OREGON STATE UNIVERSITY

2019 NASA SL TEAM

104 KERR ADMIN BLDG. # 1011

CORVALLIS, OR 97331

Critical Design Review

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Acronym Dictionary

9DOF Nine Degrees of Freedom. 15

ABS Acrylonitrile Butadiene Styrene. 16, 27, 123, 125

AGL Above Ground Level. 15, 43, 44, 50, 52, 57, 169, 170, 185, 190

AIAA American Institute of Aeronautics and Astronautics. 221

APCP Ammonium Perchlorate Composite Propellant. 187

ARRD Advanced Retention and Release Device. 15, 44, 45, 47, 51, 52, 58, 59, 109, 139–141, 144, 148, 149, 167, 175, 179, 190

ASL Above Sea Level. 45, 46, 54

ATI Allegheny Technologies Incorporated. 221

ATU Avionics Telemetry Unit. 8, 9, 16, 29, 44, 62–65, 74, 81, 82, 157–160, 174, 178

BEAVS Blade Extending Apogee Variance System. 5, 6, 8, 10, 17–19, 28–30, 40, 68, 69, 71, 74, 94, 95, 104, 212, 222, 235, 236

CAD Computer-Aided Design. 18, 20, 139

CAM Computer-Aided Manufacturing. 40

CAR Canadian Association of Rocketry. 187

CDR Critical Design Review. 139, 182, 188, 225

CEMF Counter Electromotive Force. 145

CNC Computer Numerical Control. 40

CV Computer Vision. 17, 132, 134, 135, 137

DC Direct Current. 122, 167

DDM Design Decision Matrix. 6, 58, 139, 147

DOF Degrees of Freedom. 30

EMI Electromagnetic Interference. 145

FAA Federal Aviation Administration. 167, 186, 199

FEA Finite Element Analysis. 9, 29, 114–116, 129

FHP Fore Hard Point. 5, 9, 11, 18, 139, 141, 146, 147, 150, 238–241

FMEA Failure Mode Effects Analysis. 6, 99–117, 198, 209

FN Foreign National. 182

FRR Flight Readiness Review. 30, 183, 188, 189, 195

GLONASS Global Navigation Satellite System. 62

GPIO General Purpose Inputs and Outputs. 134

GPS Global Positioning System. 15, 17, 19, 41, 44, 62–64, 81, 83, 132, 133, 135, 138, 151, 152, 158–160, 174, 178, 203, 210

HPR High Powered Rocketry. 79, 80, 89

HRIT Horizontal Rotary Indexing Tool. 32–35

HVAC Heating Ventilation & Air Conditioning. 34

IC Integrated Circuit. 81, 158–160

ICE Innovative Composite Engineering. 19, 59, 221

IMU Inertial Measurement Unit. 15, 50, 64

JHA Job Hazard Analysis. 32, 34, 91, 92, 196, 208, 210

LED Light Emitting Diode. 133, 134, 210, 211

LiPo Lithium Polymer. 65, 74, 81, 82, 133, 157–159, 210

LRR Launch Readiness Review. 195

MPRL Machine Product and Realization Laboratory. 31, 32, 34–40, 196, 208

MSDS Material Safety Data Sheet. 198

NAR National Association of Rocketry. 85, 88, 89, 93, 105, 187, 199, 209

NASA National Aeronautics and Space Administration. 51, 183, 186, 188, 199, 221

NEMA National Electrical Manufacturers Association. 29

NTS Not To Scale. 9, 66, 67

OROC Oregon Rocketry. 199

OSGC Oregon Space Grant Consortium. 10, 17, 221, 222

OSRT Oregon State Rocketry Team. 9, 10, 15, 16, 19–22, 27, 29–31, 43, 44, 46–48, 51–62, 64, 68, 74, 81, 91, 92, 99, 104, 112, 118, 135, 137, 139, 142, 150, 151, 162–164, 166, 168, 169, 171, 174, 180–184, 186, 196, 197, 199, 200, 212, 221–226

OSU Oregon State University. 35, 91, 100, 188, 196, 208, 209, 221

PCB Printed Circuit Board. 8, 9, 16, 17, 62, 64, 65, 79–81, 145, 146

PDR Preliminary Design Review. 16, 19, 45, 58–60, 120, 139, 142, 147, 150, 182, 185, 225

PEARS Payload Ejection and Retention System. 3, 5, 7, 9, 10, 17, 18, 24, 52, 71, 99, 117, 125, 139, 140, 142, 145–150, 166, 167, 174–176, 179, 206, 237–241

PID Proportional-Integral-Derivative. 30

PLA Polylactic Acid. 23–25, 39, 127–130

PLEC Payload Ejection Controller. 9, 11, 62, 99, 117, 134, 139–150, 175, 240

PPE Personal Protective Equipment. 31–37, 39, 40, 79, 80, 82, 88, 91, 92, 153, 154, 171, 179, 197, 210

PWM Pulse Width Modulation. 132

RDO Rover Deployment Officer. 139

RF Radio-Frequency. 4, 16, 19, 20, 23, 25, 26, 63, 64, 81, 82, 132, 133, 135, 137, 144, 145, 158–160, 177, 201

RPM Revolutions per Minute. 33, 34, 123, 125

RRC3 Rocket Recovery Controller 3. 6, 8, 41–44, 50, 56, 57, 164, 165

RSO Range Safety Officer. 84, 87–89, 187, 189, 197, 199

RX Receive. 62

SCAR Soil Collection and Retention. 2, 5, 6, 19, 98, 126, 128–131, 138, 242–245

SL Student Launch. 51, 159, 181, 182

SO Safety Officer. 74, 75, 208, 209

SPDT Single Pole Double Throw. 17, 139, 141, 142, 147, 149, 150, 177

SPI Serial Peripheral Interface. 63, 64, 82

STEM Science, Technology, Engineering and Mathematics. 4, 181, 183, 225

STL Stereolithography. 39

TI Texas Instruments. 16, 63, 81, 82

TRA Tripoli Rocketry Association, Inc.. 187, 199, 209

UART Universal Asynchronous Receiver-Transmitter. 63, 64

USB Universal Serial Bus. 74, 81, 82

USLI University Student Launch Initiative. 56, 135, 153, 167, 176, 187

VMC Vertical Milling Center. 33–36, 39, 40

1 Summary of CDR Report

1.1 Team Summary

Table 1: Team Summary Chart

Team Name	Oregon State Rocketry Team
Mailing Address	104 Kerr Admin Bldg #1011 Corvallis, OR 97331
Name of Mentor	Joe Bevier
NAR/TRA Number, Certification Level	NAR #87559 Level 3, TRA #12578 Level 3
Contact Information	joebevier@gmail.com, (503) 475-1589

1.2 Launch Vehicle Summary

The launch vehicle is 123.5 in. long and weighs 48.9 lbf. The motor is a Cesaroni L2375-WT motor. The launch vehicle will reach an apogee altitude of 4,500 ft. The airframe is a 6.25 in. inner diameter fiberglass tube. The launch vehicle is recovered in two independent sections: the aft section with the motor, and the fore section with the payload. At apogee, the launch vehicle will have two simultaneous separation events: the aft section will separate from the fore section and release a first drogue parachute, and the fore section will separate from the nosecone and release a second drogue parachute. At 700 ft Above Ground Level (AGL), the main parachutes, which are both held in with an Advanced Retention and Release Device (ARRD) and a tender descender in series, are released. The drogue parachutes are cruciform, and have a diameter of 1.5 ft. The main parachutes are toroidal, the fore has an 8 ft diameter parachute, and the aft has an 8 ft diameter parachute. The launch vehicle will exit the 1515, 12 ft rail at 88.8 $^{ft}/_{s}$.

1.3 Payload Summary

The Oregon State Rocketry Team (OSRT) has chosen to design and build a deployable rover which collects a soil sample. The rover will be contained within the fore section of the airframe. Upon landing, the rover will be ejected from the airframe using black powder charges. The rover will have two coaxial, independently driven wheels with a chassis suspended between them. A spring-loaded stabilizer arm will act as a third point of contact with the ground. An Arduino Teensy 3.6 development board will autonomously control the motors to move the rover, receiving input from a sensor array including active sonar, passive sonar, Global Positioning System (GPS), and a Nine Degrees of Freedom (9DOF) Inertial Measurement Unit (IMU). An auger will be mounted in the center of the chassis. When the rover is deployed the auger will periodically gather soil samples and store them in an internal containment unit. After collection, the rover will autonomously drive to a scientific base station where it will perform an additional scientific experiment.

2 CHANGES MADE SINCE PDR

2.1 Changes Made to Vehicle Criteria

The OSRT will use an 8 ft diameter toroidal parachute for both sections instead of a 10 ft and 7 ft toroidal parachute for the fore and aft sections, respectively. This change was made due to a change in weight in the aft and fore sections of the launch vehicle. The packing of the main parachutes has been updated to use a folding method recommended by OSRT mentors instead of the folding method recommended by the parachute manufacturer. This will allow both main parachutes to inflate more quickly when they are released from the airframe. A few aspects of recovery integration have been modified as well. The rigging of all riser attachments have been reorganized, the main parachute retention method has been changed to include two Tender Descenders. The rigging setup has been changed to run off a single riser instead of two connected in series, and the brand of e-matches being used has been changed - the brand switched to is more readily available.

Fin dimensions were adjusted to maintain a similar stability margin of 2.1 calibers.

The primary design change for the Avionics Telemetry Unit (ATU) is the redesign and replacement of the existing OSRT Printed Circuit Board (PCB) with a new revision to support integration of the 433 MHz transceiver hardware. This redesign allows for the Texas Instruments (TI) CC 1200 433 MHz transceivers to operate with the speed and reliability benefits of embedded traces as discussed in section 3.3.2. Additionally the PCB has significantly reduced in physical size.

The body tube of the launch vehicle was originally intended to have a fiberglass to carbon fiber transition in both the fore and the aft sections. Per resources available, OSRT has changed the design to have only one transition in the aft section and no transition in the fore section. This means that the fore section will be entirely G12 fiberglass as to maintain Radio-Frequency (RF) transparency.

In addition to the material of the body tube changing, there has also been an increase in length of the launch vehicle. The launch vehicle will be 23.5 in. longer than originally proposed in Preliminary Design Review (PDR). All of this length change is reflected in the body tube. The aft section has increased by 14.75 in. The fore section has increased by 7 in.

The 360° camera system has changed slightly since the Preliminary Design Review. Instead of using metal plates on each the top and bottom, wood bulkheads will be used. The bottom bulkhead will also be the most aft bulkhead of the canister. A threaded rod will secure the system together, attached from the aft bulkhead to the fore bulkhead. The two Acrylonitrile Butadiene Styrene (ABS) components holding the cameras were also made smaller to conserve weight.

To conserve weight, the pressure seal no longer has four threaded rods extending throughout the bay. Instead, six bolts will replace the rods and serve the same purpose. These bolts tighten two bulkheads to one another, compressing the rubber and expanding it to the inner wall of the airframe.

To conserve weight and ease assembly, radial screws will secure the bulkheads to the inside the fore and aft airframe instead of a threaded rod.

2.2 Changes Made to Payload Criteria

The chassis of the rover has been simplified, removing the modular components from the original design. Higher standards for rover performance brought a need for a pair of drive motors with higher torque. A matching mount was designed to fit the new motor and interface with the chassis. The shaft-wheel interface is now simpler and integrates with Payload Ejection and Retention System (PEARS) more cleanly. A team effort to cut weight involved changing the wheel to an open design. The functionality of the PEARS did not change, although many of the specific components were changed to components with a more appropriate weight and strength. An additional design feature was included which will allow the assembly to be orientated easily during integration to align the Single Pole Double Throw (SPDT) switch to the access hole in the airframe.

The scientific base station which the rover will navigate to has been modified to conduct a pH experiment instead of an X-Ray fluorescence experiment. The motivation for this change was budgetary concerns with X-Ray fluorescence. A GPS module was added to navigate the rover near the base station before Computer Vision (CV) will be used to dock the rover.

2.3 Changes Made to Project Plan

The team successfully acquired an $11,000 grant from Oregon Space Grant Consortium (OSGC) via the Undergraduate Team Experience Award and has been reaching out individually to other organizations in an effort to secure corporate sponsorship, with success.

The subscale launch was delayed two times due to inclement weather conditions at the launch site and over the mountain passes. Subscale launches were completed on December 8th, 2018 and January 4th, 2019. Delays to the Blade Extending Apogee Variance System (BEAVS) test launches occurred because the control system and PCB were still being finalized. The BEAVS test launches will now be conducted in parallel with the full scale launches.

3 VEHICLE CRITERIA

The launch vehicle is 123.5 in. and 48.9 lbf. An overview of the launch vehicle Computer-Aided Design (CAD) can be seen in Figures 1 and 2 with a transparent airframe for clarity of the components. Shown in Figure 1 are the nosecone, fore airframe, aft airframe, the BEAVS extended blades, four fins, and the motor retainer. Shown in Figure 2 from nosecone tip to motor retainer the launch vehicle systems are: fore avionics bay, fore parachutes, fore ejection bay, fore ballast bay, Fore Hard Point (FHP), PEARS, the rover payload, aft parachutes bay, aft ejection bay, aft avionics bay, camera bay, aft ballast bay, BEAVS, motor, and finally motor retainer. Not pictured in either CAD model are the fore coupler, aft canister, or parachutes. A full description of the design and integration of each of the systems follows.

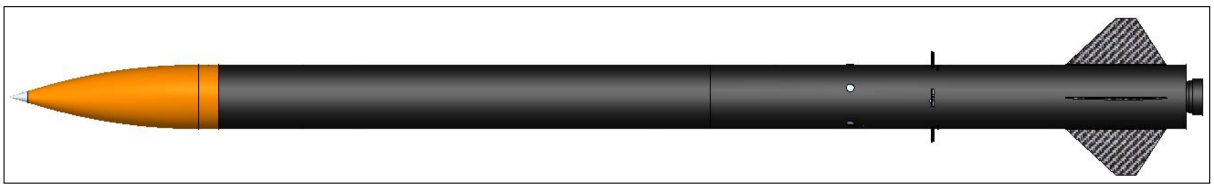

Figure 1: Full assembly of the launch vehicle from the exterior, with BEAVS extended.

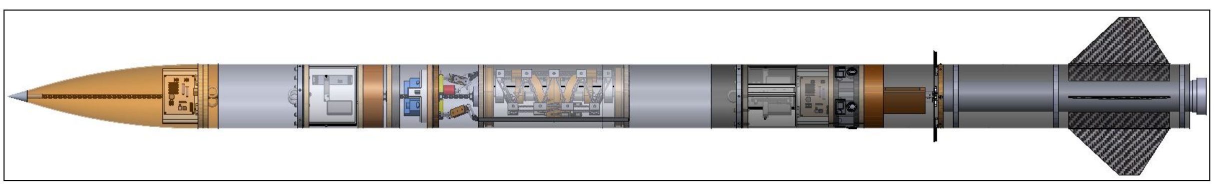

Figure 2: Full assembly of the launch vehicle with a transparent airframe, with BEAVS extended.

3.1 Design and Verification of Launch Vehicle

3.1.1 Mission Statement

The launch vehicle will successfully deliver the payload to the target altitude, deploy recovery systems at apogee, and safely land the airframe on the ground within 2,500 ft of the launch site. The vehicle will remain reusable throughout the entire process. The mission will be determined a success for the launch vehicle when the following criteria have been met:

- The launch vehicle travels in a stable configuration toward apogee
- The launch vehicle reaches the specified height within tolerance range
- The airframe successfully separates into two recovery sections
- The drogue parachutes deploy successfully

- The main parachutes deploy successfully
- Both airframe sections land on the ground, without causing structural damage
- The payload ejects successfully

3.1.2 Body Tube

The airframe will be split into two sections, the fore and aft body tubes. To accommodate the rover and its subsystem, Soil Collection and Retention (SCAR), the inner diameter of the airframe is 6.25 in. Both tubes will be donated by Innovative Composite Engineering (ICE) and based on their manufacturing specifications and mandrel sizes, the inner diameter was chosen to be 6.25 in., consistently across both body tubes. Members of OSRT traveled to ICE to manufacture the airframe with assistance from ICE. Material options for the aft tube will be carbon fiber and fiberglass, with a seamless transition from one material to the next within the same body tube. The material for the fore tube will be fiberglass. The carbon fiber and the fiberglass sections will have slightly different thicknesses, but will maintain the same strength ratings. Each of these materials brings unique characteristics that allow for a better airframe design. Carbon fiber has a higher Young's Modulus than fiberglass and will be able to perform reliably when placed under high compressive stresses. Fiberglass is RF transparent, ideal for allowing electronic components to transmit signals from the airframe for avionics.

The fore body tube changed since PDR from having a transition between both materials to only consisting of fiberglass. On board the fore section is the payload retention system, which receives transmissions from the ground station. The payload is also equipped with a GPS device for tracking. Both systems require fiberglass to communicate with other electronics. The section of the body tube that did not require fiberglass was a small part which was originally carbon fiber. The increased weight caused by the seamless transition negated the benefit of the carbon fiber section. Therefore, the body tube will no longer contain a transition. The total length of the fore body tube will be 49 in. The dimensional drawing can be seen in Figure 83.

The aft section will consist of both carbon fiber and fiberglass, where the transition will sit shortly above the motor. To reduce weight as much as possible while maintaining RF transparency, the carbon fiber section will be where the motor and fins are located, while the fiberglass will be where the BEAVS, the Camera System, Aft Avionics Bay, and Aft Recovery System are located. There will be small holes and slots throughout the aft body tube, which will not significantly impact the structural integrity of the body tube, for the following components:

1) Fins
2) BEAVS
3) Camera System
4) Access ports for external arming of separation and ejection charges

The total length of the aft body tube will be 50 in. The dimensional drawing can be seen on Figure 84.

3.1.3 Nosecone

Based on time restrictions and negating manufacturing errors made in the past by OSRT when trying to create their own nosecone, the best option was to purchase a commercially available nosecone. Alternatives were considered for material and shape selection but the final choices were based on two of the strongest restrictions: RF transparency and ease of purchase. The material will be fiberglass and the shape will be 5:1 ogive, commercially purchased with an initial outer diameter of 7.5 in.

The high compressive strength of fiberglass and its toughness make it ideal for the constant forces present during launch. The nosecone houses the fore avionics and will be transmitting radio frequencies so that the team can track the position of the launch vehicle. Fiberglass is RF transparent, unlike carbon fiber. Based on the engineering requirements set for the nosecone (weight, ease of purchase, strength, ease of manufacture, RF transparency), the decision was made to use fiberglass.

The nosecone will be under constant loading and may experience deformation. Fiberglass will deform until ultimately breaking and carbon fiber will suddenly break. Having a functional nosecone is critical and while it is unlikely either material will fail, the failure mode of fiberglass is preferred since it is less likely to damage the components that it houses if failure does occur.

The tip of the nose cone will be made of aluminum. The use of aluminum will allow for an easier manufacturing process and serve as an anchoring point for the internal subsystem. The nosecone tip will be small; making the weight of the aluminum compared to fiberglass negligible. Aluminum can handle high compressive stresses making it suitable for the tip of the nose cone. The combination of manufacturability and properties suitable for the external forces make aluminum ideal for the nosecone tip.

The nosecone follows a 5:1 ogive profile. The ogive shape was chosen because of its performance in the subsonic region of flight. In addition, the 5:1 ogive nosecone is one of the few profiles commercially available with an outer diameter over 6.25 in. Due to the large outer diameter of the launch vehicle, the nosecone cannot be purchased off the shelf. Instead, a 7.5 in. nosecone will be purchased and cut down to fit the body of the launch vehicle. A custom coupler will then be used to connect the nosecone to the airframe. The aerodynamic impact of cutting down the nosecone should not be significant due to the low speed of the launch vehicle, and the nosecone will still be close to tangent to the body. The procedure for this can be found in section 3.1.15.2 and the dimensional drawing can be seen in Figure 85. The CAD model of the ogive nosecone with an aluminum tip can be seen in Figure 3.

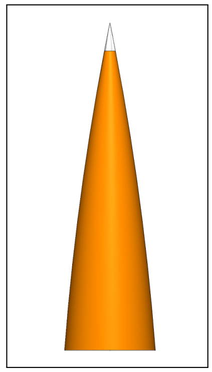

Figure 3: Nosecone Assembly

3.1.4 Fins

The launch vehicle will use four trapezoidal clipped delta fins. The fin shape was chosen for its aerodynamic performance and ease of manufacturing. The thickness of the fins was selected to be 0.125 in. with a square profile. While other fin profiles were considered, a square leading edge with no taper in thickness was chosen to maintain a simple manufacturing process.

The trailing edge of the fins is located two inches up from the bottom edge of the aft airframe. The location of the fins above the bottom of the airframe requires larger fins to maintain a stability margin of 2.1 calibers. The two inch location was selected from many combinations of trailing edge location and sweep length of the trapezoidal fins to maximize projected altitude while maintaining a minimum 45° angle from the bottom of the motor retainer to the trailing tip chord edge. This angle calculation can be seen in Equation 1.

$$\theta = tan^{-1}(\frac{(TrailingEdgeDistance) + (RootChord) - (SweepLength) - (TipChord)}{(FinHeight) + (AirframeRadius)}) \tag{1}$$

The 45° angle is to prevent fin damage upon landing of the aft airframe. The larger the distance from the trailing edge to the bottom of the aft airframe, the larger the sweep length can be to maintain the 45° minimum angle.

To maintain precise manufacturability, OSRT has decided to utilize solid carbon fiber fins. Carbon fiber was selected because it will remain ridged during the expected flight speeds, it will resist fractures during landing events, and it is relatively easy to manufacture. Using G5000 RocketPoxy, an epoxy that is specified to bond carbon fiber and fiberglass together, OSRT will be able to firmly secure the fins with three fillets: one outside of the body tube, one inside the body tube, and one outside of the motor tube. The G5000 RocketPoxy is also beneficial for its performance in high heat conditions.

3.1.5 Motor

The motor selected by OSRT is the Cesaroni L2375-WT. The high thrust-to-weight ratio of 12.0 will help counter weather-cocking during ascent. The launch vehicle will exit the rail at 88.8 $^{ft}/_{s}$, well above the minimum required velocity of 52 $^{ft}/_{s}$. With 0 mph crosswinds, the launch vehicle with the Cesaroni L2375-WT will achieve an apogee altitude of 5,296 ft. The motor thrust curve of the Cesaroni L2375-WT can be seen in Figure 42.

3.1.6 Motor Retention

The launch vehicle's motor retention system consists of three components: a motor retainer, a motor tube, and centering rings. The motor retainer that OSRT will utilize is a 6061-T6 Aluminum 75 mm Motor Retainer, manufactured by AeroPack. This motor retainer will be epoxied with G5000 RocketPoxy onto the end of a G12 fiberglass motor tube, manufactured by Madcow Rocketry. Baltic birch plywood will be the material of choice for the $^{1}/_{2}$ in. thick centering rings, which will be epoxied into the body tube with G5000 RocketPoxy and will also have the motor tube epoxied to them.

3.1.7 Bulkheads

The launch vehicle will use several bulkheads integrated into the airframe. Bulkheads will be made of $^{1}/_{2}$ in. marine grade plywood and need to be able to withstand axial, bending, and torsion forces experienced during launch and recovery. The plywood will withstand these forces and is also easy to manufacture.

Bulkheads will be secured into the airframe using six radial machine screws. These screws will provided plenty of support to withstand the forces during launch and recovery. The main reason for using machine screws instead of a threaded rod is to conserve weight and ease the assembly of the launch vehicle. Using machine screws instead of a threaded rod also means that new bulkheads will have to be manufactured for each flight. This is not an issue because bulkheads are quick and easy to manufacture and the OSRT has an abundance of plywood.

After our bulkhead test results using the Instron machine as seen in Section 6.1.2, OSRT determined that wooden bulkheads could withstand the forces expected from the recovery system. Completing testing showed that the wooden bulkheads could not be used to hold radial bolts with the full forces experienced by recovery, however they can if an aluminum ring is used to bolt to the airframe, and the bulkhead is attached directly to the aluminum ring. Figure 5 displays the aluminum ring and bulkhead attachment, allowing the bulkhead to be attached from the exterior of the airframe.

3.1.8 Pressure Seal

To minimize the ejection charge size, a pressure seal is needed just fore and aft of any parachute bay. To create this seal, two different types of bulkheads are used to compress a 1/8 in. santoprene sheet so that it presses against the inner wall of the airframe. To tighten the bulkheads together, six evenly spaced 1/4-20 bolts line the bulkhead ring. Once in place, these bolts are tightened, pulling the bulkheads together. Figure 4 shows the pressure seal for the fore avionics bay and Figure 5 shows the pressure seal for the fore ejection bay and aft electronics bay.

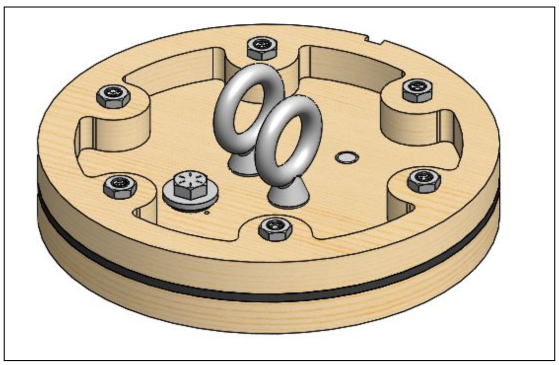

Figure 4: Fore avionics pressure seal.

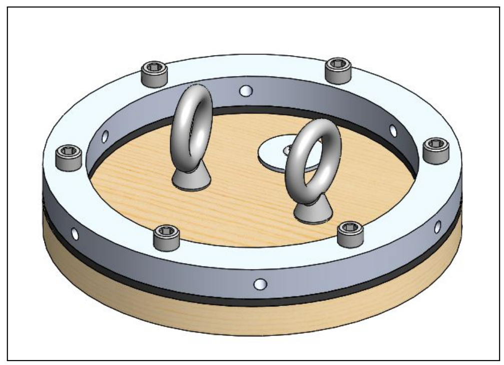

Figure 5: Fore ejection and aft electronics seal.

The fore ejection and aft electronics bays have an aluminum ring instead of a wooden one. This is because the ring is mounted to the airframe using six 10-24 bolts. A wooden piece is not strong enough to hold up to the forces during recovery so an aluminum ring is implemented instead.

3.1.9 Fore Avionics Bay

The avionics are responsible for reporting the position of the launch vehicle, particularly after the parachutes have deployed and the airframe has safely landed. Avionics send a signal to the ground station so that the team can recover the airframe and deploy the rover. It is very important that the avionics can send the signal so anything surrounding the avionics needs to be RF transparent. Placing the avionics in the nosecone has two major advantages: It saves valuable space and it provides the avionics with an RF transparent casing. There are few other components that would fit as well in the nosecone and the fiberglass material that the nosecone is made from allows the avionics to send signals unimpeded.

