at the bay bulk plates so that e-matches can be installed without disassembling the avionics bay. This layout is shown in more detail in figure 3.2.1 and section 3.2.6.2 below.

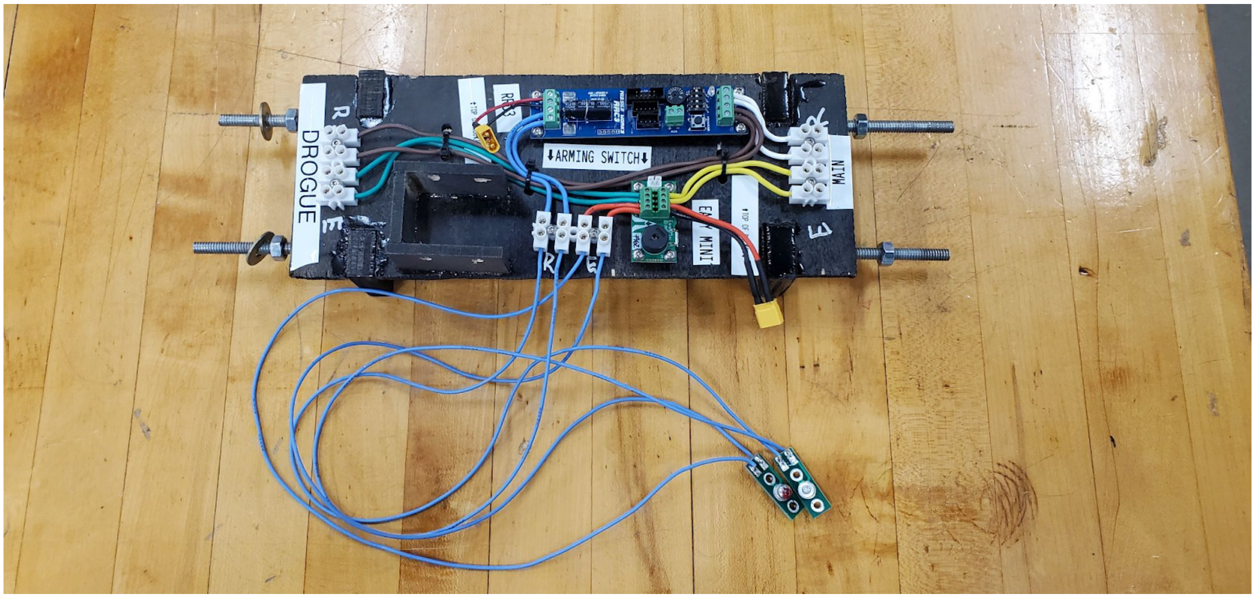

Figure 3.25: The Avionics bay sled with all components except batteries installed

3.2.4. Redundancy Features

The primary source of redundancy in the recovery system is within the electronics subsystem. The two deployment altimeters are produced by different manufacturers, meaning that a software fault in one altimeter will not cause a mission failure; additionally, each has a completely independent electrical system so that a dead battery or malfunctioning switch cannot cause the system to fail. Outside the electronics portion of the recovery system, it is difficult to directly add redundancy without simultaneously introducing other failure modes; for example, adding a second cord in parallel would increase the risk of tangling of the parachute shroud lines more than it would reduce the risk of cord breakage. Instead, redundancy is introduced indirectly through packing methods; for example, the Kevlar harness is packed below the parachute in the tube so that friction between the harness and the chute during deployment will help the chute come out.

3.2.5. Parachute Sizes & Descent Rates

The drogue parachute selected for this mission is the SkyAngle Cert3 drogue, at 6.3 sq. ft. surface area, while the main parachute is a SkyAngle Cert3 XXL, at 129.0 sq. ft. surface area.

When updated to account for the measured liftoff weight of the rocket, SkyAngle's provided descent rate calculator predicted a descent rate under drogue chute of 33.9 m/s and a descent rate under main chute of 4.4 m/s [2], while the actual observed descent rates per the altitude-assurance flight computer were 28.1 m/s and 5.1 m/s, respectively. While the decrease in drogue chute descent rate is not particularly concerning and may be explained by the body drag of the rocket not being included in the calculation, the increased descent rate under main would put us over competition guidelines for kinetic energy at impact; we have contacted SkyAngle to resolve any possible discrepancies or errors on our part that could lead to this increase in descent rate.

3.2.6. Schematics

3.2.6.1. Rigging Schematic

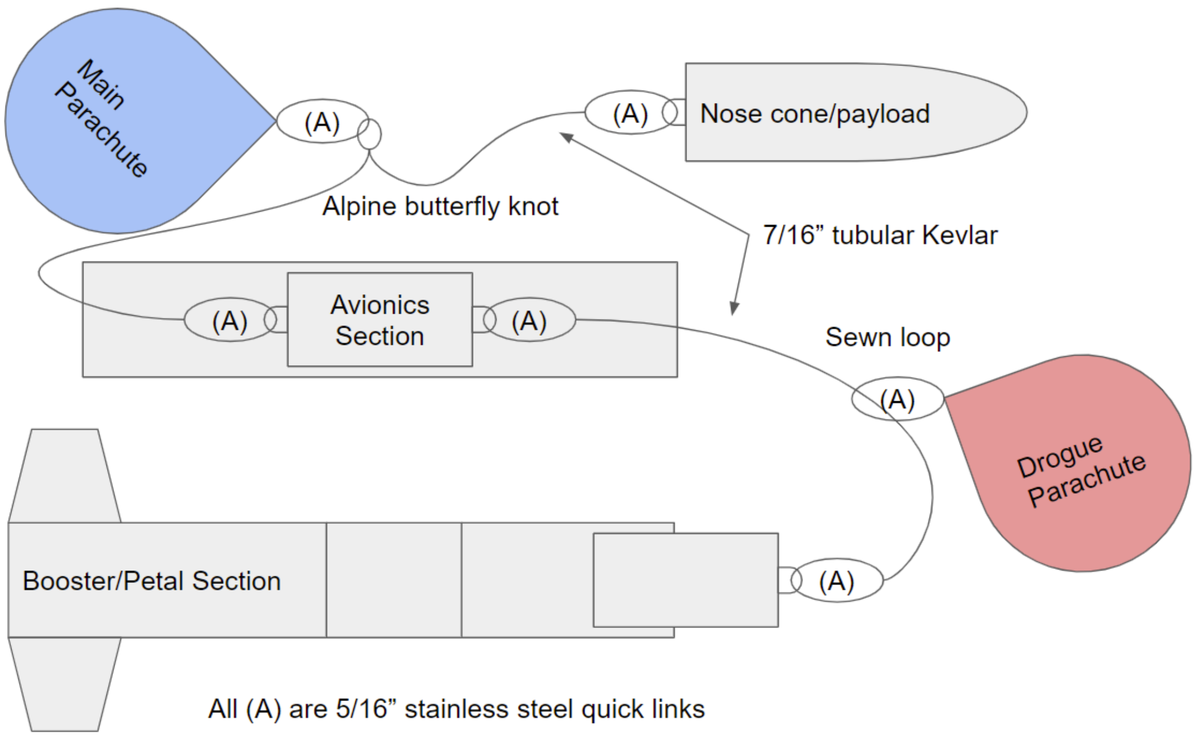

Figure 3.26: Rigging Schematic

3.2.6.2. Main Avionics Bay Electrical Schematic

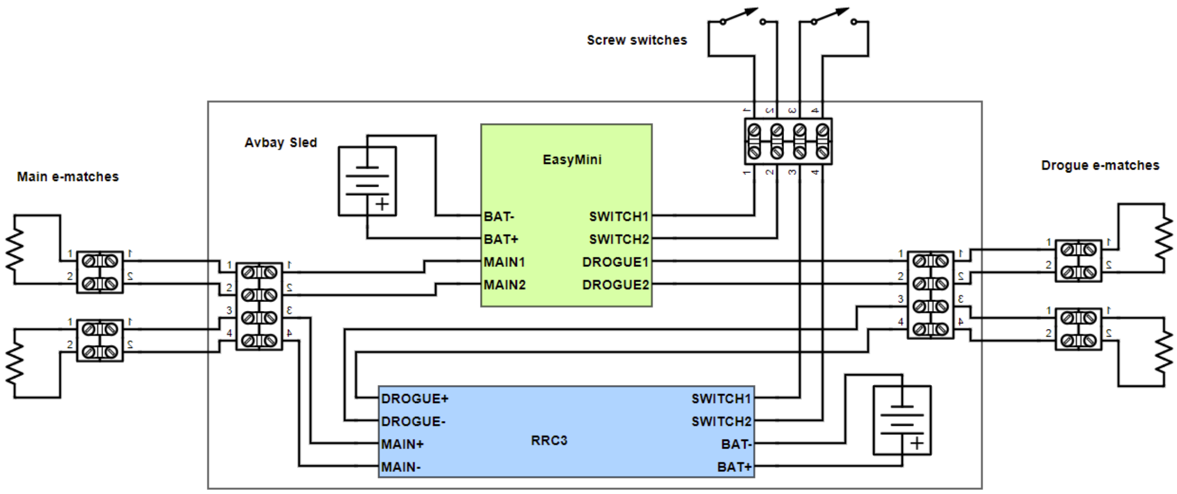

Figure 3.27: Main Avionics Bay Electrical Schematic

3.2.7. Interference with transmitters

Potential transmitter interference is being addressed by surrounding the critical mission hardware in insulated foil. During a payload test, it was determined the shielding of the foil is enough to decrease the power transmitted by over 99%.

3.3. Mission Performance Predictions

3.3.1. Flight Profile Simulations 6-DOF (fine) + 2 DOF (coarse)

Predictions of the vehicle's flight performance were made using two different flight profile simulations. The first was a coarse, 2-DOF simulation developed by students using Simulink and run in MATLAB. The second was a 6-DOF simulation performed in OpenRocket.

3.3.1.1. Coarse Profile

The coarse profile was performed using a 2-DOF vehicle simulation developed by students using Simulink and run with MATLAB. Updated vehicle information was passed into the simulator including the vehicle mass, thrust curve, and launch angle. The flight profile obtained by this simulation was for a 10 degree rail cant and is shown below.

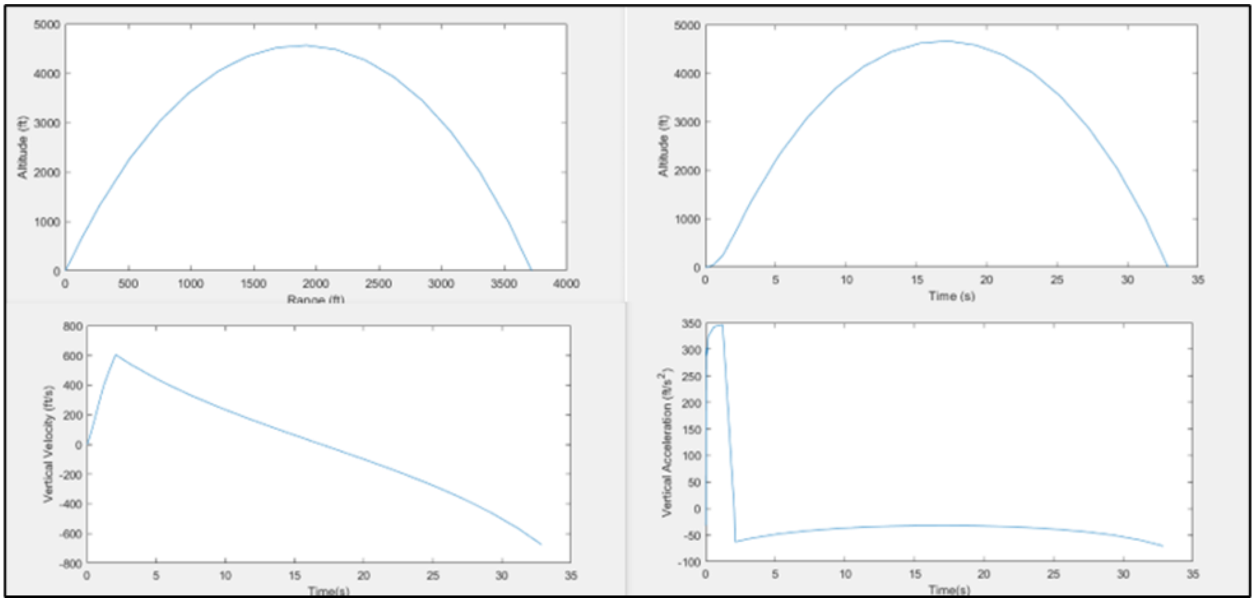

Figure 3.28: 2-DOF flight profile made using Simulink for a 10 degree rail cant

3.3.1.2. Fine Profile

The fine profile was performed in OpenRocket, using a Runge-Kutta 4 simulation and OpenRocket's Extended Barrowman aerodynamic simulation method. Simulations were performed for vertical flight, 5 degrees launch angle, and 10 degrees launch angle; the results of those simulations are shown below.

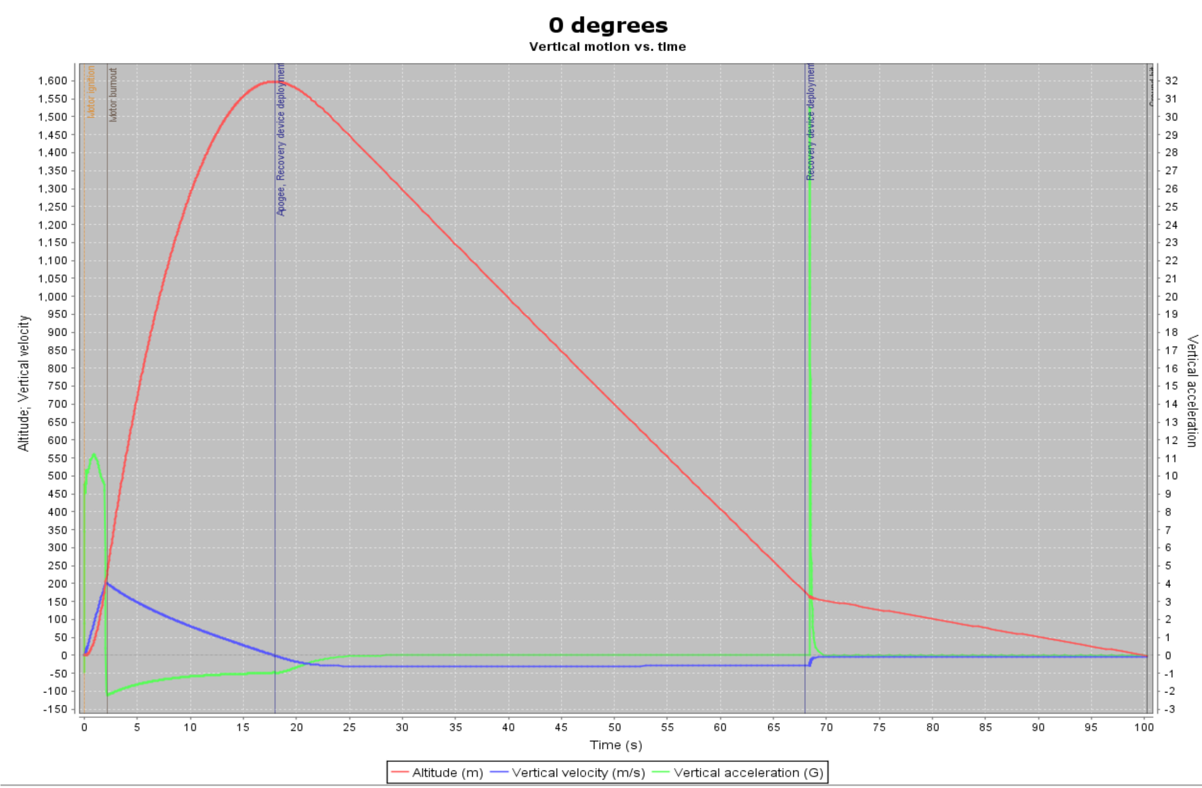

Figure 3.29: Vertical Flight Simulation

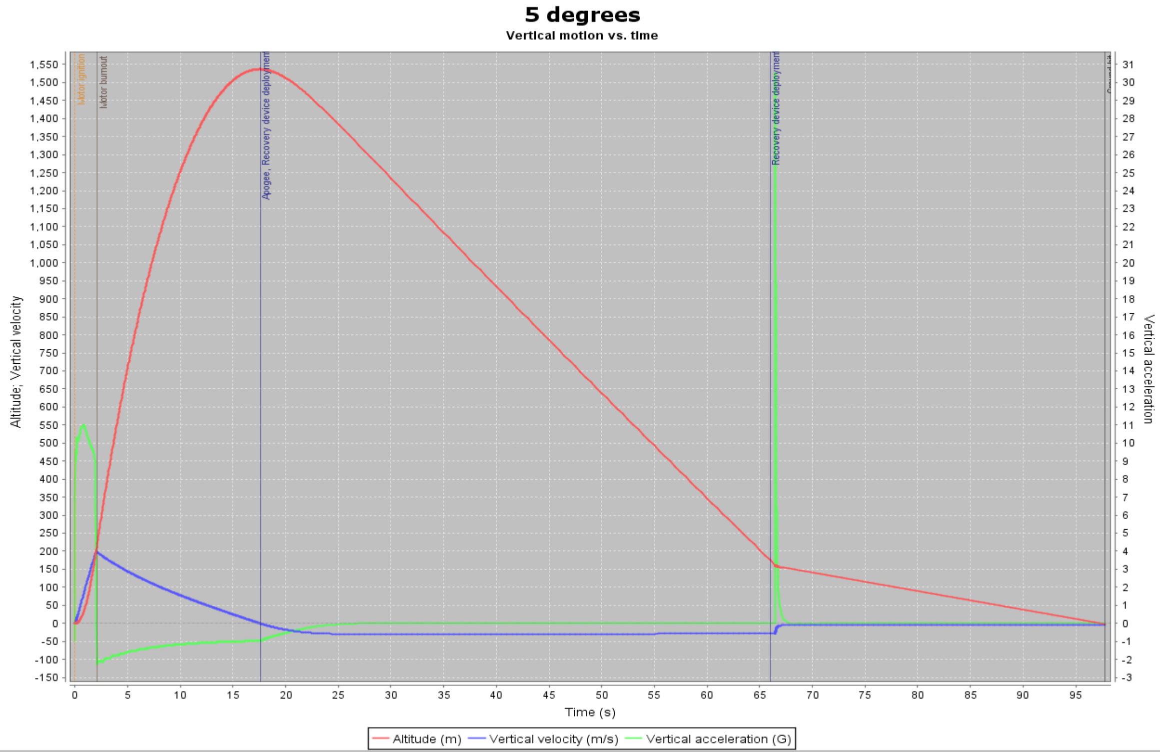

Figure 3.30: 5 degrees Launch Angle Simulation

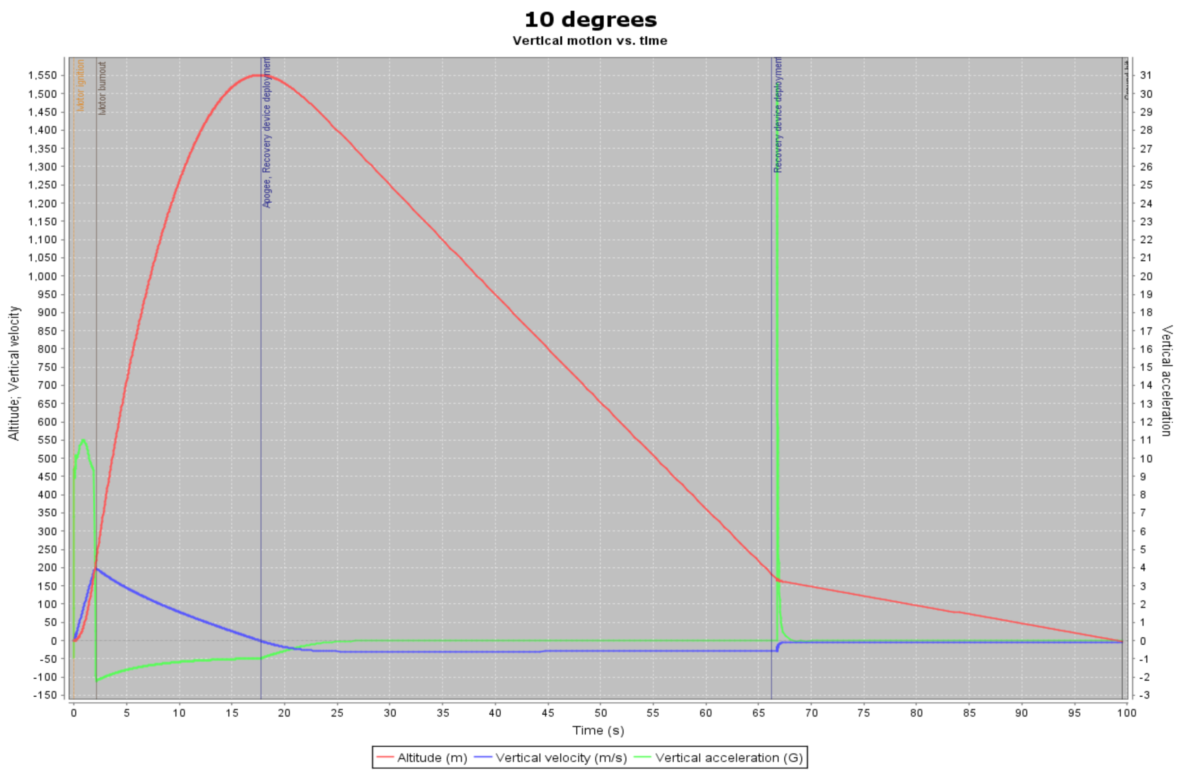

Figure 3.31: 10 degrees Launch Angle Simulation

3.3.1.3. Analysis and Comparison

Both the coarse and fine profile provide meaningful information about the vehicle performance. The coarse flight profile shows that at a 10 degree rail cant, the vehicle reaches an apogee of 4664 ft. What this suggests is that the vehicle will be within the competition requirements of achieving an apogee between 4000 and 6000 ft. The fine flight profile suggests that the vehicle will achieve an apogee of 5080 ft. These two simulations roughly agree and their discrepancies can be attributed to what the coarse flight profile fails to simulate: wind speed and energy transfer to angular momentum. What is important to note is that the fine flight profile suggests that our vehicle will perform above the 5000ft target and so the Altitude Assurance system can function to lower that apogee.

3.3.2. Stability Margin and CP CG Relations

Based on Openrocket's Extended Barrowman method, the center of gravity of the vehicle is at 95.6" from the nose cone tip while the center of pressure is at 127.0". This yields a static stability margin of 5.62 calibers. However, being considerably longer than most high-power rockets in comparison to its diameter, this vehicle is subject to an additional constraint: its center of pressure must be behind its center of gravity by at least 10% [3]. This is also satisfied by the current design, as the distance of 31.5 inches represents approximately 19% of the rocket's length.

3.3.3. Landing Kinetic Energy

Kinetic energy calculations for each tethered section were performed for ground-hit events. These calculations used the ground-hit velocity reported by OpenRocket and the mass of each tethered section. A 20 mph wind speed was used to determine the worst-case results. The table below summarizes the kinetic energy calculations.

Table 3.1 Summary of Kinetic Energy Calculations

	Forward Section	Mid Section	Aft Section
Mass (lbm)	5.23	10.09	19.62
Ground-Hit Velocity (ft/s_	16.7	16.7	16.7
Kinetic Energy (ft-lbf)	22.7	43.7	85.0

The worst case kinetic energy of the aft tethered section at ground hit was determined to be greater than the maximum allowable 75 ft-lbf. From our Vehicle Demonstration Flight, we have used our measured flight profile to update the drag coefficients of our parachutes. We found that the advertised drag coefficient of our main parachute was less than what was determined from our flight. The team is currently in contact with the manufacturer about this, however, the team may attribute this discrepancy to parachute packing. To rectify this, the team plans to use a pilot chute in deploying our main parachute in subsequent flights of the vehicle.

3.3.4. Expected Descent Time

The expected descent time calculations were based on the OpenRocket recovery simulation. The table below summarizes the expected descent time in a worst-case event of 5° launch rail cant with no Altitude Assurance functionality to ensure a 5000ft apogee.

Table 3.2 Summary of Expected Descent Time Calculation

Flight Time (s)	100
Time to Apogee (s)	17.9
Expected Descent Time (s)	82.1

3.3.5. Drift Calculations

The drift calculations were based on a simple worst-case formula:

$$Drift = Wind\ Speed \times Descent\ Time$$

The following is the result of each drift calculation at various wind speeds.