An additive manufactured block made from Polylactic Acid (PLA) provides mounting points for electrical components. PLA was chosen due to it being high strength while still light weight. Additionally, PLA parts can be manufactured through additive manufacturing. This makes manufacturing more simple and precise. The block has a hole through the middle so that it can slide onto the 3/8 in. threaded rod that goes through the nosecone. The block is also hollow when possible to conserve weight. A washer followed by a nut sits atop the block to secure it in place vertically, while four screws through the nosecone bulkhead limit rotational movement. Below the bulkhead are two eye bolts to provide a mounting point for the parachutes. Locknuts hold these bolts in place and washers are used to help to disperse the forces more evenly throughout the bulkhead. A pressure seal is located aft of the avionics to minimize the necessary ejection charge size. Details about this pressure seal can be found in the pressure seal section. Figure 6 shows the 3D model of the fore avionics bay with transparent nosecone.

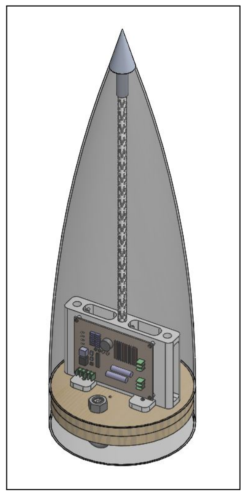

Figure 6: Fore Avionics Bay

3.1.10 Fore Ejection Bay

The fore ejection bay is located just fore of the PEARS and just aft of the parachutes. It provides a mounting point for the parachutes upon deployment and also houses the altimeters. The altimeters track the ascent and descent of the launch vehicle and are used to fire the ejection charges at the correct time. Two additive manufactured PLA plates sit within the bay to provide mounting points for the altimeters and other electrical components. These plates slide into place using slots built into the wall. Figure 7 shows the fully assembled bay and Figure 8 displays the bay without a pressure seal and how the plates slide into place.

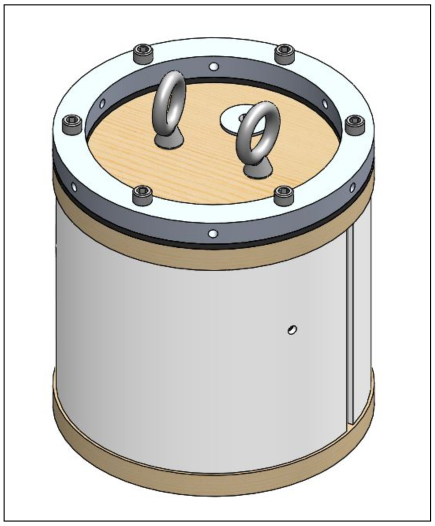

Figure 7: Fore Ejection Bay Assembly

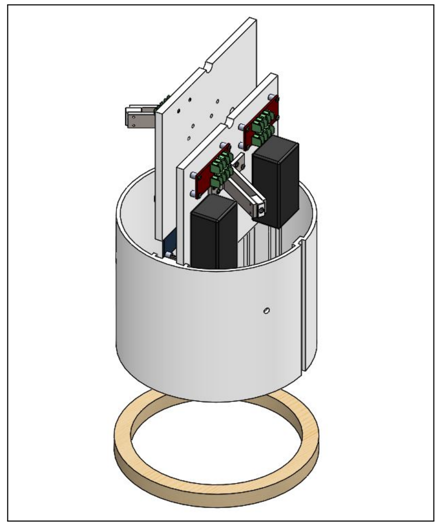

Figure 8: Fore Ejection Bay Exploded

Unlike the avionics, the altimeters must be RF shielded so that no unwanted signals interrupt with the altimeters readings and fire the ejection charges prematurely. An additive manufactured PLA wall lines surrounds the altimeters and other electronics. Within the wall, a conductive spray paint is used to line the inner surfaces, including the bulkhead that caps the bay. The conductive spray paint creates a Faraday cage which does not allow RF signals through and creates a shielded bay. While integrating the bay into the airframe, there is a possibility that static charges could build up and fire the ejection charges prematurely. To eliminate this risk, a single pole double throw switch is installed on the bulkhead to shunt the circuit. Once the bay is installed, the switch will be flipped so that the circuit is armed.

It is important to be able to arm and disarm the altimeters from the exterior of the airframe to minimize the effect of a charge firing prematurely. For this reason, the static port holes used to pressurize the bay for the altimeters will also serve as access points for the altimeter switches. The switches are turned by an Allen wrench and are raised off of the block so that they sit just within the body wall to make arming easier.

Rotating the bay once it is within the airframe is difficult due to its extremely tight fit. However, it is critical that the holes for the altimeter switches in the body wall are aligned precisely with the holes in the airframe. To simplify integration, a rail will be mounted along the inner wall of the airframe. A channel is cut out of the bay so that it can slide along the rail and stay aligned throughout the integration process. Below the bay is a wooden ring that is permanently fixed to the airframe. Its purpose is to limit the movement of the bay vertically.

The aluminum retention ring is mounted using six radially mounted bolts. With the altimeters bay attached, the rail will guide the bay rotationally and the fixed bulkhead ring will limit the bay vertically so that integration is simple and consistent. Once in place, six 10-24 bolts are fastened from the exterior of the airframe. After the aluminum ring is secure, a 1/4 in. socket is used to tighten the bolts and compress a 1/8 in. santoprene sheet, creating a pressure seal against the inner wall of the airframe.

3.1.11 Aft Electronics Bay

The aft electronic bay combines the aft avionics and the aft altimeters bays into one component separated by an additive manufactured bulkhead coated in RF shielding spray paint. The overall design is the same as the fore ejection bay with extra length for the avionics. The outer diameter is slightly smaller due to the whole bay being within the canister design. The bulkhead at the bottom of the altimeters bay must screw into the mounting block so that it can separate the avionics and the altimeters, creating a quality RF shield. The added length is 3.5 in. Along the side of the bay is a channel that helps to align the bay rotationally. When integrated into the canister, the rail will slide within the slot and align the bay to the correct orientation. The same sealing method as the fore ejection bay is used here as well. Figure 9 shows the aft ejection bay assembled and Figure 10 shows an exploded view of the assembly without the pressure seal.

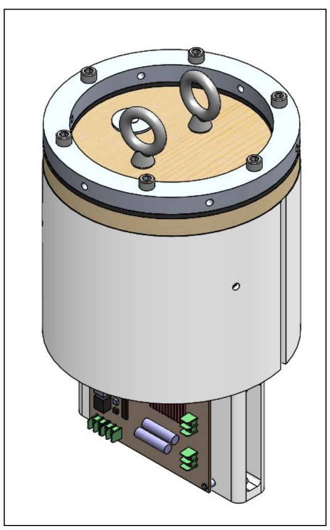

Figure 9: Aft Electronics Bay Assembled

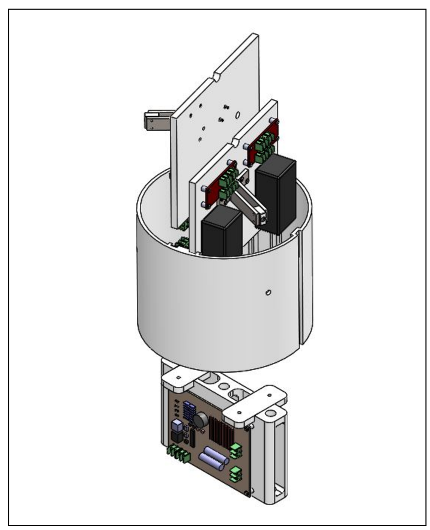

Figure 10: Aft Electronics Bay Exploded

3.1.12 Fore Coupler / Aft Canister

There will be two couplers in the airframe. One to attach the nosecone to the fore section, and the other to attach the fore section to the aft section. The couplers need to be lightweight, RF transparent, and strong enough to withstand the forces of flight. To satisfy these requirements, G12 fiberglass will be used for both couplers; this is the same material as the airframe.

The fore coupler will be 12 in. in length and will be laid up in a piece of excess airframe to ensure a proper fit into the nosecone and fore airframe. The coupler will protrude 4 in. into the nosecone and 8 in. into the fore body tube. The fore coupler will be assembled into the nosecone permanently using G5000 RocketPoxy and assembled into the fore airframe with shear pins. A drawing of the fore coupler can be seen in Figure 97.

Instead of a traditional coupler, the OSRT decided to implement the canister for the aft coupler. This component connects the fore and aft body tubes and also eases assembly of the launch vehicle. Four components will be pre-assembled into the canister and then the canister will be assembled into the airframe. The canister length is 22.25 in. and will house, from aft to fore, the camera system, aft avionics bay, aft ejection bay, and packed parachutes. A rail within the canister will assist alignment of these components. The assembled canister can be seen in Figure 11. This includes all components except for the packed parachutes.

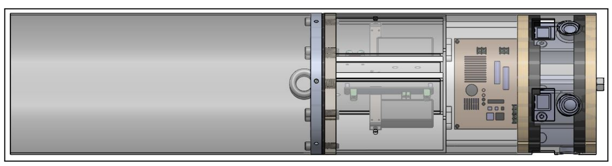

Figure 11: Assembled Canister

The bulkhead with all recovery components attached to eyebolts, is mounted using six radially mounted bolts. When in position, the holes are drilled from the exterior of the airframe to simplify assembly. This means that, for every flight, a new bulkhead must be manufactured. However, it does have many benefits for the recovery team and overall on sight assembly.

3.1.13 Camera System

The camera system will use five GoPro Hero cameras. Each camera will record the flight of the launch vehicle separately, and then the footage from each camera will be stitched together with software to create a 360° panoramic video. Using a manual or remote trigger system, each camera can be controlled as one. A trigger system is not critical for this system to work, but will make producing the 360° video much easier.

The main constraint with this component is weight and it was designed to be as light as possible. Using additive manufactured ABS camera casings, the GoPros are securely supported between each bulkhead. Since GoPro cameras are already very durable, the ABS camera casings can be smaller and lighter to only keep the cameras in place. A threaded rod connecting each of the bulkheads will protect the cameras from forces experienced during flight. This component can be seen in Figure 12.

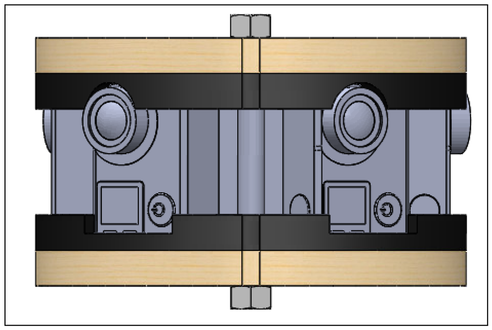

Figure 12: 360° Camera System

The 360° camera system will be pre-assembled into the canister. This will make assembly of the launch vehicle easier. Each bulkhead will be secured into the canister with radial screws and the aft bulkhead of the 360° camera system will be the aft most bulkhead in the canister. A notch in this system and in the canister will keep the cameras aligned with the holes cut out of the airframe.

3.1.14 Blade Extending Apogee Variance System

The BEAVS is composed of three separate systems working together to adjust the apogee altitude of the launch vehicle. The three systems are a mechanical system, an electrical system, and a control system.

3.1.14.1 BEAVS Mechanical System

The BEAVS will be used to accurately adjust the apogee altitude. This uses an active and passive system. The active system is displayed in Figure 13 and deploys blades from the interior of the launch vehicle after motor burnout to increase the drag profile. The deployed blades will extend out of the airframe aft of the center of gravity and the center of pressure. The passive system is a pair of ballast bays in the fore and aft, which can be used to adjust the apogee altitude based on launch day conditions. The passive system is displayed in Figure 14.

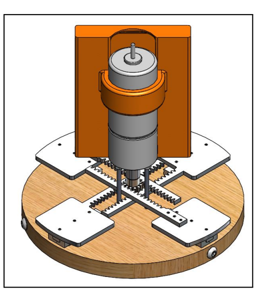

Figure 13: Mechanical system of the BEAVS.

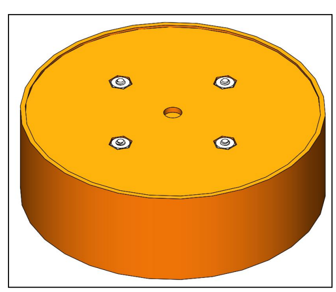

Figure 14: One of the two identical ballast bays.

The linear guide rail was selected to be a 0.28 in. (7 mm) thick rail with linear guide blocks rated for operation at a moment of 25.2 in-lbf. At full extension, the distributed load caused by drag on the blades can be approximated as the midpoint between the airframe and the tip of the blade. The distance between this midpoint and the center of the linear guide block is used as the moment arm, which allows the system to remain within operational limits provided by the manufacturer with 21.9 lbf of drag force per blade.

The drag coefficient with blades retracted is 0.51 and the drag coefficient with blades extended is estimated at 0.67. The drag contribution from each blade is 1/4 of the difference in the forces with the blades extended or retracted. The drag forces were calculated according to the formula below, where C_D is the coefficient of drag, ρ is the density of air (assumed to be sea level), v is the maximum velocity of the launch vehicle, and A is the cross sectional area.

$$F_D = \frac{1}{2} C_D \rho v^2 A \tag{2}$$

At maximum velocity, a force of 34.8 lbf of drag is applied with blades extended and 21.2 lbf of drag force with the blades retracted. This is a force of 3.4 lbf per blade, providing a safety factor of 6.4 for the linear rail and guide block with blade deployment at maximum velocity.

The blades will be driven by a central spur gear which is 24 pitch with a 14.5° pressure angle. They are made of 1/8 in. 6061 aluminum. A Finite Element Analysis (FEA) study was conducted to ensure safety of the blade during deployment. The results of the FEA show a safety factor exceeding 10 for the majority of the blade. The only areas which are below a safety factor of 10 exist at edges of the constraints placed in the FEA simulation. The safety factor is still in excess of 3.9 at maximum drag force on the blade, validating the material choice.

3.1.14.2 BEAVS Electrical System

The electrical system consists of an additional OSRT designed ATU, the same as used in the nosecone and the aft section for tracking. The ATU will collect data for the control system and perform the motor actuation. For more details about the ATU, see section 3.3.2. In addition to the sensors used on the ATU, the BEAVS electrical system will drive a servo motor and use a rotary encoder.

The motor alternative which will be used will be a DC motor with a 1:5.2 gear reduction attached, capable of 21.23 oz-in. at 480 rpm. The DC motor also has a rotary encoder which it will use for position accuracy. This has changed from a National Electrical Manufacturers Association (NEMA) stepper motor because the motor can operate at higher speeds while maintaining position accuracy. The hall effect encoder and gear reduction is included from the manufacturer.

3.1.14.3 BEAVS Control System

The control system of the BEAVS has been modified for ease of implementation and computational efficiency. The desired set point will now be defined by OSRT prior to flight, based off of OpenRocket simulations. There will be a minimum of 5 set points during flight which the control system targets with each blade actuation. The state of the rocket has been defined in 6 Degrees of Freedom (DOF) with respect to altitude because that will be measured by the system throughout flight.

At any specific altitude and flight angle, there is a velocity which will reach exactly the set point altitude with no disturbances. An iterative process was used to determine the correct trajectory for a range of flight angles with each desired set point using altitude as the independent variable. This involved simulating the flight given initial conditions which were output from OpenRocket at motor burnout, then modifying the initial velocity until the vertical velocity at the set point was 0 m/s. An adaptive ordinary differential solver was applied to ensure accuracy for all altitude steps, then the state variables were all mapped with equivalent altitude spacing with linear interpolation between the points output by the adaptive ordinary differential equation solver. The state of the launch vehicle can then be saved for reference by the control system at all points along the simulated trajectory.

The control system references these tables of trajectories based off of the altitude and flight angle to determine the desired velocity of the launch vehicle. With the launch vehicle velocity and the desired velocity, the control system determines a time to actuate the blades from the airframe. A Proportional-Integral-Derivative (PID) controller using only the proportional constant will scale the error between the desired and actual trajectory after each blade deployment. This will account for disturbances such as wind.

3.1.14.4 BEAVS Testing Plan

The original testing plan has been delayed numerous times. This is because OSRT has focused resources on the aerodynamics and recovery subteam which are critical for mission success. Two copies of the system will be built, one for the subscale airframe and one for the full scale airframe. The version for the full scale launch vehicle will never be active during flight until the version for the subscale airframe has successfully proven the concept and control system. If the system cannot be tested on the full scale launch vehicle prior to Flight Readiness Review (FRR), the BEAVS will not be active during the competition flight. The physical system will be present in the full scale launch vehicle regardless of test results by FRR so the aerodynamic simulations will remain unchanged.

3.1.15 Manufacturing Plans

All of the primary systems of the launch vehicle which have to be manufactured by OSRT have been designed for manufacture. The design for manufacture was completed through development of full manufacturing plans displayed below. The following manufacturing plans do not represent every single component to be manufactured by OSRT.

3.1.15.1 Composites

The following procedure is a guide on how to handle composites.

Table 2: Composites Manufacturing Plan

Materials Required	Tools Required	Personal Protective Equipment (PPE) Required
Airframe	End Mill	Nitrile Gloves
Nosecone	Sanding Belt	Safety Glasses
Couplers	Acetone	Respirator
Fins	Drills	Coveralls
Composites	Vacuum	Closed Toed Shoes

- Safety Consideration: To enter the shop and use the equipment, all team members must be wearing safety glasses and closed toed shoes, have tied back loose clothing and long hair, removed loose jewelry, and be wearing certification name tag. The Machine Product and Realization Laboratory (MPRL) safety procedures should be reviewed prior to beginning work.
- Safety Consideration: Team members must wear respirators, safety glasses, gloves for sanding with sandpaper.
- Safety Consideration: If the belt sander is being used, coveralls must be worn. This is done to prevent skin or respiratory damage from composite dust and fragments.
- Safety Consideration: When using the belt sander, the part must be held at least 6 in. from the sander to prevent injury to hands. Use proper tools to hold part if necessary.
- Safety Consideration: Use a shop vacuum whenever a tool or machine does not have a direct vacuum system.

1) Sand with belt sander to face parts.
2) Sand with sand paper to get tight fit.
3) Repeat fitting and sanding until parts fit.
4) When done sanding a part, apply acetone to a rag and clean off the worked area or part.

3.1.15.2 Nosecone

The commercially available 7.5 in. fiberglass 5:1 Ogive Nosecone will be cut down to match the inner diameter of the body tube. This step is necessary for fitting the coupler between the nosecone and the fore body tube. Reducing the nosecone size is also necessary to create a seamless transition from the edge of the nosecone to the outside of the airframe.

Table 3: Nosecone Manufacturing Plan

Materials Required	**Tools Required**	**PPE Required**
Nosecone	End Mill	Nitrile Gloves
Centering Ring	Cutting Fixture	Safety Glasses
Airframe	Acetone	Respirator
	Calipers	Long Sleeves
	Sanding Belt	Closed Toed Shoes

- Safety Consideration: Ensure all HVAC ventilation systems are on and filters are clean. Ensure operator and all nearby personnel have the above PPE. Ensure a Job Hazard Analysis (JHA) has been filled out and signed by a safety officer prior to manufacturing.
- Safety Consideration: To enter the shop and use the equipment, all team members must be wearing safety glasses and closed toed shoes, have tied back loose clothing and long hair, removed loose jewelry, and be wearing certification name tag. The MPRL safety procedures should be reviewed prior to beginning work.

1) Begin by marking the nosecone with a reference line indicating where it will be cut by inserting the centering ring shown in Figure 15 through the tip until it sits tightly on the outer surface of the nosecone.
2) Adjust the centering ring visually so that it sits concentric to the rest of the nosecone.
3) Push the nosecone with the attached centering ring inside the airframe until the two surfaces come in contact.
4) Mark a circular line around the nosecone where the two surfaces come in contact. **Note:** this is not the cut line, only a reference line.
5) Remove the nosecone from the airframe.
6) Acquire fixture plate referenced in Section 1.
7) Clamp down Horizontal Rotary Indexing Tool (HRIT) to Bridgeport Vertical Mill work table.
8) Place Nosecone Fixture Insert into fixture plate and fasten it down with four radial set screws.
9) Clamp wide end of nosecone into HRIT.
10) Insert the tip of nosecone through the center ring in the cutting fixture.
11) Ensure the nosecone is parallel to the work surface and parallel to the table slots.

12) Clamp down the fixture.
13) With edge finding tip on the end mill, rotate the HRIT, ensuring that the tip follows the previously marked line on the nosecone. Adjust if necessary.
14) Move the work table in the x-direction so that the tip will be cutting the desired length of the nosecone.
15) Using a 1/4 in. end mill and Revolutions per Minute (RPM) set to 1,500, cut into the nosecone, slowly rotating, leaving a 1/4 in. uncut section every 90 degrees.
16) When rotating is finished, the end mill should end flush with the initial slot.
17) Shut off the machine, unclamp the fixture and dispose of fiberglass dust appropriately.
18) Using a fiberglass power trimmer, cut the 4 uncut sections.
19) Sand the cut edge until the nosecone can lay flat on a level surface.
20) Clean all tools and put all equipment away.

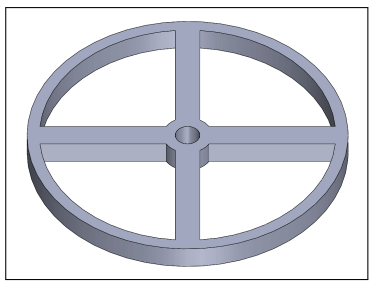

Figure 15: Nosecone fixture insert

3.1.15.3 Fin Slots

A 6061 aluminum fixture plate will be utilized to precisely manufacture all four fin slots and can be seen below in Figure 16. The fixture consists of a hole in a plate that will hold the loose end of the aft body tube firmly during manufacturing. The opposite end, the end with the fin slots, will be clamped down using a HRIT.

Table 4: Fin Slot Manufacturing Plan

Materials Required	Tools Required	PPE Required
12x12x0.750 in. 6061 Aluminum Sheet	Fadal Vertical Milling Center (VMC) 4525	Nitrile Gloves
Aft Body Tube	Machine Clamps	Certified Safety Goggles
	Machine Tools	Respirator
	Bridgeport Vertical Mill	Close Toed Shoes
	HRIT	Long Sleeves
	1/8 in. End Mill	Long Pants

- Safety Consideration: Ensure all Heating Ventilation & Air Conditioning (HVAC) ventilation systems are on and filters are clean. Ensure operator and all nearby personnel have the above PPE. Ensure a JHA has been filled out and signed by a safety officer prior to manufacturing.
- Safety Consideration: To enter the shop and use the equipment, all team members must be wearing safety glasses and closed toed shoes, have tied back loose clothing and long hair, removed loose jewelry, and be wearing certification name tag. The MPRL safety procedures should be reviewed prior to beginning work.

1) Manufacture fixture for cutting the fin slots.
   a. Program Fadal VMC 4525 to cut slots in 6061 aluminum sheet in EdgeCAM.
   b. Clamp down each corner of the 6061 aluminum sheet.
   c. Turn on coolant.
   d. Run program.
   e. Once program finishes, clean off the fixture plate.
   f. Remove fixture plate from the Fadal VMC 4525.
2) Manufacture fin slots.
   a. Clamp down HRIT to Bridgeport VMC work table.
   b. Insert fore end of aft body tube through the fixture.
   c. Insert undersized bulkhead into aft end to ensure the body tube does not flex.
   d. Clamp aft end of aft body tube into HRIT.
   e. Ensure the body tube is parallel to the work surface and parallel to the table slots.
   f. Clamp down fore end fixture.
   g. Insert edge finder into spindle and spindle to 1,500 RPM.
   h. Use the edge finder to locate the aft end of the body tube.
   i. Once located, zero out the x-axis.
   j. Raise the spindle above the body tube and shift the table such that the spindle is shifted towards the fore end of the body tube by a length of half the diameter of the edge finder.
   k. Zero out the x-axis.
   l. Press a square block up against the body tube.
   m. Use the edge finder to locate the edge of the square block (also the outer edge of the body tube).
   n. Move the work table, such that the spindle moves over the center of the body tube, by a distance of the radius of the outside of the body tube.
   o. Move the work table, such that the spindle moves back towards the square block, by a distance of half of the edge finder diameter.
   p. Zero out the y-axis.
   q. Insert 0.125 in. end mill into spindle and set spindle to 1,500 RPM.
   r. Starting at (x,y) = (0,0), move the work table such that the spindle advances towards the fore end

of the body tube to the location of the aft end of the fin slot.

s. Zero out the x-axis.

t. Turn spindle on.

u. Lower spindle until end mill enters into the body tube.

v. Advance spindle towards the fore end of the body tube until fin slot is cut.

w. Raise spindle until end mill is out of the body tube.

x. Turn spindle off.

y. Rotate HRIT by 120°.

z. Repeat Steps t-y, alternating the spindle travel direction in Step v, such that the fin slots are all the same distance from the aft end of the body tube.

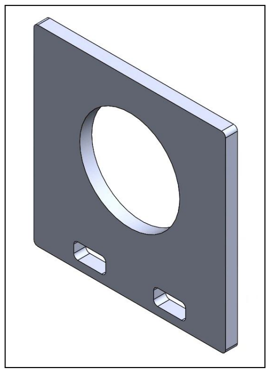

Figure 16: Fin Slot Fixture

3.1.15.4 Bulkheads

The Oregon State University (OSU) MPRL will be used to manufacture bulkheads. The manufacturing plans for these components can be seen below.

Table 5: Bulkhead Manufacturing Plan

Materials Required	Tools Required	PPE Required
5 ft x 5 ft x 1/2 in. Marine Grade Plywood Sheet	Bridgeport VMC Z-axis rotary fixture Calipers Table Saw	Safety Glasses Closed Toe Shoes

Manufacturing Instructions:

- Safety Consideration: To enter the shop and use the equipment, all team members must be wearing safety glasses and closed toed shoes, have tied back loose clothing and long hair, removed loose jewelry, and be wearing certification name tag. The MPRL safety procedures should be reviewed prior to beginning work.
- Safety Consideration: The rotary table is very heavy. Dropping it could injure the user, others, and damage the rotary table.

1) Use table saw to cut plywood into 6.5x6.5 in. squares.
2) Mount plywood square into VMC.
3) Use VMC edge finder tool to properly align plywood square.
4) Cut 3/8 in. hole into center of plywood square.
5) Remove plywood square from VMC.
6) Clean VMC.
7) Mount Z-axis rotary fixture to VMC.
8) Mount plywood square into into Z-axis rotary fixture on the VMC.
9) Use VMC edge finder tool to properly align plywood square.
   - Safety Consideration: Do not remove too much material per pass. Doing so may cause damage to the bit and may cause injury to the user and others in the vicinity.
10) Use Z-axis rotary fixture and VMC to cut plywood square into a 6.25 in. diameter disk.
11) Use calipers to check the diameter of the bulkhead.
12) Note: Do not alter the thickness of the plywood. This needs to remain at 1/2 in.
13) Remove bulkhead from Z-axis rotary fixture.
14) Remove Z-axis rotary fixture from VMC.
15) Clean VMC and work area.

3.1.15.5 Epoxy

The following procedure provides a guide for making and handling epoxy.

Table 6: Epoxy Manufacturing Plan

Materials Required	Tools Required	PPE Required
G5000 RocketPoxy Components to be Epoxied	Dowel Craft Sticks Acetone Scale Sandpaper Paper Towels Mixing Container	Nitrile Gloves Safety Glasses Respiratory Mask (if sanding)

- Safety Consideration: Nitrile gloves must be worn to prevent skin contact with epoxy to avoid rash or other skin damage.
- Safety Consideration: To enter the shop and use the equipment, all team members must be wearing safety glasses and closed toed shoes, have tied back loose clothing and long hair, removed loose jewelry, and be wearing certification name tag. The MPRL safety procedures should be reviewed prior to beginning work.

1) Be sure that all appropriate PPE is worn and the needed materials are prepared.
2) **Note:** For epoxying, use mixing sticks to mix a 1:1 ratio of resin and hardener (a scale will assist in achieving this ratio). Use a dowel to get hard to reach locations and use a gloved finger dipped in acetone to create smooth fillets.
3) Wipe the necessary surfaces with a paper towel and acetone to remove any unwanted finishes, dirt, etc.
4) Use 60 grit sandpaper to rough up the surfaces for epoxy.
5) Wipe all dust created by sanding off of the surfaces with acetone.
6) In a cup, mix equal ratios of epoxy by weight or volume. Once the epoxy has been mixed, it can be worked with for approximately 30 minutes, but it is easiest to apply soon after mixing while viscosity is low.
7) Apply the epoxy where needed, creating a fillet on the desired surfaces.
8) If possible, create an even fillet by rubbing a finger (with glove), craft stick, etc. along the edge of the surfaces.
9) Place the components in a safe location so that the epoxy is flat and cannot run or drip. Allow 6 hours for the epoxy to harden before handling. Allow 24 hours for the epoxy to harden before placing the part in high stress conditions.

3.1.15.6 Fin and Motor Tube Mounting

The following epoxy procedure will be followed to achieve the highest strength for retaining the fins and motor mounting tube to the airframe by providing the most amount of 0.5 in. fillets.

Table 7: Fin and Motor Tube Epoxy Manufacturing Plan

Materials Required	**Tools Required**	**PPE Required**
Lower Airframe	Dowel	Nitrile Gloves
Centering Ring	Mixing Sticks	Safety Glasses
Motor Mount Tube	Acetone	
Fins	Scale	
Motor Retainer		
G5000 RocketPoxy		

- Safety Consideration: Nitrile gloves must be worn when working with epoxy to avoid skin damage.
- Safety Consideration: To enter the shop and use the equipment, all team members must be wearing safety glasses and closed toed shoes, have tied back loose clothing and long hair, removed loose jewelry, and be wearing certification name tag. The MPRL safety procedures should be reviewed prior to beginning work.

1) **Note:** Refer to Epoxy 3.1.15.5 section for instructions on how to handle epoxy.
2) **Note:** Wait 6 hours between each application of epoxy.
3) **Note:** Clean off any stray epoxy.
4) **Note:** Do one fin at a time, allowing at least 12 hours between each fillet for drying. Do all fins before epoxying to the body tube.
5) Epoxy middle centering ring into airframe at top of fin slots, using wood blocks set to 9 in., resting the ring flush on top of the blocks and leaving both the airframe and the blocks inside vertically.
6) Epoxy the upper centering ring to the motor tube 0.5 in. from the edge of the fore side of the motor tube (making sure the centering ring is perpendicular to the airframe and both sides have fillets).
7) Put fillets on middle centering ring, and epoxy motor tube to middle centering ring with 0.5 in. extending from aft of lower airframe. Fillet motor tube and epoxy upper centering to the airframe with blind fillet below.
8) Place lower airframe into fin fixture.
9) Place generous amount of epoxy on motor tube where fin will mount.
10) Press fin through slot in airframe and into the pre-applied epoxy.
11) Press fin down and forward to ensure fin is properly in place.
12) Create fillet on either side of fin along the motor tube by sliding glove covered finger down the length of fin.
13) Press remaining fins through the remaining slots.
14) Press fin alignment fixture into place, holding all fins in place.
15) Epoxy the fins to the body tube both on the inside of the body tube and outside of the body tube. Fillet the inside and the outside of fin-body tube joint.
16) Place epoxy along back ends of fins.
17) Place epoxy along inside of the airframe and outside of the motor tube where the last centering ring will be placed.
18) Slide in centering ring until it contacts and lays flat against the fin ends.
19) Make epoxy fillets on the outside of the last centering ring, along the body tube and motor tube to centering ring contact points.
20) Epoxy on motor retainer making sure inner stop makes contact with the edge of the motor tube.
21) Clean off any excess epoxy with a rag.

3.1.15.7 Fore Avionics Bay

The fore avionics consist of an additive manufactured block made with PLA and two bulkheads to create a pressure seal and to provide a mounting point for the fore parachutes. To manufacture the avionics mount, the following process is implemented:

1) Create a 3D model of the fore avionics mount.
2) Create a 3D model of the avionics tabs.
3) Convert the models into a high resolution Stereolithography (STL) files.
4) Use slicer to convert the STL files into G-code.
5) Upload the G-code into the 3D printer.
6) Preheat the nozzle and insert filament.
7) Clean print bed.
8) Start G-code.
9) Check the print for defects.

The bulkheads will be manufactured primarily according to Section 3.1.15.4, with several additional holes placed for eyebolts and sealing bolts using a VMC. The bulkheads will be manufactured according to the following process:

Table 8: Fore Avionics Bulkheads

Materials Required	**Tools Required**	**PPE Required**
Marine Grade Bulkhead x2	Manual VMC Z-axis rotary fixture	Safety Glasses Closed Toe Shoes

- Safety Consideration: To enter the shop and use the equipment, all team members must be wearing safety glasses and closed toed shoes, have tied back loose clothing and long hair, removed loose jewelry, and be wearing certification name tag. The MPRL safety procedures should be reviewed prior to beginning work.

1) Secure the bulkhead in a Haas vice in a manual VMC so that the center hole is in the Z (vertical) direction.
2) Zero the mill in the X and Y directions so that (0,0) is at the center of the bulkhead.
3) Reference the drawing in 88 to determine placement and sizing of holes.
4) Drill all holes using peck drill method.
5) Remove the bulkhead plate from the Haas vice.
6) Repeat steps 1-5 using the drawing Figure 88 to determine placement and hole sizing.

3.1.15.8 Blade Extending Apogee Variance System

The BEAVS will have two main types of components which need to be manufactured: bulkheads and blades.

The bulkheads will be manufactured primarily according to Section 3.1.15.4, with several additional holes placed for mounting of the linear guides using a vertical mill. The blades will be manufactured according to the following process:

Table 9: Required equipment for BEAVS manufacturing

Materials Required	**Tools Required**	**PPE Required**
6061 1/8 in. aluminum plate	Manual VMC Fixturing Computer Numerical Control (CNC) VMC Involute Cutter Deburring Tool	Safety Glasses

- Safety Consideration: To enter the shop and use the equipment, all team members must be wearing safety glasses and closed toed shoes, have tied back loose clothing and long hair, removed loose jewelry, and be wearing certification name tag. The MPRL safety procedures should be reviewed prior to beginning work.

1) Secure the 6061 1/8 in. aluminum plate in a Haas vice in a manual VMC so the 1/8 in. is in the Z (vertical) direction.
2) Zero the mill in the X and Y directions.
3) Reference the drawing in Figure 102 to determine placement and sizing of holes.
4) Drill all holes in the aluminum using peck drill method.
5) Remove the aluminum plate from the Haas vice.
6) Deburr the part as necessary.
7) Secure aluminum plate to fixture secured in CNC VMC.
8) Mill profile of blade using G-Code created with assistance from a Computer-Aided Manufacturing (CAM) software. Do not include rack tooth profiles in the G-code.
9) Remove the blade blank from CNC VMC and secure vertically in a Haas vice of a manual VMC with the 1/8 in. in the X direction.
10) Deburr the part as necessary.
11) Zero the manual VMC in the Z and Y directions.
12) Use the involute cutter to create a rack tooth profile in according to the drawing in Figure 102.
13) Deburr the part as necessary.

14) Move the Z height to cut the next rack tooth profile, repeating until all of the teeth in the rack have been cut.

3.2 Subscale Flight Results

Two subscale flights were conducted. These launches took place in Brothers, Oregon on December 8th, 2018 and January 4th, 2019.

3.2.1 Flight Data

For both the first and second subscale flight, two altimeters and two avionics systems were flown. The avionics systems are nearly identical, and they receive, process, and transmit GPS information over the 900 MHz band from the launch vehicle to a ground station that plots and records the data. The two altimeters flown were a Missile Works Rocket Recovery Controller 3 (RRC3) sport altimeter and a PerfectFlite StratoLoggerCF altimeter. The StratoLoggerCF was the primary altimeter, and the RRC3 was the secondary altimeter. For the first flight, it was intended for the StratoLoggerCF to have no apogee delay and the RRC3 to have a one second apogee delay, but both were unintentionally set to a one second delay. This resulted in what appeared to be a slightly late separation event at apogee. The data pulled from the flights will be presented in the next three sections. For the second flight, the altimeters were set to the correct delays.

3.2.1.1 PerfectFlite StratoLoggerCF Data

Shown in Figures 17 and 18 are the flight data the PerfectFlite StratoLoggerCF altimeter recorded during the first and second subscale launches respectively.

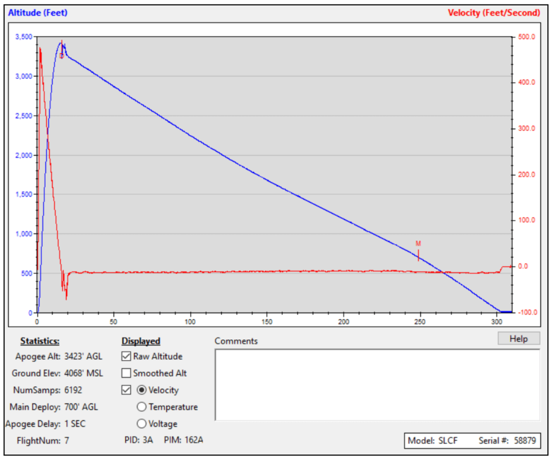

Figure 17: StratoLoggerCF altimeter flight data for launch on 12/8.

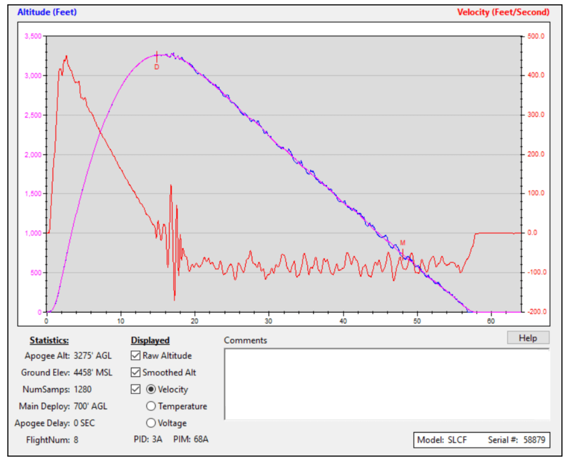

Figure 18: StratoLoggerCF altimeter flight data from launch on 1/4.

Shown in Tables 10 and 11 are the recorded maximum altitude, impact velocity, impact kinetic energy, and total descent time the StratoLoggerCF altimeter recorded during the flights.

Table 10: StratoLoggerCF altimeter important data points for launch on 12/8.

Maximum Altitude [ft]	Impact Velocity [ft/s]	Fore Impact KE [ft-lbf]	Aft Impact KE [ft-lbf]	Total Descent Time [s]
3423	13.2	14.3	31.1	287.25

Table 11: StratoLoggerCF altimeter important data points for launch on 1/4.

Maximum Altitude [ft]	Impact Velocity [ft/s]	Fore Impact KE [ft-lbf]	Aft Impact KE [ft-lbf]	Total Descent Time [s]
3259	78	500.7	1086	56

3.2.1.2 Missile Works RRC3 Data

Shown in Figures 19 and 20 is the flight data the Missile Works RRC3 altimeter recorded during the first and second subscale launches respectively.

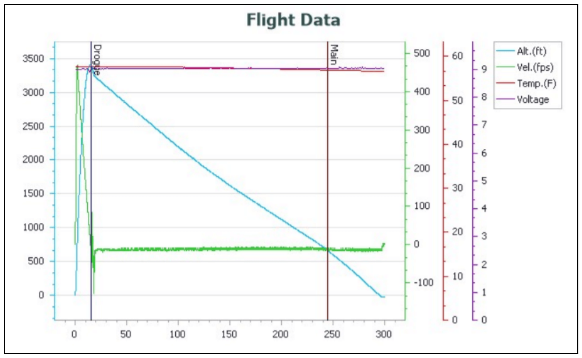

Figure 19: RRC3 altimeter flight data for launch on 12/8.

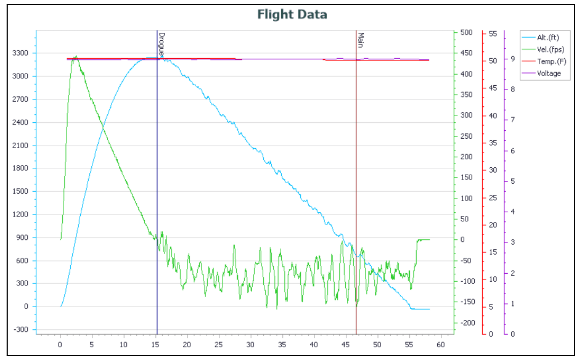

Figure 20: RRC3 altimeter flight data for launch on 1/4.

Shown in Tables 12 and 13 are the recorded maximum altitude, impact velocity, impact kinetic energy, and total descent time for the RRC3 altimeter.

Table 12: RRC3 altimeter important data points for launch on 12/8.

Maximum Altitude [ft]	Impact Velocity [ft/s]	Fore Impact KE [ft-lbf]	Aft Impact KE [ft-lbf]	Total Descent Time [s]
3402	13.0	13.9	30.1	281.25

Table 13: RRC3 altimeter important data points for launch on 1/4.

Maximum Altitude [ft]	Impact Velocity [ft/s]	Fore Impact KE [ft-lbf]	Aft Impact KE [ft-lbf]	Total Descent Time [s]
3249	76	475.3	1031	55

3.2.1.3 Discussion

During the first launch, when the launch vehicle sections separated at apogee, the main parachute was pulled out of the airframe (see Section 3.2.4.2 for more detail). Due to the main parachute deploying at apogee, the descent time was over 4 and a half minutes. This is also evident in both Figures 17 and 19, as the slopes are consistent throughout the total descent, indicating the launch vehicle was never descending under just the drogue parachute. Both altimeters were set to release the main parachute at 700 ft AGL, and this point is marked in both Figures 17 and 19. Because both altimeters fired the main charge at the appropriate time, OSRT can conclude that the integration of the retention method for the main parachute was the cause of failure instead of the altimeters sending current to the main parachute output port at apogee. The total descent time under the main parachute from 700 ft AGL was 51 seconds, and the calculated descent time through a MATLAB script OSRT developed was 48.1 seconds. The measured impact kinetic energy was between 50 and 53 ft-lbf, which is well below the maximum allowable landing kinetic energy.

The recovery integration was modified for the second subscale launch to ensure the parachute could not slip out before the Tender Descender and ARRD released. Separation at apogee successfully deployed the drogue parachute. Figures 18 and 20 mark when the drogue and main e-matches were fired. Both altimeters sensed apogee roughly 15 seconds into the flight. The StratoLoggerCF fired its main e-match at 699 ft AGL and the RRC3 fired its main e-match at 666 ft AGL. The main parachute, however, was never pulled from the airframe, resulting in a high impact velocity and landing kinetic energy. Both the Tender Descender and ARRD had released when the launch vehicle was examined after landing. The OSRT has concluded that the failure was due to high friction forces between the deployment bag and the airframe. The deployment bag measures 4.5 in. in diameter, while the airframe measures 3.9 in. in diameter. This required more force to pull the deployment bag from the airframe than the drogue parachute was able to provide.

3.2.1.4 Avionics Data

The ATU ground station malfunctioned and was nonoperational during the first subscale launch and the malfunction was not noticed until the flight was underway. The data gathered and plotted by the ground station is only a subset of the total GPS data which is recorded and stored in the SD cards on-board the flight ATUs.

Recovery and manual analysis of flight data indicates that both ATUs were armed for initial inspection at 9:38 AM PST and turned off at 10:14 AM PST. They were then armed for assembly at 10:20 AM PST, with the aft ATU losing power at 7:47 PM PST and the fore ATU losing power at 7:53 PM PST, giving a concurrent uptime of more than 9 hours per ATU, with a total uptime of over 10 hours per ATU, satisfying the competition requirement for launchpad battery longevity. ATU data indicates a flight duration of 345 seconds and a final and maximum drift distance of 5036 ft.

One GPS unit suffered electrical damage during routine testing between subscale launches. The second ATU was converted into a non-transmitting data logger prior to the second subscale launch to test data logger functionality. The unmodified ATU successfully communicated with the ground station for the duration of the flight. The ATU was powered on at 9:06 AM PST, but impact of the launch vehicle with the ground at 1:30 PM PST rendered serial logging via the ATU nonoperational and thus battery testing inconclusive. Collected ATU data indicates a logged flight duration of 53 seconds, maximum drift distance of 1423 ft, and a final drift distance of 428 ft.

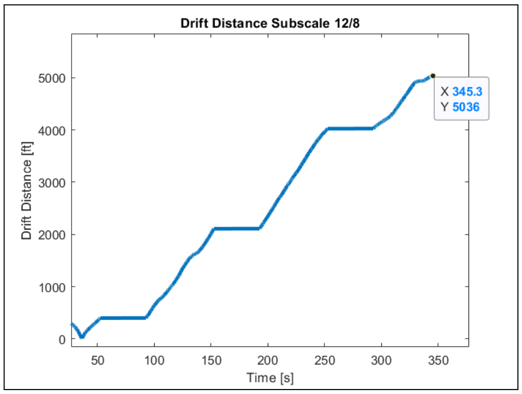

Figure 21: Subscale launch drift plot from 12/8

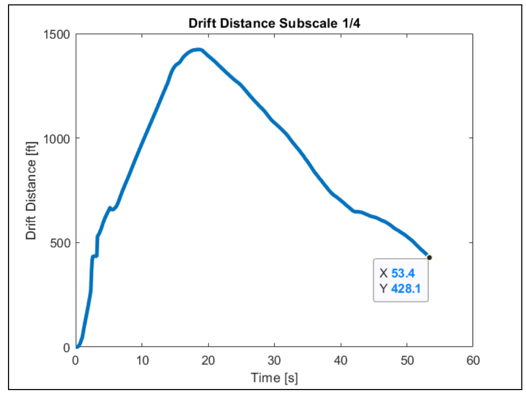

Figure 22: Subscale launch drift plot 1/4

3.2.2 Scaling Factors

The subscale launch vehicle was designed and manufactured to match the leading full scale launch vehicle designs from PDR as closely as possible. Since PDR, several changes to leading designs have been made.

The fins were designed to match the leading design from PDR: four trapezoidal fins. The only differences between the subscale and full scale fins will be the dimensions to maintain a full scale stability of 2.1 calibers.

A 4:1 ogive nosecone was used to accurately match the leading design choice from PDR. Due to purchasing difficulties, a 5:1 ogive nosecone has been selected for the final design. The difference between the two nosecone shapes should not significantly effect the performance if accounted for in simulations.

A single compartment recovery system using an ARRD and Tender Descender was used to match the full scale recovery system design as closely as possible. Due to purchasing difficulties, two Tender Descenders will be used in the full scale launch vehicle. The Tender Descender appeared to function properly in both launches, despite the recovery failures preventing the main parachute from releasing when intended in both launches.

A 7 ft toroidal parachute was used to match the drag properties of the full scale launch vehicle, though a 8 ft toroidal parachute was chosen for the fore section and a 8 ft toroidal parachute was chosen for the aft section. The parachutes differ in diameter from the subscale launch, however the descent times match simulations closely.

3.2.3 Launch Day Conditions Simulation

The December 8th subscale launch was performed in Brothers, Oregon, at an elevation of 4,600 ft Above Sea Level (ASL). Launch day conditions are from Bend Municipal Airport, approximately 35 miles west of the launch site. At the time of launch, air temperature was 45°F, with three mph winds coming from the southeast. Air pressure was recorded at 26.7 in-Hg. Inserting these factors into OpenRocket, the simulated apogee altitude is 3,921 ft for this subscale launch.

The January 4th subscale launch was also performed in Brothers, Oregon. For this launch, winds aloft were determined from the closest location which data is available from the National Weather Service: Redmond, OR. Redmond is approximately 42 miles north west of the launch site. At the time of launch, ground level winds were 5 mph and a ground temperature of 42°F. The OpenRocket simulation with the January 4th launch day conditions predicts an apogee altitude of 3,913 ft.

3.2.4 Subscale Flight Analysis

3.2.4.1 Parachute Analysis

The main parachute yielded a descent trajectory consistent with that of the simulations used to predict the descent of the subscale and full scale launch vehicle. Using the altimeter data from the fist subscale flight, the launch vehicle had a landing velocity of 13.38 $^{ft}/_{s}$ and an impact kinetic energy of 52.3 ft-lbf. These numbers are similar to those of the simulation used and are more favorable than what the simulation provides. The simulations provided a landing velocity of 14.55 $^{ft}/_{s}$ and a impact kinetic energy of 63.55 ft-lbf. This means the simulation results calculated a landing kinetic energy that is 17.7% higher than the actual kinetic energy.

In order to analyze the descent time, altimeter data from the first and second subscale launch must be used. In the first subscale flight, the main parachutes deployed at apogee, so data used will be from 700 ft to 0 ft ASL. On the second launch, the main parachutes did not deploy, so data used will be from apogee to 700 ft ASL. This will allow the OSRT to analyze the descent as if all parachutes deployed ideally. With this combination, the subscale descent time is 86.8 seconds and the theoretical value calculated on MATLAB is 64.620 seconds. This shows that the descent is actually 34% slower. By combining data from both flights, the assumption is made that the main parachute deploys and expands instantaneously. However, including that 34% error in the full scale descent models, both sections of the airframe land in under 90 seconds.

3.2.4.2 Recovery Integration

Shown in Figure 23 was the intended subscale recovery integration design.

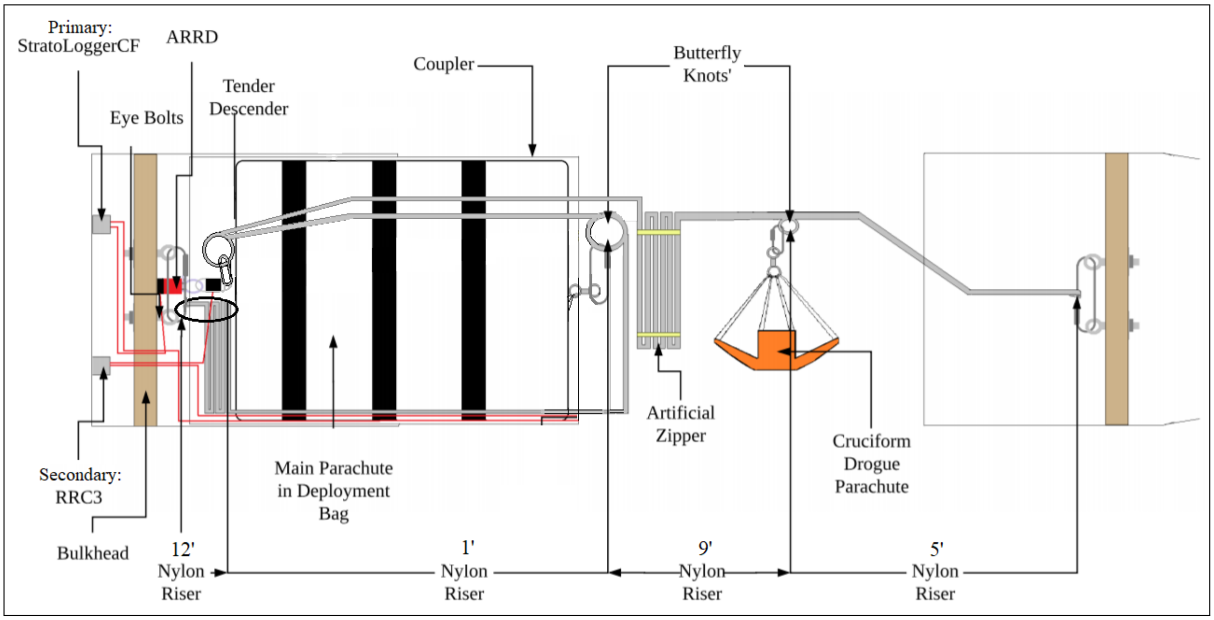

Figure 23: Initial Subscale Recovery Integration Design

The aft bulkhead has two eye bolts and an ARRD bolted to it with a nyloc nut. Four e-matches were threaded through the bulkhead and placed on the bulkhead with some slack. Two of the e-matches attached to the Tender Descender and ARRD, while the remaining two were the primary and backup ejection charges. All of these pieces have a rubber washer to aid with a pressure seal. A Tender Descender is attached to the ARRD, and an extra wide quick link is attached to both eye bolts. The top loop of the deployment bag and the aft loop of the shock cord are attached to this quick link. A butterfly knot is tied 12 ft down the riser, and it is attached to the main parachute swivel with a quick link. One ft up the riser is another butterfly knot which is attached to the Tender Descender. A third butterfly knot is tied 10 ft down the riser, and it is attached to the drogue parachute swivel with a quick link. The end of the riser, which is an extra five ft, is attached to an extra wide quick link. This quick link is attached to two eye bolts attached to the fore bulkhead in the same fashion as the aft bulkhead.

This recovery system was demonstrated successfully through ejection demonstrations three consecutive times, leaving OSRT confident the recovery system would perform nominally. However, the system was challenging to successfully integrate.

At the launch site, OSRT asked for advice from one of the team's mentors to determine if there was an easy way to improve the recovery integration process. He analyzed the recovery integration system and suggested eliminating the knot located furthest aft. The top of the deployment bag, the swivel at the base of the main parachute, and the knot in the riser were attached to a quick link. This quick link was then attached to the end of the Tender Descender. The rest of the recovery integration system stayed the same as what was previously planned. The system flown in the first subscale flight can be seen in Figure 24. The team conducted pull tests on the system, which showed the deployment bag was able to slip approximately halfway out of the airframe. This presented the risk of the main parachute deploying at apogee. After the pull tests, the team discussed the feasibility of switching back to the original recovery configuration and launching, however the team decided the changes and assembly process would take longer than the launch window. The wind conditions were minimal, so due to the time constraints OSRT decided to proceed with the launch.