Table 3.3 Summary of Expected Drift Calculations

Wind Speed (mph)	Wind Speed (ft/s)	Expected Drift (ft)
0	0	0
5	7.33	601.8
10	14.67	1204.4
15	22	1806.2
20	29.33	2408.0

Since the worst-case drift of 2408 ft is less than the required maximum of 2500 ft, we expect our vehicle to be within competition requirements.

4. Payload Criteria

4.1. Design

4.1.1. Changes since CDR

4.1.1.1. Ground Station Design

The Ground Station Rotating Antenna design has been flushed out. The components are manufactured and functional. It completes the objective of rotating one degree at a time with sufficient accuracy. We are using custom 3D printed parts to connect the Yagi antenna's pole to a pulley, and to connect the Yagi pole to the pole attached to the tripod. The tripod will be staked into the ground on launch day. More details follow in 4.1.2.2.

4.1.1.2. Raspberry Pi HAT

We designed a custom Raspberry Pi HAT with sockets for all of the payload's sensors and communication devices. A custom PCB allows us to both constrain the footprint of the payload and also allow for the Xbee's 2mm pin pitch (different from the rest of the electronics). The PCB is the motherboard for all of our sensor daughterboards which include gyroscopes, accelerometers, altimeters, and bidirectional radio. One feature of this PCB is ground station based power protection, allowing for the Pi or an external battery to power the board. This external battery can also power the Raspberry Pi. There is also a solder-jumper for the BNO055 chip that allows its I2C address to be changed. Finally, there is a jumper that allows for the Raspberry PI H.A.T. required EEPROM to be written to, only to be used as part of the manufacturing process. There are future improvements for the next boards. A picture of the setup is shown in Figure 4.1.

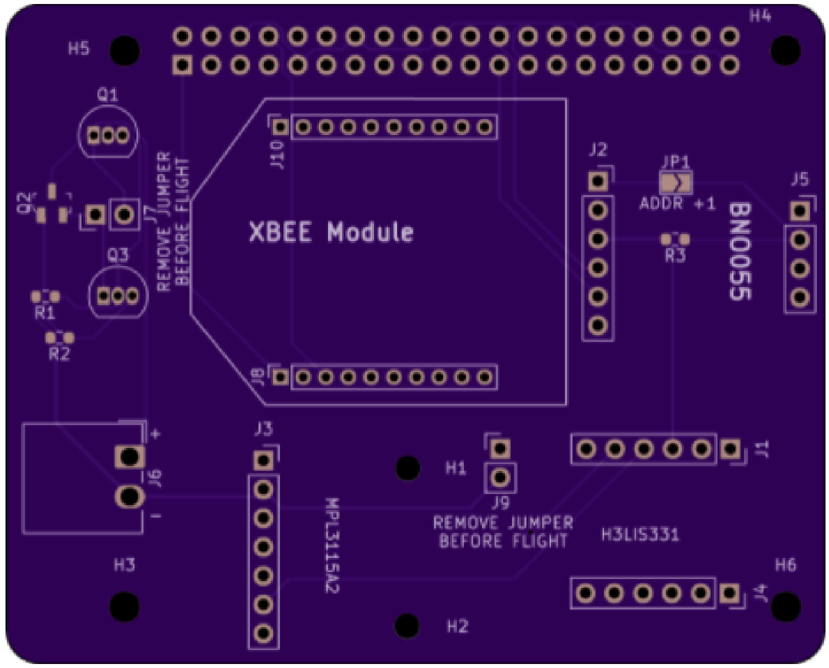

Figure 4.1: The custom PCB design for the Raspberry Pi

4.1.1.3. Raspberry Pi Case

In the payload integration design in the CDR it was reported that the Raspberry Pi had a case to account for the differences in heights of the FUNcube and the Pi. Having the components and laying them out as designed showed that the case is unnecessary. Instead, the FUNcube will be zip tied down and both the Pi and the SDR will sit on the sled.

4.1.1.4. Battery Holder

The reported dimensions of the battery that we ordered at the time of the CDR did not match the actual dimensions, so the battery holder was altered to match this as well as for FDM printing streamlining. The holes in the bottom are for zip ties that will hold the battery in place. The hole on the side of the case is where the battery's wires will come through.

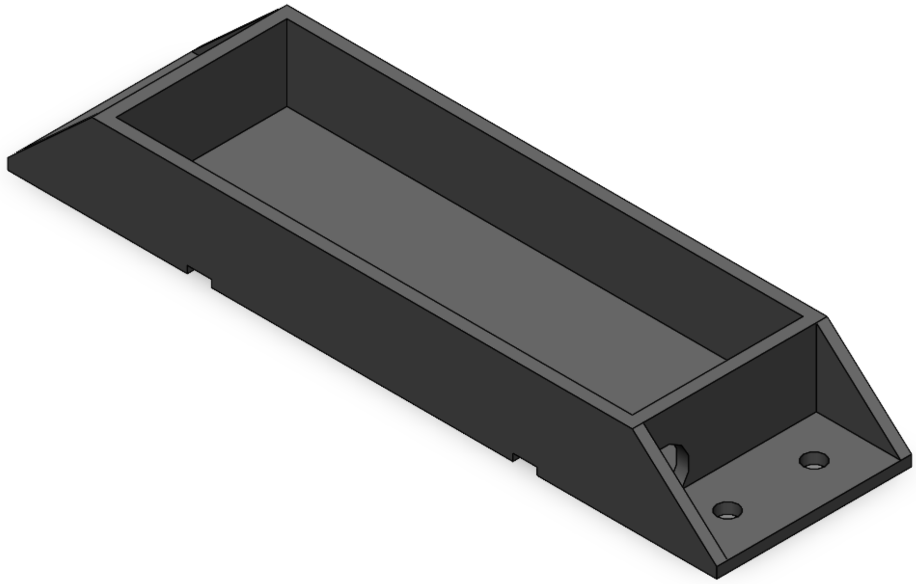

Figure 4.2: The updated battery holder for the payload

4.1.2. Structural Elements

4.1.2.1. Integration

The integration of the payload comes in the form of a shock mounted sled located in the nose cone of the launch vehicle. The Payload Bulkhead is part of the recovery system. The main parachute connects to the U-bolt. Four springs shock-mount the payload to decrease the chance of damage to the system as well as decrease the amount of high-acceleration that needs to be measured. The battery is mounted on the back of the sled in a 3D-printed holder. The Bulkhead is printed out of Nylon 66 30% Glass Filled filament on an FDM 3D-printer, and the plates and sled are made out of MDF. The Wedge is XPS Foam. Aluminum spacers are there to add rigidity to the Upper and Lower Plates in case of non-axial loading.

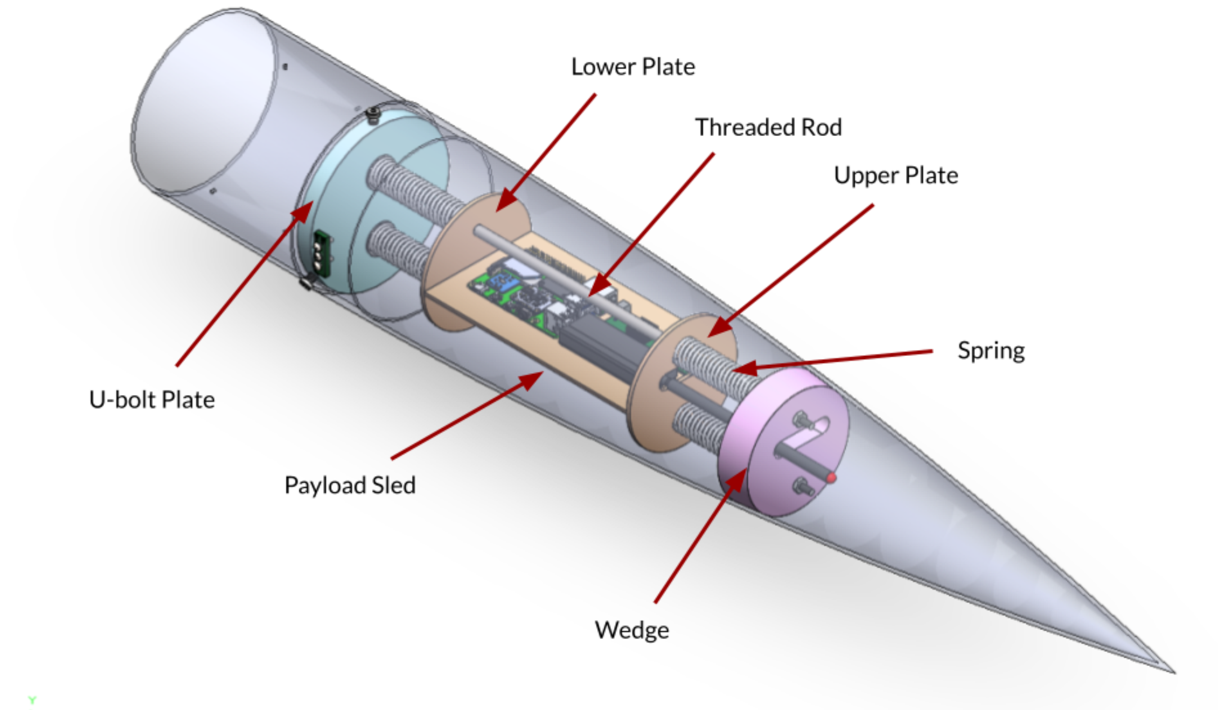

Figure 4.3: The locations and names of the payload integration

4.1.2.2. Ground Station Rotating Antenna

As mentioned in 4.1.1, the ground station rotating antenna design has been updated since the CDR. We are using a NEMA 17 stepper motor with 5mm pitch belts and custom 3D-printed pulleys to rotate the antenna and send the angle data using the Raspberry Pi in the rocket.

All 3D printed parts are depicted in orange.

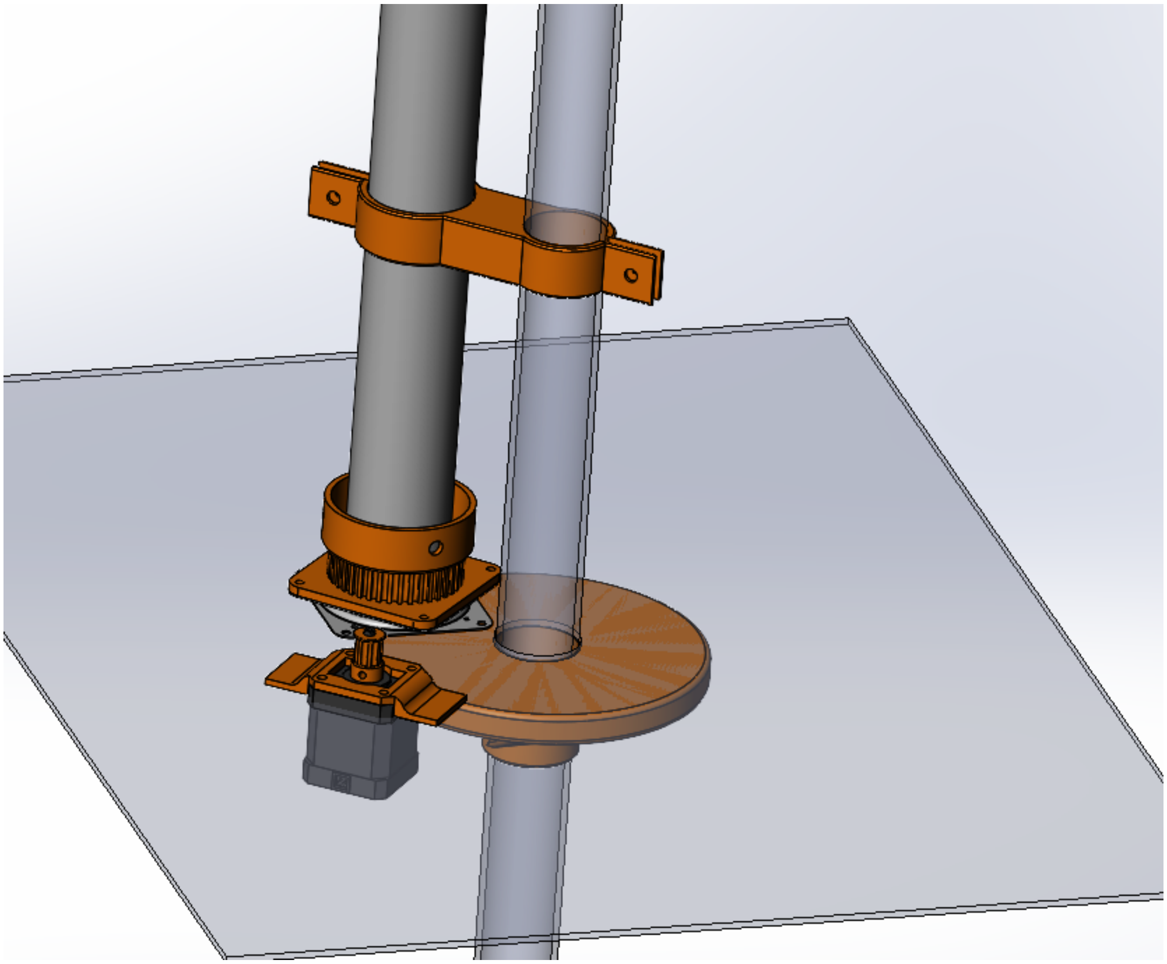

Figure 4.4: Ground Ground Station Rotating System CAD

4.1.2.3. Table Support

The support mounted on the tripod pole (the transparent pole in Figure 4.4) supports the weight of the Yagi-Uda antenna and its pole. The extra structure underneath the Yagi pole (the pole on the left) is to make sure the support can stand the load of the Yagi. Both the table and part of the bearing are screwed on the support.

4.1.2.4. Pole connecters

The two connectors connecting the Yagi pole and the tripod pole keep the Yagi pole orthogonal to the ground while being able to rotate freely without noticeable friction. The clamp-like design at both ends ensures the end connecting to the tripod pole has enough friction to grip on the pole, while the other end connecting to the Yagi pole keeps the pole straight. There are two connectors on the stand, one at the lower part of the Yagi pole close to the Yagi Pulley and one at the upper part of the Yagi pole close to the antenna, to keep the pole orthogonal to the ground.

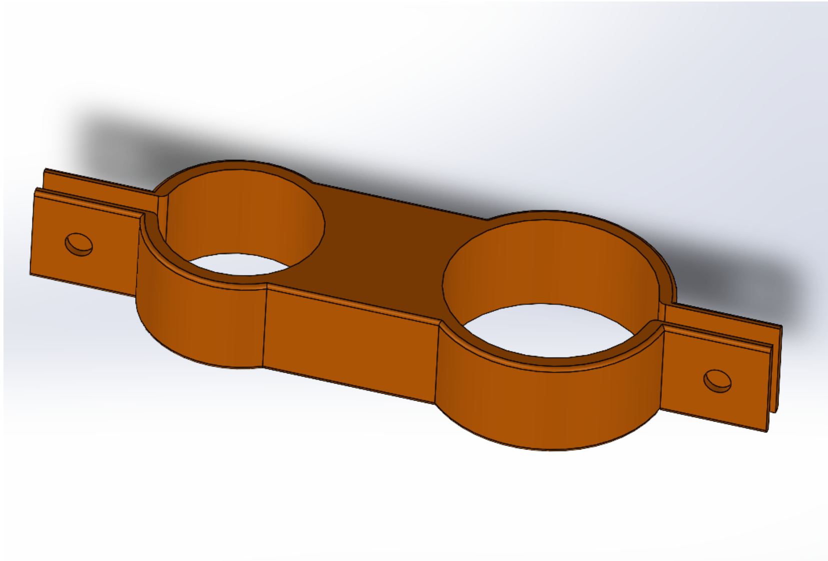

Figure 4.5: Pole Connecter CAD

4.1.2.5. Yagi Pulley

The Yagi Pulley is connecting both the bearing and the Yagi pole, meanwhile being the pulley of part of the rotational system, connected to the stepper pulley by a belt. The Yagi pole sits in the top section of the Yagi Pulley and is secured by screws from three directions. The lower section of Yagi Pulley is screwed with the bearing so when the stepper motor drags the belt then rotates the pulley, the Yagi Pulley, the pole, and the bearing can rotate with it.

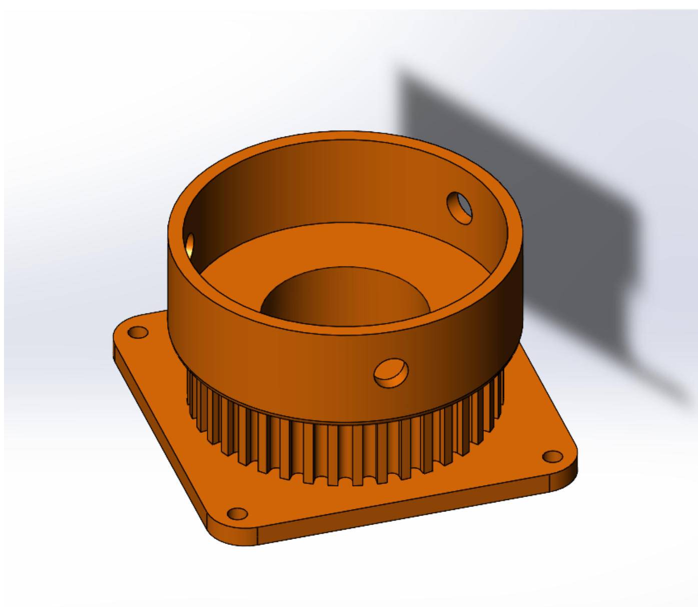

Figure 4.6: Yagi Pulley CAD

4.1.3. Electrical Elements

The payload has been divided into individual subsystems. Table 4.1 lists the payload subsystems and their objectives with small changes since the CDR.

Table 4.1: Payload Systems Summary

Payload Systems	Objective	Component(s)
Flight Computer	Process the data collected from the other subsystems, determine the location of the payload, control and power all electrical components on the rocket	Raspberry Pi 4 Model B
Telemetry	Collect and send payload data to the ground station including the final location determination	Xbee Module (x2), EggFinder RX GPS, EggFinder RX Module MPL31152A
Inertial Measurement Unit (IMU)	Determine the location of the landed rocket using accelerometer data	BNO055, H3LIS331
RF System	Determine the location of the landed rocket using data from radio frequency communication	HackRF One SDR, FUNcube Pro+ SDR, Yagi Antenna, Whip Antenna, 20 MHz Bandpass Filter, Amplifier
Power Delivery	Store and deliver power to the payload on the rocket	Buck Converter, 2.2 Ah Lithium Polymer Battery
Ground Station Computer	Run the RF System at the ground station and manage the motion of the rotating Yagi antenna as well as receive and display telemetry data via a GUI	Raspberry Pi 4 Model B

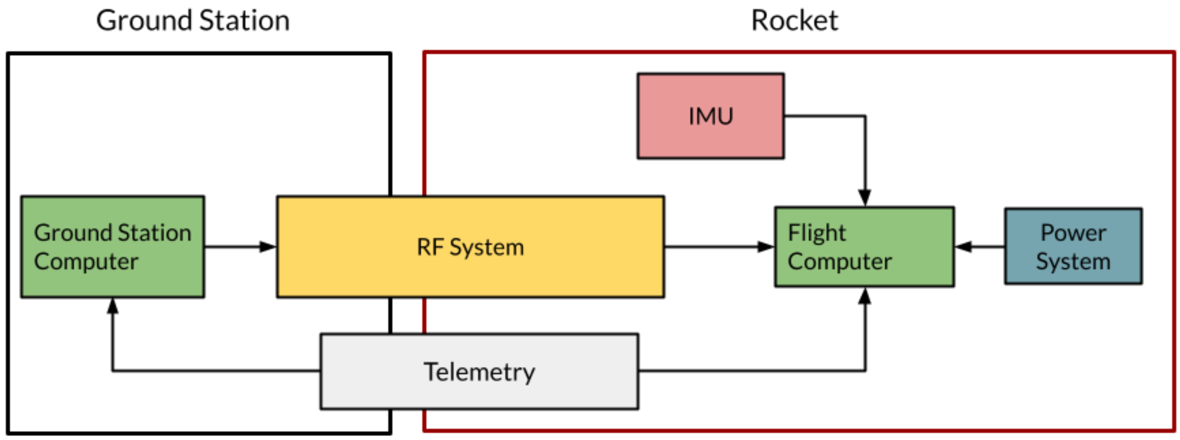

Figure 4.7: Payload Systems Block Diagram

The block diagram below (Figure 4.8) describes the components that make up the payload and how they will interface with each other to accomplish the payload goals.

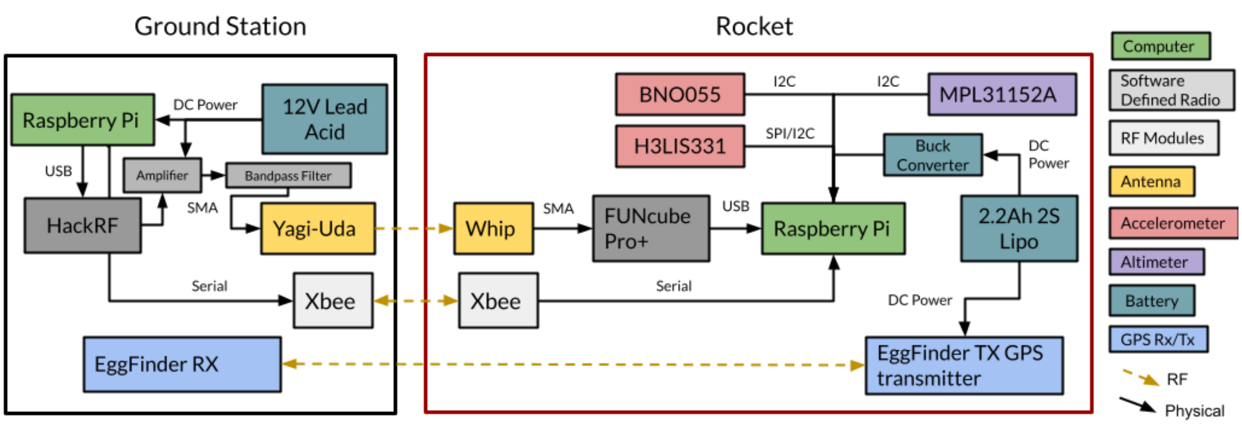

Figure 4.8: Payload and Ground Station Integration Block Diagram

The two locations that make up the payload system are the Rocket and the Ground Station. The Ground Station consists of the Ground Station Computer (Raspberry Pi 4), part of the RF System (HackRF One, Amplifier, 20 MHz bandpass filter and the Yagi-Uda directional rotating antenna). It will have its own Xbee RF module for receiving the payload location and telemetry. The Rocket will have the other half of the RF System (Whip antenna, FUNcube Pro+), the Flight Computer (Raspberry Pi), the Power Delivery System (2200mAh 2S LiPo and buck converter), the IMU (BNO055 and H3LIS331), and the Telemetry System (Eggfinder TX GPS Transmitter, Xbee, MPL31152A). Each component interfaces with one another as noted by the text above each arrow. I2C and SPI are communication protocols; the Eggfinder TX GPS Transmitter will operate at a frequency of 915 MHz; the Xbee transmits at 902 MHz; and the Yagi transmits at 426 MHz. The 12V Lead Acid battery will connect to a power strip to power the ground station electronics, but since it has no special requirements, its specs were not optimized beyond sufficient run time.

The systems that will be talked about in more detail are the RF system and IMU system because they are the unique methods used to compete in the payload competition.

4.1.3.1. IMU System

Upon ignition, the raspberry pi microcontroller will record a series of data from the MPL31152A, BNO055, and H3LIS331 modules throughout the flight and in real-time, calculate the rocket's displacement from the data. The Flight Computer will translate the displacement to the gridded launch field, and, just before landing or upon landing, will transmit the calculated location via the Xbee to the Ground Station.

4.1.3.2. RF System

The RF system consists of two subsystems: the Ground System Station and the Payload Station.

4.1.3.2.1. Ground System Station

The Ground System Station consists of a HackRF One SDR, a rotating Yagi-Uda antenna on an elevated rotating stepper motor-driven mount, and a Raspberry Pi 4 Model B.

Following the flowchart outlined in Figure 4.2, the HackRF One transmits a BPSK modulated signal at 250 mW on 426 MHz through a low noise amplifier and a 426 MHz bandpass filter. The 70cm amateur band was chosen due to its reliable line-of-sight performance, and the BPSK modulation scheme was chosen for its simplicity in implementation compared to similar modulation schemes, such as QPSK. The HackRF One is a widely documented COTS device that interacts well with the chosen digital signal processing toolkit. The toolkit we chose is GNU Radio, a development suite itself chosen for its active community, native Linux compatibility, and tools suited for straightforward signal processing applications.

The transmitted signal begins with a callsign designated before the launch belonging to an individual present at the ground station, and follows with the current angle of the Yagi-Uda antenna. The Yagi-Uda's design creates high directional gain, increasing the likelihood that its transmitted signal is received by the Payload Station. The antenna sweeps from left to right, continuously transmitting until the callsign needs to be retransmitted or the procedure is ended. The precise definitions for the angle increments and length of transmitted signal will be determined in a future test. Both the control of the stepper motor and the GNU Radio transmission are controlled by the Raspberry Pi Ground Station Computer detailed in Section 4.8.

4.1.3.2.2. Payload Station

The Payload Station is comprised of the FUNcube Dongle Pro+ and a Raspberry Pi 4 Model B, continuously listening for a signal from the Ground System Station while the payload is active.

The FUNcube Dongle Pro+ has the highest resolution of any commercial SDR available and is directly compatible with the GNUradio toolkit with the use of open-source plugins. The dongle is connected to a USB 3.0 port on the payload computer. The Payload Station demodulates the signal, retrieves the Yagi-Uda antenna's angle, and associates the angle with the measured signal strength at the Payload Station in dB.

In order to calculate the angle at which the payload is located, the payload system records two pieces of information from each transmission from the ground station

- Angle data that is sent by the ground station
- Signal strength

The angle with respect to the ground station that the payload is located is calculated by taking the average of all recorded angles, weighted with the signal strength, using the equation below. This method of weighted averaging affords a higher precision of final angle values, as the main lobe of the Yagi antenna signal has a vertical beam width of 52°.

$$\theta_f = \frac{\sum_{i=1}^{n} \theta_i S_i}{\sum_{i=1}^{n} S_i}$$

Where

θ_f is the final angle of the payload with respect the ground station

θ_i is the individual angle value that is recorded

S_i is the individual signal strength that corresponds to the individual angle value recorded

n is the number of angle values recorded

The distance is estimated using the equation described in Section 4.2.1. The final angle and distance is converted to cartesian coordinates on the payload computer using the relations $x = r cos\theta$, $y = r sin\theta$.

4.1.4. Flight Reliability Confidence

The goal of the payload is to send the position of the rocket upon landing with an error of 125ft. The Raspberry Pi on the rocket will translate this location to the gridded launch field and send back the corresponding box. A partial success of the payload is to send back any location. On the path of reaching this goal, the payload could fail at many points. The flowgraph below demonstrates the different failure points that the payload could experience. We assumed that the launch vehicle flight is successful and that all events are independent.

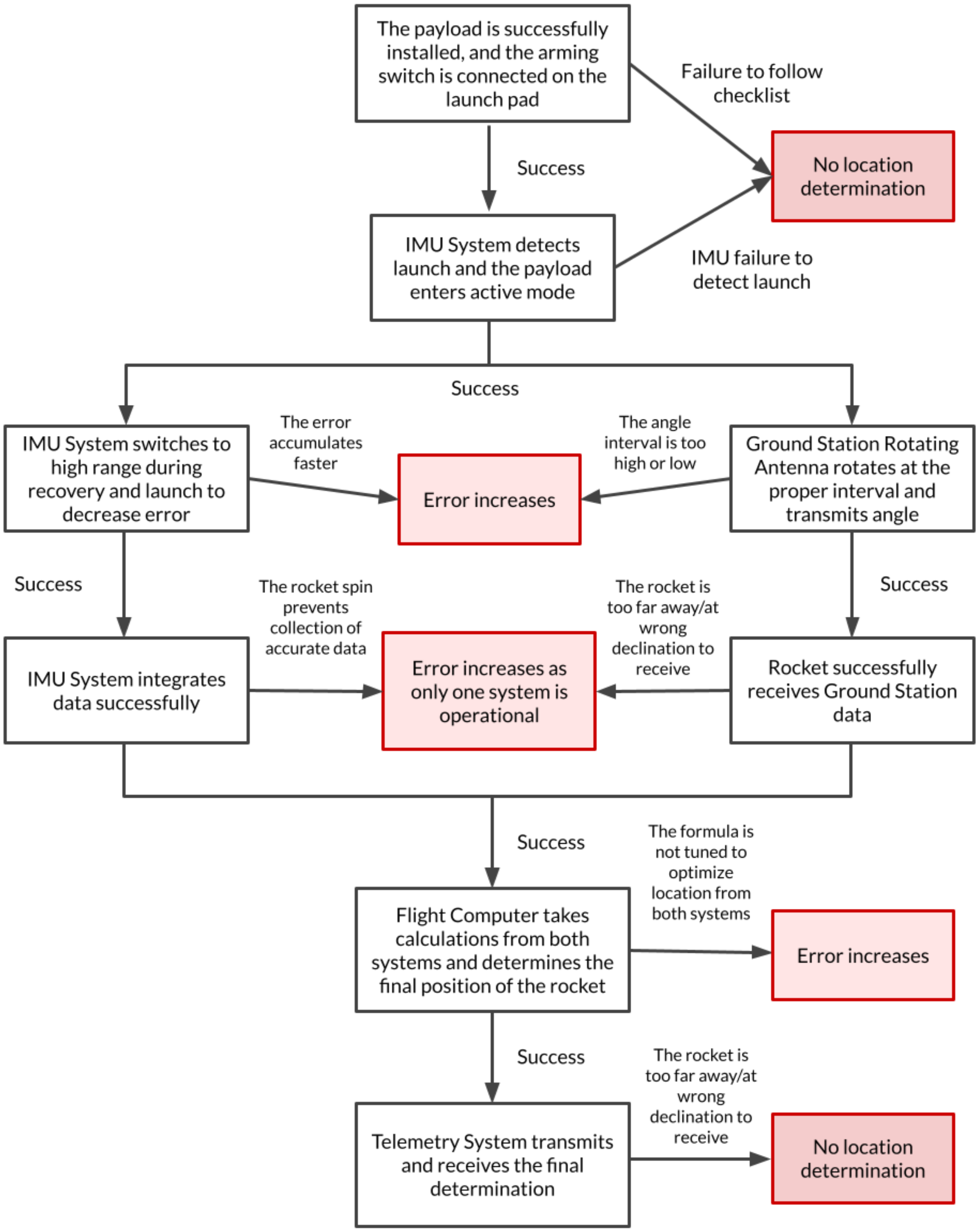

Figure 4.9: This flow chart demonstrates where the major failure points are located and what results in them failing

The major failure points have different probabilities and mitigations. The table below showcases the probabilities associated with them and the ways to mitigate them. Mitigated probabilities are listed to give an estimate of the probability of the payload to succeed during a launch. All probabilities are estimated based on perceived difficulty and past experience.

Table 4.2 Probabilities of Major Failure Points

Failure Point	Probability of failure	Mitigation	Mitigated Probability
Failure to follow checklist	.2	Have VP check checklist completion before rocket is placed on the launch pad	.05
IMU failure to detect launch	.05	Do extensive tests or decrease sensitivity	0
IMU System acculimates error as it fails to switch to high-/low-range	.1	Do extensive testing or decrease sensitivity	0
The angle interval is too high or low	.1	Do extensive testing	0
The rocket spin prevents collection of accurate data	.1	None	.1
The rocket is too far away/at wrong declination to receive	.3	Adjust when to start the rotating antenna to prevent	.2
The formula is not tuned to optimize location from both systems	.15	Conduct extensive testing	0
Probability of Success	**.33**	**Prob. with Mitigation**	**.68**

Without mitigation, the probability of complete success is 33%. This value is not acceptable, but with mitigation the probability increases to 68%. The source of failure with the highest probability is the failure to communicate with the rocket at any time. This could be caused by incorrect orientation of the Yagi antenna or inconvenient location of the rocket in relation to the ground station. Even with mitigation, this probability is the highest. With more testing to find the best place to communicate with the rocket (at what height or stage of descent), this probability could be decreased more. Another point worth noting is that failure to follow the procedure when preparing for launch results in direct failure of the entire payload system. If the battery is not charged or plugged in, or the arming switch is not armed, the payload will not function. Failure to communicate and failure to follow the checklist are the failures that will result in a non-functional payload, and will be focused on when building and testing the payload.

4.1.5. Construction

4.1.5.1. Integration

The payload sled design described in the CDR was manufactured as designed. Some liberties were taken due to the restrictions in tools. For example, the two plates (upper and lower) were designed to be 4 in, but no hole-saw was available with this dimension. Thus, with the restriction that the hole could be no bigger than 4.2 in, we found a 4.125 (4 ⅛) in hole saw to make both plates. The sled was made to the specified dimensions in the design within the margin of error. The actual dimensions are in Figure 4.15. The plates and sled were made out of MDF as specified in the CDR. The sled and the plate were epoxied together using a square to keep them as perpendicular as possible. Next, the threaded rods were cut to length. The Wedge part was initially 3D printed out of PLA and used as a template to sculpt it out of foam to the final shape. The curve was estimated with the PLA parts and nose cone as reference. The U-bolt bulkhead was printed out of Nylon, as reported in the CDR.

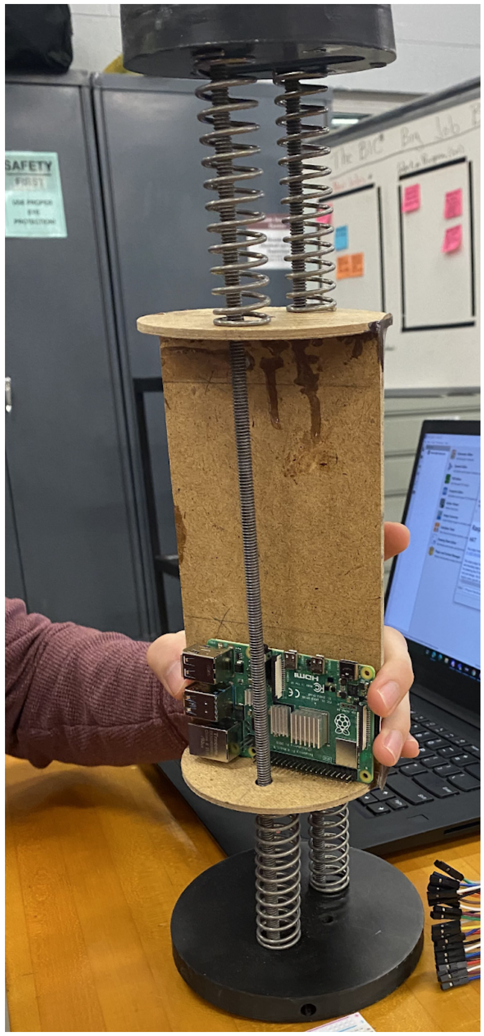

Figure 4.10: The nearly completed payload integration. The Wedge and U-bolt mount are in the prototyping stage, so are made from PLA plastic.

4.1.5.2. Electronics Mounting

The electronics on the payload sled were, for the Vehicle Demonstration flight, screwed on individually with M2 screws and nuts. A temporary perf-board was created with the IMU electronics and barometer soldered on.

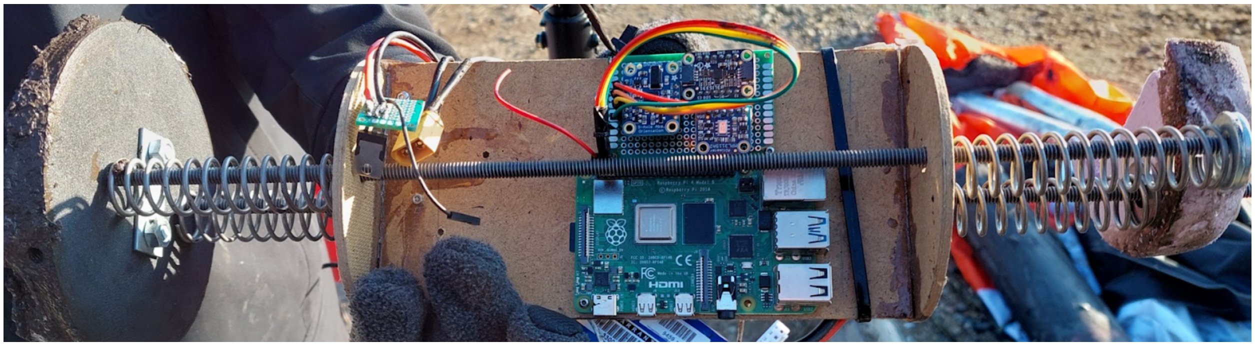

Figure 4.11: The Vehicle Demonstration Flight configuration of the payload

The final payload will include screwed mounts for the Pi, the buck converter, and the battery mount. The Pi HAT (PCB) will attach to the Pi, so the sensors will be located above the Pi rather than next to it. The custom PCB will be zip-tied to the Pi. The FUNcube will be zip tied to the sled to prevent movement. Figure 4.12 below shows the updated electronics configuration. The PCB is not pictured, but the sensors are where they would be if it were there.

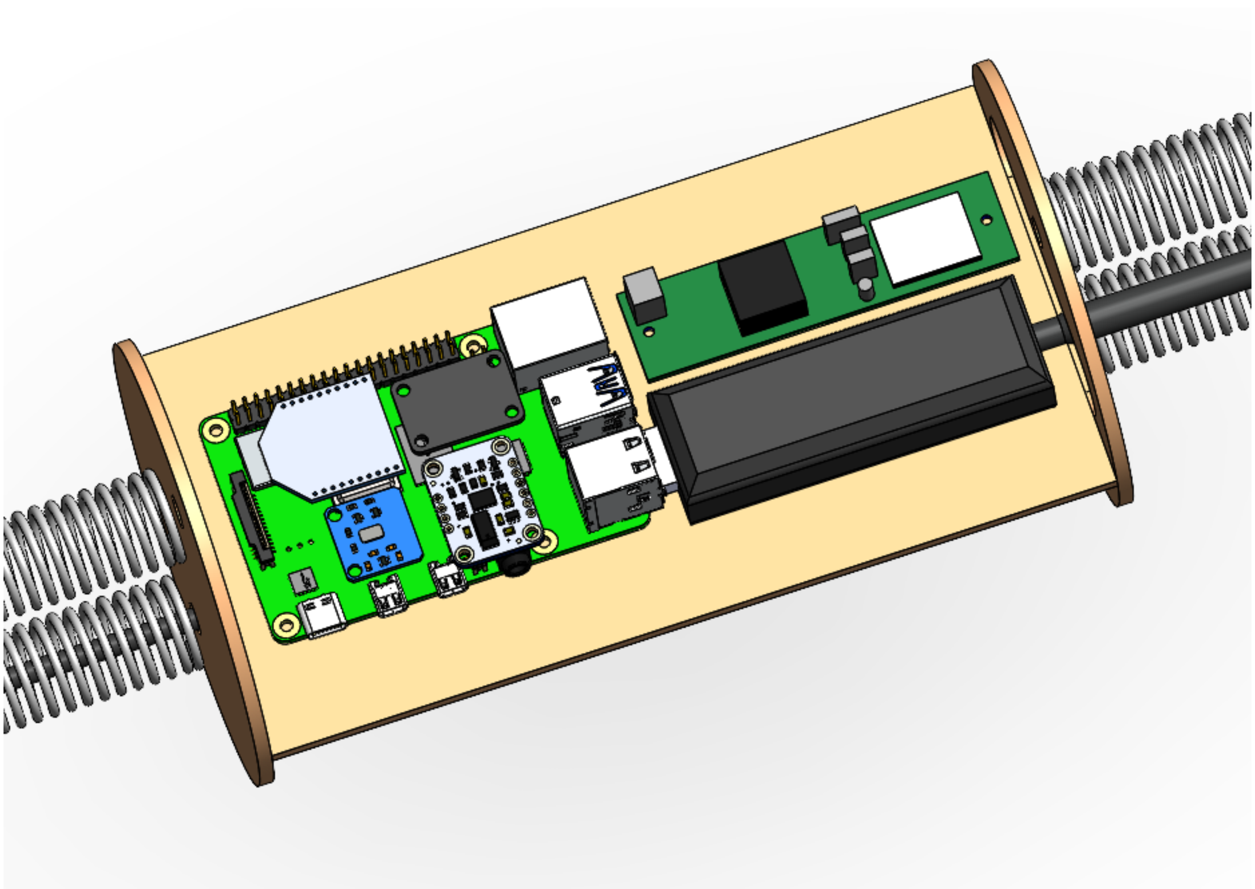

Figure 4.12: Electronics configuration of payload

4.1.5.3. Ground Station Rotating Antenna

The manufactured rotating antenna system is shown in the pictures below. It is very similar to what was designed as the 3D printed parts have low tolerance compared to hand-manufactured parts. The table is not the same dimensions as the CAD dimensions were merely estimated based on limited information. The poles were acquired from scrap and as such their diameters and length are as we found them. The 3D printed parts were designed to accommodate the pipes.

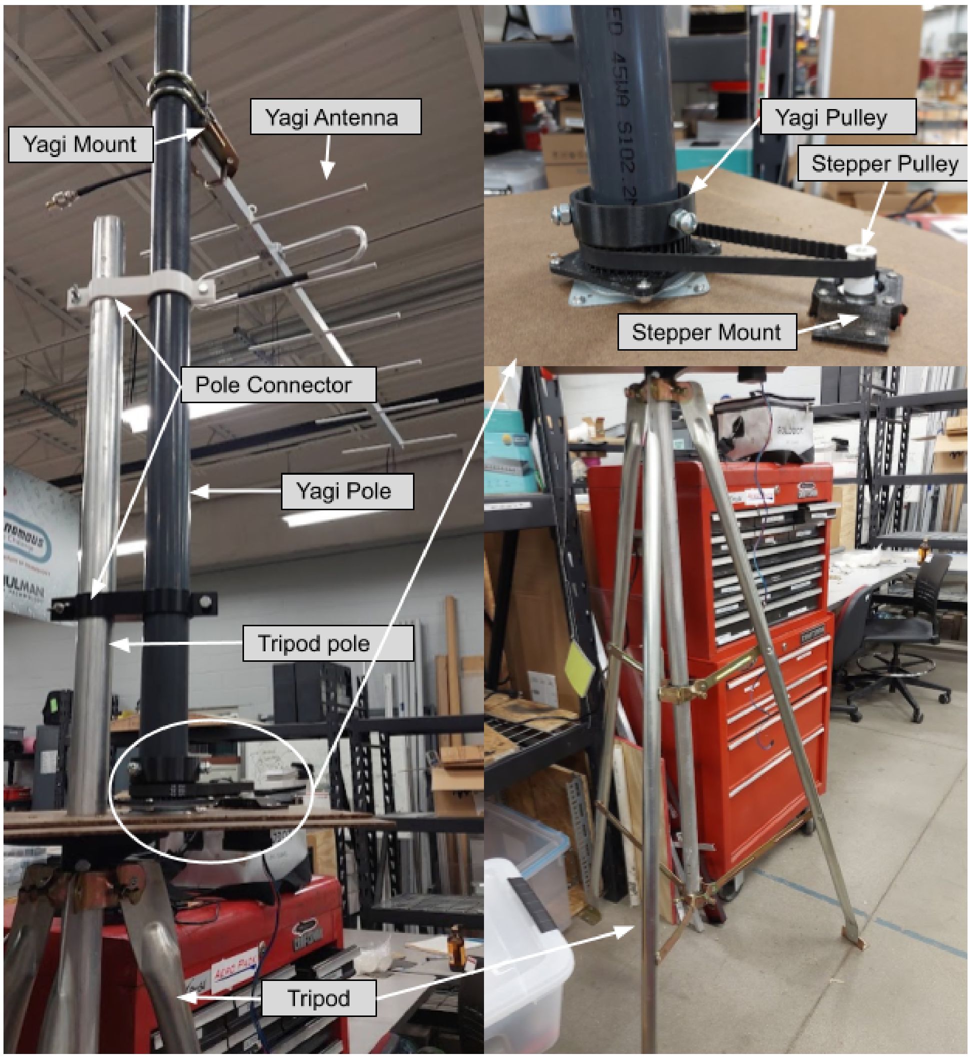

Figure 4.13: The manufactured Ground Station Rotating Antenna

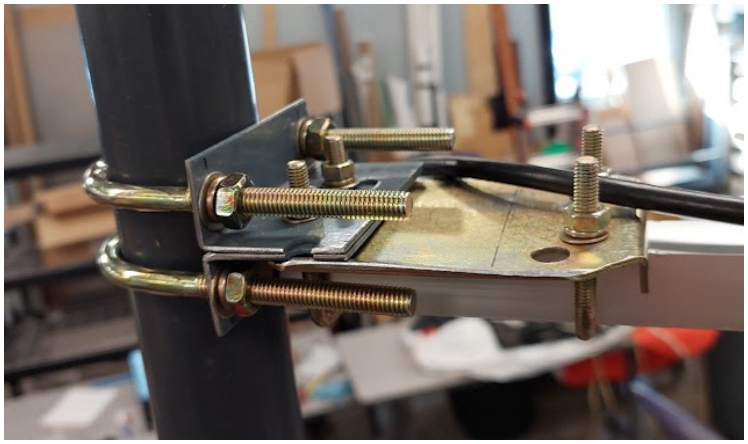

Figure 4.14: The Yagi Mount

The Yagi Pole is a gray PVC pipe while the Tripod Pole is aluminum. The default mount that came with the Yagi was inadequate, so it was altered as shown above. The Yagi mount was made from scrap L-shaped metal that was cut to size and the default mount (seen in a brass color).

4.1.6. Schematics

The following figures are the dimensions of the as-built payload components. These only include the integration and the ground station.

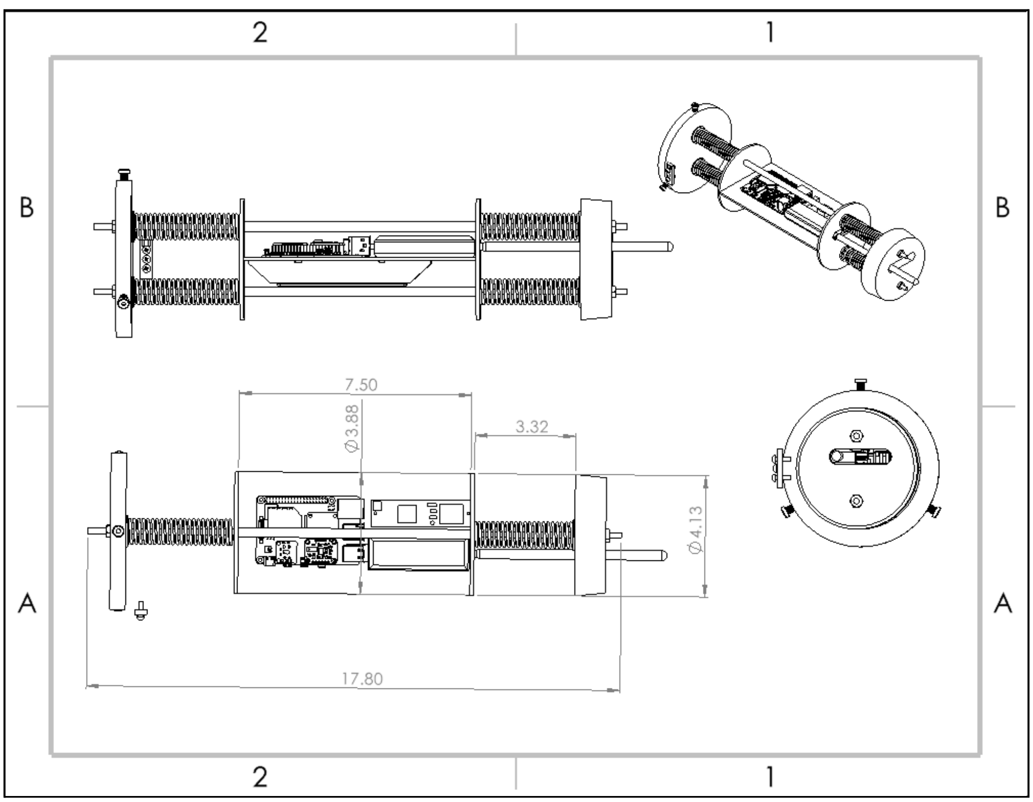

Figure 4.15: Manufactured Payload Integration with as-built dimensions

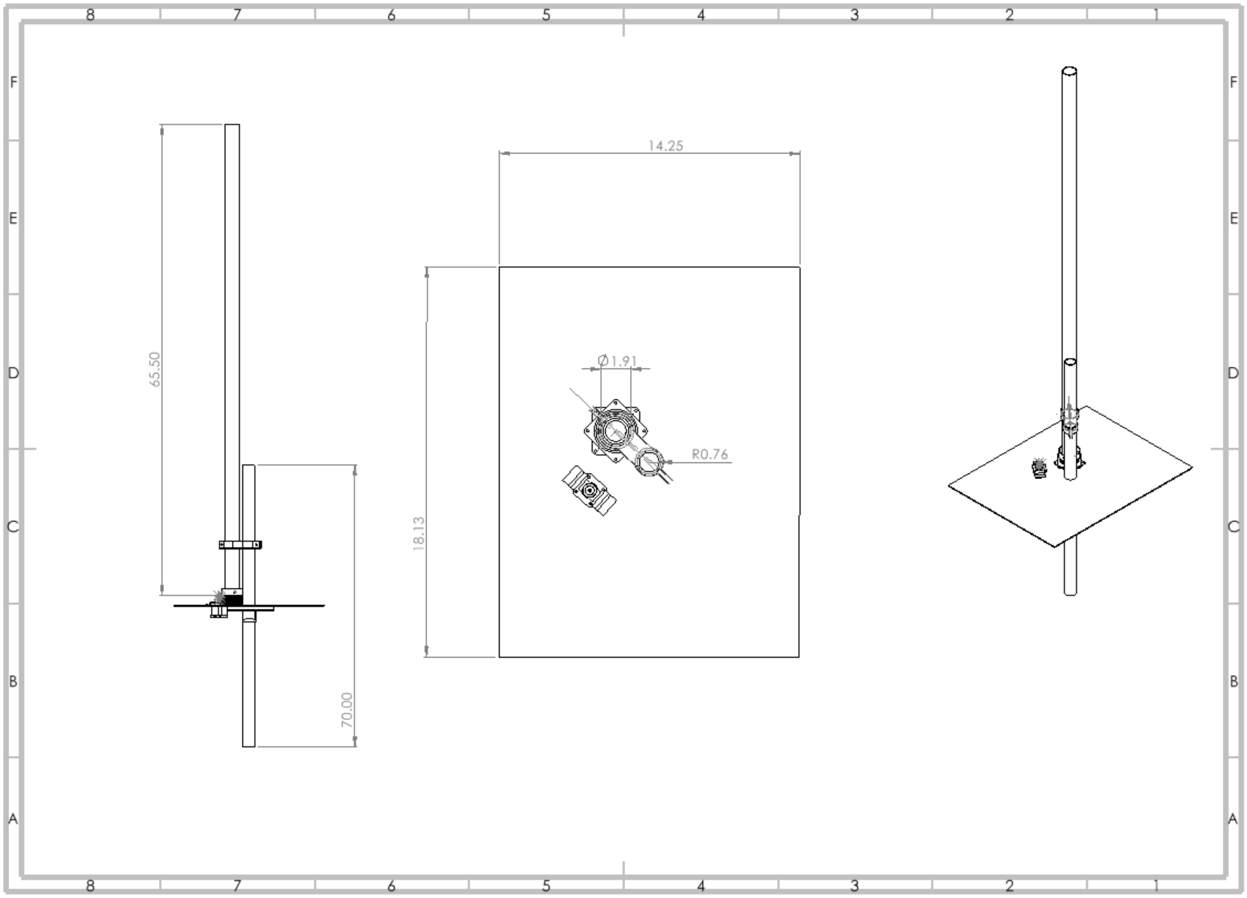

Figure 4.16: The Ground Station Rotating Antenna as-built dimensions

4.1.7. Payload Demonstration Flight Plans

The current planned date of the Payload Demonstration Flight is March 26th. This is subject to change due to weather and readiness. The success criteria for this flight is as follows: the Telemetry System should be logging and sending data back to the ground station (including the final location determinations), the IMU System should be integrating and logging, and the RF system should have a location determination using angle and distance calculations. The accuracy of the system will not be considered, but not evaluated as testing and code tuning can be conducted outside of this single flight.