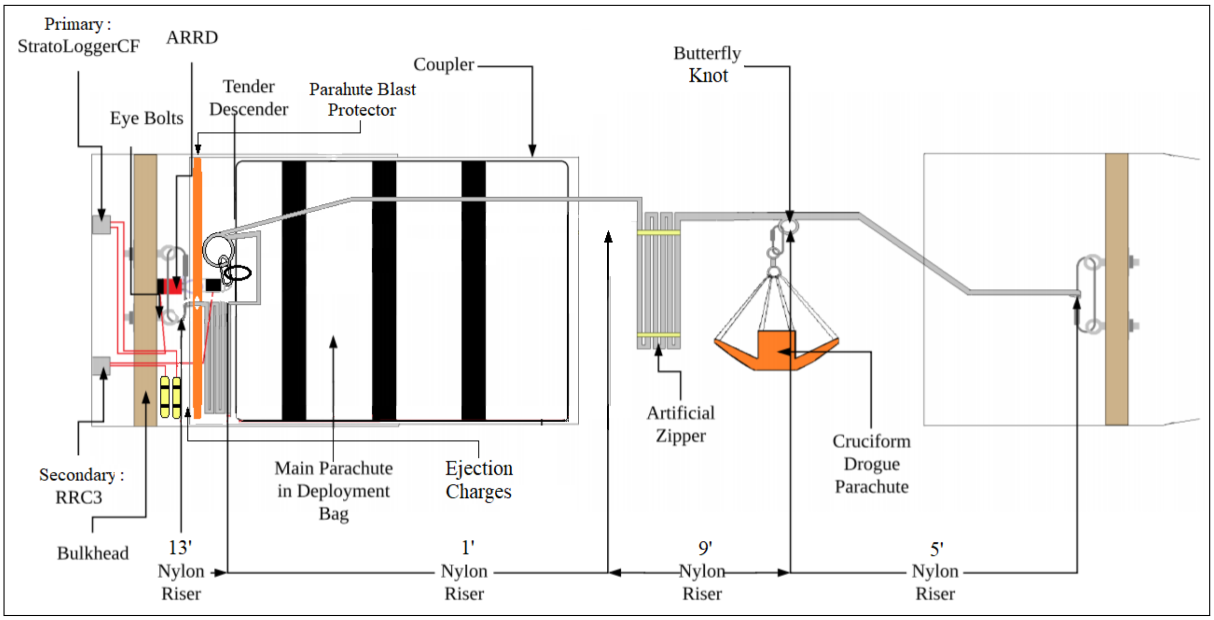

Figure 24: Flown subscale recovery integration design.

As seen in Section 3.2.1, this recovery system failed to retain the main parachute and deployment bag system within the airframe. After the failure to retain the main parachute, OSRT performed an ejection demonstration to confirm the failure point. Shown in Figure 25 is the result of the ejection demonstration.

Figure 25: Subscale ejection demonstration.

The deployment bag is hanging halfway outside of the airframe and the parachute is partially outside of the deployment bag. The wind would have easily pulled the main parachute from the airframe, causing an early deployment of the main parachute. Based off of these results, the recovery integration design was modified to be easier to integrate, while retaining the main parachute.

Shown in Figure 26 is the recovery integration system flown in the second subscale launch. Due to the recovery failure, this system will be modified for full scale.

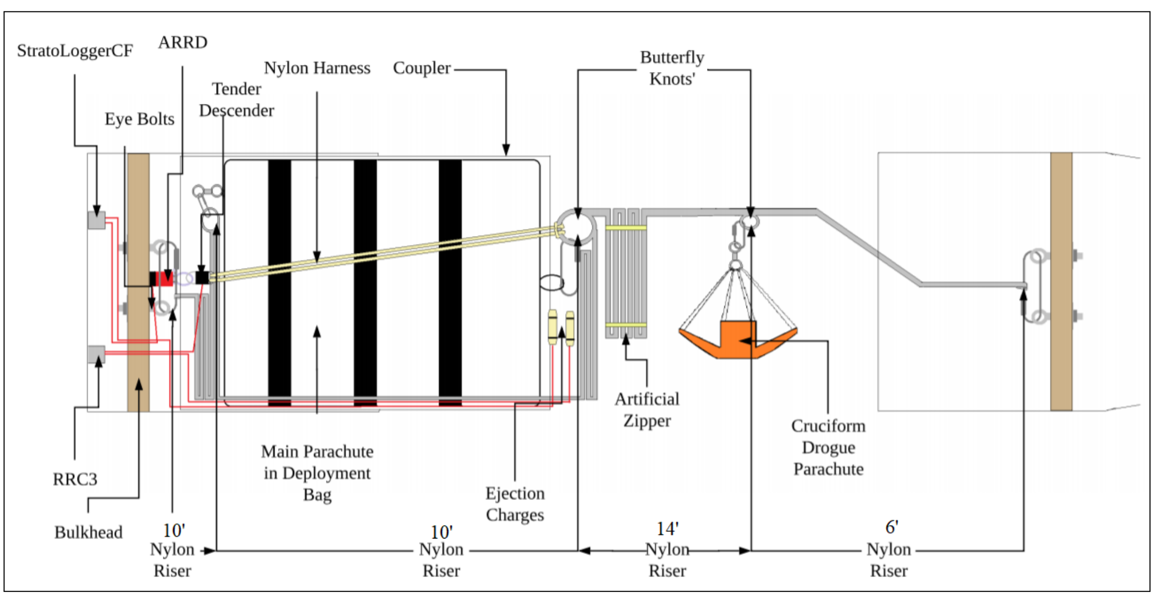

Figure 26: Full scale recovery integration design.

The main changes include flipping the orientation of the deployment bag, so the open end is facing the inside of the airframe, changing the length of the riser (previously, a 28 ft riser was being used - this has been replaced with a 42 ft riser), changing location of the ejection charges, and changing attachment points on the riser. Below is a description of Figure 26

Nothing was changed with the bulkhead attachment points. Ejection charges are wired through the bulkhead and sealed in the same way, but these charges are extended to the edge of the coupler. The eye bolts still have an extra wide quick link attached to them. The aft end loop of the riser will be hooked to this quick link. The main parachute swivel will be attached to a butterfly knot 10 ft down the riser with a quick link. 10 ft down the riser is a second butterfly knot. This is attached to the loop at the top of the deployment bag with a quick link. This knot is also attached to a 2 ft riser folded in half. The other end of this riser is attached to the Tender Descender. A third butterfly knot is tied 14 ft down the riser, and the drogue swivel is attached to this loop with a quick link. The end of the riser is 6 ft further down the riser (the extra two ft. of riser is accounted for with the knots ad end loops). This end is attached the fore bulkhead in the same manner as the previous design.

3.2.4.3 Flight Profile Analysis

The first subscale launch had a projected altitude of 3,877 ft AGL with actual launch day conditions input into the OpenRocket simulation. The actual subscale rocket achieved an apogee altitude of 3,423 ft AGL during the December 8th launch. The second subscale launch on January 4th had a projected altitude of 3,867 ft AGL with actual launch day conditions input into the OpenRocket simulation. The actual subscale rocket on January 4th achieved an apogee altitude of 3,250 ft AGL. Both subscale launches had a significant undershoot in apogee altitude from simulation to actual launch. The December 8th launch had a difference of 454 ft, and the January 4th launch had a difference of 617 ft.

The drag coefficient was calculated for both the subscale flights using the Missileworks RRC3 flight data. Due to the inconsistencies in the RRC3 velocity calculations, the drag coefficient estimates are inaccurate. The calculated values are -3.45 and -3.50 for the first and second flights respectively. For future flights, the IMU data will be logged to assist in this calculation, however the IMU data was never logged.

3.2.5 Changes to Full Scale Based on Subscale Flight

3.2.5.1 Aerodynamics and Propulsion Changes

Both subscale flights achieved an apogee altitude significantly lower than the predicted altitudes from the OpenRocket simulations. Based on the results from the subscale flights, the full scale simulations may predict an apogee altitude over 600 ft higher than the actual full scale flight. In preparation of the over prediction of the OpenRocket simulations, the design of the full scale launch vehicle is for the OpenRocket simulations to achieve an apogee altitude above 5,000 ft. If the full scale launch vehicle experiences a significant undershoot like the subscale rocket, the apogee achieved will be close to the target altitude of 4,500 ft and remain within National Aeronautics and Space Administration (NASA) Student Launch (SL) altitude window of 3,500 ft to 6,000 ft. If the full scale launch vehicle does not experience the significant undershoot that the subscale rocket experienced, ballast within NASA SL criteria will be used to lower apogee altitude closer to the target 4,500 ft while maintaining a stability of 2.1 calibers with ballast bays in the fore and aft section.

3.2.5.2 Structures Changes

One challenge of integration on the subscale flight was to tighten a nyloc nut on the top of the threaded rod which extended from the motor. This meant that parachutes could not be attached to the ejection bay prior to insertion into the launch vehicle. By switching to radial bolts through the outside of the airframe, the parachutes can be attached to the ejection bay and installed at once, since the radial bolts are installed through the wall of the airframe. To explore changing to radial bolts, OSRT performed compression testing on a small section of the carbon fiber airframe with radial bolts. These results are summarized in Section 6.1.2.

3.2.5.3 Parachute Changes

The subscale flight fell significantly slower than expected, resulting in a landing kinetic energy around 17% lower than expected for the subscale flight which the main parachute deployed. The team would rather simulate above the actual landing kinetic energy than below, so the simulation still remains valid for parachute sizing of the full scale. No significant changes have been made to the parachutes based on the subscale flight.

3.2.5.4 Recovery Integration Changes

After the recovery failure during the second launch, changes were made to the recovery integration design for full scale. These changes include adding a second StratoLoggerCF altimeter to each altimeter bay (totalling three altimeters igniting e-matches in each bay) and cutting the ARRD for a second Tender Descender. The main parachute packed in a deployment bag fit loosely inside the full scale airframe, sliding freely just by tilting the airframe. When either Tender Descender release, the main should be released from the airframe. To provide extra redundancy, the second StratoLoggerCF will be wired to two deployment charges sitting below the main parachute to be ignited 100 ft lower than the Tender Descender release height. If excessive friction prevents the main parachute from being pulled out by the drogue after either Tender Descender separates, the charges will expel it.

On both launches, the Tender Descender and ARRD appeared to perform properly. However, the manufacturer of the ARRD has stopped production of the device and OSRT only has one available. The ARRD will be replaced by a Tender Descender due to unavailability of ARRDs. The PEARS will use the ARRD, while the recovery system will use two Tender Descenders in series. Both devices were validated by the subscale flights.

3.2.5.5 Flight Profile Changes

The subscale flight did not result in any significant changes to the flight profile. The only change is an additional event at 600 ft AGL (100 ft below the Tender Descender release) where black powder charges eject the main parachute if it has not been pulled out by the drogue.

3.3 Recovery Subsystem

3.3.1 Finalized Selected Components

3.3.1.1 Recovered Sections

The OSRT will recover the launch vehicle in two independent sections. Both sections will have lower mass than if there were one recovered section. Therefore the impact velocity can be higher while still maintaining the same landing kinetic energy. This allows the OSRT to use smaller parachutes, which are easier to integrate into the airframe and will eject and inflate in a more controlled manner. The increased rate of descent will also decrease the drift radius.

Recovering the launch vehicle in two sections increases the overall complexity of the design. There needs to be a set of altimeters and ejection charges for each independent section, and more bulkheads in the airframe. This will increase the total weight of the launch vehicle but will increase the performance and reliability of the recovery system.

3.3.1.2 Recovery Compartments

The OSRT will use one recovery compartment for each independently recovered section of the launch vehicle. This means the drogue and main parachute will be stored in the same compartment. At apogee, the drogue will be ejected during separation using black powder charges. At 700 ft AGL the main parachute will be released by two Tender Descenders connected in series for a redundant main deployment. Once released, the drogue parachute will pull the deployment bag that is holding the main parachute out of the airframe. Once the parachute shroud lines are fully extended, the drogue parachute will pull the deployment bag off of the main parachute. This allows for a controlled inflation of the main parachute outside of the airframe to reduce the chance of tangling.

Using one recovery compartment decreases the complexity of the overall design by reducing the number of bulkheads, ejection charges, and separation points. This design also allows for an open end of the airframe for payload ejection.

3.3.1.3 Canopy Shapes

The OSRT has limited experience and equipment to fabricate its own parachute. Therefore only parachutes from reputable vendors were considered. A toroidal main parachute will be used as the main parachute for the fore and aft sections of the launch vehicle. This canopy has the highest coefficient of drag compared to other shapes considered. This allows the OSRT to use a smaller parachute to achieve the same descent behavior. Although this canopy has a higher risk of entanglement, the inflation of the parachute will happen outside of the airframe, reducing this risk. A Fruity Chutes toroidal parachute is shown in Figure 27.

A cruciform parachute will be used for the drogue parachute for the fore and aft sections of the airframe. Cruciform parachutes have a low coefficient of drag and good stability at any speed. This makes them good drogue parachutes. The small number of shroud lines decreases the risk of entanglement upon ejection. A Top Flight Recovery cruciform parachute is shown in Figure 28.

Figure 27: Fruity Chutes Toroidal Parachute

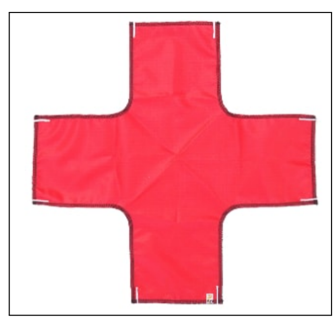

Figure 28: Top Flight Recovery Cruciform Parachute

3.3.1.4 Canopy Size

This section outlines the process followed to determine the appropriate size for all parachutes. The values used for the coefficient of drag for the toroidal and cruciform parachutes are listed in Table 14.

Table 14: Values for Coefficient of Drag

Variable	Value
$C_d, toroidal$	2.2
$C_d, cruciform$	0.4

Fruity Chutes toroidal parachutes have a coefficient of drag of at least 2.2, and in some cases over 3. The OSRT decided to analyze the parachutes with a drag coefficient of 2.2, as it would give the safest results, keeping the kinetic energy upon landing within requirements.

Given that the density of air is a function of altitude, it was calculated using the barometric formula for density. It was assumed that the standard temperature lapse rate, T_b, was not equal to zero. The equation used to solve for density is as follows:

$$\rho = \rho_b[\frac{T_b}{T_b + L_b(h - h_0)}]^(1 + \frac{g_0 M}{R^* L_b}) \tag{3}$$

T is the standard temperature in K, L is the standard temperature lapse rate in $^K/_{ft}$, h is the height ASL in ft, g_0 is gravitational acceleration in $^{ft}/_{s^2}$, M is the molar mass of air in $^{kg}/_{mol}$, R^* is the universal gas constant in $^{ft^2}/_{sK}$, and the subscript b corresponds to the layer of the atmosphere. The projected flight will not leave the first layer of the atmosphere ($b = 0, h < 36,089ft$).

$$KE = \frac{1}{2}mv^2 \tag{4}$$

KE is kinetic energy in $ft - lbf$, m is mass in $slugs$, and v is velocity of the system in $^{ft}/_s$.

$$D = \frac{1}{2}C_d \rho_{air} v^2 A_r \tag{5}$$

D is drag around the parachute in lbf, where C_d is the coefficient of drag of the parachute, ρ_{air} is the density of air in $^{slugs}/_{ft^3}$, v is the velocity of the system in $^{ft}/_s$, and A_r is the reference area of the parachute in ft^2, which is the cross sectional area.

$$A_r = \frac{1}{4}\pi(d_o^2 - d_i^2) \tag{6}$$

The reference area can be defined in terms of the outer and inner diameters of the toroidal parachute, where d_o is the outer diameter and d_i is the inner diameter. Typically, the ratio between outer and inner diameters for this shape of parachute is 5:1. Using this, the reference area equation becomes:

$$A_r = \frac{6}{25}\pi d_o^2 \tag{7}$$

Plugging equation 7 into equation 5 and solving for the outer diameter gives:

$$d_o = \sqrt{\frac{25W_{lv}}{3\pi\rho_{air}C_d v^2}} \tag{8}$$

To calculate the reference area of the drogue parachutes, Equation 9 was used.

$$A_{xform} = 2DW - W^2 \tag{9}$$

Width, w, is the length of the short edge and diameter, D, is the diameter of the drogue parachute.

Based on these calculations and the toroidal and cruciform parachutes that are readily available online, the OSRT decided use a 8 ft toroidal main parachute and a 1.5 ft cruciform drogue parachute for the fore section, and an 8 ft toroidal main parachute and a 1.5 ft cruciform drogue parachute for the aft section. These sizes will ensure the landing kinetic energy of each section is below 75 ft-lbf. Based on MATLAB and OpenRocket models, these sizes also yield a descent time under 90 seconds and a drift radius under 2500 ft.

3.3.1.5 Bridle and Shock Cord Material

The OSRT will use nylon webbing for its bridle and shock cord material. This material is more elastic than Kevlar which will reduce the snatch load and reduce the chance of the cord failing. Nylon webbing is also softer and thicker in size than Kevlar which will reduce the chance of zippering upon release of the main parachute. A Kevlar sleeve and Nomex blanket will be used to wrap the nylon bridle near the ejection charges to compensate for the poor thermal resistance of nylon. The OSRT will use 1 in. nylon webbing with a rating of 4,000 lb. This results in a large factor of safety for the forces the launch vehicle is expected to experience. A 1 in. nylon webbing shock cord from Fruity Chutes is shown in Figure 29.

Figure 29: 1 in. Nylon Webbing Shock Cord

3.3.1.6 Packing Method

The OSRT will use a deployment bag to pack both main parachutes. A Nomex blanket will be placed between the deployment bag and the ejection charges to add more thermal protection to the parachute. The packing method of the parachute in the bag is a method recommended by OSRT advisers that will unravel and inflate quickly upon the removal of the deployment bag. The use of a deployment bag will increase the extraction and inflation control of the parachute because the deployment bag will remain on the parachute until its shroud lines are taut, ensuring that inflation occurs outside the airframe. The deployment bag will also add protection to the parachute and simplify storage and assembly of the recovery system. The OSRT decided it was unnecessary to use a deployment bag for both drogue parachutes. The drogue parachutes will be folded around the shroud lines and then wrapped around a Nomex blanket for thermal protection from the ejection charges.

3.3.1.7 Altimeters

According to Rule 2.3 under launch vehicle requirements in the University Student Launch Initiative (USLI) handbook, at least one barometric altimeter is required to be located within the launch vehicle. This altimeter has to be capable of igniting ejection charges, sensing altitude based off of the external pressure, and recording altitude and pressure at consistent time intervals. A minimum of two altimeters is needed for OSRTs full scale launch vehicle. Six altimeters capable of igniting ejection charges will be contained in the launch vehicle: three in the fore section and three in the aft section. A seventh altimeter only capable of recording altitude and pressure at consistent time intervals will be located with the fore avionics bay. The altimeters capable of igniting ejection charges will be the Missile Works RRC3 and the PerfectFlite StratoLoggerCF. One Missile Works RRC3 and two StratoLoggerCF will be located in both the fore and aft sections. The seventh altimeter will be a Jolly Logic AltimeterThree.

Missile Works RRC3 has a proven track record with OSRT. Many flights have been flown successfully with these altimeters. The RRC3 has many advantages: it provides three outputs, meaning it can ignite three ejection charges. Only two outputs are necessary for the launch vehicle, but in the case one output is malfunctioning, the third could be used instead of having to replace the altimeter. The altimeter provides noise reduction for more accurate pressure readings and can log 15 flights.

The PerfectFlite StratoLoggerCF altimeter has many great features, and it has been flown by OSRT with success. The altimeter can have a delay set at apogee, making it perfect for a back-up altimeter, and the altitude which the main parachute is released can be set in 1 ft increments. However, after both altimeters have been flown, OSRT noticed that the StratoLoggerCF sensed and fired closer to the correct altitudes, making it more ideal for primary instead of secondary.

The Jolly Logic AltimeterThree is a newer altimeter capable of connecting with a tablet or a smartphone. The altimeter has many great functions. All of the data from the flight is sent directly to the paired device, showing a 2D plot of the flight trajectory labeled with burnout thrust time, maximum altitude and time to reach it, descent rates under main and drogue parachutes, and landing velocity. Additionally, the AltimeterThree is very small and lightweight. The OSRT is in possession of one of these altimeters, so it will be attached to the fore ejection bay. The AltimeterThree provides no additional functionality, however it provides the team with the ability to rapidly view flight data after recovery.

One of the StratoLoggerCF altimeters will be used as the primary altimeter in both the fore and aft sections, and the RRC3 will be the secondary altimeter in both the fore and aft sections. The StratoLoggerCF altimeters will have no apogee delay, and the main parachute deployment altitude will be set to 700 ft AGL. The RRC3 will have an apogee delay of one second, and the main parachute deployment altitude will be set to 700 ft AGL. The second StratoLoggerCF altimeter in both the fore and aft sections will be connected to two ejection charges each set to fire at 600 and 550 ft AGL. The primary StratoLoggerCF altimeters will be connected to the primary ejection charges and the forward Tender Descender. The RRC3 altimeters will be connected to the secondary ejection charges and the aft Tender Descenders.

Shown in Figures 30 and 31 are the manufacturers schematics for the Missile Works RRC3 and the PerfectFlite StratoLoggerCF altimeters respectively.

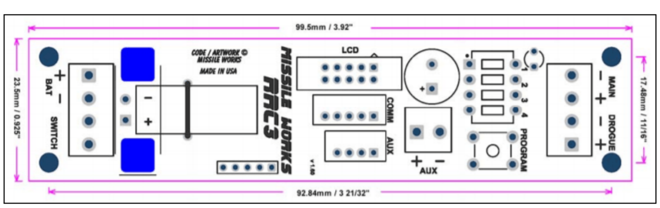

Figure 30: RRC3 Schematic

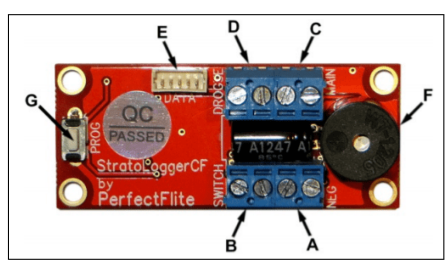

Figure 31: StratoLoggerCF Schematic

Looking at Figure 30, the battery and switch attach to the terminal on the left side. For the right terminal, the main parachute e-match is wired to the top two ports, and the drogue e-match is wired to the bottom two ports. If a third output port is needed, the e-match would be wired to the AUX port.

Looking at 31, the letters represent the following:**A** is the battery terminal block; **B** is the power switch terminal block; **C** is the main ejection output terminal block; **D** is the drogue ejection output terminal block; **E** is the data I/O connector; **F** is the beeper. **G**is the preset program button.

3.3.1.8 Main Parachute Retention

In OSRTs PDR submission, several methods of retention were considered. The design choice decided upon was two Tender Descenders connected in series. Since the submission, two design choices have been considered: two Tender Descenders connected in series and an ARRD connected to a Tender Descender in series. Shown in Table 15 is a Design Decision Matrix (DDM) for the two choices. Below is a list of the chosen constraints:

- Space Efficiency: The overall length of the launch vehicle needs to be limited to reduce weight.
- Reliability: The recovery components need to function reliably.
- Redundancy: Relying on one release mechanism is risky. Including a second component raises the chances of successfully releasing.
- Ease of Attachment: The recovery components need to attach to the bulkhead easily.

Table 15: Main Parachute Retention DDM

Design		**Two Tender Descenders**		**One Tender Descender and One ARRD**	
Requirement	Weight	Rating (1-5)	Score	Rating (1-5)	Score
Space Efficiency	6	3	18	4	24
Reliability	9	3	27	4	36
Redundancy	5	3	15	4	20
Ease of Attachment	4	3	12	4	16
Total		**72**		**96**	

Using one ARRD connected in series with a Tender Descender is slightly more space efficient - an ARRD is slightly shorter than an L2 Tender Descender. ARRDs function more reliably than Tender Descenders. Both systems are redundant, but using two different devices increases redundancy by avoiding the same error causing the same device to fail. An ARRD is easier to attach to a bulkhead. While a Tender Descender requires an attachment point on the bulkhead, an ARRD just requires a nut and a hole in the bulkhead. One Tender Descender in series with one ARRD is what was used in both subscale launches. The manufacturer of the ARRD has since stopped producing the item; due to the unavailability of ARRDs, two Tender Descenders in series will be used in both the fore and aft sections.

3.3.1.9 Reduction of Zippering Chance

In OSRTs PDR submission, the team decided that an artificial zipper would be implemented to reduce the risk of the airframe being zippered. In Rick Newlands' "Parachute Recovery System Design for Large Rockets," he presents a method for reducing zippering called an artificial zipper. An artificial zipper, pictured in Figure 32, which is a variation of a frangible tie which uses tape instead of sewn sections of shock cord, will be incorporated into the drogue section of shock cord. This will reduce the difference in relative velocity between the drogue parachute and the airframe. While z-folding the nylon shock cord, the folds can be taped together. When the ejection charges are fired, the tape will tear, dissipating some of the load, slowing the drogue parachute. This slowing of velocity lowers the snatch load experienced by all recovery components. Consequently, this lower velocity will decrease the force impacted on the edge of the airframe, decreasing the chance of zippering the airframe.

Figure 32: Artificial Zipper

In addition to an artificial zipper, the airframe will have additional strength added to the ends where the parachutes are deployed. This is done through the addition of extra layers of fiberglass for the top 6 in. by the manufacturer, ICE.

3.3.1.10 Ejection Charges

It was determined in OSRTs PDR submission that the type of ejection charge which will be used is black powder. Black powder is the most commonly used method for separating high powered rockets and launch vehicles. It is reliable and has been proven over and over to work.

The ejection charges are made of black powder and surgical tubing. The surgical tubing is 1/2 in. inner diameter and 3/4 in. outer diameter. One end of surgical tubing is plugged with about half of an inch of santoprene and sealed shut with a zip-tie. It is then filled with half of the prepared black powder. The igniter end of an e-match is placed into the black powder and the rest of the black powder is funneled over the igniter. The charge is plugged with another piece of santoprene and the powder is compressed between the two end pieces. The charge should have almost no give when squeezed. This end of the charge is also sealed with a zip-tie. Figure 33 displays a properly assembled ejection charge.

This provides a more reliable charge than alternatives such as alternatives considered such as cups with masking tape sealing them by reducing the susceptibility to human error. All charges are examined to ensure the explosion is through the wall of the surgical tubing, not by ejecting the santoprene plug. This ensures that the tightness of the zip-tie used does not effect the charge. Figure 34 displays two ejection charges which exploded through the wall of the surgical tubing during a subscale flight.

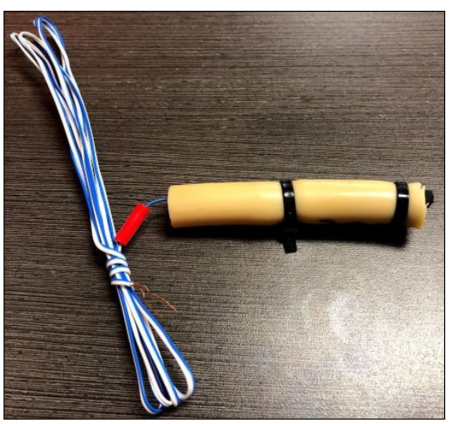

Figure 33: An example of an assembled ejection charge.

Figure 34: Ejection charges exploding through the wall of the surgical tubing.

3.3.1.11 Ejection Charge Sizing

To determine how large the charges should be, the following equations are used:

$$BlackPowder(g) = (CompartmentDiameter)^2 * CompartmentLength * 0.006 + 1 \tag{10}$$

$$BlackPowderAft(g) = (6.107in.)^2 * (10.5in.) * 0.006 + 1 = 3.35grams \tag{11}$$

$$BlackPowderAft(g) = (6.107in.)^2 * (10.5in.) * 0.006 + 1 = 3.35grams \tag{12}$$

The addition of one at the end of the equation is to be sure that the charges are strong enough and to account for any pressure loss due to faulty seals. The components have been engineered to handle more than what is necessary for the charges to deploy the parachutes so adding an extra gram of black powder will not hurt any components. Ejection testing will be done to confirm the ejection charge sizes. Testing will begin using the size listed above. If the charge size is not large enough, the charge size will increase by 0.5 grams until five successful ejection tests are completed in a row.

3.3.1.12 E-matches

Every ejection charge will be ignited with an electric match, which will be referred to as an e-match. The lead on the e-matches will be in the middle of all ejection charges, surrounded by black powder, and the opposite end is wired directly to the altimeters. Both the primary and secondary charges will be threaded through a hole drilled in the bulkhead of the altimeter bay.

The e-matches OSRT has been using and will continue using are FireWire Initiators. These e-matches will be purchased by one of the team's mentors.

When using an e-match, the two wires should always be twisted around each other in a uniform manner. An e-match can resonate as an antenna if it is near an odd multiple of 1/4 wavelength of the frequency in question. Most of these devices, however, have very weak signals and are far enough away to not cause induced currents. Twisting the e-matches around each other will cancel out any resonance within the wires.

3.3.1.13 Arming Switch

Being able to arm the altimeters from the exterior of the airframe is important from a safety stand point because it deals with arming devices directly responsible for igniting the ejection charges. While contained within the airframe, the hazard of a premature charge firing is relatively small compared to when the charges are on the exterior of the airframe. Arming the altimeters is simple and is done by turning a switch with an Allen wrench. To get the Allen wrench to the switch while the altimeter bay is integrated, there must be pre-existing holes in the airframe. The static port holes in the airframe allow the bay to pressurize so that the altimeters can obtain pressure readings, however, that is not the only use for the static port holes.

They are also used to access the switches, which are located directly within the holes. Arming is done with a 3/32 in. Allen wrench and only when the launch vehicle fully prepared to be launched.

3.3.2 Avionics

The ATU system is composed of in flight units that receive, save, and encode GPS data before wirelessly transmitting it to a ground station that saves selected GPS data while providing a user interface that plots position information. The ground ATU is also responsible for triggering the Payload Ejection Controller (PLEC) once the launch vehicle has come to a standstill and clearance is given.

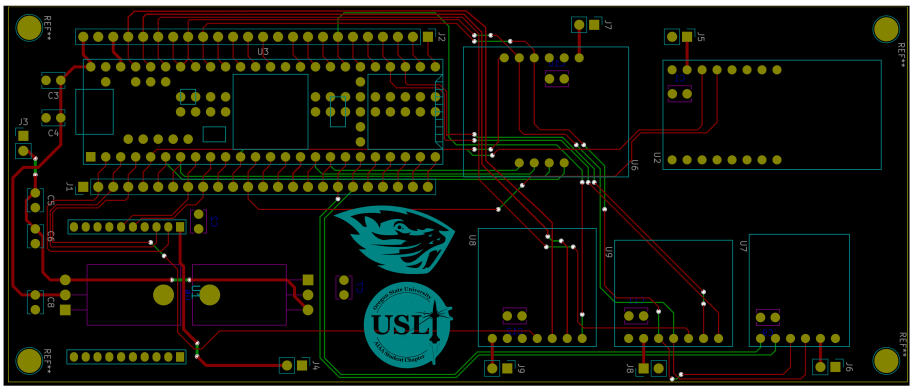

Figure 35: Diagram of Previous ATU PCB Revision

3.3.2.1 GPS Module & Antenna

The GPS system responsible for collecting and transmitting telemetry data is a SparkFun Venus GPS that the OSRT has tested and proven previously reliable. Functional GPS for recovery and competition purposes requires high Receive (RX) sensitivity, low power consumption, low time to first fix, and high position update frequency. High RX sensitivity and position update frequency ensure reliable transmission and reception of data even when under high signal attenuation or noise. Low power consumption and time to first fix give the ATU a high operational time and enable GPS lock to be attained or reattained quickly during pre-launch preparation and flight. High sensitivity and position update frequency also guarantee more reliable coordinate data and greater positional accuracy. The SparkFun Venus GPS unit was chosen because it satisfies mission requirements more effectively than alternative options from previous design considerations. SparkFun also offers thorough documentation and platform support, and the system is easy to integrate. The OSRT have also considered implementation of a different chip for the addition of Global Navigation Satellite System (GLONASS) support, but no design changes have yet been made due to resource and time constraints on the avionics team.

The GPS also utilizes an active antenna. The vast distance over which GPS satellites transmit renders the received signals very weak. In order to ensure maximum performance in a moving embedded system, a high gain active antenna capable of 30 dB of gain prior to baseband down conversion was chosen and implemented. This will aid in signal retention and lower the time to first fix.

3.3.2.2 RF Transceivers

The RF transceivers are responsible for data transmission between the ground and flight ATU. Key performance metrics include transmission strength, power consumption, range, reliability, data throughput, and ease of implementation. Transmission strength, range, and reliability determine the quantity and stability of data sent over the RF link. Power consumption is critical for determining potential ATU uptime. Ease of implementation is critical for a custom system and determines the variety and extent of features that can be added to the system and utilized effectively.

The ATU utilizes both a 900 MHz XBee Pro RF transceiver with XBee's software libraries and a Texas Instruments CC 1200 on the 433 MHz band using embedded code generated and configured via the SmartRF software suite. 900 MHz is designated as a commercial band by the federal government and thus no radio license is required to operate any hardware. However, since the 900 MHz is an open use frequency, 900 MHz devices are prone to interference from other devices on the band. To combat this, the ATU will primarily rely upon the 433 MHz transceivers as the 433 MHz band requires a Ham radio license to operate on, thus limiting the number of devices that can be actively causing interference over the frequency. The 900 MHz hardware remains on the system largely as a redundancy measure, and as a fallback in case any unforeseen circumstances render the 433 MHz hardware inoperable or less effective than necessary. The ATUs will run either with the 433 MHz transceivers at 250 mW or with the 900 MHz transceivers at 210 mW and the 433 MHz transceivers at 40 mW, depending on mission priorities.

Both the 900 MHz and 433 MHz bands offer line of sight range, high data throughput, and reasonable power consumption - which fits the mission profile requirements outlined previously. Both the XBee and TI modules were chosen due to high data throughput and relative ease of implementation. The XBee specifically already possesses software libraries that easily integrate with the control system code. The TI modules will require more work to implement, as SmartRF Studio code must be used to configure registers and other hardware modules. SmartRF Studio exports C code that can be integrated directly into the control system code, making implementation slightly more difficult but still within reasonable expectation. Both devices support Universal Asynchronous Receiver-Transmitter (UART) and Serial Peripheral Interface (SPI).

3.3.2.3 Ground & Launch Vehicle RF Antennas

The RF antennas for both the ground station and flight units have similar design requirements: both must have high gain, a low size profile, and a radiation pattern that allows consistent and reliable data transmission between the two systems despite unknown orientation between the ground station and launch vehicle during flight. A whip antenna is the chosen solution for the flight ATU on both frequency bands due to high gain, small form factor, omnidirectional radiation pattern, and low cost. The ground station utilizes a Terrawave T09150Y11206T Yagi antenna for optimal radiation spread, high gain, and high signal directionality in the face of power constraints given by the competition requirements.

3.3.2.4 Controllers

On-board data processing and routing is necessary for successful operation of the ATU. GPS packets must be filtered and encoded in a manner that ensures efficient bandwidth usage, dependable data transfer, and information retention. Both sides of the ATU system use a Teensy 3.6 microcontroller with an ARM Cortex-M4 180 MHz processor running embedded C and C++ code to satisfy mission requirements. The Teensy supports UART and SPI and boasts on on-board micro SD card slot that enables embedded data logging, providing a redundant way to corroborate or substitute for ground station data in the event of system malfunction. The Teensy was chosen due to high clock speed, low form factor, low power consumption, and support for preexisting software libraries.

The OSRT has also succeeded in creating a custom PCB for integrating all necessary components onto a single system. GPS, RF transceivers, and the Teensy microcontroller will all be able to communicate via traces rather than through prototyping or bread-boarded at home systems. This increases signal reliability and makes the system increasingly less likely to suffer from communication issues between each of the individual components within an ATU. Use of a custom PCB also enables higher data throughput and faster response times from each of the components while removing potential bottlenecks from wiring.

A new revision of the OSRT ATU PCB has been designed and is being implemented for inclusion of the 433 MHz transceiver hardware along with the 900 MHz system. This new PCB will also support integration of a data logging module with an onboard IMU, accelerometer, and sensors for barometric pressure, altitude, and temperature to provide further redundancy to the launch vehicle's computational systems.

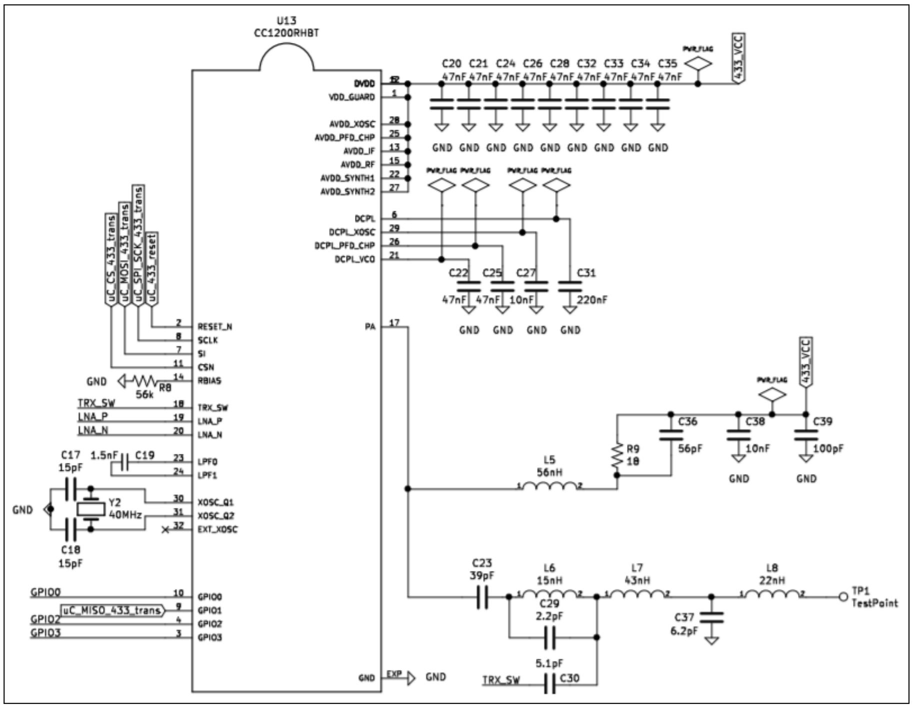

Figure 36: CC1200 Hardware Schematic for New ATU PCB Revision

3.3.2.5 Batteries

The ATU requires a power delivery system that is reliable, high duration, low form factor, and satisfies the voltage, current, and energy constraints of each of the electrical components in the system. Rechargeable prismatic Lithium Polymer (LiPo) batteries are used due to high current and power capacity requirements. Each ATU, along with the ground station, has its own identical power delivery system. Long-lasting power delivery is necessary to reach the operational uptime required by the competition. On-pad testing with the subscale launch has demonstrated that the current ATU system is capable of around ten hours of concurrent operation.

3.3.3 Recovery Integration

The final recovery design will consist of two separate dual deployment recovery systems: one in the fore section and one in the aft section. Figure 37 shows the expected flight of the full scale vehicle.

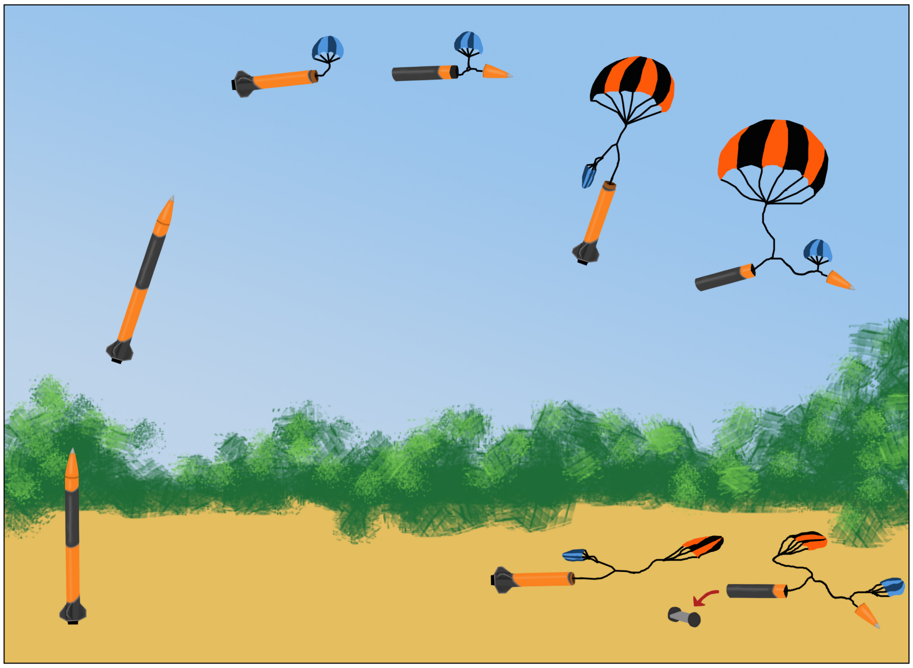

Figure 37: Recovery Separation Events (Not To Scale (NTS))

The two dual deployment systems are nearly identical. The fore system is shown in Figure 38, and the aft system is shown in Figure 39.

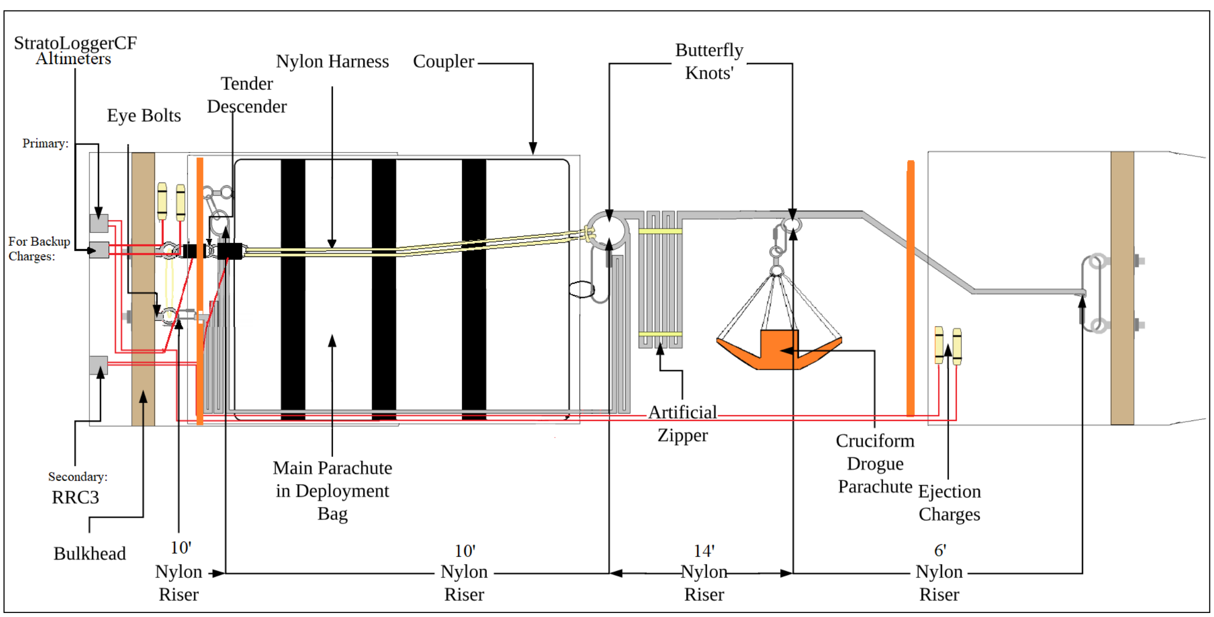

Figure 38: Fore Recovery Integration (NTS)

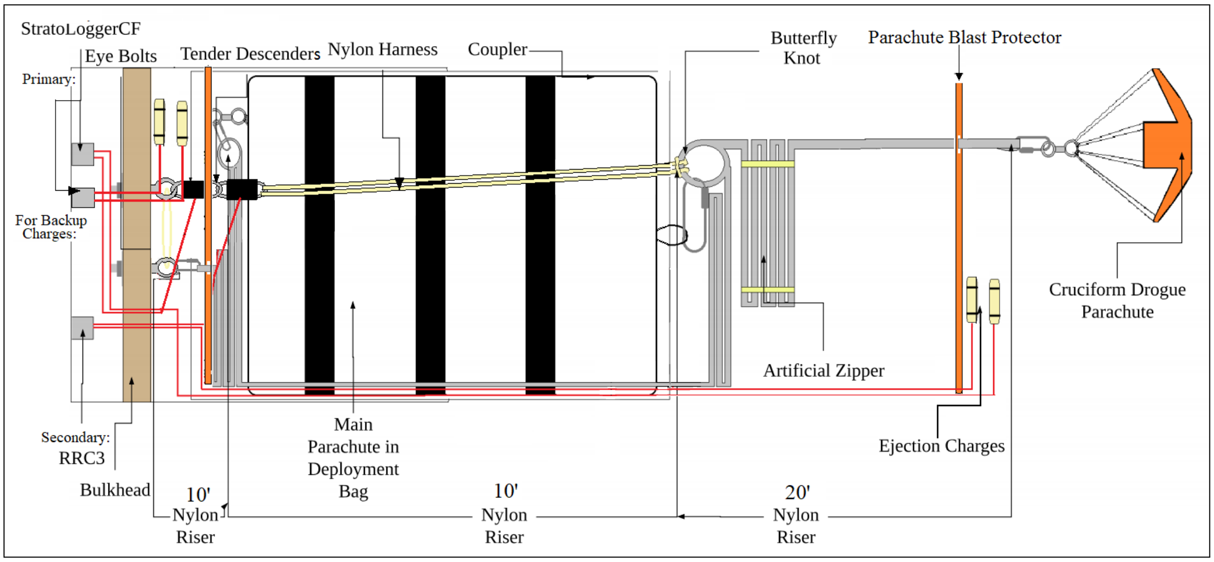

Figure 39: Aft Recovery Integration (NTS)

In the fore recovery system, the aft bulkhead has two eye bolts bolted to it with nylocs. The eye bolts are aligned and located along the center of the bulkhead. Two Tender Descenders in series are attached to one of the eye bolts, and two e-matches are threaded through the bulkhead and attached to them. Four more e-matches attached to ejection charges are threaded through the bulkhead. Two of these have 10 in. of slack, and the other two are located at the bottom of the recovery system, taped to the wall of the airframe. All e-matches are connected to to altimeters in the Altimeter Bay. All of these components attached to, or threaded through, the bulkhead have rubber washers to aid with a pressure seal. An extra wide quick link is attached to both eye bolts. The end of the riser closest to the main parachute is looped around this extra wide quick link. The main parachute swivel will be attached to a butterfly knot 10 ft down the riser with a quick link. 10 ft down the riser from the first butterfly knot is a second butterfly knot. This is attached to the loop at the top of the deployment bag with a standard quick link. This knot is also attached to a 2 ft riser, folded in half, with a cow hitch. The other end of this riser, which has pre-sewn loops, is attached to the Tender Descender. Just past this knot is a parachute blast protector. The ejection charges and cellulose insulation are wrapped with this heat shield. Cellulose insulation is also placed on both sides of the heat shield. A third butterfly knot is tied 14 ft down the riser from the previous knot, and the drogue swivel is attached to this loop with a quick link. Between the deployment bag knot and the drogue parachute knot is an artificial zipper. The end of the riser is 6 ft further down the riser. This end is attached the fore bulkhead in the same manner as the aft bulkhead.

The aft recovery system is the same up until where the drogue parachute attaches to the riser. The third butterfly knot is not tied into the riser. Instead, the drogue parachute is attached to the end loop with a standard quick link.

All recovery components in both the fore and aft sections have been specified to withstand 50 Gs of acceleration for each respective sections weight. This number was chosen based off of advice from mentors and previous rocketry teams.

3.4 Mission Performance Predictions

3.4.1 Simulations

3.4.1.1 Flight Profile

The OpenRocket simulation shows that the launch vehicle will reach an apogee altitude of 5,296 ft with no wind. Upon exit of the twelve ft rail, the launch vehicle will be traveling 88.8 ft/s. The launch vehicle will reach apogee in 17.9 s. The 1.5 ft drogue parachute will deploy at apogee for both the fore and aft sections The 8 ft main parachute for the fore section and the 8 ft main parachute for the aft section deploying at 700 ft during descent. With 0 mph winds, both sections will return to the ground 72 s after separating at apogee for a total flight time of 89.9 s. With no wind, the fore section will hit the ground at 14.4 ft/s. and the aft section will hit the ground at 13.8 ft/s. The OpenRocket model can be seen in Figure 40.

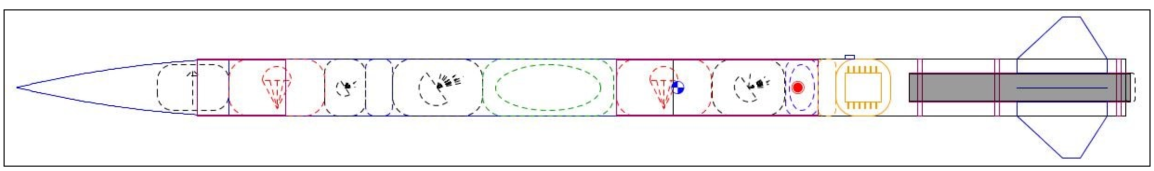

Figure 40: OpenRocket of OSRT Launch Vehicle

3.4.1.2 Altitude Predictions

Altitude projections are slightly decreased with the presence of horizontal cross winds. The projected apogee altitude was simulated at 0, 5, 10, 15, and 20 mph winds. A plot of the flight profile at 10 mph winds can be seen in Figure 41. The projected altitudes for each of the wind speeds can be seen in Table 16. All of the projected altitudes are without ballast or the presence of the BEAVS system. Ballast bays and the BEAVS system will be used to achieve an exact apogee of 4,500 ft depending on launch day conditions.

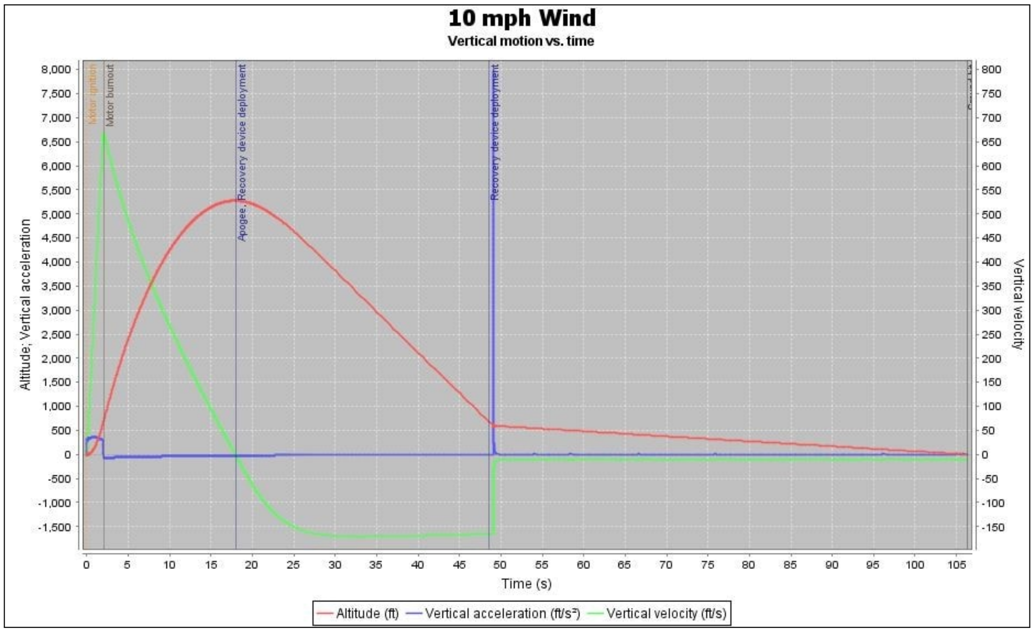

Figure 41: OpenRocket Flight Profile with 10 mph Winds

Table 16: Altitude predictions with varying wind speeds and no ballast.

Wind Speed (mph)	Projected Altitude (ft)
0	5296
5	5290
10	5274
15	5251
20	5206

The BEAVS will include a pair of ballast bays which maintain a constant stability, while also adjusting the apogee altitude based on wind conditions. Ballast calculations between fore and aft were determined based on the ratio of distances of the ballast bays to the center of gravity of the launch vehicle. The distance to the aft ballast bay is 48.3% of the distance to the fore ballast bay, which means the mass in the fore ballast bay should be 48.3% of the mass in the aft ballast bay to maintain stability. Simulations were performed in OpenRocket, with results displayed in Table 17.

Table 17: Ballast for varying wind speeds.

Wind Speed (mph)	Aft Ballast (lbf)	Fore Ballast (lbf)	Stability (cal)	Apogee Altitude (ft)
0	0.8	4.09	2.45	4726
5	0.8	4.09	2.45	4720
10	0.8	4.09	2.45	4706
15	0.8	4.09	2.45	4668
20	0.8	4.09	2.45	4628

3.4.1.3 Motor Thrust Curve

The motor thrust curve of the Cesaroni L2375-WT used in the OpenRocket simulations can be seen in Figure 42.