4.2. **Testing**

4.2.1. Test Completed

4.2.1.1. Xbee Test

One new test added since the submission of the CDR is the Xbee Test. In order to make sure we have consistent communication at all ranges, we did a range test using the provided XCTU software from Digi. It simply sends packets to the remote module and measures whether it is lost on the way to, from, or whether it is successful. We determined a successful test would have over 50% successful communication at 2500 ft. This simulates our maximum drift distance. The first trial was completed by one person walking with an Xbee away from the other module until about 2500ft was achieved. The test was conducted in a park nearby the university with few radio wave obstructions. The second trial sent 100 packets of data to the other Xbee while at 2500ft and the receiving Xbee was held aloft. In the third trial, we placed both Xbees on the ground to simulate communication when the rocket has landed.

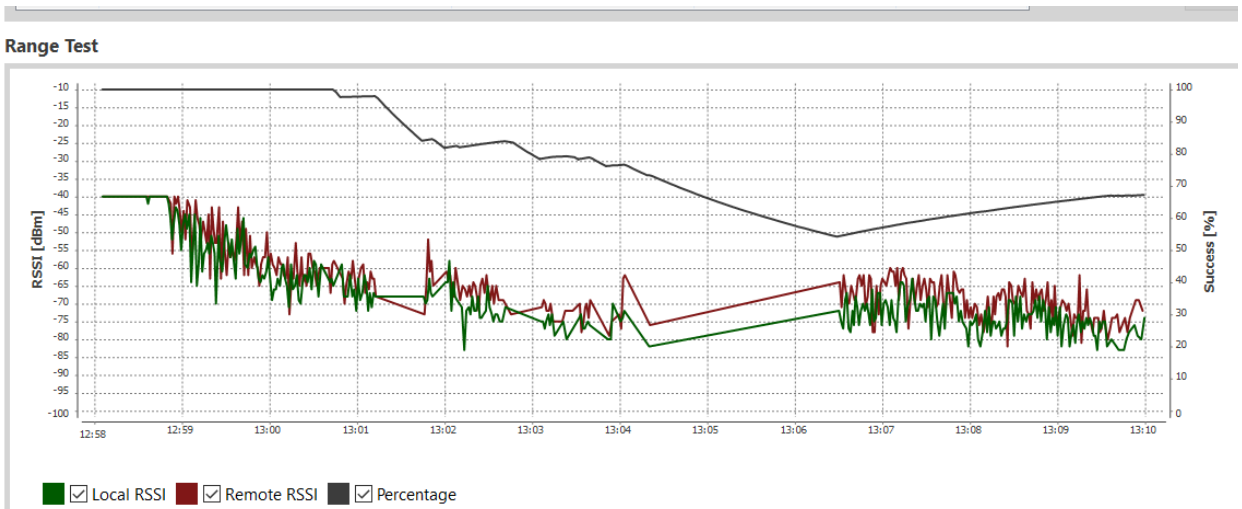

Figure 4.17: Trial 1. The large interruptions were caused by the received Xbee being underneath power lines

Figure 4.18: Trial 2: at 2500 while the Xbees are held aloft

The reason for the dip in success at the beginning of Tial 2 is not clear, but mostly likely a random deviation. The test ended with a 93.07% success rate. The local module (the one running the test) was receiving the packets at -78 dBm while the remote (the module 2500 ft away) was receiving the packet at -75 dBm.

Figure 4.19 Trial 3: where both Xbees are on the ground at 2500ft.

Trial 3 has a 98% success rate: higher than Trial 2. The received decibels on both sides were approximately the same as Trial 2.

All tests resulted in a success rate of over 50%. The lowest value it achieved in any trial was due to the nearby power lines. Preliminary tests also showed that transmission failed when cars passed between the two modules, as expected. With this test completed, we can be sure that the Xbees are capable of transmitting our maximum drift distance.

4.2.1.2. Locating Test for RF 1

The goal of this test was to confirm that the distance can be calculated by measuring the received power, and comparing it with the transmitted power using the Friis transmission equation [4]. The payload receiving antenna was placed at known distances away from the ground station antenna, and the received power in dBm is recorded.

$$P_r = P_t + D_t + D_r + 20log_{10}(\frac{\lambda}{4\pi d})$$

Where:

P_r is the received power in dB

P_t is the transmitted power in dB

D_t is the directivity of the transmitting antenna (10 dBi for our system)

D_r is the directivity of the receiving antenna (0 for our system)

λ is the wavelength of the transmitted signal

d is the distance of the payload from the ground station

The above equation was used to calculate the transmitting power. This test would be deemed successful if the calculated values of the transmitted power are constant, with a margin of error of 5%.
The distance and transmitting power from this test are shown below in Table 4.3.

Table 4.3 Distance and Calculated Transmitting Power from RF Locating Test 1

Distance (feet)	Calculated Transmitting Power (dB)
7	-7.1
65	0.4
165	5.5
207	-2.9
338	-4.7

Due to large margins of error in the distance measurement device, the transmitting power could not be ascertained accurately.
Thus, this test will be repeated with revised methods prior to the Payload Demonstration Flight, along with RF Locating Tests 2-4 described in the CDR.

4.2.1.3. Interference Test

The goal of the interference test is to evaluate the effectiveness of aluminum foil at shielding radio frequencies. The success criteria is a 50% reduction in power (Watts).

The methodology is as follows: the Hack RF One was used to transmit at 426 MHz. The FUNcube is held at 50 in away (the approximate distance between the transmitters and the Avionics Bay altimeters. The peak power is recorded using the program SDRSharp. Then the HackRF is covered in aluminum foil one layer thick on all sides. The peak power is recorded again on the FUNcube from 50 in away. The table below shows the results.

Table 4.4 Interference test result

Trial	Result (dBm)
50 in without foil	-40.7

50 in with foil	-69.5

There was a significant 28.8 dBm decrease which corresponds to a 99.9% reduction in power. The percent decrease is calculated by subtracting the starting value from the final value and dividing it by the starting value. This is more than adequate to pass this test, so we will continue planning to use aluminum foil to shield our electronics.

Figure 4.20 The setup for the interference test. The tape measure is extended to 50 in

4.2.1.4. Battery test

As described in the CDR, our Power Delivery System is theoretically capable of powering the payload for at least 3 hrs while it is on the pad. A test was conducted to verify this metric.

Our 2.2 Ah Lipo battery was first charged to 4.2V per cell (8.4 total). The electronics powered were the IMU System, the Telemetry System (GPS transmitter as well).

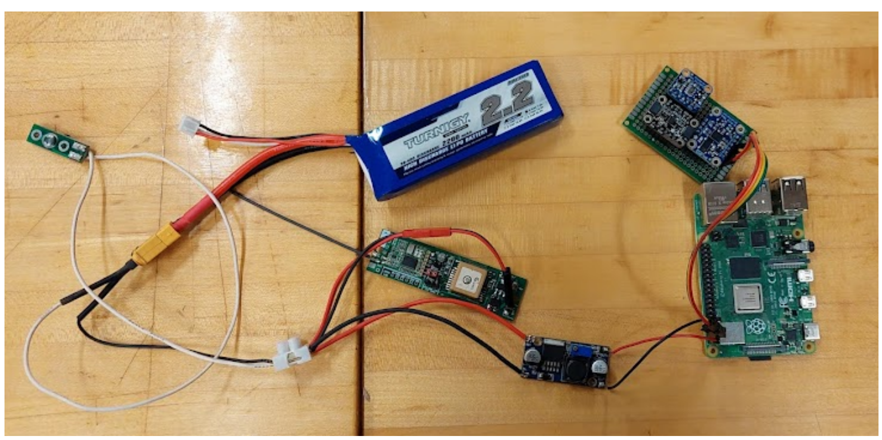

Figure 4.2.5 The battery tests

All of the electronics were running in standby. We let all electronics run until the battery reached 3V per cell (6V total) or until 4 hours passed. All systems were able to achieve the full 4-hour runtime, with both the altimeter and payload batteries reading 4.0 V per cell at the end of the timed period.

4.2.2. Tests in progress

4.2.2.1. Shock Mount

The test stand for this test is almost completed. It is constructed out of a 10ft-long 1515. There are smaller pieces of rail on the bottom that hold it upright. The carriage that will connect the payload (or other test pieces) still needs to be manufactured.

5. Demonstration Flights

5.1. Full-Scale Launch, Feb. 26

5.1.1. Summary

Table 5.1 Success Criteria and Result

Success Criteria	Result
Successful launch and recovery of all vehicle systems	Success
Successful dual-deployment recovery events	Success
Successful deployment of Rose Petal airbrakes	Fail
Successful acquisition of on-board data logging devices	Success
Vehicle drift less than 2500 ft.	Fail
Tethered vehicle sections landing kinetic energies less than 75 ft-lb	Fail
Vehicle Demonstration Flight Result	Partial Success

Table 5.2 Flight Summary

Date of Flight	02/26/2022
Location of Flight	Quad Cities Rocket Club launch site 23550 1850 E. Ohio, IL 61349
Launch conditions	Clear skies, 13mph winds from the west
Motor flown	Cesaroni L2375
Ballast flown	0lbs
Final payload flown?	No
Air brake system status during test flight	Did not deploy
Official target altitude	5000ft

Predicted altitude from simulations	5266 ft (no altitude assurance) 5000 ft (altitude assurance)
Measured altitude	4348* ft (RRC3) 5223 ft (EasyMini) 5285 ft (altitude assurance computer)

5.1.2. Flight Data

5.1.2.1. RRC3 Flight Data

Table 5.3 RRC3 Flight Data

Apogee	4348 ft*
Maximum speed	641 ft/s
Time to apogee	17 s
Descent time	75 s
Drogue descent rate	70 ft/s*
Main descent rate	43 ft/s*

* data suspected to be erroneous

5.1.2.2. EasyMini Flight Data

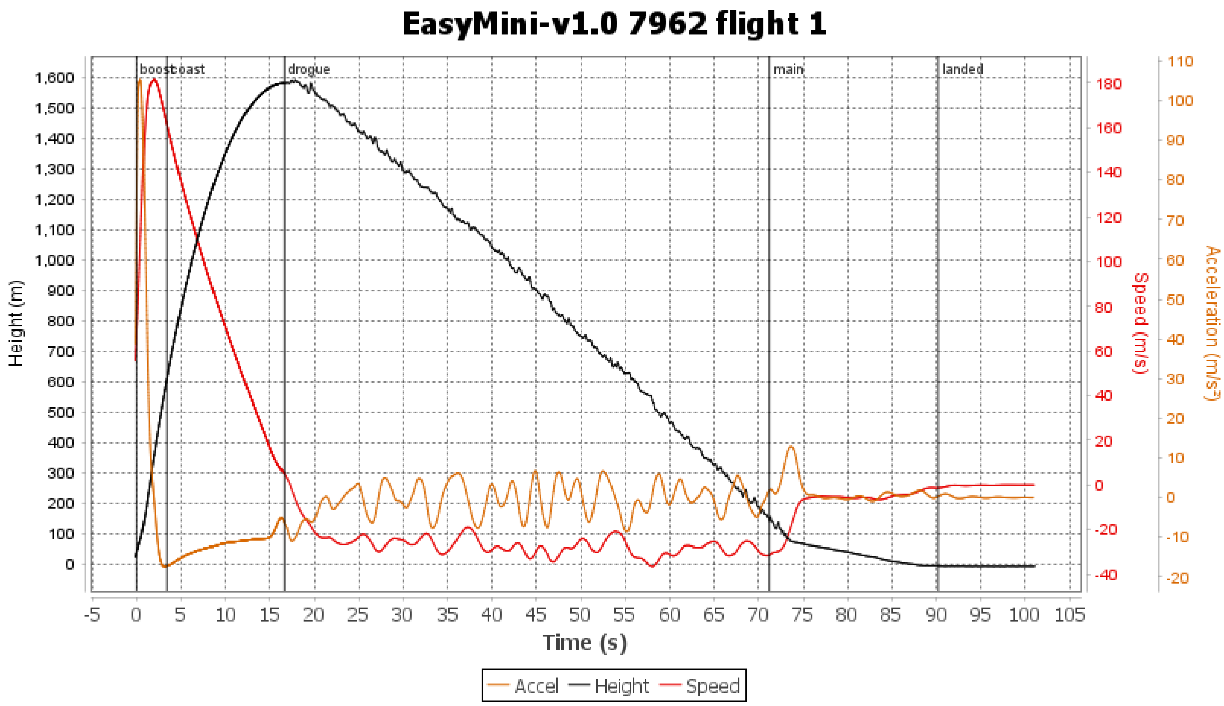

Figure 5.1 EasyMini Flight Data

5.1.2.3. Petal Computer Flight Data

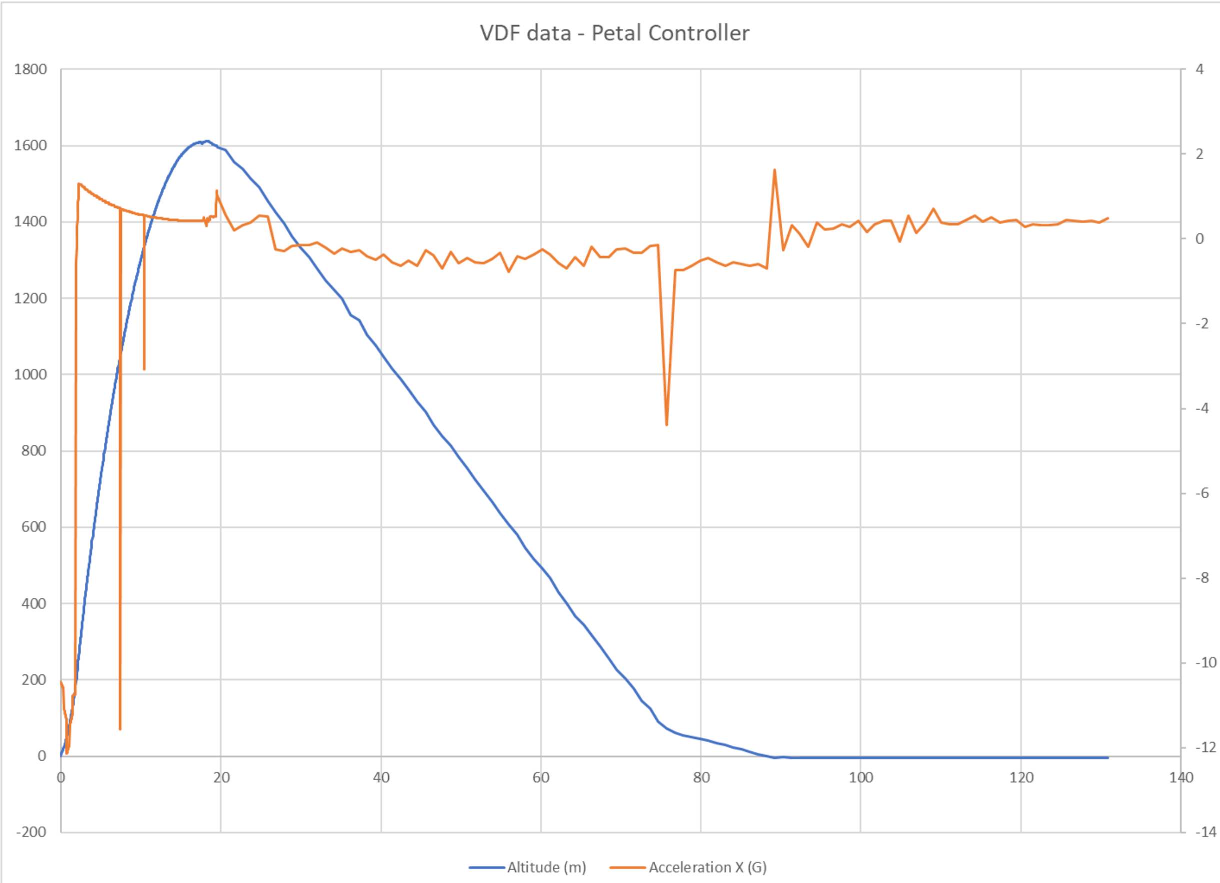

Figure 5.2 Petal Computer Flight Data

5.1.2.4. GPS Trace

Figure 5.3 GPS Trace

5.1.3. Analysis

Due to limitations of the pad equipment available on launch day, the launch rail was not able to be tilted to the competition-standard 5 to 10 degrees; instead, the rocket was launched near-vertically. Additionally, a 12-foot rail was not available at the time; a

10-foot rail was used instead, which still fulfilled competition exit velocity requirements at a projected exit speed of 61.7 ft/s per Openrocket.

The altitude assurance system was intended to be active for a fixed duration during this flight to provide a drag estimate, but due to oversights in the tank section layout it was not possible to access the ball valve from outside the rocket once that section of the airframe was assembled. As a result, the cylinder did not receive air pressure and the petals did not cycle; however, we were able to verify that the solenoid was activated at the correct time, validating our launch and burnout detection logic. This issue will be rectified by the addition of an access port as discussed in section 3.1.1 above.

Upon clearing the pad, the rocket made an immediate turn of approximately 18 degrees southward, close to the expected weathercocking angle for a ground wind speed of 14 mph.[1] However, the GPS trace shows that above ground level the wind shifted to the southeast and increased in speed as altitude increased, likely due to low-level wind shear or similar phenomena, which can lead to ground-level winds being drastically different from winds at altitude [5]. As a result, the rocket entered apogee with a significant amount of downwind speed, a scenario not accounted for by the drift calculations recommended by the competition handbook. As a result, the rocket drifted significantly further than expected, reaching approximately 3000 feet from the original launch site. Descent rates under drogue were significantly lower than predicted, at 28.1 m/s rather than the predicted 33.9 m/s; however, the descent time and drift under drogue are both well within a safe range, so this is not particularly a cause for concern. More concerning is the descent rate for the main parachute, which increased from 4.4 m/s predicted to 5.1 m/s observed. This is believed to be due to the chute not fully stabilizing, as it was only fully open for approximately 15 seconds; for future flights, a pilot chute will be added to the canopy as recommended by the manufacturer.

Datalogging for the flight was performed by three devices: the two main deployment altimeters and a home-built altimeter board using a BMP280 barometer intended to operate the altitude assurance. Of those, the EasyMini and altitude assurance computer both yielded altitudes within expected margins of the no-petal-actuation simulated altitude, with the EasyMini recording 5223 ft and 5285 ft respectively against the simulation's 5266 ft. However, the RRC3 yielded a much lower altitude of 4348 ft. With two closely agreeing measurements contradicting it, we consider this measurement to be an error; this altimeter will be replaced with another RRC3 for future flights and flown in a separate test vehicle to verify its accuracy before it is used for deployment again.

[1] Weathercock angle = arctan(14 mph (windspeed) / 61.7 ft/s (launch speed)) = 18.41 degrees

Upon recovery, the vehicle system received varying magnitudes of damage. The altitude assurance housing suffered major damages at three points by the time the launch vehicle was returned to the workshop. It broke along printlines at the neck, which housed the piston and two of the four aluminum channel guides. In addition, due to travel logistics, the launch vehicle was not inspected for damages immediately after the launch vehicle landed, so the team cannot conclude whether the damage happened during flight, landing, or transportation. From the damage the team has come to the conclusion that the print settings and the design itself need modification. One possible experiment would be to increase the infill density to 90% from the current infill density of around 20%. Additionally, the metal tip of the nose cone had been knocked loose; this part was installed by the manufacturer, and while its impact tolerances were not specified, we were able to verify that our nose cone impacted with a kinetic energy comparable to other high-power rockets of the same scale; therefore, it is likely that this damage was the result of a manufacturing defect and will not cause further issues once repaired. There was no damage to the payload save for the XPS foam wedge breaking in half upon disassembly. The nose cone was filled with mud, so excess force was required to release it from its wedge position which resulted in the damage.

Figure 5.4 Figure of broken petal housing showing thin filament use

5.1.4. Conclusion

Our next planned flight is March 12th with another one on March 26th. We will conduct another flight testing the Rose Petals as well as in order to meet success criteria on drift and kinetic energy. In order to meet kinetic energy requirements, we will decrease the weight of the booster section (the one not meeting the requirement) as well as improving our deployment techniques to ensure that the parachute is fully inflated. We will also be logging timestamped GPS data rather than a simple plot so that we can verify that our drift from apogee meets competition requirements. March 26th will be our Payload

Demonstration Flight. We will test the failed aspects of the Feb. 26th flight again. Another flight in April before Launch Day is likely needed to do additional testing and software tuning.

6. Safety and Procedures

6.1. Summary of Hazard Analysis Methodology

Table 6.1 Probability of Event

Category	Value	Description
Improbable	1	Less than 10% chance
Unlikely	2	10-35% chance
Possible	3	35-65% chance
Likely	4	65-90% chance
Probable	5	Greater than 90% chance

Table 6.2 Severity of Event

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

Table6.3 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

6.2. Personnel Hazard Analysis

Table 6.4 Personnel Hazard Identification

Identified Hazard	Causes	Effects	Mitigations
Fire	- Open flames - Mishandling of equipment - Improper wiring	- Severe burns - Loss of part or project - Death	- Store flammable substances in flammables cabinet, fire extinguisher placed nearby, no open flames, test circuitry before use
Airborne particle exposure	- Sanding dust - Metal shavings - Paint - Aerosols	- Skin laceration or irritation - Eye damage - Respiratory distress	- Proper use of PPE and safety training, use paint booth and ventilated workspace where necessary
Electric Shock	- Improper wiring - Device failure - Test equipment misuse	- Extreme personal injury - Hardware damage/loss - Mission delays	- Members will not work alone and will be trained on use of high-voltage electrical equipment
Entanglement with machines	- Improper use of machinery - Machinery failure	- Severe lacerations - Crushed limbs - Fatal injuries	- Use PPE, follow dress codes in machine shops, adhere to required safety training
Epoxy Contact	- Surface contamination - Broken PPE - Resin spill	- Skin irritation - Eye irritation - Epoxy sensitivity	- Discard broken PPE, limit exposure, wear proper PPE, limit use to specified working surfaces
Eye Irritants	- Solder and epoxy fumes - Flying debris - Airborne particles	- Possible temporary vision loss - Eye irritation - Blindness	- Wear proper PPE, document irritants and limit exposure, use workspace ventilation booth, locate and train on use of eyewash station for every team member

Falling tools or materials	- Mounting failure - Improper use of storage racks	- Tool damage - Storage rack damage - Personal injury	- Store frequently used tools in easy to access locations, adhere to 5S standards of lean production
Fiberglass Contact	- Airborne particles created during fabrication - Fiberglass skin irritation	- Skin irritation - Respiratory Issues - Splinters	- Wear N95 respirators during fabrication, only sand fiberglass in sanding booth
Flying debris	- Improper use of machinery - Machinery failure	- Blunt force trauma - lacerations	- Maintain a safe distance from machines under operations, ensure those working on machinery are properly certified by the BIC
Exposure to Hazardous Fumes	- Working with inadequate ventilation - Improper soldering and welding practices - Epoxy handling - Activities from other teams in shared workspace	- Eye irritation/damage - Lung irritation/damage - Lightheadedness - Shortness of breath and nausea - Possible nerve damage	- Maintain proper PPE when working with fuming materials or maintain a safe distance from fuming materials in a well-ventilated environment
Hazardous Waste Contact	- Chemical spills - Incidental contamination	- Skin contact may cause rashes to burns - May require hospitalization	- Follow hazardous waste disposal techniques set by BIC/KIC
Exposure to Unsafe Noise Levels	- Use of BIC/KIC machine shop - Loud power tools - Other BIC/KIC teams	- Increased rate of higher frequency hearing damage	- Use proper PPE, maintain a safe distance from active machinery
Improper use of tools	- Use of BIC/KIC machine shop - Soldering irons	- Damage to equipment is unlikely - Injury may range from deep lacerations	- Ask BIC/KIC personnel or team Safety Officer before using high-risk tools, attend BIC safety training

		- Burns to lost fingers	
Soldering or Welding Injuries	- Worker inattentiveness - Distractions during fabrication - Lack of fixturing equipment	- Second or third-degree burns - Hardware damage due to reflex response	- Only solder and weld during work hours and in predefined locations, make sure all personnel are aware when work is being performed, use sufficient fixturing equipment
Tripping	- Carrying unsafe loads - Unclean workspace - Worker inattentiveness	- Equipment damage - Sprains and bruises - Fractured bones, concussion, death (unlikely)	- Maintain well lit work areas. Adhere to 5S workspace standards of organization. Maintain walking areas.
Contact with Launch Vehicle Debris	- Faulty parachute ejection - Severe winds	- Blunt damage to the rocket or payload - Concussion - Fractured skull - Death	- Keep a close eye on the vehicle or have someone spot the vehicle for those who are unable - Audibly call in-flight events such as deployments or loose parts
Launchpad Fire	- Flammable debris blown across launch pad - Flammable fuel spilled	- Heat damage to parachute - Motor - Electronics	- Remove brush, dry debris, and other flammables around the launch pad area and have a fire extinguisher on hand
Personnel Injury from Terrain	- Uneven footing, potholes, nails, etc.	- Sprained or broken ankles - Small puncture wounds	- Watch footing around terrain, travel in groups, maintain cell phone contact
Airborne Debris	- High wind speeds - Systems on the rocket breaking mid-flight	- Blunt force trauma - Lacerations	- Maintain a reasonable and safe distance from energetic devices

Contact Burns	- Contact with motor after flight - Standing too close to the launchpad	- Mild to severe burns	- Proper handling of the rocket will be used - NAR-mandated setback distances will be observed
Heat Stroke	- Prolonged exposure in a high-temperature environment	- Possible hospitalization	- Ensure team members limit exposure to dangerously high temperatures - Provide water
Hypothermia	- Failure to wear appropriate clothing	- Possible hospitalization	- Ensure team members limit exposure to dangerously low temperatures
Dehydration	- High environment temperature - Low fluid consumption	- Fatigue - Dizziness - Confusion - Immediate medical treatment	- Ensure access to cool drinking water at team events - Provide shaded areas available for rest

Table 6.5 Personnel Hazard Mitigation

Identified Hazard	Pre - Mitigation Risk (Probability/Severity/Total)			Post - Mitigation Risk (Probability/Severity/Total)		
Fire	2	5	10	2	4	8
Airborne particle exposure	3	3	9	2	2	4
Electric Shock	2	4	8	2	3	6
Entanglement with machines	3	5	15	2	5	10
Epoxy Contact	4	2	8	2	2	4
Eye irritation	3	4	12	2	4	8
Falling tools or materials	2	4	8	2	2	4
Fiberglass Contact	3	3	9	1	2	2
Flying debris	2	4	8	2	1	2
Exposure to Hazardous Fumes	4	3	12	1	3	3
Hazardous Waste Contact	2	3	6	2	2	4
Exposure to Unsafe Noise Levels	3	3	9	3	1	3
Improper use of tools	3	3	9	1	2	2
Soldering or Welding Injuries	4	2	8	3	1	3
Tripping	2	3	6	2	2	4
Contact with Launch Vehicle Debris	1	5	5	1	3	3
Launchpad Fire	2	3	6	1	3	3

Personnel Injury from Terrain	2	2	4	1	2	2
Airborne Debris	3	3	9	3	2	6
Contact Burns	1	4	4	1	3	3
Heat Stroke	3	3	9	2	2	4
Hypothermia	1	3	3	1	2	2
Dehydration	3	3	9	2	2	4

6.3. **Failure Modes and Effects Analysis (FMEA)**

6.3.1. Vehicle System FMEA

Table 6.6 Vehicle Systems FMEA Hazard Identification

Identified Hazard	Causes	Effects	Mitigations
Structural Failure Under Intended Loading	- Inadequately-designed structure - Not all failure modes considered during analysis - Material defects during construction	- Unpredictable competition performance - Vehicle cannot be reflown - Falling debris exceeds competition limits for kinetic energy upon landing	- Design airframe to withstand compression load at a safety factor of 2
Airframe Overloaded During Launch	- Motor improperly packed - Loose components cause local shock loading - High winds - Improper parachute deployment	- Falling debris exceeds competition limits for kinetic energy upon landing	- Multiple checks to internal packing - System testing with a variety of parameters

Hidden Structural Damage Prior To Launch	- Accidental damage during transportation or construction	- Falling debris exceeds competition limits for kinetic energy upon landing	- Check for cracks and material inconsistencies during construction
Structural Damage During Landing	- Miscalculation of landing energy or improper parachute deployment	- Significant repairs needed	- Test recovery system extensively
Bond Line Failure	- Lack of checks to bond line Rushed construction	- Falling debris exceeds competition limits for kinetic energy upon landing	- Multiple checks to bond lines
Component Mounting Failure During Launch	- Failure to utilize correct mounting techniques	- Launch failure - Destruction of component	- Multiple checks to mounting - Tests of mounting techniques
Structural Failure Of Deployment Systems	- Improper design of deployment subsystem - Construction errors	- Falling debris exceeds competition limits for kinetic energy upon landing	- Multiple checks of deployment systems during launch - Tests of deployment systems
Structural Failure During Deployment	- Insufficient damping in parachute attachment - Construction errors - Jammed structures	- Mission failure	Same as above
Aerodynamic Instability	- Location of masses change within the vehicle - Dynamic instability due to drag flaps	- Vehicle exceeds competition limits for kinetic energy on landing	- Static stability margin is measured as part of preflight checklist - Final vehicle configuration is tested at Vehicle Demonstration Flight

			- Drag flaps will command closed if high vibrations are detected
Electronics Failure Of Deployment Systems	- Parts dead on arrival - Insufficient charge of battery - Damage from aerodynamic forces	- Unpredictable competition performance - Vehicle does not separate - Vehicle exceeds competition limits for kinetic energy upon landing - Personal injury	- Remove-before-flight tag arms vehicle - Dissimilar redundancy in altimeter selection - Test altimeters upon arrival and before flight
Electronics Fire	- Overcharge of battery - Short circuit wiring	- Vehicle and/or falling debris exceeds competition limits for kinetic energy upon landing	- Teach all members the proper handling of the batteries and wiring - Multiple checks for proper wiring
Battery Depletion During Launch	- Unintended draw on electronics - Battery is not charged prior to launch	- Deployment electronics not functional - Flight altimeter not functional for scoring - Vehicle exceeds competition limits for kinetic energy upon landing	- Tests of battery under launch conditions - Potential redundant battery systems
Failure Of Airframe To Separate	- Over-tight fitting tolerances between airframe components - Unintended mechanical locking between airframe components	- Vehicle exceeds competition limits for kinetic energy upon landing	- Tests of airframe separation

Internal Hardware Damaged During Separation	- Damage to internal electronics	- Failure to successfully calculate and to test the recovery system	- Test the recovery system multiple times
Recovery Hardware Does Not Eject	- Damage to airframe, electronics, and possible damage to property	- Vehicle exceeds competition limits for kinetic energy upon landing	Same as above
Damage To Parachute	Same as above	Same as above	Same as above
Parachute Does Not Open	Same as above	Same as above	Same as above
Excessive Vehicle Drift During Recovery	- Failure to test and successfully simulate recovery system	- Vehicle exceeds competition limits for recovery drift	Same as above
Altitude Assurance Initialization Failure	- Failure to test, successfully simulate, and properly construct altitude assurance	- Flaps do not actuate, apogee overshoot - Flaps actuate before burnout, destabilization	- Extensively test, validate simulations, and carefully construct altitude assurance
Altitude Assurance Control Scheme Failure	- Excessive loads jam control mechanism - Faulty control logic - Incorrect apogee prediction model	Same as above	- Final vehicle configuration is tested at Vehicle Demonstration Flight
Altitude Assurance Does Not Halt At Apogee	Same as above	Same as above	- Final vehicle configuration is tested at Vehicle Demonstration Flight
Mechanical Failure Of Altitude Control Hardware	Same as above	Same as above	Same as above

Structural Failure Of Altitude Control Hardware	Same as above	- Falling debris exceeds competition limits for kinetic energy upon landing	- Altitude Control Structure will be designed with a factor of safety appropriate for critical systems.
Uneven Deployment Of Drag Flaps	- Failure to test and successfully simulate drag flaps	- Aerodynamic instability of launch vehicle - Failure to deploy recovery systems - Vehicle exceeds competition limits for kinetic energy upon landing	- Testing and successfully simulating drag flaps
Motor Cannot Ignite	- Faulty product or packing of motor - Faulty igniter installation	- Vehicle fails to launch - Failure to compete with all other systems	- Test motor packing and ensure product is in good condition - Multiple sign-offs on motor assembly and installation Igniter retention using support rod
Motor Does Not Provide Design Thrust	- Faulty product or packing of motor	- Vehicle fails to reach 4000 ft	- Altitude Assurance actively adjusts flight trajectory if too much thru
Motor Explodes	- Imperfections in motor grain packing cause localized high pressure regions	- Mission fails	- Test motor and check datasheets for verification
Motor Retention Mechanism Breaks	- Imperfections in motor grain packing cause localized high pressure regions	- Falling debris exceeds competition limits for kinetic energy upon landing	Same as above

Motor Misalignment	- Poor construction quality of motor mount	- Unpredictable vehicle trajectory	Same as above
Motor Damages Internal Components	- Heat conduction through structure - Failure of bulkhead	Same as above	Same as above

Table 6.7 Vehicle Systems FMEA Hazard Mitigation

Identified Hazard	Pre - Mitigation Risk (Probability/Severity/Total)			Post - Mitigation Risk (Probability/Severity/Total)		
Structural Failure Under Intended Loading	2	3	6	2	2	4
Airframe Overloaded During Launch	2	4	8	2	2	4
Hidden Structural Damage Prior To Launch	1	4	4	1	2	2
Structural Damage During Landing	3	3	9	2	3	6
Bond Line Failure	3	4	12	2	3	6
Component Mounting Failure During Launch	2	4	8	1	3	3
Structural Failure Of Deployment Systems	3	4	12	2	2	4
Structural Failure During Deployment	3	3	9	2	2	4
Aerodynamic Instability	4	3	12	3	3	9
Electronics Failure Of Deployment Systems	2	4	8	2	2	4
Electronics Fire	1	5	5	1	3	3
Battery Depletion During Launch	2	4	8	2	2	4
Failure Of Airframe To Separate	4	5	20	3	4	12
Internal Hardware Damaged During Separation	2	3	6	1	3	3
Recovery Hardware Does Not Eject	3	5	15	2	4	8
Damage To Parachute	2	4	8	1	4	4
Parachute Does Not Open	3	5	15	2	5	10

Excessive Vehicle Drift During Recovery	2	2	4	2	1	2
Altitude Assurance Initialization Failure	2	2	4	2	1	2
Altitude Assurance Control Scheme Failure	2	2	4	2	1	2
Altitude Assurance Does Not Halt At Apogee	3	2	6	2	2	4
Mechanical Failure Of Altitude Control Hardware	3	4	12	2	3	6
Structural Failure Of Altitude Control Hardware	3	2	6	2	2	4
Uneven Deployment Of Drag Flaps	2	4	8	2	3	6
Motor Ignition Incapability	1	4	4	1	3	3
Motor Does Not Provide Design Thrust	2	4	8	1	3	3
Motor Explodes	1	5	5	1	4	4
Motor Retention Mechanism Breaks	1	4	4	1	3	3
Motor Misalignment	2	4	8	1	3	3
Motor Damages Internal Components	2	4	8	1	3	3

6.3.2. Payload and Payload Integration FMEA

Table 6.8 Payload and Payload Integration FMEA Hazard Identification

Identified Hazard	Causes	Effects	Mitigations
Mounting Failure During Flight	- Rushed implementation or lack of training	- Damaged payload bay	- Multiple checks
Mounting Failure During Landing	Same as above	Same as above	Same as above

Hardware Misassembly	Same as above	Same as above	- Bench test payload prior to launch
Faulty Control Logic	- Oversight or lack of checks	Same as above	- Multiple checks from multiple people to ensure correct logic
Failure to Arm Electronics	- Oversight or lack of checks	- Mission Failure	- Make switches clear and accessible - Train to verify correct beep codes before stepping away from rocket
Failure to Detect Landing	- Failure to test sensors - Incorrect wiring	- Premature determination of vehicle location	- Testing of sensors under multiple conditions
Wiring Failure Between Controller and Hardware	- Oversight or lack of checks - Improper placement of electronics bay - Loose or misassembled components	- Electronics fire - Effects range from small burnout on pins to explosion mid flight	- All electronics will be checked by multiple students before the launch
Telemetry Transmission/Reception Failure	- Interference - Parachute Interrupts Telemetry	- Miscommunication with other sensors and main controller	Same as above
Sensor Hardware Failure	- Parachute covers sensors - Aerodynamic effects influence barometric readings - Mismounting or misalignment of	- Bad readings to determine location	Same as above
Battery Depletion Prior to Data Transmission	- Lack of testing	- Loss of the sensor data	- Test the battery under launch conditions

		Failure of payload competition	
Debris	- Debris not removed from launch site	- Interference with the launch vehicle causing a postponed launch to mission failure	- Clear area before the launch
Premature Deployment	- Deployment charge self-ignites - Deployment electronics trigger charge early	- Vehicle exceeds competition drift limit	- Testing of the launch vehicle and verification of simulations
Late Deployment	- Failure to successfully calculate and to test the recovery system	- Vehicle exceeds competition limits for kinetic energy upon landing	- Testing of the launch vehicle and verification of simulations
Failure To Arm Electronics	- Oversight of electronics arming	- Vehicle exceeds competition limits for kinetic energy upon landing	- Remove-before-flight tag arms vehicle - Electronics arming is made explicit in pre-flight checklist

Table 6.9 Payload and Payload Integration FMEA Hazard Mitigation

Identified Hazard	Pre - Mitigation Risk (Probability/Severity/Total)			Post - Mitigation Risk (Probability/Severity/Total)		
Mounting Failure During Flight	2	5	10	2	4	8
Mounting Failure During Landing	3	3	9	2	2	4
Hardware Misassembly	2	4	8	2	3	6
Faulty Control Logic	3	5	15	2	5	10
Failure to Arm Electronics	4	2	8	2	2	4

Failure to Detect Landing	2	4	8	2	2	4
Wiring Failure Between Controller and Hardware	3	3	9	1	2	2
Controller Hardware Failure	2	4	8	2	1	2
Telemetry Transmission/Reception Failure	4	3	12	1	3	3
Sensor Hardware Failure	2	3	6	2	2	4
Battery Depletion Prior to Data Transmission	3	3	9	1	2	2
Debris	1	3	3	1	2	2
Premature Deployment	2	2	4	2	1	2
Late Deployment	2	2	4	1	2	2
Failure To Arm Electronics	2	4	8	2	2	4

6.4. Environmental Concerns

Table 6.10 Environmental Hazards Identification

Identified Hazard	Causes	Effects	Mitigations
Launchpad fire	- Dry environment - Flammables near launchpad during motor ignition	- Grass fire - Charred launch field	- Launch pad cleared as part of pre-flight checklist
Fire at landing site	- Dry environment - Unintentional motor ejection	- Launch field fire	- Flights will be cancelled in the event of high grass fire risk (e.g. very dry weather)

Collision with spectator drones	- Launch environment carelessness	- Possible complete mission failure	- Visually verify safe launch conditions prior to ignition, and coordinate with range safety officers to verify conditions at time of launch
Vehicle Fouled by Foreign Objects	- Unclean team preparation area	- Cascaded mission hazards	- Vehicle and payload inspection as part of pre-flight checklist
Inclement Weather	- Poor launch planning	- Component material embrittlement	- Independently measure launch conditions, and/or coordinate with other teams and range safety officers to verify conditions at time of launch
Wet Launch and Landing Sites	- Prior inclement weather effects present launch conditions	- Component material weathering	- Design vehicle to withstand wet environments
Components overheat on launchpad	- Overexposure to sun - High temperature launch day conditions	- Component material melting or failure	- Ensure proper protection of mission components on launch day as part of launch day guidelines
Launch debris left on site	- Rocket ejects debris during flight - Failure to collect waste generated during mission operations - Catastrophic mission failure	- Littering during launch operations	- Track waste generated during launch operations and provide trash bags for immediate disposal - Design vehicle to fail in minimal independent sections - Construct external vehicle components from materials

			that can be visually identified at the launch site - Visual environmental inspection as part of post flight checklist
Vehicle lost on recovery	- Recovery subsystem failure - Vehicle destruction	- Failed mission - Littering during launch operations	- Ensure redundancy in recovery design
Team equipment left on site	- Negligence of launch day operations	- Equipment must be repurchased	- Post flight checklist
Launch vehicle stuck in tree	- Unintended collision trajectory	- Potential vehicle and payload loss	- Do not perform test launches at sites with trees - Plan for wind drift as allowed by RSO
Launch vehicle collision with structures	- Unintended collision trajectory - Wind turbines and buildings present at launch fields	- Launch vehicle and payload destruction - Potential damage to structures	- Evaluate launch day conditions with special consideration to intended vehicle trajectory as part of pre-flight checklist

Table 6.11 Environmental Hazards Mitigation

Identified Hazard	Pre - Mitigation Risk (Probability/Severity/Total)			Post - Mitigation Risk (Probability/Severity/Total)		
Launchpad fire	3	4	12	2	3	6
Fire at landing site	2	4	8	1	2	2
Collision with spectator drones	2	4	8	1	4	4

Vehicle Fouled by Foreign Objects	1	3	3	1	2	2
Inclement Weather	1	5	5	1	1	1
Wet Launch and Landing Sites	2	2	4	1	2	2
Components overheat on launchpad	3	3	9	2	3	6
Launch debris left on site	2	3	6	1	3	3
Vehicle lost on recovery	3	5	15	2	5	10
Team equipment left on site	2	3	6	1	3	3
Launch vehicle stuck in tree	2	5	10	1	5	5
Launch vehicle collision with structures	2	5	10	1	5	5

6.5. Project Risks

Table 6.12 Project Risk Hazards Identification

Identified Hazard	Causes	Effects	Mitigations
Time	- Poor time management - Improper delegation of tasks - Students shifting focus away from competition	- Document Writing/Vehicle Fabrication is rushed - Failure to meet deadlines	- Establish a reasonable timeline and adhere to it - Evenly distribute tasks among students
Miscommunication	- Students not requesting help - Poor attitude towards people and leadership	- Project requirements are completed incorrectly - Project requirements are not completed because they are assigned to no one	- Have a good relationship with the team - Foster a friendly and inviting atmosphere

Scope	- Failure to maintain focus on core design - Adding too many features that may deviate from requirements	- Project becoming infeasible due to complexity	- Stay on track of project plan - Regularly reevaluate our design requirements
Resource	- World-wide shortages - Equipment breaking down - Students unable to participate	- Insufficient resources to complete project	- Order parts as early as possible
Budget	- SGA not providing us enough funding - No sponsorships	- Insufficient funds to finish vehicle advancements	- Request for funding early on in the process to avoid late delivery
Performance	- Wrong motor type or poor selection of vehicle aerodynamics	- Not enough thrust to reach desired apogee - Overshooting the vehicle beyond 6000 feet	- Testing in environments similar to launch site

Table 6.13 Project Risk Hazards Mitigation

Identified Hazard	Pre - Mitigation Risk (Probability/Severity/Total)			Post - Mitigation Risk (Probability/Severity/Total)		
Time	5	5	25	4	2	8
Communication	3	3	9	2	2	4
Scope	2	3	6	2	2	4
Resource	3	4	12	2	4	8
Budget	4	4	16	4	3	12
Performance	3	4	12	3	2	6

6.6. Launch Operation Procedures

In order to prevent interruption in the flow of the document, all operation procedures are included in the appendices A through F.

7. Project Plan

7.1. Testing

7.1.1. Vehicle Systems

7.1.1.1. Ground Test

A ground based black powder ejection test was conducted prior to the vehicle demonstration flight. The test article is the vehicle recovery system, which includes parachute packing, black powder charges, and electronics. The team will vary the amount of black powder used, starting with the amount calculated in the CDR of 5 grams for the main parachute and 2.5 grams for the drogue parachute.

The test began with the assembled launch vehicle, excluding the booster . This did not include any batteries, black powder, pressurized air, or other energetic devices. This test aims to demonstrate the vehicle's readiness to be assembled on launch day. The vehicle was then disassembled, taken to an approved testing site outdoors on campus, and reassembled with blackpowder. The procedure outlined in Appendix C was followed. The recovery system was deployed using a 12 volt battery system.

As shown in the photos below, each parachute was fully ejected from the launch vehicle, along with their respective recovery harness. This test was witnessed by the team advisor and safety officer. And, the test footage analyzed for completeness. This test is considered successful.

Figure 7.1 Drogue Chute Deployment Test

Figure 7.2 Main Chute Deployment Test

7.1.1.2. Battery Test

Per requirement 2.7, the avionics and recovery system must be capable of remaining in a launch ready configuration for at least two hours and testing is needed to verify this functionality. The testing objective is to ensure functionality of the avionics and recovery electronics. The testing variable is the selected 2S lipo battery for the avionics and recovery system. This test will be considered a success when the avionics and recovery system has been powered on and flight ready for at least three hours.

To conduct this test, the avionics and recovery system were placed on the team's workbench, powered on. The system was left alone, but not unattended, for three hours. After this time, the system was checked for power. Upon still being powered on the system was visited again at approximately four hours after initial power on. In which case, the system was found to still be powered and the test considered a success. See the pictures below for testing time stamps.