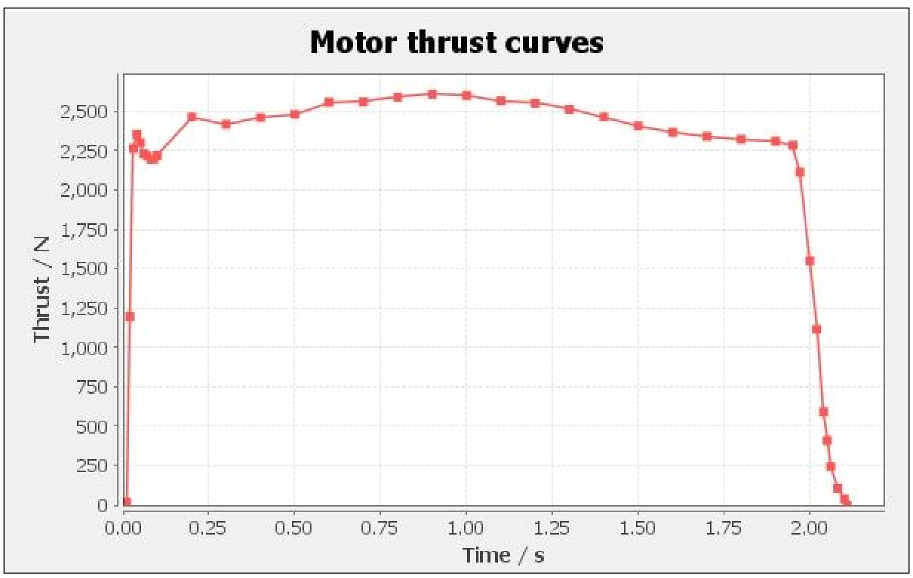

Figure 42: Motor Thrust Curve of Cesaroni L2375-WT

3.4.1.4 Component Weights

The component weights can be seen in Table 18. The components are separated into what was used to create the OpenRocket simulation.

Table 18: Component Weights

Component	Component Description	Weight (lbf)
Motor	Motor, Motor Tube, Fore Enclosure, Centering Rings, Motor Retainer	10.87
BEAVS	Mechanical System, Aft Ballast, Electrical System	2.68
Camera	Camera, Fixture, Electronics	2.65
Aft Avionics/Ejection Bay	Avionics, Altimeters, Fixture, Charges	2.33
Aft Parachutes	Drogue Parachute, Main Parachute, Shock Chord, Deployment Bag, Blankets, Connection Hardware	3.38
Payload	Rover, PEARS	8.89
Fore Hard Point	Hard Point, Fore Ballast Bay	0.87
Fore Ejection Bay	Altimeters, Fixture, Charges	1.72
Fore Parachutes	Drogue Parachute, Main Parachute, Shock Chord, Deployment Bag, Blankets, Connection Hardware	3.47
Fore Avionics Bay	Avionics, Fixture	0.65
Nosecone	Fiberglass Nosecone, Aluminum Nosecone Tip	1.54
Fins	Fins, Epoxy	1.41
Aft Airframe	Fiberglass and Carbon Fiber Tube, Fore/Aft Coupler	4.85
Fore Airframe	Fiberglass Tube, Fore/Nosecone Coupler	3.59

3.4.2 Stability Margins

Fins were designed to achieve a stability margin of 2.1 calibers with the component weights given in Table 18. The OpenRocket model with each component weight and length input gives a center of gravity at 73.02 in. aft of the nosecone tip. To achieve a stability of 2.1, the center of pressure is located 86.29 in. aft of the nosecone tip. The center of gravity can be seen as the blue dot in Figure 40. The center of pressure is represented by the red dot in Figure 40. RockSim was also used to calculate the stability margin of the launch vehicle. The same component weights and lengths were input into a RockSim model. The center of gravity was calculated to be 72.91 in. aft of the nosecone tip. The center of pressure was calculated to be 86.24 in. from the nosecone tip. These locations determine a stability margin of 2.13 calibers. The slight difference in values can be attributed into how the two different programs estimate weights for components like the airframe, fins, and nosecone. The values are very similar, giving confidence in a safe static stability margin.

3.4.3 Kinetic Energy Analysis

A MATLAB script was used to calculate the landing kinetic energies of each recovered section of the airframe. This code was verified to be accurate based on the results of the subscale launch. The weight, landing velocity, and landing kinetic energy of each section are shown in Table 19. It can be seen that with both main parachutes successfully deploying, the kinetic energy at landing is under the maximum value of 75 ft-lbf but is close. By adding the 17% buffer found by comparing the theoretical data and actual data from the subscale launch, these values are comfortably below the maximum value.

Table 19: Landing Kinetic Energy

Measurement	Fore Section	Aft Section	Nosecone
Weight (lbf)	18.51	23.081	2.2
Velocity with Main and Drogue Deployed(ft/s)	13.2	14.0	13.2
Kinetic Energy with Main and Drogue Deployed (ft-lbf)	50.2	69.8	7.0
Velocity with Only Drogue Deployed (ft/s)	111.0	112.0	111.0
Kinetic Energy with Only Drogue Deployed (ft-lbf)	3,480.6	4,499	421.2
Velocity with no Parachutes Deployed (ft/s)	115.0	116.0	115.0
Kinetic Energy with no Parachutes Deployed (ft-lbf)	3,804.2	4,826.5	452.2

3.4.4 Expected Descent Times

A MATLAB script was written to calculate the descent time of each section of the airframe. This simulation was verified to be accurate by the results of the subscale launch. Under a 1.5 ft cruciform drogue parachute and a 8 ft toroidal main parachute for both the fore and the aft sections, the trajectory of the descent for both sections were calculated on MATLAB and accounts for the changing air densities at different altitudes as well as the acceleration and deceleration of the launch vehicle at apogee and at deployment. This is shown in Figure 43. It can be seen that both sections land in under 90 s. The exact descent time can be seen in Table 20.

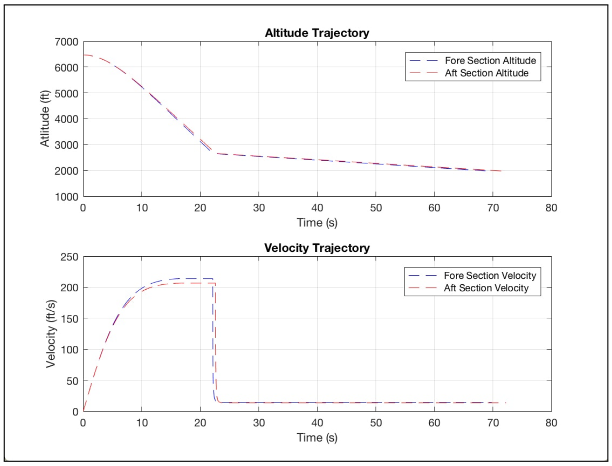

Figure 43: Descent Trajectory

3.4.5 Drift Calculations and Analysis

A MATLAB script was written to calculate the drift of the descending launch vehicle sections. This simulation was verified to be accurate by the results of the subscale launch. The wind speed was assumed to be a constant crosswind that does not impact the vertical trajectory. Weather cocking was not included in this calculation so it was assumed that apogee occurred directly above the launch pad. This is a conservative approach because weather cocking pushes the launch vehicle the opposite direction of the drift. These calculations are shown in Table 20. These are compared with drift calculations from OpenRocket.

Table 20: Drift and Descent Time

Wind Speed (mph)	**0**	**5**	**10**	**15**	**20**	**Descent Time (s)**
Drift of the Fore Section (ft)	0	552	1,104	1,657	2,209	75.3
Drift of the Aft Section (ft)	0	526	1,052	1,576	2,104	71.7
OpenRocket Simulation (ft)	8	206	574	651	1,185	72.7

It can be seen that the drift calculations done on MATLAB and OpenRocket differ significantly, but all values stay under the maximum allowable drift radius of 2,500 ft. This difference is because the OpenRocket simulation includes weather cocking in the analysis. The descent time for all sections also stays below the maximum allowable descent time of 90 s.

4 Safety

4.1 Launch Concerns and Operation Procedures

Throughout the design process, OSRT has remained aware of assembly and launch day concerns. This includes consideration of all elements of launch day preparation and assembly. Design decisions have been made in order to aid the assembly process. A series of checklists have been developed by OSRT, which represent all assembly processes in detail.

4.1.1 Pre-Field Inspection

- **Necessary Items:** aft section; fore section; nosecone; coupler; motor casing; motor retainer; BEAVS; denatured alcohol; paper towels; Fore ATU LiPo; Aft ATU LiPo; 2 balance chargers; multimeter; 5 Universal Serial Bus (USB) hubs; 5 micro-USB cables, camera batteries
- Safety Consideration: Ensure all objects not related to pre-field inspection are removed from work area. Use caution handling launch vehicle components. Use caution when handling LiPo batteries to avoid battery damage and explosion. Safety Officer (SO) must sign off on the pre-field inspection.

1) Inspect fins for any chips or surface damage.
2) Inspect epoxy fillets at fins for cracks or damage.
3) Inspect aft section of airframe for zippering or delamination.
4) Inspect fore section of airframe for zippering or delamination.
5) Inspect motor retainer for cracks or bends.
6) Inspect airframe for dirt, and clean off any dirt.
7) Check couplers and airframe for shear pins and remove any found.
8) Inspect nosecone for chips or cracks.
9) Inspect nosecone tip for scratches or deformation.
10) Inspect BEAVS for any cracks or bends.
11) Inspect motor casing for any marks, dents, or other visible damage.
12) Charge all batteries:
    - Fore ATU LiPo and record voltage
    - Aft ATU LiPo and record voltage
    - Camera batteries

- Safety Consideration: Failure to record and repair any damage from the flight may result in complete mission failure of mission.

4.1.2 Pre-Flight Inspection

- **Necessary Items:** aft section; fore section; nosecone; coupler; motor casing; motor retainer; denatured alcohol; paper towels
- Safety Consideration: Remove all objects not related to pre-flight inspection from the work area. Keep all sharp objects away from airframe components and use caution handling them; damage to the airframe can cause potential hazards. SO must sign off on Pre-flight inspection.

1) Inspect fins for any chips or surface damage.
2) Inspect epoxy fillets at fin attachment points for cracks or damage.
3) Inspect aft section of airframe for zippering or delamination.
4) Inspect motor retainer for cracks or bends.
5) Inspect airframe for dirt and then clean.
6) Check airframe, couplers and canister for shear pins and remove any found.
7) Inspect nosecone for chips and cracks.
8) Inspect nosecone tip for scratches or deformation.
9) Inspect motor casing for any marks, dents, or other visible damage.

- Safety Consideration: Failure to record and repair damage from any previous flights may result in complete mission failure.

4.1.3 Recovery Preparation

Three separate procedures will be needed for proper parachute and recovery preparation. The first procedure will be the drogue parachute packing procedure. The second procedure will be the main parachute folding and packing procedure. The third procedure will be the preparation of recovery components to be integrated into the airframe.

Additionally, the avionics system must be prepared and armed before the launch vehicle is assembled.

4.1.3.1 Drogue Parachute

- **Necessary Items:** 2 1.5 ft X-form drogue parachutes, 2 swivels, masking tape, and 2 red REMOVE BEFORE FLIGHT tags.
- Safety Consideration: Ensure all sharp objects, heat sources, and corrosive materials are removed from work space. Work space should be clear of any items not related to harness and parachute prep. Failure to follow all steps will result in complete mission failure due to recovery failure.

1) Get the 18 in. X-form drogue parachute (check the marking on center square to check size).

2) Ensure there are no tears in the parachute nylon.
3) Ensure deployment bag is in good condition.
4) Ensure shroud lines are untangled.
5) Inspect the shroud lines for burns or tears and ensure there is no fraying.
6) Secure the drogue to a swivel using a cow hitch so that the center of the shrouds (marked in black) are in the center of the hitch.
7) Pull the drogue up and ensure the shrouds are not tangled.
8) Roll the drogue parachute:
   a. Fold the parachute in half so 2 opposite squares are on one another.
   b. Fold the remaining 2 squares under the top and create a point in the center of the parachute.
   c. Bring the shroud lines together and lay them running up along the right 3rd line of the chute so the swivel is at the top.
   d. Fold the right 3rd of the chute over the shroud lines.
   e. Lay the rest of the shroud lines running down along the left 3rd line of the chute so the swivel is at the bottom again.
   f. Fold the left 3rd of the chute over the shroud lines, only 1-2" of the shrouds should be exposed out the bottom.
   g. Tightly roll the drogue parachute from the top until it is bundled.
   h. Wrap the bundle with masking tape to secure it closed and label the tape "18 in."; place a REMOVE BEFORE FLIGHT tag under the tape. This tag should be labeled "#3".
9) Ensure all extraneous masking tape is removed prior to launch.

- Safety Consideration: Ensure REMOVE BEFORE FLIGHT tag is placed under the tape holding it closed.

Repeat this procedure for both the fore and aft drogue parachutes.

4.1.3.2 Main Parachute

- **Necessary Items:** two 96 in. Standard Iris Parachutes, two 5.5 in. by 7 in. deployment bags, masking tape, 2 swivels, and 4 red REMOVE BEFORE FLIGHT tags.
- Safety Consideration: Ensure all sharp objects, heat sources, and corrosive materials are removed from work space. Work space should be clear of any items not related to harness or parachute prep. Failure to follow all steps will result in complete mission failure due to recovery failure.

1) Lay out parachutes so that each set of shrouds is below them.
2) Gather 4 shrouds to the right, 4 shrouds to the left, and 4 shrouds to the middle, excluding the center shrouds.
3) Wrap tape around the right shroud lines at the farthest bottom point of the lines to keep them together.

4) There are 2 shrouds on top and 2 shrouds on bottom. Take 2 lines that are opposite and diagonal of each other and pull them together so that they are aligned with the center shrouds. This is now the center line.
5) Ensure that the gores laying on top of each other are opposite colors (orange and black).
6) Pull on the center shroud lines until the spill hole is aligned with the bottom of the parachute.
7) Take the closest gore to the center and fold the stitched line onto the center line. Repeat this process for one side of the canopy until all the gores are folded.
8) Repeat the previous step for the opposite side.
9) Ensure the two sections are opposite colors.
10) Flatten the folded canopy as much as possible by pushing out all the air.
11) Fold the right side of the canopy in half by taking the furthest edge of the outside and folding it onto the center line.
12) Repeat the previous step for the opposite side.
13) Fold the canopy in half along the vertical center line.
14) Ensure the canopy is folded into a long thin rectangular shape.
15) Pack the folded canopy into the deployment bag with the shock cord side facing out by compressing the canopy until it fits.
16) Take all of the shroud lines and fold them over the deployment bag. Then, double back the shrouds to the bottom of the bag, and the guide the folded section through the bands on the bag.
17) Repeat the previous step for the second section of bands.
18) Fold the deployment bag flap over the shroud lines. Take the masking tape and tape the deployment bag shut.
19) Grab the REMOVE BEFORE FLIGHT tag labeled "#1". Attach the tag to the deployment bag.
20) Grab the REMOVE BEFORE FLIGHT tag labeled "#2". Attach the tag to the bottom of the shrouds.
21) **NOTE:** Ensure all masking tape is removed prior to launch BEFORE the REMOVE BEFORE FLIGHT tags are removed.

- Safety Consideration: Ensure REMOVE BEFORE FLIGHT tag is placed under the tape holding the tag closed.

Complete these steps for the fore and aft main parachutes.

4.1.3.3 Recovery Harness

- **Necessary Items:** 2 packed 18 in. X-form drogue assemblies; masking tape; 2 96 in. Iris Ultra main parachutes packed in deployment bag assemblies; two 18 in. x 18 in. parachute blast protectors; sharpie; 2 42 ft nylon risers; 7 standard quick links; 5 extra wide mouth quick links; 4 3 ft Kevlar sleeves; Kevlar cord; two 2 ft nylon risers.

- Safety Consideration: Ensure that a REMOVE BEFORE FLIGHT tag is placed under the masking tape holding it closed.

1) Get two 42 ft nylon risers.
2) Repeat the following steps for both risers. The first system to be made is the fore section.
3) Inspect the riser for any tearing or excessive scorching; inspect the butterfly loops (if still tied) for any stressed areas.
4) Skip this step for the aft riser. Tie/ensure a single butterfly loop is located 6 ft from the nosecone stitched loop. This loop is for the drogue and will be referred to as loop #1.
5) Slide the Kevlar sleeve over the drogue end of the riser. Secure the sleeve to the riser just below the stitched loop with masking tape.
6) Tie/ensure a single butterfly loop is located 14 ft from loop #1. This is for the deployment bag and will be referred to as loop #2.
7) Tie/ensure a single butterfly loop is located 10 ft from loop #2. This is for the main parachute and will be referred to as loop #3.
8) Check that there is about 10 ft left of riser between the stitched loop and loop #3.
9) Tape an artificial zipper along the riser between loop #1 and loop #2. The artificial zipper should be 6 thicknesses of the riser.
10) Place the drogue swivel on a standard quick link, and attach this quick link to loop #1. Ensure quick link is tightened all the way down. For the aft section, attach it to the stitched loop at the drogue end of the riser.
11) Place the main swivel on a standard quick link, and attach this quick link to loop #3. Ensure the quick link is tightened all the way down.
12) Slide the second Kevlar sleeve over the main parachute end of the riser. Secure the sleeve to the riser just above the stitched loop with masking tape.
13) Attach a wide-mouth quick link to each end of the riser. Leave the quick links fully open. For the aft section, only the main side of the riser has a wide mouth quick link.
14) Slide an 18 in. x 18 in. parachute blast protector over each end of the riser to the end of each Kevlar sleeve.
15) Secure each parachute blast protector in place with a length of Kevlar thread. Take some of the thread and pass it through the hole in the parachute blast protector. Pass the thread through the sewn loop. Cut 6.5 ft of thread. Ensure the length of thread has passed through both loops and tie the ends together with two square knots. Repeat this with the other parachute blast protector.
16) Ensure the parachute blast protectors cannot slide further along the riser than the end of the Kevlar sleeves.
17) Measure 8 in. down the 2 ft nylon riser. Attach this point of the riser to loop #2 with a cow hitch.

18) Connect a standard quick link to loop #2 and to the loop at the top end of the deployment bag.

4.1.4 Fore Ejection Bay Assembly

Necessary Materials: Altimeters PCB, 4 black powder charges (primary and secondary for main and drogue parachutes), fore altimeters sleds, fore body wall, fore ejection pressure seal, 2 new 9V batteries.

Necessary Tools: Wire cutters, multimeter, small flat-head screwdriver, Phillips-head screwdriver, 7/16 in. socket, 1/2 in. socket, socket wrench, socket extension, 3/32 Allen wrench.

Necessary PPE: Safety glasses, leather gloves, face shield, non-synthetic sleeves.

- Safety Consideration: Only members with High Powered Rocketry (HPR) Level 1 certifications will handle black powder.
- Safety Consideration: Black powder charges should be kept separate from any ignition or heat sources.
- Safety Consideration: Notify people in the area that black powder is being used. Wear appropriate PPE.

1) Test 9 V batteries with multimeter. Batteries should read no lower than 9 V.
2) Place the batteries into the battery cases.
3) Secure the batteries by tightening screws on the cases.
4) Retest all connections with the multimeter.
5) Test altimeters by rotating the Allen wrench switch clockwise.
6) After the altimeter beeps, rotate the switch counter-clockwise by one quarter turn.
7) Insert charge leads through the fore ejection pressure seal.
8) Cut extra leads leaving approximately 2 in. to connect to.
9) Insert the leads into the appropriate terminals.
10) Secure leads by tightening terminal screws.
11) Screw pressure sealing washer onto the fore side of the pressure seal. Check that all leads are sealed by the washer.
12) Insert the fore ejection altimeter mounts into the body wall.
13) Attach the body wall to the pressure seal by installing four 6-32 bolts.
14) Insert the fore ejection bay into the fore body tube along the aligning rail.
    - Safety Consideration: Be sure that the charges are not being pinched or rubbed throughout the installation process.
15) Check that the altimeter switches are accessible from the exterior of the airframe through the static port hole.
16) Secure the fore ejection bay with six 10-32 bolts mounted radially on the airframe.
17) Compress the sealing bulkheads by tightening all six sealing bolts.

4.1.5 Aft Electronic Bay Assembly

Table 21: Aft Electronic Bay Assembly

Materials Required	Tools Required	PPE Required
Aft Altimeters PCB	Multimeter	Safety glasses
4 black powder charges (primary and secondary)	Small flat-head screwdriver	Leather gloves
Aft altimeters sled	Phillips-head screwdriver	Face shield
Aft body wall	7/16 in. socket	Non-synthetic sleeves
Aft ejection pressure seal	1/2 in. socket	
2 new 9V batteries	Socket wrench	
Wire cutters	Socket extension	
Aft Avionics	3/32 Allen wrench	
Aft Avionics sled		

- Safety Consideration: Only members with HPR Level 1 certifications will handle black powder.
- Safety Consideration: Black powder charges should be kept separated from any ignition or heat sources.
- Safety Consideration: Notify the area that black powder is being used. Wear appropriate PPE.

1) Test 9V batteries with multimeter. Batteries should read no lower than 9V.
2) Place the batteries into the battery cases.
3) Secure the batteries by tightening screws on the cases.
4) Retest all connections with the multimeter.
5) Test altimeters by rotating the Allen wrench switch clockwise.
6) After the altimeter beeps, rotate the switch counter-clockwise by one quarter turn.
7) Insert charge leads through the aft ejection pressure seal.
8) Cut extra leads leaving approximately 2 in. to connect to.
9) Insert the leads into the appropriate terminals.
10) Secure leads by tightening terminal screws.
11) Screw pressure sealing washer onto the fore side of the pressure seal. Check that all leads are sealed by the washer.
12) Insert the aft ejection mounts into the slots in the aft body wall, watching for any pinched or disconnected wires.
13) Connect the aft body wall to the pressure seal by installing four 6-32 bolts through the bulkhead.
14) Secure the avionics to back of the aft ejection body wall with four 6-32 bolts.
15) Insert the aft ejection bay into the aft body tube along the aligning rail.
    - Safety Consideration: Be sure that the charges are not being pinched or rubbed throughout the installation process.
16) Check that the altimeter switches are accessible from the exterior of the airframe through the static port hole.

17) Secure the fore ejection bay with six 10-32 bolts mounted radially on the airframe.
18) Compress the sealing bulkheads by tightening all six sealing bolts.

4.1.6 ATU Preparation

Necessary Items: ATU flight unit, fully charged LiPo battery, multimeter and probes, electrical tape and/or zip ties, micro-SD card, Teensy 3.6, XBee RF transceiver, TI CC1200 RF transceiver (embedded on PCB, GPS unit, OSRT PCB)

- Safety Considerations: Any electronics loose on the ATU will cause serious physical or electrical damage to internal components during launch. Make sure that components are secure to prevent electrical shorting or physical shock. Do not contact battery leads to any other electrically conductive components or system damage and personal harm can occur. Use caution when handling LiPo batteries to avoid battery damage and explosion.

1) Check battery voltage and charge of the ATU LiPo battery, acceptable voltage range is > 7.7 V.
   - Safety Consideration: do not initialize system if battery voltage is outside of the acceptable range.
2) Fit battery lead into flight unit sled slot (GPS side of slide).
3) Ensure GPS wire is securely wrapped around battery housing and antenna is zip tied or taped to ATU sled.
4) Insert micro-SD card into Teensy 3.6 - clear old data via computer prior to launch.
5) Electrical tape SD card into place to make secure.
6) Make sure all Integrated Circuit (IC) components are securely connected to the PCB - double check pins and connectors (including XBee, GPS, Teensy, CC1200, and any antennas).
7) Secure all IC components and the PCB to ATU sled via electrical tape and/or zip-ties (including XBee, GPS, Teensy, CC1200, and any antennas).
8) Double check boards are secured to avionics sled.
9) At least 1 hour 30 minutes prior to launch vehicle integration, plug ATU board into battery to ensure GPS lock.
10) Check for solid orange light on Teensy and flashing red light on GPS module.
11) Wait for GPS lock, indicated by flashing red light; can take up to 30 minutes.

Repeat all steps for both ATUs - fore and aft units. Completion of this procedure will arm ATUs for operation.

4.1.7 Ground Station Preparation

- **Necessary Items:** ATU ground station, Windows computer with Python and necessary libraries, fully charged LiPo battery, micro USB cable, Yagi antenna, 433 MHz antenna.

- Safety Considerations: Make sure that electronics are secure to prevent electrical shorting or physical shock. Do not contact battery leads or wires to any other electrically conductive components or system damage and potentially personal harm could occur.

1) Check battery voltage and charge of ATU LiPo, acceptable voltage range is > 7.7 V.
   - Do not initialize system if battery voltage is outside of the acceptable range.
2) Ensure that the most current version of Arduino and the Teensy Bootloader are installed on computer for SPI troubleshooting and output analysis.
3) Ensure that Matplotlib, Pyserial, and UTM Python packages are installed on computer. Using Pip (Python installer) is the easiest method.
4) Attach antenna(s) to RF transceivers (XBee and/or TI CC1200).
5) Plug micro-USB into Teensy.
6) Plug battery into ground station.
7) Plug USB into computer.
8) Delete, rename, or move the 'output.txt' file in the same directory as the ground station .py script.
9) Run latest ground station .py script using PowerShell ISE or Visual Studio - if graphs don't appear, close program and reopen (check for errors in PS/VS).
10) If program continues to not work, power cycle ground station by first unplugging USB, then battery, then continuing from step 6.
11) Point antenna at rocket.

Repeat steps 8 and 9 whenever program needs to be restarted or troubleshoot. Power-cycling consists of steps 6 to 10 with as many repetitions as necessary. Program malfunctioning should be fixed by first repeating step 9 several times, then following instructions in step 10.

Note: output.txt file will be overwritten if it isn't moved or renamed prior to restarting the program.

4.1.8 Aft Section Preparation

- **Necessary Items:** aft section; motor retainer; denatured alcohol; paper towels
- Safety Consideration: Remove all flammable objects/substances from the immediate area. Remove all sharp objects from the immediate area. Cover hands and arms in case of frayed edges in the fiberglass or carbon fiber. Wear appropriate PPE.

1) Inspect fins for any chips or surface damage.
2) Inspect epoxy fillets at fins for cracks or damage.
3) Inspect aft section of airframe for zippering, delamination, or chipping.
4) Inspect motor retainer for cracks or bends.
5) Inspect airframe for dirt; clean if necessary.

6) Check airframe and canister for shear pins and remove any found.
7) Inspect nosecone for chips and cracks.
8) Inspect motor casing for any marks, dents, or other visible damage.
9) Ensure fin alignment by checking with fin alignment fixture.