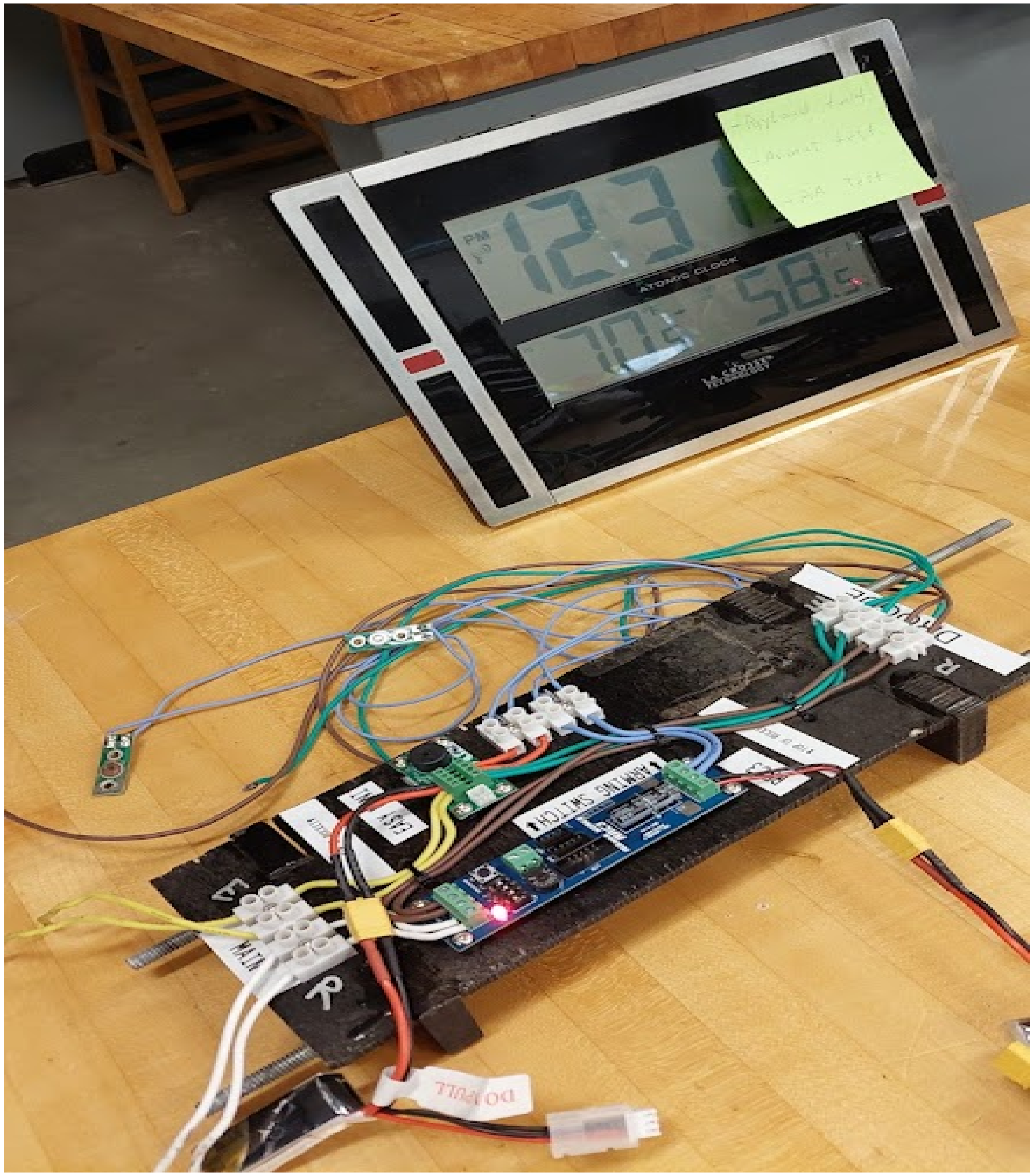

Figure 7.3 Battery Test

7.1.2. Payload

A description of payload testing is summarized here, but referenced in paragraph form in Section 4.2

Table 7.1 Payload Testing

Test	Objective	Success	Results and Lessons
Foil Interference Effectiveness	Measure the effectiveness of aluminum foil in preventing radio waves from entering the payload	Success	Foil is more than enough to shield the electronics
Battery	Ensure the payload battery lasts the required 3 hours on the pad in sleep mode	Success	Payload was able to run for more than 4 hours without reaching low-battery status
RF Locating 1	To confirm distance measurement method with the RF subsystem works as expected	Unsuccessful	More robust methods for testing are required. Testing will be repeated prior to PDF
Xbee	Ensure the Xbee modules can communicate with a 50% success rate at 2500 ft	Success	2500ft resulted in an over 90% success rate, so we have no concerns that the distance is too far

Requirements Compliance

7.1.3. Competition Requirements Verification

Section	Requirement
1.1	Students on the team will do 100% of the project, including design, written reports and presentations. Teams will submit new work. Excessive use of past work will merit penalties.

Verification Plan:
Because the team has not previously participated in NASA SL, no past work exists and no verification is needed around re-use. In order to ensure students complete 100% of work, team members may only consult with outside help, and must individually complete all design work, written reports, and presentations. Advisors will be given access to team documents for supervising, but will not be not given editing privileges. This requirement will be verified by the team president and vice president by reviewing all documentation prior to submission and inspecting all physical construction after each work day.

Section	Requirement
1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel.

Verification Plan:
The team president is in charge of the project plan. This plan will be inspected for completeness by the vice president and team advisor. This project plan will be recorded and maintained in Click Up project management software, which will be available for all team members at all times. The president will maintain deadlines, determine milestones, and log actionable items in the software.

The team treasurer will maintain the budget. This budget will be inspected for completeness by the president after each purchase request. The team treasurer will maintain an updated budget spreadsheet located in the team's Google Drive account, which is viewable to all team members at all times.

Section	Requirement
1.3	Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities

	during Launch Week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.

Verification plan:
The team president will identify Foreign Nationals on the team and compile a list for inclusion with competition documents. This list will be inspected for completeness by the vice president immediately prior to submission.

Section	Requirement
1.4	The team must identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR). Team members will include: 1.4.1. Students actively engaged in the project throughout the entire year. 1.4.2. No more than two adult educators.

Verification plan:
The team president will maintain a list of members interested in attending Launch Week. This requirement will be verified by demonstration of completion to all active team members. A list of active team members who will attend launch week will be assembled by polling all team members at least one week prior to submission. An up-to-date list will be submitted to SL Management along with the CDR submission package, and all active team members will be included on this message via blind carbon copy.

Section	Requirement
1.5	The team will engage a minimum of 250 participants in direct educational, hands-on science, technology, engineering, and mathematics (STEM) activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events must occur between project acceptance and the FRR due date.

Verification plan:
The team public affairs officer will coordinate STEM engagement events. These will be verified by demonstration to the team president. The public affairs officer will record the number of participants for each event in a spreadsheet available to the team. The team president will assess the progress of STEM engagement via checkpoints set at the end of every month. If engagement is not meeting the checkpoints, the team vice-president will assist in the planning and coordination of engagement events.

Section	Requirement
1.6	The team will establish and maintain a social media presence to inform the public about team activities.

Verification plan:
The team will have a social media presence established and run by the public affairs officer. The social media presence will be demonstrated to the team and community by regular posting and activity. Additionally, the public affairs officer may give any team member access to any social media accounts in order to facilitate a more engaging social media presence.

Section	Requirement
1.7	Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No milestone documents will be accepted beyond the 72-hour window. Teams that fail to submit milestone documents will be eliminated from the project.

Verification plan:
The team president will monitor and track all deliverable deadlines in Click Up per requirement 1.2, maintaining a project plan. The vice-president will be responsible for periodically inspecting Click Up and ensuring the team's progress towards completion of competition deliverables. Additionally, both the president and vice-president receive all email notifications from the NASA management team.

Section	Requirement
1.8	All deliverables must be in PDF format.

Verification plan:
The team president will draft the email that contains the deliverables, and the Vice President will inspect the email before it is sent and check for the PDF documents.

Section	Requirement
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.

Verification plan:
The Vice President creates the initial document with preliminary sections, including the table of contents. They will update the table as writing continues, and before the document is submitted, the President will inspect the table of contents prior to document submission.

Section	Requirement
1.10	In every report, the team will include the page number at the bottom of the page.

Verification plan:
The Vice President is in charge of creating the initial document with preliminary sections, including page numbers at the bottom of the page. The page numbers will automatically update as the writing continues, and the President will verify this requirement before submitting the document.

Section	Requirement
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.

Verification plan:
The President is in charge of acquiring the equipment necessary to perform a video teleconference. This will include an external camera and stand to ensure high quality video from our university's Information Technology Department. The presentation team will perform a test presentation prior to the selected presentation date to ensure all equipment is fully functional and provide time to resolve any technical difficulties.

Section	Requirement
1.12	Teams will track and report the number of hours spent working on each milestone.

Verification plan:
Every individual member will keep track of the amount of time they work on each document. The president will compile each person's individual time after document completion and prior to document submission.

Section	Requirement
2.1	The vehicle will deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). Teams flying below 4,000 feet or above 6,000 feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.

Verification plan:
The Vice President is responsible for overseeing the development and testing of the Altitude Assurance system which will assure that the vehicle reaches a target altitude of 5000 ft as prescribed in the Project Silverstein PDR report. The Vice President will lead testing of the Altitude Assurance system during the subscale reflight, vehicle demonstration flight, and payload demonstration flight. Simulation of the launch vehicle performance will be inspected by the Vice President at least one week before each test flight.

Section	Requirement
2.2	Teams shall identify their target altitude goal at the PDR milestone.

Verification plan:
In our PDR milestone, we identified a target altitude of 5000ft. The PDR was inspected by the Vice President to ensure this was included in the document.

Section	Requirement
2.3	The vehicle will carry, at a minimum, two commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events (see Requirement 3.4).

Verification plan:
The Vice President is responsible for overseeing the final design of the launch vehicle. The Vice President will inspect the final design of the launch vehicle at least one week before the submission of the CDR deadline. If two commercially available barometric altimeters are not present in the Avionics Bay, a redesign of the Avionics Bay will be issued.

Section	Requirement
2.4	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.

Verification plan:
This requirement will be accomplished via demonstration and analysis. In the Recovery section, we determined what parachutes, chord, and black powder charges will be necessary to achieve a low landing kinetic energy. We will demonstrate these calculations are complete by launching the full-scale rocket and inspecting any damage. Any damage that is sustained will be analyzed, and the factor of safety will be increased before the next flight. The Vice President will lead this effort.

Section	Requirement
2.5	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.

Verification plan:
The team Vice President will be responsible for ensuring compliance of the launch vehicle architecture. Compliance will be verified by demonstrating the design is complete. A vehicle design consisting of 3 independent sections has been demonstrated to all members of the team in a joint meeting prior to the completion of the CDR.

Section	Requirement
2.5.1	Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.

Verification plan:
The team Vice President will be responsible for ensuring compliance of the launch vehicle architecture. Compliance will be verified by demonstrating the design is complete. A vehicle design in which each coupler located at a point of separation contained a shoulder of at least six inches has been demonstrated to the team prior to the completion of the CDR.

Section	Requirement
2.5.2	Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.

Verification plan:
The team vice president will be responsible for ensuring compliance of the launch vehicle architecture. Compliance will be verified by demonstrating the design is complete. A vehicle design in which the nose cone contained a shoulder of at least three inches has been demonstrated to the team prior to the completion of the CDR.

Section	Requirement
2.6	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.

Verification plan:
With the checklists created by the Safety Officer, Vice President, and other members, we have an order in which the rocket should be compiled before and on launch day. These are arranged such that as much work as can be done before is done with verification by several members of the team. The 2 hour minimum will be achieved through testing of our preparation time before launch day.

Section	Requirement
2.7	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, although the capability to withstand longer delays is highly encouraged.

Verification plan:
The team vice president will be responsible for ensuring compliance of critical on-board components. Compliance will be verified by hand calculations of critical components' power usage and estimated power on time for a selected battery, shown in section 4.7.

And, by a test which demonstrates the critical components' ability to remain in launch-ready configuration for at least three hours. This test will take place prior to the first full scale vehicle demonstration.

Section	Requirement
2.8	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.

Verification plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Because the final motor selected for the mission ships with an igniter capable of firing off a standard 12-volt DC firing system and no obstructions exist for the igniter in the design, a redesign was not issued.

Section	Requirement
2.9	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).

Verification plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Because the final vehicle design does not employ the use of external circuitry or special ground support equipment, a redesign was not issued.

Section	Requirement
2.10	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR),

	Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).

Verification plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final motor choice. Because the leading motor choice described in the report does use a commercially available APCP propulsion system approved by NAR and TRA, a reselection was not issued.

Section	Requirement
2.10.1	Final motor choices will be declared by the Critical Design Review (CDR) milestone.

Verification plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Because the leading motor choice described in the report does not exceed 5120 N-s in impulse, a reselection was not issued.

Section	Requirement
2.10.2	Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment will not be approved. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.

Verification plan:
The Treasurer will purchase the decided motor and extras as soon as possible to mitigate worries of delayed shipping. Should the motor still not arrive on time and there is no other option and it is out of the team's control, the team would have to accept the late motor delivery and make adjustments to other parts of the rocket by prioritizing on those portions.

Section	Requirement
2.11	The launch vehicle will be limited to a single stage.

Verification plan:
The design of the rocket as decided by the Vice President and the rest of the team does not include a second stage. By simple inspection, this requirement is fulfilled.

Section	Requirement
2.12	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class)

Verification plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the PDR report, the Vice President has inspected the vehicle design. Because the leading motor choices described in the report did not exceed 5120 N-s in impulse, a reselection was not issued. Because of this, the selection for the final motor choice did not exceed 5120N-s in impulse.

Section	Requirement
2.13	Pressure vessels on the vehicle will be approved by the RSO

Verification Plan:
The team Safety Officer will be responsible for acquiring the approval for any on board pressure vessels by the RSO. The safety officer will communicate RSO approval to the president and vice president. The launch vehicle is prohibited from launching until approval is received.

Section	Requirement
2.13.1	The minimum factor of safety [for a pressure vessel on the vehicle] (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.

Verification Plan:
The team Safety Officer will be responsible for ensuring that a selected pressure vessel and system design maintain at least a 4:1 factor of safety for burst and max operating pressure.

Section	Requirement
2.13.2	Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank

Verification Plan:
The team Vice President will be responsible for the final design of any vehicle system utilizing a pressure vessel. The design will be inspected for the inclusion of a pressure relief valve that sees full tank pressure. Additionally, the pressure relief valve will be inspected to ensure its operational range is suitable for use in the chosen pressure vessel design. The vice president will issue a redesign of the pressure vessel system if the relief valve is omitted or does not meet the pressure requirements of the system.

Section	Requirement
2.13.3	The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event

Verification Plan:
The team Safety Officer will be responsible for maintaining a complete and accurate log of all pressure tank events and uses. This log will include a description of the tank, relevant safety information, and dated entries for each pressurization, depressurization, and the person or persons administering each event. This log will be periodically inspected by the president and included in all milestone reports.

Section	Requirement
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.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle simulations and calculations. Because simulations have shown that the static stability margin of the vehicle is above the minimum static stability margin, a redesign was not issued.

Section	Requirement
2.15	The launch vehicle will have a minimum thrust to weight ratio of 5.0 : 1.0

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle simulations and calculations. Because neither simulations nor calculations have shown that the thrust to weight ratio of the vehicle is below 5.0:1.0, a redesign was not issued.

Section	Requirement
2.16	Any structural protuberance on the rocket 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 the rocket's stability

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Because all structural protuberances on the final vehicle design are located aft of the burnout center of gravity, a redesign was not issued.

Section	Requirement
2.17	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle simulations and calculations. Because neither simulations nor calculations have shown that the vehicle accelerates below 52 fps at rail exit, a redesign was not issued.

Section	Requirement
2.18	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.

Verification Plan:
The Safety Officer is responsible for ensuring that all batteries are marked and colored, but the members of the team working on the design of the bays will ensure they are protected to avoid combustion if recovery is to fail. The Vice President will inspect the batteries before any launch ensuring that they are clear of deformation or puncters and they are clearly marked and labeled. The vice president will also inspect the final design of any launch vehicle system utilizing lithium polymer batteries for addicate protection from impact prior to CDR submission. The vice president will issue a redesign if the current design does not adequately protect the batteries.

Section	Requirement
2.19.1	The launch vehicle will not utilize forward firing motors.

Verification Plan:
As the Vice President is in charge of the final design, they will inspect the design to ensure that the launch vehicle will not utilize forward firing motors. This inspection will occur at least 2 weeks before the submission of the CDR.

Section	Requirement
2.19.2	The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)

Verification Plan:
The Vice President is responsible for the review of the final rocket design, and will verify that no motors that expel titanium sponges are utilized or referenced within. The design review will occur at least 2 weeks before the submission of the CDR.

Section	Requirement
2.19.3	The launch vehicle will not utilize hybrid motors.

Verification Plan:
The Vice President is responsible for the review of the final rocket design, and will verify that no hybrid motors are utilized or referenced within. The design review will occur at least 2 weeks before the submission of the CDR.

Section	Requirement
2.19.4	The launch vehicle will not utilize a cluster of motors.

Verification Plan:
The Vice President is responsible for the review of the final rocket design, and will verify that a cluster of motors is not used or referenced within. The design review will occur at least 2 weeks before the submission of the CDR.

Section	Requirement
2.19.5	The launch vehicle will not utilize friction fitting for motors

Verification Plan:
The Vice President is responsible for the final design and review of the launch vehicle, and will verify that the motors for the launch vehicle are secured without the use of friction fitting. The design review will occur at least 2 weeks before the submission of the CDR. This review will include the verification of how the motors are secured and that none of the design utilizes friction fittings for the motors.

Section	Requirement
2.19.6	The launch vehicle will not exceed Mach 1 at any point during flight.

Verification Plan:
The Vice President is responsible for reviewing the launch vehicle, and will verify that the launch vehicle cannot exceed Mach 1 in rocket simulation before the launch vehicle is utilized.

Section	Requirement
2.19.7	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).

Verification Plan:
The Vice President is responsible for the final design and review of the launch vehicle, and will verify that the vehicle ballast will not exceed 10% of the total unballasted weight of

the rocket as it would sit on the pad. This verification will occur at least 2 weeks before the submission of the CDR. This review will include recalculation of the total unballasted rocket weight and vehicle ballast weight.

Section	Requirement
2.19.8	Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).

Verification Plan:
The vice president is responsible for reviewing the final design of the launch vehicle and payload. The vice president will inspect the design presented by team members prior to the submission of the CDR. A redesign will be issued for any design which includes a transmitter exceeding 250mW of power prior to landing.

Section	Requirement
2.19.9	Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.

Verification Plan:
The payload team will inspect the frequencies used by other teams and inquire about interference. As a preemptive measure, the team has a range of frequencies it can transmit at, and all telemetry will be encoded. If a team relies heavily on one frequency, all of our transmitters have a range of at least 15mHz that they can transmit, so we can change our transmission frequency to comply with this requirement.

Section	Requirement
2.19.10	Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.

Verification Plan:
The vice president will be responsible for the final design of the launch vehicle. They will inspect the design for the use of any dense or lightweight metals. Designs utilizing dense metals will not be allowed. Team members must demonstrate to the vice president through analysis, such as FEA, the necessity of any lightweight metals included on the launch vehicle. The vice president will issue a redesign of the launch vehicle if the analysis does not justify the use of a chosen lightweight metal.

Section	Requirement
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.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Because the final vehicle design incorporates dual deployment of a drogue chute at apogee and a main chute at 600ft., a redesign was not issued.

Section	Requirement
3.1.1	The main parachute shall be deployed no lower than 500 feet

Verification Plan:
The team safety officer will be responsible for the configuration of the recovery altimeters. Altimeter configuration will be inspected by the team president prior to launch day and again at the team's work table on launch day. The launch vehicle will not be allowed to fly until both altimeters are configured with main parachute deployment greater than 500 feet.

Section	Requirement
3.1.2	The apogee event may contain a delay of no more than 2 seconds

Verification Plan:
The team safety officer will be responsible for the configuration of the recovery altimeters. Altimeter configuration will be inspected by the team president prior to launch day and again at the team's work table on launch day. The launch vehicle will not be allowed to fly until an event delay of 2 seconds or less is configured.

Section	Requirement
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Because the design incorporates electronic deployment of both the drogue and main chutes and a motor ejection design is not used, a redesign was not issued.

Section	Requirement
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.

Verification Plan:
The team safety officer is responsible for the coordination and planning of all ground ejection test. The team will not be allowed to travel to the launch site until a successful ground test is demonstrated to the team vice president and advisor.

Section	Requirement
3.3	Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle simulations and calculations. Because neither simulations nor calculations have shown that the maximum kinetic energy of any independent section does not exceed 75 ft-lbf at landing, a redesign was not issued.

Section	Requirement
3.4	The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the CDR report, the Vice President will have inspected the vehicle design and made sure that the altimeters used on the launch vehicle are redundant and commercially available.

Section	Requirement
3.5	Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the CDR report, the Vice President will have inspected the vehicle design and ensured that each of the redundant altimiters have a dedicated power supply and that the recovery electronics are powered by commercially available batteries.

Section	Requirement
3.6	Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the CDR report, the Vice President will have inspected the design and verified that each altimeter is armed by a dedicated mechanical arming switch accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.

Section	Requirement
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).

Verification Plan:
The Vice President is responsible for the review of the final design of the launch vehicle. Thus, during the review of the final design, which occurs at least one week before the submission of the CDR report, the Vice President will verify that the design of the arming switch on the launch vehicle will allow for the arming switch to be locked in the ON position, and unable of being disarmed due to flight forces.

Section	Requirement
3.8	The recovery system electrical circuits will be completely independent of any payload electrical circuits.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the CDR report, the Vice President will have inspected the

design and verified that the recovery system electronics are independent of all payload electronic systems.

Section	Requirement
3.9	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Because the design incorporates removable shear pins for deployment of both the drogue and main chutes, a redesign was not issued.

Section	Requirement
3.10	The recovery area will be limited to a 2,500 ft. radius from the launch pads.

Verification Plan:
The Vice President will finalize the design of the rocket which includes the maximum drift based on several wind conditions (Section 3.7.1). On top of analyzing our predicted drift, during our practice flights, the Vice President will determine our experimental drift to ensure it meets this requirement.

Section	Requirement
3.11	Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down).

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the CDR report, the Vice President will have inspected the design and verified through CFD that the drag produced by the drogue and main parachutes is low enough to limit descent time to 90 seconds while also meeting the Section 3.2 requirement.

Section	Requirement
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.

Verification Plan:
The payload team has a Eggtimer GPS Transmitter that will be constantly transmitting the GPS location of the rocket throughout the flight. The Vice President will inspect its functionality before the FRR to ensure this requirement is met.

Section	Requirement
3.12.1	Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic GPS tracking device.

Verification Plan:
The vice president is responsible for the final design of the launch vehicle and payload. The final design will be inspected by the vice president and verified by a secondary inspection of the safety officer for the inclusion of a GPS tracking device on any rocket section or untethered payload.

Section	Requirement
3.13	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the CDR report, the Vice President will have inspected the design and ensured that the recovery system is adequately shielded. Ground testing will also be conducted in order to verify that no adverse effects occur to the recovery system as a result of other electronic systems.

Section	Requirement
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.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the CDR report, the Vice President will have inspected the design and ensured that the recovery system altimeters are in another compartment separate from other RF transmitters or magnetic wave producing devices.

Section	Requirement
3.13.2	The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the CDR report, the Vice President will have inspected the design and ensured that the recovery system is adequately shielded. Testing will be conducted in order to verify that the shielding is adequate to avoid excitation of the recovery system by other transmitting devices.

Section	Requirement
3.13.3	The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the CDR report, the Vice President will have inspected the design and ensured that the recovery system is adequately shielded. Testing will be

conducted in order to verify that the shielding is adequate to avoid excitation of the recovery system by other transmitting devices.

Section	Requirement
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.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least one week before the submission of the CDR report, the Vice President will have inspected the design and ensured that the recovery system is adequately shielded. Testing will be conducted in order to verify that the shielding is adequate to avoid interference from other onboard devices.

Section	Requirement
4.1	Teams shall design a payload capable of autonomously locating the launch vehicle upon landing by identifying the launch vehicle's grid position on an aerial image of the launch site without the use of a global positioning system (GPS). The method(s)/design(s) utilized to complete the payload mission will be at the teams' discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.

Verification Plan:
The payload team has created a system that, in design, fulfills this requirement, but testing and analysis is required after the system is built. The payload team will conduct testing on the RF and IMU Systems using the Flight Computer, and ensure that this requirement is met.

Section	Requirement
4.2.1	The dimensions of the gridded launch field shall not extend beyond 2,500 feet in any direction; i.e., the dimensions of your gridded launch field shall not exceed 5,000 feet by 5,000 feet

Verification Plan:
The Vice President is responsible for ensuring this requirement is met. The gridded launch field shown in Section 4.9 has dimensions of 2,500 ft on both sides. The Vice President inspected the gridded launch field.

Section	Requirement
4.2.1.1	Your launch vehicle and any jettisoned components must land within the external borders of the launch field.

Verification Plan:
The Vice President is responsible for ensuring drift calculations are performed for the launch vehicle and any jettisoned components. Our current launch calculations meet this requirement

Section	Requirement
4.2.2	A legible gridded image with a scale shall be provided to the NASA management panel for approval at the CDR milestone.

Verification Plan:
The President is responsible for sending the gridded image to the NASA management panel for approval, but the Vice President is responsible for ensuring that the image is legible. This requirement will be completed through inspection before the image is submitted.

Section	Requirement
4.2.2.1	The dimensions of each grid box shall not exceed 250 feet by 250 feet.

Verification Plan:
The Vice President is responsible for ensuring that the gridded image has box dimensions that do not exceed 250 ft. In its CDR state, the image has box dimensions of 250ft on each side (Section 4.9).

Section	Requirement
4.2.2.2	The entire launch field, not to exceed 5,000 feet by 5,000 feet, shall be gridded

Verification Plan:
The Vice President will ensure that the launch field image is accurately gridded before its submission to the NASA management panel.

Section	Requirement
4.2.2.3	Each grid box shall be square in shape.

Verification Plan:
The Vice President is responsible for ensuring that the gridded image has boxes that are square.

Section	Requirement
4.2.2.4	Each grid box shall be equal in size, it is permissible for grid boxes occurring on the perimeter of your launch field to fall outside the dimensions of the launch field. Do not alter the shape of a grid box to fit the dimension or shape of your launch field.

Verification Plan:
The Vice President is responsible for ensuring that each grid box is equal in size before its submission to the NASA management panel.

Section	Requirement
4.2.2.5	Each grid box shall be numbered

Verification Plan:
The Vice President is responsible for ensuring that each grid box is numbered before its submission to the NASA management panel.

Section	Requirement
4.2.2.6	The identified launch vehicle's grid box, upon landing, will be transmitted to your team's ground station.

Verification Plan:
The payload design accounts for this requirement using the GUI controlled by the Ground Station Computer. The Flight Computer does the work to determine the grid box, and it will send via the Telemetry System the determined box to the Ground Station Computer. The Vice President will inspect the work of the payload design team before the FRR to ensure the requirement is met.

Section	Requirement
4.2.3	GPS shall not be used to aid in any part of the payload mission.

Verification Plan:
The Vice President is responsible for the oversight of the final launch vehicle design and will verify that GPS is not used or referenced in any part of the payload mission's documentation or hardware.

Section	Requirement
4.2.3.1	GPS coordinates of the launch vehicle's landing location shall be known and used solely for the purpose of verification of payload functionality and mission success.

Verification Plan:
The Vice President is responsible for ensuring the completion of this requirement through analysis and inspection. The payload team has created a payload design that transmits the GPS coordinates continuously throughout the flight. The GPS has its own transmitter and is thus completely separate from the rest of the payload. The Flight Computer determines the location of the rocket and does not have access to the GPS data. The Vice President will ensure the payload functions as designed before the FRR by overseeing the full payload test.

Section	Requirement
4.2.3.2	GPS verification data shall be included in your team's PLAR.

Verification Plan:
The President is responsible for the filing of all team documents and will verify, before the submission of the PLAR, that GPS verification data is included within.

Section	Requirement
4.2.4	The gridded image shall be of high quality, as deemed by the NASA management team, that comes from an aerial photograph or satellite image of your launch day launch field.

Verification Plan:
The Vice President is responsible for the quality of the gridded image and will ensure that it is an aerial photograph of satellite image.

Section	Requirement
4.2.4.1	The location of your launch pad shall be depicted on your image and confirmed by either the NASA management panel for those flying in Huntsville or your local club's RSO. (GPS coordinates are allowed for determining your launch pad location).

Verification Plan:
The Vice President is responsible for ensuring the completion of this requirement. Up to this point, the launch pad coordinates that are used for the gridded image depicted in Section 4.9 are from a frequently asked questions post on the NASA.gov website (https://www.nasa.gov/stem/studentlaunch/faqs.html). The Vice President will confirm with the NASA management panel two weeks before the FRR is due via email to ensure our coordinates are correct and have not been updated.

Section	Requirement
4.2.5	No external hardware or software is permitted outside the team's prep area or the launch vehicle itself prior to launch

Verification Plan:
The Safety Officer will be responsible for ensuring that no external hardware or software exists, intentionally or accidentally, outside of the team prep area. The Safety Officer will take physical steps to bring hardware or software back to the prep area should it be identified outside of the prep area.

Section	Requirement
4.3.1	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.

Verification Plan:
The vice president is responsible for the final payload and vehicle mission design. Prior to CDR submission the, the vice president will inspect the payload and vehicle mission design to ensure no energetic devices are used.

Section	Requirement
4.3.2	Teams shall abide by all FAA and NAR rules and regulations.

Verification Plan:
The Safety Officer is responsible for ensuring all team members and all team-related projects abide by all FAA and NAR rules and regulations.

Section	Requirement
4.3.3	Any 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 at the CDR milestone by NASA.

Verification Plan:
The team has determined an experiment element which jettisons from the launch vehicle is not necessary to successfully complete the payload mission. Because of this, there will be no verification needed for RSO permission prior to a jettison event.

Section	Requirement
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.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Because the design does not incorporate the use of any unmanned aircraft system to be deployed during descent, a redesign was not issued.

Section	Requirement
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).

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Because the design does not incorporate the use of any unmanned aircraft system to be deployed during descent, a redesign was not issued.

Section	Requirement
4.3.6	Any UAS weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Because the design does not incorporate the use of any unmanned aircraft system to be deployed during descent, a redesign was not issued.

Section	Requirement
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report.

Verification Plan:
The President is the primary administrator of the team and is responsible for the filing of all USLI documents. It is the Safety Officer's responsibility to complete the checklists, but the President will verify that a launch and safety checklist is complete, completed, and included in the FRR report.

Section	Requirement
5.2	Each team shall identify a student safety officer who will be responsible for all items in section 5.3.

Verification Plan:
The President is responsible for the overseeing of the team Officers and will verify, at every change of the team's roster, that a student Safety Officer has been identified and elected by the team. If there is no Safety Officer, the President will ensure that there is an election and that a new Safety Officer is selected at the next meeting in which a majority student population is present.

Section	Requirement
5.3.1	The safety officer will monitor team activities with an emphasis on safety during: 5.3.1.1. Design of vehicle and payload 5.3.1.2. Construction of vehicle and payload components 5.3.1.3. Assembly of vehicle and payload 5.3.1.4. Ground testing of vehicle and payload 5.3.1.5. Subscale launch test(s) 5.3.1.6. Full-scale launch test(s) 5.3.1.7. Competition Launch 5.3.1.8. Recovery activities 5.3.1.9. STEM Engagement Activities

Verification Plan:
The team Safety Officer has and will be an important part of every design decision. They have and will green-light every design decision with an emphasis on safety by being present at design meetings and reading over all aspects of technical documents. They have

been and will be present at every launch and ground test in order to ensure the completion of checklists and the following of RSO rules. All construction of the launch vehicles will take place during broadcasted meeting times. If the Safety Officer cannot attend, they will appoint someone present to oversee construction with an emphasis on safety.

Section	Requirement
5.3.2	The safety officer will implement procedures developed by the team for construction, assembly, launch, and recovery activities.

Verification Plan:
The Safety Officer is responsible for fulfilling this requirement. They have made checklists located in the Appendix that list the procedures for payload, recovery electronics, pneumatic, recovery, and rocket motor preparation. The Safety Officer is in charge of implementing these checklists, and the Vice President or the President will verify their completion during any activity they are needed for.

Section	Requirement
5.3.3	The safety officer will manage and maintain current revisions of the team's hazard analyses, failure modes analysis, procedures, and MSDS/chemical inventory data.

Verification Plan:
The Safety Officer will check over and update the teams Safety Section (containing hazard analyses, failure modes analysis) at least 2 weeks before the submission of any document. In addition, the Safety Officer created procedures for preparing our rocket for launch (see Appendix) and will change them as needed. The President will verify the completion of updating of all the required documents.

Section	Requirement
5.3.4	The safety officer will assist in the writing and development of the team's hazard analyses, failure modes analysis, and procedures.

Verification Plan:
The team president is responsible for assigning responsibilities for the rest of the team leadership. The team president will inspect the progress made and work done by each member of the team leadership. As the hazard analyses, failure modes analyses, and procedures were developed, the president verified that the team safety officer was involved.

Section	Requirement
5.4	Teams will abide by all rules set forth by the FAA

Verification Plan:
The Safety Officer is responsible for ensuring the team's adherence to FAA guidelines.

7.2. Updated Derived Requirements

7.2.1. Vehicle Derived Requirements

Requirement	Justification
Metallic components may only be used when non-metallic alternatives are proven insufficient.	The competition rules prohibit the use of excessive and/or dense material in the construction of the vehicle per Req. 2.23.10. This is to ensure that the vehicle is constructed with minimal use of metallic materials.

Verification Plan:

The Team Vice President is responsible for the final design of the launch vehicle. Adherence to this derived requirement requires testing, analysis, and final inspection of the vehicle.

Metallic component use must be justified via one of several alternative methods:

- Material failure calculations, simulations, and/or testing of non-metallic alternatives shows that metals are required.
- COTS components are utilized and no non-metallic alternatives exist
- Where fiber composites are structurally sound, a detailed feasibility study shows their use to be infeasible
- Hardware is determined to be in the critical load path of the recovery harness, since metals are well-characterized materials with ductile failure

An audit of all metallic components has been performed in advance of submission of the Critical Design Review, and all components have been appropriately justified. No later than one week prior to the submission of the Flight Readiness Review, the Vice President will perform an audit of all mechanical testing to ensure any components with testing-based rationale have been appropriately validated.

Requirement	Justification
The airframe design and construction must be able to accommodate multiple internal arming switches which have clear external access.	Per Req. 3.6, altimeters must be activated by a dedicated arming switch which is externally-accessible. Per Req. 3.7, these arming switches must not be able to be disarmed during flight. Internal arming switches for altimeters and other electronics must be internal to the airframe to protect these switches from aerodynamic manipulation.

Verification Plan:

The Team Vice President is responsible for the final design of the launch vehicle. This derived requirement is enforced via inspection of the design to ensure internal arming switches are present in the design, can be wired into their respective systems from the locations selected, and are freely accessible from the outside of the vehicle. An audit of the vehicle design has been performed before the submission of the Project Silverstein CDR.

Requirement	Justification
Each vehicle subsystem must have a center of mass along the centerline of the vehicle.	Rocket trajectory is simulated using masses lumped to the centerline of the vehicle. Asymmetry in the mass may cause unexpected deviation from the flight profile.

Verification Plan:
The Team Vice President is responsible for the final design of the launch vehicle. This derived requirement will be verified by analysis of the design and inspection of the as-built system. Led by the Vice President, each vehicle subsystem team will perform an audit of their respective subsystem to ensure mass components are strategically placed. During the audit, members will verify that the current system design is symmetrically balanced through the use of an appropriate CAD model or hand calculation, or demonstrate the ability for components to be easily rearranged. An example of this would be a 3d-printed mounting bracket for the subsystem, which can be easily modified and re-printed. This audit will take place during the construction of the full scale launch vehicle and must be completed at least 48 hours prior to the full-scale test flight. Any subsystem found to not be meeting this requirement will have its mass adjusted accordingly.

Requirement	Justification
The airframe will be restricted from designs utilizing asymmetric structural response.	Rocket trajectory is simulated by ignoring structural response. Asymmetry in the structural response may cause unexpected deviation from the flight profile.

Verification Plan:
The Team Vice President is responsible for the final design of the launch vehicle. This derived requirement will be verified by either inspection of the design or by simulation of the structural response. Where symmetric geometries are utilized on the vehicle, inspection of the design to confirm symmetry will be completed no less than 1 week before the completion of the Critical Design Review. Where asymmetric geometries are used, structural analysis must be performed to demonstrate that off-axis deformation of the structure is no greater than 1% of the total deformation under load. This audit has

been performed in advance of submission of the Critical Design Review, and all systems have been found to be compliant.

Requirement	Justification
Altitude Assurance System will be restricted to extending drag-producing devices aft of the burnout CG.	Extended drag-producing devices that are a part of the altitude assurance system are classified as structural protuberances by the RR-SL team. Per Req. 2.16, these devices may only act aft of the burnout CG.

Verification Plan:
The Team Vice President is responsible for the final design of the launch vehicle. Under guidance of the Vice President, the Altitude Assurance team will perform an audit of the Altitude Assurance subsystem to ensure that the device is positioned below the burnout CG, using both analysis and inspection of the as-built rocket. The burnout CG is known from both OpenRocket calculations and physically balancing the assembled rocket with no propellant. This audit has been performed in advance of submission of the Critical Design Review, and all systems have been found to be compliant.

Requirement	Justification
The Altitude Assurance System must be capable of decreasing launch vehicle apogee by 300 m.	Performance calculations, petal performance, margin, req 2.1

Verification Plan:
The Team Vice President is responsible for the final design of the launch vehicle. Under guidance of the Vice President, the Altitude Assurance team will verify this requirement via analysis of the design. The team will perform an audit of the Altitude Assurance subsystem every time that a change is made to the flight model to ensure that the drag produced by the petals is sufficient to decrease the launch vehicle apogee by 300 m. These calculations will be additionally refined with every test of the Altitude Assurance subsystem to ensure that the drag model accurately represents the flap behavior. This audit was performed in advance of submission of the Critical Design Review.

7.2.2. Recovery Derived Requirements

Requirement	Justification
All energetic devices must be handled using COTS electronics.	The team is not experienced in experimenting with energetic devices. Handling energetic devices with COTS electronics will remove variability

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle, and will verify this requirement via inspection of the design. All energetic devices will be identified individually, and any electronics used to interface with these devices will be subsequently identified. Any non-COTS components identified during this audit will be listed, and the responsible team members will select alternatives. This audit has been performed in advance of submission of the Critical Design Review, and all hardware has been found to be compliant.

Requirement	Justification
All harness components must be rated to at least 5000 lb breaking strength unless otherwise recommended by the manufacturer.	Parachute deployment often results in harsh and unpredictable shock loads to harnesses, and a failure in recovery has the greatest potential to create dangerous debris. Therefore, all recovery items are sized to 5000lb based on recommendations from OneBadHawk and Wildman Rocketry.

Verification Plan:
The Vice President and Safety Officer will collaborate to verify rated breaking strengths of all components used in the recovery harness. This audit will occur before any flight of the vehicle to ensure that the correct components are used.

7.2.3. Payload Derived Requirements

Requirement	Justification
The method used for locating the rocket will be strictly applicable to communication with a probe on another planet	Derived from Req. 4.1, the team determined that the phrasing "adhere to the intent of the challenge" as indication that our solution should be viable on another planet with no existing technology

Verification Plan:
As this derived requirement is deeply integrated into the design of the payload, the payload team is responsible for ensuring compliance, which will be done via analysis and inspection of the design. The team has and will analyze the current methods in use for

communicating with other planets, and has eliminated any methods deemed "not in the spirit of the competition." The team will continue to seek input from the NASA panel of judges and advisors in order to conceptually verify that our approach to locating the rocket represents a viable solution to interplanetary probe communication. The Vice President will further verify this requirement by inspecting the work of the payload team. Both the audit internal to the payload team and the separate audit from the Vice President have been performed in advance of submitting the Critical Design Review.

Requirement	Justification
The payload experiment must fully fit inside the nose cone	The vehicle team has concluded that the payload must fit entirely inside the nose cone

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle, and will verify this requirement via inspection of the system during both design and construction. Under direction of the vice president, the payload team will perform an audit of the payload experiment every time that the nose cone is changed to ensure that the system fits entirely inside the nose cone. Their design will be further verified by the CAD model to fit the nose cone. This audit has been performed in advance of submission of the Critical Design Review, and all systems have been found to be compliant. The construction of the Payload Integration System is complete, and this requirement is met.

Requirement	Justification
The payload must not deploy from the launch vehicle	The vehicle team has determined that the added safety and mission risk caused by payload deployment are not necessary to successfully complete this year's mission

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle. At least two weeks before the submission of the CDR report, the Vice President has inspected the final vehicle design. Since the design does not incorporate the deployment of the payload system, a redesign was not issued. This requirement is met.

Requirement	Justification
The GPS Transmitter must not interface with the Flight Computer	The GPS Transmitter is used to verify the final position, so we did not want any suspicion of our using it for our calculated position. By keeping it separate, there is no chance of this.

Verification Plan:
The Vice President is responsible for the final design of the launch vehicle, and has verified this requirement via inspection of the system during the design and manufacturing. Our GPS Transmitter is powered by the same battery, but is otherwise completely separate from the rest of the payload. It even has its own antenna and will be received by a specific receiver separate from even the ground station electronics.

Requirement	Justification
The antennas on the rocket must not interfere with each other's functionality	There will be three antennas on the rocket: two transmitting and one receiving. If any decrease in functionality, the payload goals will be in jeopardy.

Verification Plan:
This requirement will be met through testing. The payload team will conduct this testing before the Payload Demonstration Flight to ensure complete functionality of all components of the payload. Results of the test will be reported by the FRR Addendum.

Requirement	Justification
The Payload Integration shock-mount should decrease the acceleration of the payload by 50%	This metric was designed to decrease a simulated 25g acceleration from recovery down to a 12.5g load which is in the range of the low-range accelerometer which is more precise than the high-range.

Verification Plan:
This requirement will be verified through testing. The Shock-Mount test will verify this metric by dropping the payload with and without the shock-mount and measuring the acceleration for both trials. If the reduction is insufficient, then new springs with a higher stiffness will be used.

Requirement	Justification
The transmitted signal from the Ground Station will be a correctly modulated BPSK signal without overmodulation	Because the competition venue will be shared with other teams, potentially including other teams operating on the same band, it is important that the modulated signal developed by our team will not interfere with signals on neighboring frequencies.

Verification Plan:
This verification will be verified through testing. Before launch, the transmitted signal will be received on an SDR and demodulated. The received waveform will be observed and is

expected to take up approximately .005 MHz at the designated transmitting frequency. If this is not the case, the GNUradio flowchart will be modified to suppress overmodulation.

Requirement	Justification
A callsign belonging to a team member present at the ground station must be transmitted every ten minutes on amateur frequencies	The amateur radio service requires by law that amateurs repeat their call sign every ten minutes and at the end of the transmission while a communication is in progress.

Verification Plan:
This verification will be verified through testing. The callsign designated before the launch will be manually transmitted when the transmitting activity is over, and will be programmed into the Python script controlling the bits sent to the transmitting SDR to automate the 10 minute interval requirement. This functionality must be verified by being received by an SDR, decoded, and listened to by a member designated by the team before launch.

7.3. Budgeting and Funding Summary

7.3.1. Line Item Budget

Table 7.1 Line Item Budget

Component Level Budget				**TOTAL:**	**$15,828.00**
Item	**Price**	**Qty**	**Shipping**	**Total**	**Vendor**
Equipment					
Voron 2.4	$940.00	1	$0.00	$940.00	3d Printers Bay
Voron 0.1	$493.00	1	$0.00	$493.00	3d Printers Bay
LiPo Battery Charger	$80.00	1	$0.00	$80.00	Hobby King
LiPo Battery Bag	$5.00	2	$0.00	$10.00	Hobby King
Soldering And Rework Station	$200.00	1	$0.00	$200.00	Amazon
Wire Brush	$15.00	1	$0.00	$15.00	Amazon
Electrical Vise	$30.00	1	$0.00	$30.00	Amazon
Solder Hands	$25.00	1	$0.00	$25.00	Amazon
Hand Clamp	$8.00	2	$0.00	$16.00	Amazon
Bar Clamp 4 Pack	$16.00	1	$0.00	$16.00	Amazon

Cobalt Drill Index	$200.00	1	$0.00	$200.00	Amazon
Pliers, Wrenches	$94.00	1	$0.00	$94.00	Amazon
		Section Total:		$2,119.00	
General Consumables					
Solder	$25.00	1	$0.00	$25.00	Amazon
B/W/R 22 Gauge	$12.00	3	$0.00	$36.00	Amazon
B/R 18 Gauge	$10.00	2	$0.00	$20.00	Amazon
Gf30 Nylon 3d Printer Filament	$185.00	1	$15.00	$200.00	3dxtech
Pla Plus Filament	$25.00	3	$0.00	$75.00	Amazon
Epoxy	$172.00	1	$0.00	$172.00	Total Boat
Fine Adjustment Cable Ties	$17.00	1	$8.00	$25.00	Mcmaster Carr
Electrical Tape	$4.00	6	$0.00	$24.00	Amazon
Solo Cups	$5.00	1	$0.00	$5.00	Amazon
Rail Buttons	$8.00	4	$5.00	$37.00	Rail Buttons
M2/M3/M4/M5 Bolts	$25.00	2	$0.00	$50.00	Amazon
Popsicle Sticks	$4.00	1	$0.00	$4.00	Amazon
Duct Tape	$13.00	1	$0.00	$13.00	Amazon
Aluminum Wide Rivets	$13.00	1	$3.00	$16.00	Mcmaster Carr
Aluminum Narrow Rivets	$10.00	1	$3.00	$13.00	Mcmaster Carr
Protoboard	$12.00	1	$0.00	$12.00	Amazon
		Section Total:		$733.00	
Rocket Body					
G12 Body Tube	$46.00	10	$27.00	$487.00	Wildman Rocketry
Nosecone	$150.00	1	$15.00	$165.00	Wildman Rocketry
Mica Insulation Sheets	$85.00	1	$14.00	$99.00	Mcmaster Carr
Spray Paint	$6.00	3	$0.00	$18.00	Amazon
14" Coupler	$78.00	2	$14.00	$170.00	Madcow Rocketry
G10 Sheet	$18.00	4	$20.00	$92.00	Wildman Rocketry

		Section Total:		$1,904.00	
Altitude Assurance					
2 Ft X 1/4" Diameter Uhmwpe Rod	$3.00	1	$11.00	$14.00	Mcmaster Carr
Ptfe Film Tape	$15.00	1	$0.00	$15.00	Amazon
16mmx75mm Air Cylinder	$12.00	2	$0.00	$24.00	Amazon
2-Way Solenoid Valve	$17.00	2	$0.00	$34.00	Amazon
Altimeter	$10.00	2	$10.00	$30.00	Adafruit
Control Computer	$15.00	2	$8.00	$38.00	Digikey
Absolute Position Encoder	$8.00	6	$12.00	$60.00	Sparkfun
		Section Total:		$215.00	
Motor					
Motor Case	$560.00	1	$20.00	$580.00	Wildman
Motor	$350.00	3	$40.00	$1,090.00	Wildman
75mm Motor Tube	$40.00	1	$7.00	$47.00	Madcow Rocketry
75mm Motor Retainer	$65.00	1	$7.00	$72.00	Wildman Rocketry
		Section Total:		$1,789.00	
Subscale					
54mm Motor Retainer	$31.00	1	$0.00	$31.00	Wildman Rocketry
Motor Reload Kit 38mm 720 Case	$104.00	1	$0.00	$104.00	Wildman Rocketry
Centering Ring	$7.00	3	$0.00	$21.00	Madcow Rocketry
Motor	$120.00	1	$40.00	$160.00	Wildman Rocketry
54mm Motor Tube	$30.00	1	$7.00	$37.00	Madcow Rocketry
4" Airframe Tube	$272.00	1	$23.00	$295.00	Madcow Rocketry
4" Coupler	$29.00	1	$16.00	$45.00	Madcow Rocketry
4" 4:1 Ogive Nose Cone	$38.00	1	$18.00	$56.00	Madcow Rocketry

		Section Total:		$749.00	
Payload					
Raspberry Pi 4 Kit	$120.00	2	$0.00	$240.00	Amazon
COTS Telemetry Modules	$80.00	2	$10.00	$170.00	Sparkfun
750 mAh 4s Battery	$38.00	2	$0.00	$76.00	Getfpv
Sd Cards	$9.00	4	$0.00	$36.00	Amazon
Mountable XT60 Plugs	$12.00	1	$0.00	$12.00	Amazon
22 awg Silicone Wire	$15.00	1	$0.00	$15.00	Amazon
18 awg Silicone Wire	$15.00	1	$0.00	$15.00	Amazon
Accelerometer	$20.00	3	$10.00	$70.00	Adafruit
Altimeter	$10.00	4	$10.00	$50.00	Adafruit
750 Mah 4s Battery	$38.00	1	$0.00	$38.00	Getfpv
		Section Total:		$722.00	
Recovery					
Rrc3 Altimeter	$74.00	2	$7.00	$155.00	Wildman
Rocket Locator				$0.00	
Recovery Harness	$72.00	2	$7.00	$151.00	Wildman
Avionics Bay	$50.00	2	$10.00	$110.00	Madcow Rocketry
750 mAh 4s Battery	$38.00	1	$0.00	$38.00	Getfpv
Hybrid Supercapacitor	$11.00	2	$4.00	$26.00	Digikey
Nylon Shear Pins	$4.00	2	$5.00	$13.00	Apogee Rockets
Skyangle Cert-3 Large	$139.00	1	$13.00	$152.00	Madcow Rocketry
Drogue Chute	$86.00	1	$29.00	$115.00	The Rocket Man
Mica Insulation Sheet	$85.00	1	$14.00	$99.00	Mcmaster Carr
		Section Total:		$859.00	
Travel					

Mileage Reimbursement (4 Per Car)	$415.00	5	$0.00	$2,075.00	N/A
Student Hotel (4 Per Room)	$135.00	20	$0.00	$2,700.00	N/A
Mentor Hotel	$135.00	4	$0.00	$540.00	N/A
Meals (Per Person)	$15.00	40	$0.00	$600.00	N/A
		Section Total:		$5,915.00	
Branding					
Stickers (Bulk Order)	$100.00	1	$4.00	$104.00	Sticker Mule
Team Presentation Polos	$18.00	20	$0.00	$360.00	Bagnoche Sports
Team Event T-Shirts	$10.00	20	$0.00	$200.00	Bagnoche Sports
		Section Total:		$664.00	

7.3.2. Funding Acquisition Plan

The Rose Rocketry Student Launch Team has continued to secure additional funding and resources since the CDR. These resources have come in the form of One Time Funding Requests (OTFR) from our Student Government Association (SGA) and company sponsorship. This is in addition to our previous SGA funding support, a $1000 team donation, and funding from the Branam Innovation Center (BIC). Our total funds raised thus far are listed below.