4.1.9 Recovery Integration

- **Necessary items:** aft section; motor assembly; aft e-bay assembly; coupler; motor retainer; 7/16 socket wrench with extender; 5/16 rubber seal; 5/16 washer; 5/16 nyloc nut; 3/32 Allen wrench; 3x 2-56 steel screws; small black flathead screwdriver; flashlight; measuring tape; assembled Recovery Section; cellulose insulation; Aft e-bay
- Safety Consideration: Ensure no open flames or sparks are in the area.
- Safety Consideration: Failure to follow all steps will result in complete mission failure due to recovery failure.
- Safety Consideration: Check the main packing looks correct, and that a REMOVE BEFORE FLIGHT tag is placed under the zip-tie holding it closed.

1) This process is going to be repeated for both the fore and aft sections. Follow the steps twice. The fore section will be done first.
2) Grab the coupler. Check to ensure the arrow is pointed up. Slide the coupler over the main parachute end of the riser and the 2 ft section of nylon cord.
3) Take the 2 ft nylon cord and attach it to the top quick link of the top Tender Descender. Ensure the Kevlar string which is attached to the body pieces of the Tender Descender is looped through this quick link. The 2 ft nylon cord should be attached to the main riser with a cow hitch.
4) Attach the two Tender Descenders together. The main body of the Tender Descenders should be tethered together, and the Kevlar string should be attached through the outside quick links. The inner quick links should not be tethered to the main body of the altimeters.
5) Attach the extra wide quick link at the nosecone end of the shock cord to the two fore bulkhead eye-bolts.
6) Ensure the sealing rods in the e-bays are loosened.
7) Safety Consideration: Failure to verify tracking functionality will result in loss of tracking ability.
8) Ensure that the aft avionics are turned on.
9) Ensure that the GPS red light is flashing.
10) Insert the aft e-bay into the aft airframe so that from the top of the bulkhead to the top of the airframe is 9.0 in. with the eye bolts up, ensuring no cords are pinched.
11) Ensure that there is 13.525 inches from the top of the nut to the top of the threaded forward retainer.
12) Insert the motor into the motor tube, inserting threaded rod through aft e-bay.
13) Secure the motor with the threaded motor retainer.

14) Ensure that the motor retainer is fully hand tightened.
15) Ensure the Aft e-bay is full pressed against washer on threaded rod.
16) Ensure ejection switches are accessible through ports on aft e-bay with 3/32 Allen wrench.
17) Fully tighten the four sealing 1/4-20 nuts on the e-bay.
18) Place rubber seal and 5/16 washer on threaded forward retainer.
19) Secure the aft e-bay with a 5/16-18 locknut on threaded forward retainer. One full thread should be visible above the locknut.
20) Ensure that one thread is visible above the locknut.
21) Ensure you can access the fingertech switches.
22) Safety Consideration: Move the e-bay to a safe location to test the e-match continuity; notify the Range Safety Officer (RSO).
23) Safety Consideration: Handle ejection charges with care. E-match leads are fragile and need to be kept intact.
24) Tape the ejection charges with shorter e-matches to the airframe just above the bulkhead. Masking tape should be used to avoid residue being left on the inside of the airframe.
25) Ensure the ejection charges with longer e-matches are pulled out of the airframe.
26) Take the coupler and slide it into place. Ensure the charges are threaded through the couple. Align the holes and place steel shear pins in them. Pull the ejection charges past the top of the coupler. Have someone hold onto the charges lightly.
27) Attach the free quick link on the Tender Descenders to the extra wide quick link at the main end of the riser.
28) Reach into the airframe and attach the extra wide quick link to the two eye bolts attached to the bulkhead.
29) Place some cellulose insulation inside the airframe. Spread it out evenly over the bulkhead surface.
30) Take parachute blast protector and spread it over the top of the tube. Push your hand down the tube to form a pocket with the blast protector.
31) Z fold the shock cord section and place it in the pocket.
32) Take the Deployment Bag assembly and push it into the pocket. Compress this into the airfame as far down as it will go. **NOTE: The deployment bag should fit loosely inside the airframe.**
33) Attach nosecone end of the shock cord extra wide quick link to the eye bolts on the fore bulkhead.
34) Z fold the rest of the riser between the deployment bag and drogue parachute and place above the deployment bag inside the airframe.
35) Place the deployment charges next to the bulkhead in the nosecone section.
36) Spread some cellulose insulation around these ejection charges.
37) Take the other parachute blast protector and place it over the ejection charges.
38) **Take the tape off the drogue parachute, and remove the red REMOVE BEFORE FLIGHT tag.**
39) Place the folded drogue parachute into the fore section of the airframe.

40) Take any leftover shock cord and place it in the section with the most space left.
41) Turn the fingertech switch on the Missile Works RRC3 until the continuity beep sequence is heard.
42) 5 second long beep

    10 second pause

    2 numbers, indicating the voltage of the battery in tenths of a volt. This should be > 9.1 V

    Pre-launch Deploy Mode (ensure the main deployment height and arming altitude are what were set).

    Three continuity beeps – repeats every 2 seconds (three beeps for continuity on both drogue and main output ports).

    If one beep (only drogue), or two beeps (only main) – remove altimeter sled and inspect.
43) Turn the fingertech switch back one quarter turn. (beeping should stop)
44) Turn the fingertech switch on the Stratologger CF until the continuity beep sequence is heard.
45) Three Beeps (Preset Prog. 3)

    Two second pause

    Seven Beeps, then two sets of 10 beeps (Main set for 700 ft)

    Two second pause

    Series of Beeps (Last recorded Altitude)

    Two second pause

    Series of beeps (Battery voltage, should be > 9.1 V)

    Two second pause

    Three continuity beeps – repeats every 2 seconds (single beep for only drogue)

    If one beep (only drogue), or two beeps (only main) – remove altimeter sled and inspect.
46) Turn the fingertech switch back one quarter turn. (beeping should stop)

4.1.10 Motor Preparation

- **Necessary Items:** Propellant grains; motor casing; forward and aft closure
- Safety Consideration: Only National Association of Rocketry (NAR) Level 2 or higher certified personnel will assemble motor.
- Safety Consideration: Remove all ignition sources from area before assembling motor. Failure to do so may cause unexpected combustion of propellant.
- Safety Consideration: Failure to follow all steps will result in a mission failure and possible injury to personnel.

1) Remove forward and aft closures.
2) Remove forward seal disk.
3) Open reload kit bag.
4) Grease all O-rings.
5) Grease sides and bottom of delay charge.

6) Place O-ring on seal disk.
7) Place seal disk on top of powder grains.
8) Place delay charge into forward closure.
9) Place O-ring on forward closure.
10) Screw in forward closure.
11) Place O-ring on aft closure.
12) Insert nozzle.
13) Screw in aft closure.
14) Tighten both enclosures.
15) Cut hole in motor cap.
16) Insert motor cap.

4.1.11 Final Assembly

- **Necessary Items:** Fully assembled aft section; fully assembled fore section; 3x 2-56 nylon shear pins
- Safety Consideration: Remove all objects not related to final assembly from work area. Keep sharp objects away from airframe; any damage to them may cause potential hazards. Safety Officer must sign off on final assembly.
- Safety Consideration: Ensure no open flames or sparks are in the area.
- Safety Consideration: Ensure all altimeters are disarmed. Failure to perform assembly without altimeters disarmed could result in premature ignition of ejection charges.
- Safety Consideration: Failure to follow all steps will result in complete mission failure due to recovery failure.
- Safety Consideration: Recovery failure will cause hazards to nearby people and to the environment.

1) Prepare the fore section according to fore section assembly checklist.
2) Prepare aft section according to the aft section assembly checklist.
3) Press the fore section onto the aft section using marks to align.
   - Safety Consideration: Do not use steel screws. Use of steel screws will cause the parachutes to not deploy and will cause significant hazards to nearby people and to the environment.
4) Screw in the fore section using 3x 2-56 nylon screws.

4.1.12 Setup on the Launch Pad

- **Necessary Items:** Assembled launch vehicle, flashlight, step stool, 3/32 Allen wrench, 2x adjustable wrench, vinegar, shop towels, flat head screwdriver.

1) Four members bring launch vehicle to launch pad.

2) Bring launch rail to a horizontal position using adjustable wrenches.
3) Use shop towel and vinegar to wipe down launch rail.
   - Safety Consideration: Failure to align launch vehicle buttons with rail may cause the breaking of these components and failure in launch.
4) Carefully slide launch vehicle onto launch rail, ensure co-linearity with launch rail.
   - Safety Consideration: Verify specified angle of launch rail before locking in place.
5) Bring launch rail to specified angle as per RSO instructions.
6) Safety Consideration: Only two team members shall be present for the arming of altimeters to ensure no distractions during the process.
7) All but two team members leave launch pad for arming of altimeters.
8) Setup the step stool.
9) Turn on the bottom StratoLoggerCF, ensure the sequence of beeps match up.
   - Three Beeps (Preset Prog. 3)
   - Two second pause
   - Single Beep, then three sets of 10 beeps (Main set for 1000')
   - Two second pause
   - 5 second siren (apogee delay enabled)
   - Two second pause
   - Series of Beeps (Last recorded Altitude)
   - Two second pause
   - Series of beeps (Battery voltage, should be > 9.1V)
   - Two second pause
   - Single continuity beep – repeats every 2 seconds (single beep for only drogue)
   - If two beeps (only main), or three beeps (both main and drogue) – remove altimeters and inspect
10) Turn on the bottom RRC3, ensure the sequence of beeps match up.
    - 5 second long beep
    - 10 second pause
    - Single continuity beep – repeats every 2 seconds (single beep for only drogue)
    - If two beeps (only main), or three beeps (both main and drogue) – remove altimeter sled and inspect
11) Turn on the bottom StratoLogger CF, ensure the sequence of beeps match up.
    - Three Beeps (Preset Prog. 3)
    - Two second pause
    - Single Beep, then Three sets of 10 beeps (Main set for 1000')
    - Two second pause
    - 5 second siren (apogee delay enabled)
    - Two second pause
    - Series of Beeps (Last recorded Altitude)

- Two second pause
- Series of beeps (Battery voltage, should be > 9.1V)
- Two second pause
- Single continuity beep – repeats every 2 seconds (single beep for only drogue)
- If two beeps (only main), or three beeps (both main and drogue) – remove altimeters and inspect

12) Turn on the bottom RRC3, ensure the sequence of beeps match up.
    - 5 second long beep
    - 10 second pause
    - Single continuity beep – repeats every 2 seconds (single beep for only drogue)
    - If two beeps (only main), or three beeps (both main and drogue) – remove altimeter sled and inspect
13) Bring all material back to setup area.

4.1.13 Igniter Installation

- Safety Consideration: Confirm with the RSO that the range is open. Failure to confirm the range is open could result in severe injury or death from premature motor ignition.

1) Check continuity of igniter using multimeter.
2) Ensure launch system is disarmed.
3) Ensure launch area is clear of all personnel except igniter installer and inspector.
4) Insert long end of igniter all the way into the hole in the motor cap.
5) Attach wire ends of igniter to launch system.
6) Clear launch area of all personnel.
7) Move to a minimum distance established by NAR Safety Code.

4.1.14 Troubleshooting

- **Necessary Items:** Component which is currently facing issues and the associated tools for that component.
- Safety Consideration: Remove all flammable objects/substances from the immediate area. Remove all sharp objects from the immediate area. Cover hands and arms in case of frayed edges in the fiberglass or carbon fiber. Wear appropriate PPE.

1) Arming switches cannot be reached through static port holes.
    a. Disarm all active charges.
    b. Pull launch vehicle from launch pad and return to assembly area.
    c. Realign altimeter that cannot be reached.
2) One of the altimeters does not arm.

a. Disarm all active charges.
b. Pull launch vehicle from launch pad and return to assembly area.
c. Check voltage of 9 V battery.
d. Disassemble faulty ejection charge.
e. Create new ejection charge with a new e-match.
f. Check new e-match resistance.
g. Follow ejection charge assembly procedure.

3) Payload ejection charge does not arm.
a. Disarm all active charges.
b. Pull launch vehicle from launch pad and return to assembly area.
c. Check voltage of 9 V battery.
d. Disassemble faulty ejection charge.
e. Create new ejection charge with a new e-match.
f. Check new e-match resistance.
g. Follow ejection charge assembly procedure.

4) Igniter continuity failure.
a. Inform RSO of issue.
b. Approach the launch vehicle when approved by RSO.
c. Use back up igniter.
d. If this one fails:
i. Disarm all active charges.
ii. Pull launch vehicle from launch pad and return to assembly area.
iii. Continue troubleshooting in assembly area.
iv. Remove and disassemble all energetics if necessary.

5) Launch vehicle does not fire upon button press.
a. Inform RSO of misfire.
b. Follow NAR HPR Safety Code, wait for 60 seconds before proceeding.
c. Follow RSO directions for dealing with misfire.

6) RSO calls off launch for safety violation, environmental concern, launch window closure, or any other concern the RSO may deem necessary to cancel the launch.
a. Disarm all active charges.
b. Pull launch vehicle from launch pad and return to assembly area.
c. Remove and disassemble all energetics.

7) Structural failure in frame noticed on pad.
a. Disarm all active charges.
b. Pull launch vehicle from launch pad and return to assembly area.
c. Determine if failure leads to not launching.

d. Remove and disassemble all energetics if necessary.

4.1.15 Post-Flight Inspection

- **Necessary Items:** aft section; fore section; nosecone; coupler; motor casing; motor retainer; denatured alcohol; paper towels
- Safety Consideration: Remove all objects not related to post-flight inspection from work area. Keep all sharp objects away from airframe components and use caution handling them; damage to the airframe can cause potential hazards. Safety Officer must sign off on Post-flight inspection.

1) Recover any wadding or cellulose insulation used to protect recovery components. Pickup any visible on ground near landing site.
2) Inspect fins for any chips or surface damage.
3) Inspect epoxy fillets at fins for cracks or damage.
4) Inspect aft section of airframe for zippering or delamination.
5) Inspect motor retainer for cracks or bends.
6) Inspect airframe for dirt.
7) Check airframe and canister for shear pins and remove any found.
8) Inspect nosecone for chips and cracks.
9) Inspect nosecone tip for scratches or deformation.
10) Check nosecone coupler for shear pins and remove any found.
11) Inspect motor casing for any marks, dents, or other visible damage.
12) Record any damage noted during post flight inspection and determine the severity of the damage and repair necessary.

- Safety Consideration: Failure to record and repair any damage from the flight may result in complete mission failure of future missions.

4.2 Safety and Environment

4.2.1 Hazard Analysis

In Table 22 is the Hazard Analysis that OSRT has developed for the mission.

Table 22: Hazard Analysis

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Ballistic flight.	A fin breaks mid-flight; poor launch rail construction; center of gravity is too close to the center of pressure.	Unpredictable flight path; falling shrapnel; poor or failed recovery.	1C	Complete pre-flight checklists; Complete post-flight checklists; Alert all individuals of flight status.	Run flight simulations for several conditions; run flight simulations using several software systems; Follow checklists in Section 4.1.2 and Section 4.1.15 - COMPLETE.	1E
Shop machinery.	Improper use of machinery; insufficient knowledge about machinery; negligence; improper PPE.	Injury to personnel; damage to machinery; poor component manufacturing.	2B	All personnel must have the appropriate certification; all personnel must wear the appropriate PPE; identify all hazards related to the task prior to working.	All capstone members have completed a basic shop course at OSU - COMPLETE. A JHA has been created and must be filled out prior to working - COMPLETE.	2E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Ejection charge fires prematurely (pre-flight).	Static charges build during installation; circuit is energized; circuit is shorted.	Uncontained explosion; injury to nearby personnel.	2C	Keep all energy sources away from e-match leads; seal leads with electrical tape when not in use; complete appropriate checklists; shunting switch.	Include a shunting switch for any component that includes ejection charges. See Section 3.1.10, Section 3.1.11, and Section 5.6 - COMPLETE Follow checklists in Section 4.1.4 - COMPLETE	2E
Exposure to hazardous chemicals.	Use of chemicals throughout manufacturing.	Rash, burns and other injuries due to chemical exposure.	3B	Wear appropriate PPE; identify all hazards related to the task prior to working.	Complete a JHA prior to working. A JHA has been created and must be completed prior to working - COMPLETE	3D
Fiberglass/Carbon Fiber particle exposure to personnel.	Machining fiberglass without proper use of PPE or ventilation.	Skin, eye and upper respiratory tract irritation.	3B	Have a vacuum near the end-mill or saw blade; wear safety glasses, gloves, and face mask.	OSRT members have been instructed on how to handle composites in Section 3.1.15.1.	4B
Launch vehicle fails to lift off from rail.	Damage to the launch rail or launch lug; faulty motor; faulty ignition.	Mission failure if motor ignites without liftoff. Possible damage to components.	2D	Mentors will inspect launch rails and verify prior to each launch. Assurance of a smooth fit and easy escape of launch vehicle.	Launch rail assembly checklist is documented. Mentors have been identified.	2E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Motor ignites unexpectedly.	Spark or other ignition source unintentionally ignites the motor.	Mission failure if launch vehicle is not ready on rail. Possible damage to components and injury to all personnel in the area.	2D	All NAR safety codes are to be followed during motor insertion and launch set-up. Motors will be handled only by designated personnel qualified for L-class motor handling.	Motor packing procedures are documented. Safety considerations of removing all possible ignition sources during assembly of the launch vehicle are in proper checklists. Qualified personnel has been identified.	2D
Flight is unstable upon leaving the launch rail.	The center of gravity differs from design, invalidating simulations.	Launch vehicle does not follow anticipated path, possibly becoming ballistic and damaging components and injuring personnel in the area.	2C	Stability margin will be designed to be 2.1 calibers.	Integration of the launch vehicle will follow written checklist to ensure center of gravity is consistent. Mass and center of gravity will be checked prior to each launch to ensure a safe static stability margin. OpenRocket and RockSim will be used to identify center of pressure to calculate static stability margin.	2E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Damage to Airframe or Fins mid flight	Misassembly of launch vehicle, or the launch vehicle reaches unanticipated supersonic speeds	If the exterior of the launch vehicle is damaged in any way mid flight may cause the vehicle to go ballistic, causing damage to interior components upon landing and possible injury to personnel in the area	2D	The airframe will be constructed of carbon fiber and carefully inspected prior to every launch. Motor will be verified of thrust prior to full scale launch. Launch vehicle will be designed to stay in sub-sonic speeds.	Pre-flight and post-flight checklists will be followed to validate structural integrity of airframe and fins. Assembly of launch vehicle will follow checklists to avoid damage to airframe. OpenRocket will be used to ensure launch vehicle will stay in subsonic speeds.	2E
Lack of stability in launch vehicle.	Blade deployment by BEAVS during flight.	Unpredictable and potentially dangerous flight path.	1A	Place BEAVS aft of center of pressure to ensure stability cannot be decreased by blade deployment.	Complete - Simulations in OpenRocket and RockSim ensure the center of pressure location is fore of the BEAVS blade deployment location.	3E
Launch vehicle exceeds desired apogee altitude.	Failure in active system of BEAVS.	Potential to exceed launch waiver ceiling for maximum apogee altitude.	2C	Use the appropriate amount of ballast in the passive system of BEAVS to control maximum apogee altitude regardless of active system performance.	Complete - appropriate ballast determined through simulations for wind conditions of 0, 5, 10, 15, 20 mph wind conditions at ground level.	3D

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Launch vehicle does not reach minimum apogee altitude.	Failure in active system of BEAVS.	Mission failure.	3B	Repeated testing of all elements of the active system.	Incomplete - Testing procedure XX will be conducted multiple times to ensure the reliability	3D
The launch vehicle goes ballistic or tumbles to the ground	Altimeters sense apogee incorrectly due to incorrect pressure sensing, causing early, late, or no separation	Possible injury to bystanders.	2C	Ensure correct static port hole sizing and spacing, and minimize/eliminate delay on firing primary ejection charges	Correct static port hole sizing procedure is followed according to primary altimeters. Secondary altimeter procedure for sizing will be considered.	3E
Launch vehicle falls to the ground without a parachute	Snatch load on shock cord from main parachute opening is too high, or unaccounted for snatch loads cause a failure in the nylon shock cord.	Launch vehicle section tumbles to the ground without a parachute. Possible injury to inattentive observer.	1D	Reduce shock load: main chutes in deployment bags, tape sections of shock cord together, place a steel slider ring around shroud lines. All components will have an appropriate safety factor for expected loads.	Test shock cords with a range of shock loads, past what is expected to be felt during launch, to ensure it will not fail.	1E
Launch vehicle falls to the ground without a parachute	Unaccounted snatch load is higher than shock rating for eye bolts	Launch vehicle section tumbles to the ground without a parachute. Possible injury to inattentive observer.	1D	Reduce shock load: main chutes in deployment bags, tape sections of shock cord together, add a bungee to reduce velocity difference between separated sections	Test eye bolts with a range of shock loads, past what is expected to be felt during launch, to ensure it will not fail.	1E
Launch vehicle falls to the ground without a parachute	Fire Damage to the riser causes a weak point where all the loads are concentrated, causing it to break at that point	Launch vehicle section tumbles to the ground without a parachute. Possible injury to inattentive observer.	1D	Ensure appropriate amount of Cellulose Insulation is used, and ensure all nylon components are protected from heat with Kevlar or Nomex	Inspect all risers before use to ensure they have sustained minimal or no heat damage	1E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Launch vehicle falls to the ground without a parachute	Excessive twisting of the risers, causing high stress, results in the snapping of the riser	Launch vehicle section tumbles to the ground without a parachute. Possible injury to inattentive observer.	1D	Ensure all swivels rotate easily	Twist a riser quickly while attached to a swivel to see how twisted the riser becomes	1E
Launch vehicle does not separate	Altimeters not connected properly to ejection charges or altimeters malfunction	Launch vehicle goes ballistic and is lost upon impact with the ground.	1C	Ensure all wires are connected correctly, all beep sequences are correct upon arming altimeters, and ejection charges are manufactured correctly.	Simulate flight with OpenRocket and RockSim to determine appropriate amount of ballast based on launch day conditions.	1D
Parachute rips	Altimeters sense apogee incorrectly due to incorrect pressure sensing, causing early or late separation	Unpredictable ejection forces acting on launch vehicle rips the parachute upon separation. This could result in a tumbling or ballistic launch vehicle. Possible injury to inattentive observer.	2C	Ensure correct static port hole sizing and spacing, and minimize/eliminate delay on firing primary ejection charges	Correct static port hole sizing procedure is followed according to primary altimeters. Secondary altimeter procedure for sizing will be considered.	3E
Main parachutes do not deploy	Failure in fore and/or aft Tender Descenders	Tumbling launch vehicle resulting in damage to launch vehicle and payload. Possible injury to inattentive observer.	1D	Repeated testing of Tender Descenders	Test all Tender Descenders in high stress situations, and ensure black powder ejection charges consistently and successfully separate the sections of the Tender Descenders.	3D

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Main parachutes do not unfurl completely	Improper packing methods were used	Possible damage to launch vehicle and payload	3B	Repeated testing of packing method to ensure parachutes will unfurl completely	Tests conducted to ensure reliability of sensor data and filtering techniques. Testing conducted to ensure mechanical system performance prior to launch. Numerous test launches to determine system reliability.	2E
Fire damage to parachutes	Improper packing methods were used	Parachutes will perform sub-optimally. Worst case scenario the launch vehicle tumbles to the ground. Possible injury to inattentive observer.	2C	Ensure all parachutes are packed appropriately.	Ensure no part of the parachute is exposed while loading into the launch vehicle.	1E
Launch vehicle falling on someone under a parachute	Wind causes launch vehicle to drift towards spectators	Possible injury to inattentive observer.	1D	Attentiveness to all descending launch vehicles, in order to move out of the way	Ensure launch vehicle is falling at a safe velocity so spectators can move out of the way	1D
Lack of stability in launch vehicle	Blade deployment by BEAVS during flight	Unpredictable and potentially dangerous flight path	1A	Place BEAVS aft of center of pressure to ensure stability cannot be decreased.	Simulations in OpenRocket and RockSim to ensure center of pressure location is fore of BEAVS blade deployment location.	3E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Launch vehicle exceeds desired apogee altitude	Failure in active system of BEAVS	Potential to exceed waiver ceiling for maximum apogee altitude.	2C	Use the appropriate amount of ballast in the passive system of the BEAVS to control maximum apogee altitude	Simulate flight with OpenRocket and RockSim to determine appropriate amount of ballast based on launch day conditions.	3D
Launch vehicle does not reach minimum apogee altitude	Failure in active system of BEAVS	Mission failure	3B	Repeated testing of all elements of the active system.	Tests conducted to ensure reliability of sensor data and filtering techniques. Testing conducted to ensure mechanical system performance prior to launch. Numerous test launches to determine system reliability.	3D
Motors overheat	Temperatures from launch and heavily torquing the motor	Motor overheats and catches on fire	2B	Use a motor that provides adequate characteristic for the project mission .	Motor supplier specification sheet verification. Payload ejection, rover mobility, and SCAR testing.	2E
Ballistic Payload falling from apogee	Retention devices release early	Payload falls at apogee	2D	Redundant retention devices of differing manufacturers rated well above the forces experienced in a most case scenario flight. Electrical components designed for system to fail close should power loss occur.	Analysis of mechanical components conducted in Section 6.2.5 shows mechanical failure will not occur	2E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Ejection attempted with payload still retained	Retention devices do not release prior to attempted ejection	Black power ejection blows out side airframe	1C	The PLEC does not allow for ejection charges to be triggered unless all retention devices are successfully released first.	Ground testing of the PLEC and the PEARS.	1E
Early ejection of Black Powder	Improper handling; working near heat or electrical storage; improper storage	Burns; shrapnel	2C	Safety glasses will be worn when near black powder being packed or set-up. All work with black powder will be preformed by a L1 certified member following explicit procedures from manufacturer for devices or checklists for packing charges. All charges will be packed on site to prevent detonation or failure when stored.	All charges are assembled and checked by following the procedures listed in Sections 4.1.4 and 4.1.5 by certified L1 members and aware from any heat or electrical source.	2E

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4.2.2 Failure Modes and Effects Analysis

4.2.2.1 Structures Failure Mode Effects Analysis (FMEA)

In Table 23 is the Structures FMEA that the OSRT has developed for the mission.

Table 23: Structures FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Airframe	Airframe buckling from high loads at landing.	Launch vehicle is not recoverable or reusable.	8	Recovery system fails to deploy.	1	7	56	Model forces acting on the eye nut and determine a factor of safety based on that force, adjusting system if necessary.

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Table 23: Structures FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
	Temperatures cause delamination of airframe materials.	Launch vehicle goes ballistic, resulting in the destruction of the vehicle.	8	Long term storage or use in high temperature conditions.	1	5	40	Model forces and increase size of eye nut to account for forces in system based on calculation of minimum thread engagement.
	Zippering along the edges of the tubes.	Launch vehicle goes ballistic, resulting in the destruction of the vehicle.	6	Recovery lines pulling across edge of tube.	5	6	180	Ensuring all black powder charges are properly sized and slightly oversized.
Nose cone	Non-Uniform, non-straight nose cone.	Non-uniform flight path, increasing drag.	5	Nose cone becomes damaged or deformed during testing or upon landing.	5	4	100	Metal nosecone tip to absorb direct force, careful inspection before and after use.
				Difficulty of getting a good nose cone with the resources available at OSU.	2	3	30	Purchase nose cone and fit to airframe outer and inner diameter.
	Nose cone detaches during flight.	Flight failure, loss of nose cone, loss of avionics.	8	Not correctly attached to recovery system or tip not properly secured to threaded rod.	3	4	96	Follow installation checklists with final inspection of launch vehicle before sealing.
				Nose cone threads strip when recovery system forces are transferred to them.	2	4	64	Analysis will be performed on required thread depth for tapped hole to prevent striping.