Table 7.2 Total Received Funding

Source	Funding amount or resource
Student Government Association	$18,000.00
Branam Innovation Center	$3000 and workspace
Anonymous donation	$1000
NASA testing stipend	$300
Oshpark PCB company	$75 voucher
Pacergy energy company	Free PCB printing
TOTAL	**$22,300.00**

By far, the Student Government Association and Branam Innovation Center have been the largest contributors to team funding and material acquisition. The BIC has designated areas for scrap metal, wood, and other materials that other competition teams no longer need. These designated scrap piles have enabled the team to acquire many materials, such as aluminum for the distributor plates, without buying expensive stock. Additionally, due to the BIC's vast resources and accessible machinery, the team has been able to manufacture all parts in house and save on costs. An example of this is utilizing the water jet to cut all of our fiberglass plates and aluminum parts in house.

Shown in table 7.2, the team has allocated more funds than it is expected to utilize. And, we have acquired all the stock and material we need for the rest of the season. SGA and BIC funds reset at the end of each fiscal year on July 1st. The team will utilize any remaining SGA and BIC funds to purchase additional materials and equipment in preparation for next season. Examples of this include tool boxes, tools, level 2 motors, G10 fiberglass, etc. Team donations are handled separately by the school and are allowed to carry over into the following fiscal year. Because of this, the team will save all of the Anonymous donation for next season. It will act as a source of emergency funding in the event SGA or the BIC is unable to provide enough funding.

7.3.3. Material Acquisition Plan

The team currently has enough material, components, and stock for the remainder of the season. Additionally, we have excess funds which can be used to purchase any unforeseen materials, stock, or equipment. The only limitation to the team's material acquisition plan, as of the FRR, is the tight timeline and turn around that would be needed as the competition date nears. However, between the excess SGA and BIC funds, anonymous donation, and willingness of other BIC teams to lend material, the Rose Rocketry Team is confident we will be able to support any future material acquisition, should the need arise.

8. Appendices

Appendix A: Flight Preparation Procedure

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

Payload Preparation

Night before:

- ☐ Charge 2200mAh battery to full
- ☐ Screw in every electrical component on the Payload Sled
- ☐ Check soldered electrical connections with a multimeter and for physical condition
- ☐ Make sure correct code is uploaded to the Payload Pi
- ☐ Ensure FUNcube Dongle Pro+ antenna is fully screwed in and secured

At work table on launch day:

- ☐ Attach the battery to the bottom of the Payload Sled
- ☐ Plug in the battery
- ☐ Put the payload integration system in the nose cone and screw in
- ☐ Ensure payload arming switch is turned off to avoid battery drain – there should be no beeping coming from the payload bay

Recovery Electronics Preparation

Before the day of the launch:

***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.
- ☐ Prepare all relevant software and documentation for altimeters:
    - ☐ EasyMini manual
    - ☐ RRC3 manual
    - ☐ Altus Metrum AltOS configuration software

    ***Launch locations may not have cellular signal, so all documentation must be downloaded ahead of time.**
- ☐ Ensure the range kit has the required items:
    - ☐ Altimeters (may be installed)
    - ☐ Batteries and connectors
    - ☐ Spare wire and wire strippers
    - ☐ Ematches

- [ ] Black powder (incl. scales and containers)
- [ ] Eyeglass screwdrivers for screw terminals
  ***Failure to include any of these components will likely make repair or modification of the avbay configuration difficult or impossible.**

- [ ] Ensure that no charges or ematches are connected to the avbay 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.**
- [ ] Assemble the avbay wiring according to the schematic below. Be sure to match standard wire colors whenever possible.

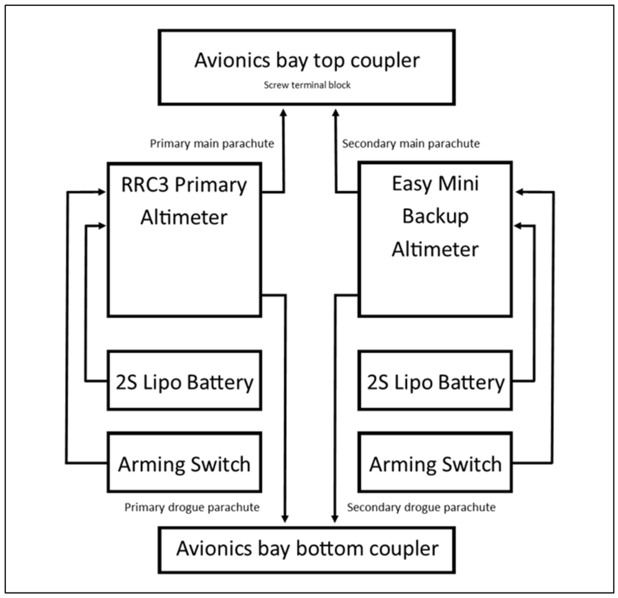

Figure 8.1 Avbay wiring schematic

- [ ] 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 shorted 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. If a GPS tracker is also included, ensure that it acquires lock; it may need to be brought outdoors to acquire signal.
  *__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.__

At the worktable on launch day:

- ☐ 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 avbay are tightened.
  A loose sled may damage itself under the acceleration of the rocket or cause wires to become disconnected in flight.
- ☐ Insert the sled assembly into the avbay and secure the nuts on the other bulkhead. Ensure that no wires are caught in the edges of either bulkhead.
  Avbay 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 or GPS lock, 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.

Airbrake and Pneumatics Preparation

Before Day of Launch:

***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 until use.**

- ☐ 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 one 2S lipo battery
- ☐ Prepare all software and dependencies for altitude control computer
  - ☐ Teensy documentation

- ☐ Altitude control computer code front team github
  - ☐ Arduino IDE
  - ☐ Any external libraries required for code compilation
- ☐ Plug the teensy into your computer and attempt to upload the latest altitude control code. **Do not continue until you are successfully able to compile and upload the latest code. It is important to ensure the altitude control computer is in a known state prior to the launch.**
- ☐ Inspect the altitude control sled and ensure all components are fastened securely.
  - ☐ Solenoid valve
  - ☐ Buck Boost Converter
  - ☐ Teensy
  - ☐ Altimeter
  - ☐ Accelerometer
  - ☐ Electronic wiring
  - ☐ Arming switch
  - ☐ Pneumatic Fitting
- ☐ Inspect Pneumatic tubing and fittings for any cracks, dents, or other defects. Replace tube or fitting if any defects are found.
- ☐ Ensure electronics are wired to the schematic below

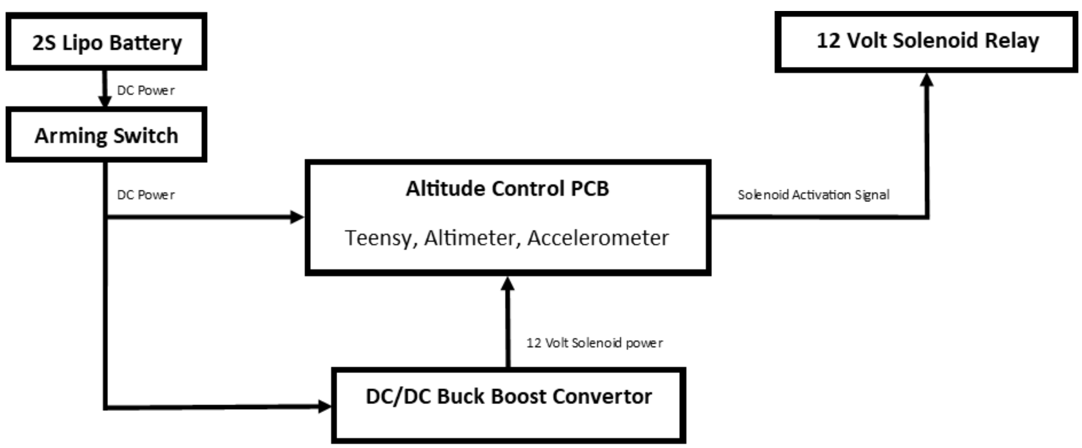

Figure 8.2 electronics schematic for day before launch

☐ Ensure the pneumatics are plumbed according to the diagram below

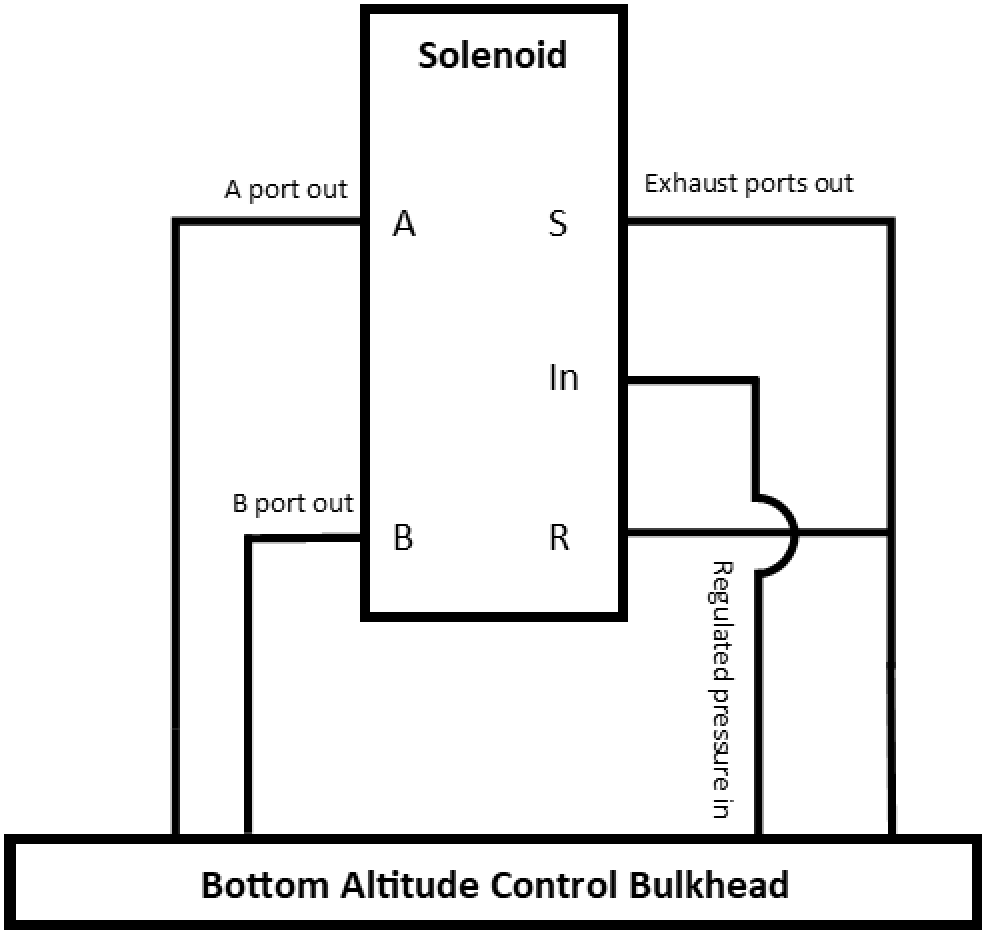

Figure 8.3 pneumatics diagram for day before launch

The following steps involve pressurized air. Safety glasses must be worn to prevent eye injury from flying debris.

☐ Connect the air tank to the external compressor and regulator assembly. Close the tank's pressure relief valve and fill the tank to 150 PSI.

☐ Check that the onboard regulator is set to 90 PSI

At this time the pneumatic system is pressurized. Ensure no person or object is closer than 12 inches to the aero brakes. The brakes should be considered live and capable of actuating at any time.

☐ Inspect the pneumatic tubing and fittings for any signs of leaks. Pay close attention to fitting joints and tube connections.Do not proceed until any leaks are addressed.

☐ Leave the altitude control system pressurized for at least ten minutes. Verify that the tank pressure is still 150 PSI. Note: do not leave the system unattended.

☐ Test deploy the aerobrakesusing the manual override on the solenoid.

☐ Arm the altitude control computer. Ensure it follows the expected boot sequence for the uploaded software. This includes the deployment and retraction of the aero brakes under computer control.

Only after successful deployment and retraction of the aero brakes under computer control is the altitude control system considered ready for launch day.

At the worktable on launch day:

***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 until use.**

- ☐ Inspect lipo batteries for any signs of damage from transport. This includes dents, swelling, broken connectors, exposed wire,etc. Notify the team safety officer of any damaged batteries before proceeding.
- ☐ Inspect the altitude control sled and ensure all components are fastened securely.
  - ☐ Solenoid valve
  - ☐ Buck Boost Converter
  - ☐ Teensy
  - ☐ Altimeter
  - ☐ Accelerometer
  - ☐ Electronic wiring
  - ☐ Arming switch
  - ☐ Pneumatic Fitting
- ☐ Inspect Pneumatic tubing and fittings for any cracks, dents, or other defects from transport. Replace tube or fitting if any defects are found.
- ☐ Ensure electronics are wired to the schematic below

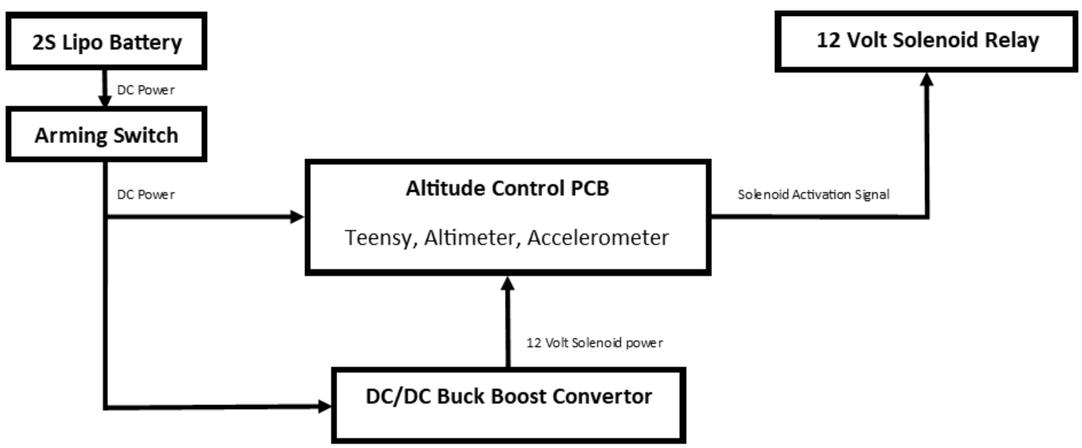

Figure 8.4 electronics schematic for launch day

☐ Ensure the pneumatics are plumbed according to the diagram below

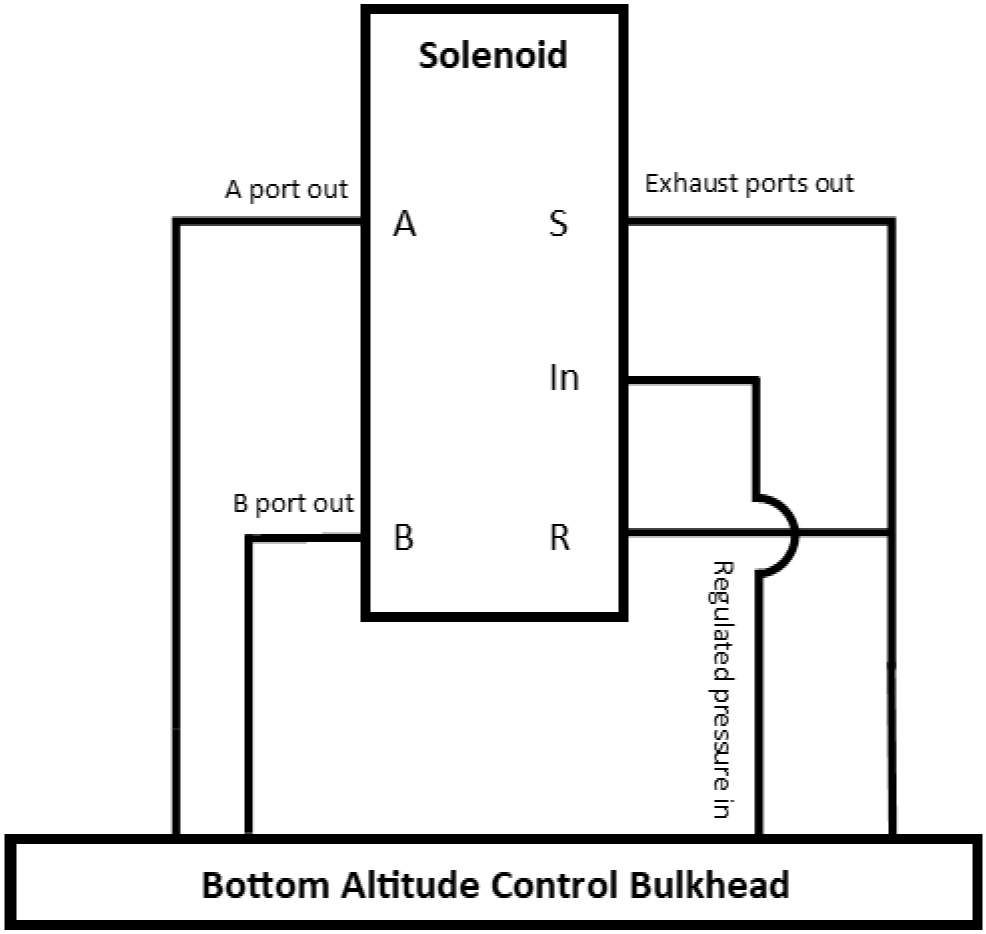

Figure 8.5 pneumatics diagram for launch day

The following steps involve pressurized air. Safety glasses must be worn to prevent eye injury from flying debris.

☐ Connect the air tank to the external compressor and regulator assembly. Close the tank's pressure relief valve and fill the tank to 150 PSI.

☐ Check that the onboard regulator is set to 90 PSI.

At this time the pneumatic system is pressurized. Ensure no person or object is closer than 12 inches to the aero brakes. The brakes should be considered live and capable of actuating at any time.

☐ Inspect the pneumatic tubing and fittings for any signs of leaks. Pay close attention to fitting joints and tube connections. Do not proceed until any leaks are addressed.

☐ Leave the altitude control system pressurized for at least ten minutes. Verify that the tank pressure is still 150 PSI. Note: do not leave the system unattended.

☐ Test deploy the aerobrakesusing the manual override on the solenoid.

☐ Arm the altitude control computer. Ensure it follows the expected boot sequence for the uploaded software. This includes the deployment and retraction of the aero brakes under computer control.

Only after successful deployment and retraction of the aero brakes under computer control is the altitude control system considered ready for launch day.

Rocket Airframe and Recovery Preparation

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

- [ ] Inspect all epoxy joints (fins, motor mount, nose cone bulkhead) for cracking or signs of wear.
- [ ] Quick-link the longest portion of the three-loop recovery harness to the top of the booster section.
- [ ] Thread the three-loop harness through the drogue airframe section. Ensure alignment and “this way up” markers are obeyed.
- [ ] Bolt the drogue tube to the booster coupler. Do not force bolts if they do not fit; double-check alignment if problems are encountered.
- [ ] Drogue harness assembly:
    - [ ] Accordion-fold the portion of the cord before the middle loop in a bundle about 12” 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 far end of the harness to the bottom of the main avionics bay.
    - [ ] 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 E.
    - [ ] Put both cord bundles into the drogue tube.
    - [ ] Put the wrapped drogue chute into 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.**
- [ ] Main harness assembly:
    - [ ] Connect the main chute and one end of the two-loop harness to the nose cone u-bolt with a quick link.
      ***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.**
    - [ ] Accordion-fold the harness as before, leaving enough unfolded to comfortably reach the other end of the main tube.
    - [ ] Fold the main chute in accordance with Appendix E.
    - [ ] Slide the folded harness into the main tube, followed by the folded parachute. Check direction and alignment markers.
    - [ ] Attach the tube to the nose cone using nylon shear pins.
- [ ] Proceed to motor preparation.

Rocket Motor Preparation

- [ ] 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.

- ☐ Before beginning motor assembly, have ready:
  - ☐ 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

    From this point onward, anyone handling the motor or reload kit components must wear safety glasses. Additionally, rubber gloves are recommended while handling grease.
- ☐ 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 following along, assemble the motor according to manufacturer instructions. Describe each step out loud as you perform it. Perform any "optional but recommended" steps (for example greasing the liner) unless a clear reason exists not to do so.

  ***Describing steps out loud both allows your 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.
- ☐ Install the motor in the rocket and hand-tighten the retainer.

Deployment Charges and Final Assembly

- ☐ Prepare charges as in Appendix F.

  ***After the following steps, the airframe will have the potential to separate violently if a charge is accidentally triggered. All personnel should stay clear of the area in front of and behind the rocket.**
- ☐ Install the main tube assembly onto the front of the avbay. Bolt into place, ensuring alignment as with other sections.
- ☐ Install the forward assembly into the front of the booster assembly and secure with shear pins.

Appendix B: Pad Setup and Launch 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.
- ☐ 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.

Flight Procedure

- ☐ Before flight, assign the following roles:
  - ☐ Visual tracker (2 or more)
  - ☐ GPS operator
  - ☐ Videographer (2 if possible)
  - ☐ Flight Event Recorder (2 if possible)
  - ☐ Radio operator
- ☐ Visual trackers: Spread out on the flight line. Ensure that you have a means of communication with the team.
  ***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 a checklist from Appendix A 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.
- ☐ Radio operator: clear the area surrounding the yagi antenna’s range of motion and ensure that the map GUI is functioning properly.
- ☐ 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.
  - ☐ The Radio Operator should ensure, as is possible, that the yagi antenna has a clear line-of-sight path towards the rocket at each position of the antenna’s entire range of motion.
- ☐ 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.
  - ☐ Event recorders and GPS operators call important events throughout the flight
  - ☐ The Radio Operator should monitor the GUI and call out relevant information that informs the flight status.

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 avbay, wire the charge well to be tested directly to a pair of wires leading out through a vent hole.

  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:
    - [ ] Nose cone ejected (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

Appendix D: Flight Event Checklist

- ☐ Liftoff
- ☐ Burnout (without airframe failure)
    - ☐ Petal deployment (if visible)
    - ☐ Petal retraction before apogee (if visible)
- ☐ Apogee (without airframe failure)
    - ☐ Primary charge
        - ☐ Drogue deploys with primary
    - ☐ Secondary charge
        - ☐ Drogue deploys with secondary
    - ☐ Petal retraction if deployed (if visible)
- ☐ Stable descent under drogue
    - ☐ Primary main charge: _______ feet
        - ☐ Main deploys with primary
    - ☐ Secondary main charge: _______ feet
        - ☐ Main deploys with secondary
- ☐ Touchdown under main

Appendix E: Parachute Folding

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

Figure 8.6 Parachute folding step one

- Double the lines in the center of the parachute.

Figure 8.7 Parachute folding step two

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

Figure 8.8 Parachute folding step three

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

Figure 8.9 Parachute folding step four

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

Figure 8.10 Parachute folding step five

- 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 gases, it will likely be damaged, resulting in a recovery failure.**

Appendix F: 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, igniter, 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 igniter into the now filled charge pouch until the element is completely covered with black powder.
- Twist charge pouch around igniter 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 igniter

Appendix G: Citations

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