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Table 23: Structures FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Fins	Fins are misaligned.	Erratic flight profile, loss of launch vehicle.	7	Damage to fins caused during transport of the rocket or by hard landing, deformation of material based on atmospheric conditions.	3	4	84	Handle fin section carefully, do not put weight on fins, inspect and repair fins after launch, manufacture fins with stiff materials.
				Fins not inserted and epoxied at right angles to body tube, or epoxy fails to cure correctly.	5	3	105	Build a fin jig for aligning the fins during the build, and allow epoxy to cure before moving.
	Fins fall off.	Erratic flight profile, loss of launch vehicle, damage to surroundings.	9	Forces at base of fin large enough to cause failure in epoxy.	3	4	108	Inspect fins before and after launch, do not launch if fins are not secure.
				Epoxy not allowed to cure properly, insufficient epoxy to maintain strength.	1	9	81	Carefully apply epoxy and inspect after drying, properly fillet all edges.
Coupler	Bending in the rocket.	Loss of launch vehicle, launch vehicle not reusable.	8	Forces experienced by the rocket create enough bending shear that the materials fail.	4	3	96	Composites laid-up in directions of highest load with enough thickness to resist the loading.

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Table 23: Structures FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Bulkhead	Epoxy attaching bulkheads to the airframe fails.	Internal components damaged, launch vehicle unrecoverable, debris injuring spectators, debris littering property.	8	Incorrect epoxy mixture used.	2	2	32	Use scale to measure epoxy ratio, use unused mixing sticks and bowls for each batch.
				Poor surface contact or dirty surface.	2	8	128	Sand area where the epoxy will be applied, clean surface with acetone.
				Insufficient amount of epoxy applied.	1	4	32	Generously apply all epoxy with fillets.
	Cross-grain failure.	Internal components damaged, launch vehicle unrecoverable, debris injuring spectators, debris littering property.	8	Plywood is stored improperly.	3	6	144	Store plywood in cool, dry areas and handle with care.
				Quality of plywood is not sufficient for experienced forces.	3	8	192	Select plywood from reputable sources, select best looking plywood.
	Fracture or shatter of bulkhead.	Internal components damaged, launch vehicle unrecoverable, debris injuring spectators, debris littering property.	8	Excess force by threaded rod.	2	2	32	Use thick plywood and large washers to be able to withstand experienced force.

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Table 23: Structures FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Threaded Rod	Failure of threaded rod under tension.	Loss of recovery system, loss of launch vehicle.	9	Force experienced by the threaded rod during any point of the flight, with the primary concern being recovery, is greater than the strength of the rod.	4	5	180	Model forces and increase size of threaded rod to have a safety factor of at least two for the entire system.
	Threaded rod is stripped from hard point.	Loss of recovery system, loss of launch vehicle.	9	Force in the system is sufficient to pull the ends of the threaded rods through the threads of the hard point mountings.	2	4	72	Design the hole depth in hard points to be higher than the minimum thread engagement length.
Shear pins	Shear pins fail to break.	Recovery system does not deploy, loss of launch vehicle, launch vehicle becomes projectile.	10	Black power detonation creates insufficient pressure on shear pins.	3	5	150	Have backup black powder ejection charges larger than primaries, test all charges with ejection test before launch.
Camera System	Trigger does not work on all shutter cables.	Will not capture full 360 without all cameras on and running.	7	Poor cable configuration.	2	5	70	Inspection of the module outside the launch vehicle before launch.
	Camera casing does not withstand forces during flight.	Cameras may break.	8	Camera casing design is structurally weak.	1	4	32	Testing will be done on the camera casing to ensure a robust design.

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Table 23: Structures FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
	Not all cameras are turned on.	Will not capture full 360 without all cameras on and running.	7	Camera batteries are not charged.	2	2	28	Cameras will be charged before each flight. Battery life will be demonstrated to last the required time.
RF Shielding	Ejection charges fire prematurely.	Parachutes are released early.	9	Radio signals interfere with altimeter readings.	3	2	54	Coat the inside of the bay with a conductive spray paint to make the bay RF shielded. Additionally, test the signal strength going in and out of the bay.
	Ejection charges do not fire.	Parachutes are not deployed.	10	Radio signals interfere with altimeter readings.	3	2	60	Coat the inside of the bay with a conductive spray paint to make the bay RF shielded. Additionally, test the signal strength going in and out of the bay.
Pressure Seal	Seal is not strong enough to withstand ejection charges.	Shear pins do not break and the parachutes do not deploy.	10	The seal allows some pressure to escape and the remaining pressure is not strong enough to break shear pins.	3	2	60	Complete and pass ejection testing consistently.

4.2.2.2 Aerodynamics and Recovery FMEA

In Tables 24, 25, and 26 are the Aerodynamics, BEAVS and Recovery Failure Mode Effects Analysis (FMEA) that OSRT has developed for the mission.

Table 24: Aerodynamics and Propulsion FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Catastrophic motor failure	Motor fails to provide sufficient thrust	Failure to reach target apogee, Major damage to all components, Possible injury to all personnel in the area.	8	The motor has a manufacturing defect or motor is damaged.	1	3	24	Motor testing will verify manufactured motor thrust. Motor to be assembled and inspected by mentor prior to launch.
Motor fails to ignite	Motor fails to ignite from igniter	Motor does not start, launch vehicle fails to leave launch pad	7	Manufacturing defect in motor, damage to ignition system, or igniter not properly assembled.	1	5	35	Motor assembly will be performed by team mentor. Igniter insertion will be completed by qualified L2 NAR member. Ignition system will be checked for continuity prior to igniter insertion.

Table 25: BEAVS FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Gear teeth mesh to actuate blades	Teeth slip	Blades remain extended in undesired position or do not actuate fully	3	Lack of precision tolerance during manufacturing. Flexibility of rack design.	3	1	9	Use CNC manufacturing to maintain precise tolerance. Design rack to be rigid enough to avoid flexibility.
Blades deploy	Blades deploy during motor burn	Control system fails to accurately predict apogee altitude	5	Lack of precision in apogee altitude.	5	2	50	Repeated testing of system to ensure reliable blade deployment time
Blades deploy	Blades fail to deploy	Apogee altitude not within desired accuracy.	2	Lack of precision in apogee altitude.	5	4	40	Repeated testing of the system to ensure reliable blade deployment time. Passive ballast system used as backup to ensure mission performance despite failure.
Blades deploy	Friction in system exceeds motor capabilities to actuate blades	Blades do not actuate	2	Lack of precision in apogee altitude.	1	8	16	Linear bearings reduce friction in direction of actuation. Blades designed to actuate perpendicular to airflow to reduce required motor torque. Selected motor to be slightly oversized to ensure reliable performance.
Rack and pinion actuates blades	Blades over extend and come off central drive gear	Blade falls out of launch vehicle	5	Motor rotates further than desired	3	1	15	Implement a retention system on design to prevent blades from over extending.

Table 26: Recovery Integration FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Ejection charges separate sections of the launch vehicle	Primary ejection charges fizzle out	Secondary charges will be relied upon to separate the airframe sections. The launch vehicle could be destroyed if the vehicle goes ballistic.	6	Black powder charges are constructed improperly.	2	1	12	Ensure all black powder charges are packed tightly and have no give, as well as electric matches being connected properly.
	All ejection charges fizzle out.	The launch vehicle goes ballistic, resulting in the destruction of the vehicle.	10	Black powder charges are constructed improperly.	2	1	20	Ensure all black powder charges are packed tightly and have no give, as well as electric matches being connected properly.
	Ejection charges ignite but do not separate the launch vehicle sections	The launch vehicle goes ballistic, resulting in the destruction of the vehicle.	10	Black powder charges are constructed improperly.	3	1	30	Ensure all black powder charges are properly sized and slightly oversized.
Altimeters sense apogee	Altimeters sense apogee at different times	The recovery bay could be over pressurized if the charges go off at the same time, blowing out the side of the airframe.	6	The altimeters malfunction.	4	6	144	The altimeters will be tested at different altitudes to ensure they are sensing correctly.

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Table 26: Recovery Integration FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Altimeters sense apogee	Altimeters sense apogee early	Unpredictable snatch loads will be experienced, possibly resulting in the failure of any given recovery component.	7	Static port holes were sized improperly, or the primary or secondary altimeters malfunction.	4	3	84	The altimeters will be tested at different altitudes to ensure they are sensing correctly.
	Altimeters sense apogee late	Unpredictable snatch loads will be experienced if the sections separate, and if the charges go off too late, the airframe sections will not separate.	8	Static port holes were sized improperly, or the primary or secondary altimeters malfunction.	4	3	96	The altimeters will be tested at different altitudes to ensure they are sensing correctly.
	Altimeters fail to sense apogee	The main parachutes are released too early, increasing the drift radius and descent time.	10	The altimeter's barometric sensor malfunctions.	3	6	180	Test altimeters at different altitude.
Altimeter senses main parachute deployment height, releasing Tender Descenders	Altimeter senses height too early	The main parachutes are released too early, increasing the drift radius and descent time.	2	The altimeter's barometric sensor malfunctions.	5	5	50	Test altimeters at several altitudes.
	Altimeters sense height too late	The launch vehicle possibly impacts the ground before the main parachute opens fully.	6	The altimeter's barometric sensor malfunctions.	3	6	108	The altimeters will be tested at different altitudes to ensure they are sensing correctly.

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Table 26: Recovery Integration FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Altimeter senses main parachute deployment height, releasing Tender Descenders	Altimeters fire the ARRD and/or Tender Descender at apogee	The main parachutes are released at apogee, increasing he drift radius drastically.	3	The release mechanism malfunctions.	6	6	108	Test Tender Descenders under high stress situations to ensure the release mechanism does not come undone.
Recovery system becomes taut as the main parachutes unfurl (includes unaccounted for snatch loads)	Shock cord snaps	The launch vehicle section tumbles to the ground.	8	High snatch loads and/or a weak point in the shock cord cause a failure.	1	3	24	Inspect all shock cords for any visible flaws to ensure the cords perform optimally.
	Shock cord tangled	Unpredictable snatch forces will be experienced by the shock cord, and it is possible the parachute does not exit the launch vehicle if the tangling is drastic enough.	7	The shock cords are folded and packed improperly.	2	3	42	Ensure all parachutes are packed correctly, by following a list of instructions. Someone will watch over ensuring all steps are followed correctly.
	Quick link fails	The launch vehicle section tumbles to the ground.	8	High snatch loads and/or a weak point in the shock cord cause a failure.	2	4	64	Inspect all quick links for visible flaws.
	Eye bolt fails	The launch vehicle section tumbles to the ground.	8	High snatch loads and/or a weak point in the shock cord cause a failure.	2	4	64	Inspect all eye bolts for visible flaws.

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Table 26: Recovery Integration FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Recovery system becomes taut as the main parachutes unfurl (includes unaccounted for snatch loads)	Bulkhead Fails	The bulkhead slips out of airframe, causing the launch vehicle to tumble to the ground.	8	The fasteners fail to hold bulkhead in place.	2	3	48	Ensure all bulkheads are securely fastened to the launch vehicle.
	Shroud lines snap	The launch vehicle section tumbles to the ground.	8	Unaccounted for snatch loads exceed the shroud lines maximum strength because separation occurs at an unpredictable time.	2	6	96	Test altimeters at various altitudes to ensure they are sensing correctly to limit the chances of unaccounted for snatch loads.
	Swivel breaks	The launch vehicle section tumbles to the ground.	8	Unaccounted for snatch loads exceed the swivels maximum strength because separation occurs at an unpredictable time.	2	6	96	Test altimeters at various altitudes to ensure they are sensing correctly to limit the chances of unaccounted for snatch loads.
Main parachute unfurls	Shroud lines tangle	The main parachute does not unfurl completely, causing increased kinetic energy upon landing.	7	Shroud lines and main parachute are packed improperly.	3	3	63	Ensure all parachutes and shroud lines are packed correctly, by following a list of instructions. Someone will watch over ensuring all steps are followed correctly.

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Table 26: Recovery Integration FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
	Parachute Rips	The kinetic energy upon landing is increased, as the vehicle will be in a semi-tumble.	7	The main parachute experienced excess heat, leaving the material susceptible to tearing.	3	5	105	Ensure the main parachute is completely stored within the deployment bag and the Nomex blanket is sufficiently protecting the deployment bag
		The kinetic energy upon landing is increased, as the vehicle will be in a semi-tumble.	7	Unaccounted for snatch loads exceed the material strength of the main parachutes.	3	6	126	Inspect all parachutes for visible tears, and ensure all parachutes are packed correctly, by following a checklist of instructions. Someone will watch over ensuring all steps are followed correctly.
Recovery system becomes taut as the drogue parachutes unfurl (includes unaccounted for snatch loads)	Shock cord snaps	Increased velocity when the main parachute deploys and a less controlled ejection of the main parachute	6	High snatch loads and/or a weak point in the shock cord.	1	3	18	Inspect all shock cords for any visible flaws to ensure the cords perform optimally.
	Shock cord tangled	Increased velocity when the main parachute deploys.	5	Improper folding and packing of the shock cord.	2	3	30	Ensure all parachutes are packed correctly, by following a list of instructions. Someone will watch over ensuring all steps are followed correctly.
	Bulkhead fails	Bulkhead slippage damages airframe	7	Fasteners fail to hold bulkhead in place.	1	2	14	Ensure all bulkheads are securely fastened to the launch vehicle.

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Table 26: Recovery Integration FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
	Bulkhead Fails	Bulkhead slips out of airframe, causing the launch vehicle to tumble to the ground	8	Fasteners fail to hold bulkhead in place.	1	2	16	Ensure all bulkheads are securely fastened to the launch vehicle.
	Shroud lines snap.	Increased velocity when the main parachute deploys and a less controlled ejection of the main parachute	6	Unaccounted for snatch loads exceed the shroud lines maximum strength because separation occurs at an unpredictable time.	1	6	36	Test altimeters at different altitudes to ensure they are sensing correctly to limit the chances of unaccounted for snatch loads.
Drogue parachute unfurls	Shroud lines tangle	The drogue parachute does not unfurl completely, causing increased velocity when the main parachute is deployed.	6	Improper packing of the shroud lines and drogue parachute.	2	3	36	Ensure all parachutes and shroud lines are packed correctly, by following a of instructions. Someone will watch over ensuring all steps are followed correctly.
	Parachute rips	Increased velocity when the main parachute deploys and a less controlled ejection of the main parachute	4	Unaccounted for snatch loads exceed the material strength of the drogue parachutes.	3	6	72	Inspect all parachutes for visible tears, and ensure all parachutes are packed correctly, by following a checklist of instructions. Someone will watch over ensuring all steps are followed correctly.

4.2.2.3 Payload FMEA

In Table 27 is the Payload FMEA that OSRT has developed for the mission.

Table 27: Payload FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Tail	Tail does not touch the ground.	The chassis will rotate instead of the wheels, preventing movement.	8	The tail is of insufficient length.	1	1	8	Tail length will be determined by 3D models.
	Tail will not unwrap from rover.	The chassis will rotate instead of the wheel, preventing movement.	8	The spring breaks or critically deforms.	2	1	16	Spring force and strength will be determined based upon the expected tail angle of rotation.
Fixed Rods	The rods disconnect from the chassis blocks.	Rover disassembles and is unable to perform mission.	5	Insufficient or weak epoxy is used on the rods and blocks.	5	3	75	Use epoxy with sufficient characteristics for the forces experienced during all mission operations.
			5	Rods break on the rover.	4	2	40	Design the rod strength to withstand all mission operations.
Chassis Blocks		Chassis disassembles or becomes structurally compromised and is unable to perform mission.	6	Chassis blocks fracture during mission operations.	2	6	72	Material choice will be determined upon the stresses expected during mission operations.
Generate torque via DC motors	Motors fail to produce adequate torque	The rover is unable to move or unable to climb slopes.	8	The motor has a manufacturing defect.	1	1	8	The payload testing phase will verify motor functionality.
				Flight forces break an electrical connection.	4	3	96	Electronics will be protected within the rover's chassis and will be examined after payload ejection tests.

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Table 27: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Generate torque via DC motors	Motors fail to produce adequate torque	The rover is unable to move or unable to climb slopes.	8	The power supply drains prior to rover ejection.	2	3	48	The rover will only power on upon ejection from the airframe.
Transmit torque from motor to wheels	Motors fail to transmit adequate torque to wheels	The rover is unable to handle gentle slopes and may become stuck.	6	Drive shaft slips	2	3	36	Shaft coupling set screws ensure 1:1 rotation.
				The drive shaft assembly becomes misaligned.	4	2	48	The drive shaft assembly has multiple attachment points to the truss to limit displacement.
				The drive shaft fails via torsion or bending.	1	1	6	Payload testing and stress simulations will prevent failure.
Soil Collection Auger	Failure to collect at least 10 mL of soil	Auger cannot collect soil and transport it to the container	8	Insufficient Motor Torque	2	1	16	Perform force calculations and over-spec the motor. Testing.
		Auger does not rotate. Auger does not deploy into soil. Auger device detaches from the Chassis.	6	Threads become stripped on any component	2	5	60	FEA. Testing. Use favorable factors of safety.
		Auger does not collect soil. Auger does not transport soil to the container.	8	Auger breaks	5	2	80	Testing. FEA. Use stronger materials.
		Auger cannot collection soil.	4	The cutting edge on the Auger become dull	5	7	140	Testing. Use an increased edge angle. Use stronger materials.
		Less than 10 mL of soil is collection	3	Automation falsely reads the amount of soil collected	5	8	120	Testing. Code the automation to collect more than 10 mL.

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Table 27: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Soil Collection Auger	Failure to collect at least 10 mL of soil	Less than 10 mL of soil is collection	6	Batteries deplete all power prematurely	3	3	54	Testing. Make sure battery life will withstand all worst case scenarios
		Auger cannot be fed into the soil. Auger does not collect soil.	4	Corrosion	2	5	40	Use corrosion resistant components when possible. Buy coated materials to resist corrosion. Seal from water contamination.
	Failure to transport the soil to the container	Soil falls out of Auger before reaching the container	4	Auger Soil Containment Tube does not rest fully tangent against Auger	4	7	112	Test. Make sure the containment tube rests tangent to the auger.
		Auger does not rotate. Auger does not deploy into soil. Auger device detaches from the Chassis.	6	Threads become stripped on any component	2	5	60	FEA. Testing. Use favorable factors of safety.
		Soil cannot be collected.	8	Soil does not fall onto the container opening.	3	4	96	Testing. Use a funnel to bias the soil onto the doors.
		Auger cannot be fed into the soil. Auger does not collect soil.	4	Corrosion	2	5	40	Use corrosion resistant components when possible. Buy coated materials to resist corrosion. Seal from water contamination.

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Table 27: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Soil Retention Container	Failure to seal the soil	Soil is not sealed.	8	Soil prohibits the doors from closing	2	2	32	Design the container to be much larger than 10 mL.
		Container detaches from the Chassis. The auger does not drop soil onto the container doors. Doors do not open/close	6	Threads are stripped on any component	2	5	60	FEA. Testing. Use favorable factors of safety.
		Gaps are present between the door and container. The doors are not rotated to the complete close position	7	Soil is not contained by the lower door	2	2	28	Make sure motor torque specifications are adequate. FEA. Testing. Foam around the edges of the doors.
		Doors do not open/close. Soil is not sealed.	4	Corrosion	2	5	40	Use corrosion resistant components when possible. Buy coated materials to resist corrosion. Seal from water contamination.
Payload Retention	Failure to Retain Payload	Payload falls from airframe during flight	9	Retention devices fail mechanically or electrical system released early	3	1	27	Redundant retention devices account for any abnormal flight forces above 50 g. Electrical system designed to keep retention devices closed should electrical failure occur.
		Payload moves around within airframe	4	Improper integration into airframe	4	6	96	Payload integration checklists ensure that payload will not be able to move during flight

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Table 27: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Payload Retention	Failure to Retain Payload	Payload is damaged, unable to complete mission	7	Improper rover integration with PEARS or integration into airframe	3	3	63	PEARS assembly checklists and integration procedure checklists ensure proper assembly and integration
	Failure to Release Payload	Payload stuck inside airframe, unable to complete mission	3	Retention devices fail in a closed position from electrical failure	2	1	6	Rigorous ground testing of all retention components conducted until electrical system is consistently successful
		Payload is damaged, unable to complete mission. Airframe damage sustained	9	Payload retained when ejection attempted	1	1	9	Ejection charges cannot be blown unless successful release of retention devices is registered by PLEC
Payload Ejection	Failure to Eject payload	Payload is stuck inside airframe, unable to complete mission	3	PLEC electrical failure or non-released retention devices	2	1	6	Rigorous ground testing of PLEC for consistent ejection success.
Payload Ejection	Damage Payload on Ejection	Payload not able to complete mission	5	Object at end of airframe which rover hits on ejection.	2	1	10	Reduced speed at which rover hits object by sizing ejection charges through rigorous ground testing

4.2.3 Environmental Hazards

In Table 28 are the Environmental Hazards that OSRT have developed for the mission.

Table 28: Environmental Hazard Analysis

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Shrapnel is ejected from launch vehicle.	Launch vehicle motor erupts; ballistic impact.	Motor tube or body tube separates into small pieces/projectiles.	3B	Motor will be packed by NAR Mentor; recovery system will not allow the launch vehicle to go ballistic.	OSRT members have been instructed on how to handle composites in Section 3.1.15.1.	4B
Ice Forms on Airframe Exterior.	Ice forms on airframe separation area; forms on static port holes.	Black powder charges fail to overcome added force from ice; inaccurate altimeter reading; failed recovery.	1D	Sufficient port holes and black powder charges to overcome ice buildup. Visual inspection in cold conditions for ice forming.	Visual inspections are done during the assembly phase. Section 4.1.2.	1E
Wadding ejected from launch vehicle during rover ejection.	A wadding of some form is needed to protect components located in the same bay as the ejection charges.	Wadding can become random trash or degrade poorly causing chemical leakage into the ground.	3A	Choose a wadding that is biodegradable and collect all excess wading when recovering launch vehicle.	A biodegradable cellulose wadding was purchased. This wadding has minimal impact if left outside and will degrade over time. Recovery of excess wadding is part of post flight checklist 4.1.15.	4B

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Table 28 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Manufacturing defects in the batteries.	Defected batteries leaking chemicals.	Chemical components of the batteries can leak into the ground and water becoming hazardous to local flora and fauna.	2C	Batteries will be inspected before use for any defects and properly disposed of if found to be faulty.	Batteries are inspected as part of assembly checklist for any defects that would cause the to be faulty.	2E
Electronics are damaged.	Electronics are exposed to excessive moisture.	Corrosion of terminals or shorted electronics.	2C	Limit exposure of electronics to humid environments.	All electronics will be stored in a cool, dry place when not in use. Testing of all electronics will be performed immediately before use.	2E
Hazardous gases are emitted from the motor.	Motor with a toxic propellant is chosen.	Toxic gases are emitted into the atmosphere.	3B	Select a motor with a clean propellant and properly dispose of all hazardous material.	White Thunder propellant is chosen which burns cleanly and limits toxic gas emitted into the atmosphere.	3D

5 Payload Criteria

5.1 Payload Objective

The payload objective is to travel at least 10 ft from the launch vehicle after landing, collect a 10 mL soil sample, store the sample in an on-board containment unit, and conduct a scientific experiment on the sample. To simulate an extraterrestrial mission, the rover collects a soil sample and drives to a scientific base station. The scientific base station is representative of a location that was setup on a previous mission. Once the rover arrives at the scientific base station, it will deposit the soil sample for analysis. Since PDR, the experiment has been modified to be a mock x-ray fluorescence experiment and a soil pH map. The data collected from the experiment will then be broadcast back to the avionics ground station, representative of Earth in an extraterrestrial mission. The purpose of the x-ray fluorescence experiment would be to determine the chemical composition of the soil, while the purpose of the pH mapping would be to determine potential spots for a human colony to test plant growth. The primary function of the rover as a whole is to perform proof of concept of a rover performing a similar mission on a different celestial body such as Mars.

5.2 Rover Mechanical

5.2.1 Chassis

The rover chassis is designed using a double truss configuration. This design is durable while also remaining lightweight. The chassis will be made of carbon fiber rods and aluminum blocks. The rods will serve as a mounting structure for other components within the chassis and the blocks will have tapped holes to mount electronics within the rover frame. A spring loaded carbon fiber tail will be attached to the rear of the rover to stabilize the rover while driving. The chassis is shown in Figure 44 (color difference for visual clarity) and the components with their respective weights are shown in Table 29.

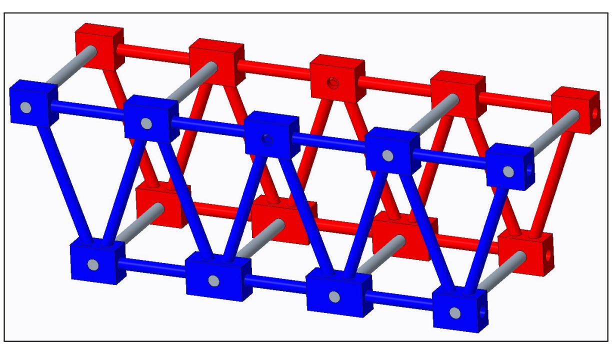

Figure 44: Chassis Assembly

A stabilizing tail will be connected to the rover to prevent the chassis from spinning in place while the drivetrain motors are in operation. A bottom view of the stabilizer is shown in Figure 45.

Using a torsion spring allows the stabilizer to be wrapped around the bottom side of the chassis during airframe integrated, but then forced outward once ejected. One of the torsion spring legs will sit within a hole placed in one of the chassis blocks shown in Figure 46.

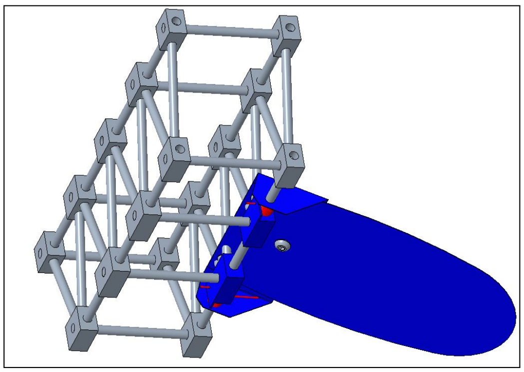

Figure 45: Rover Tail

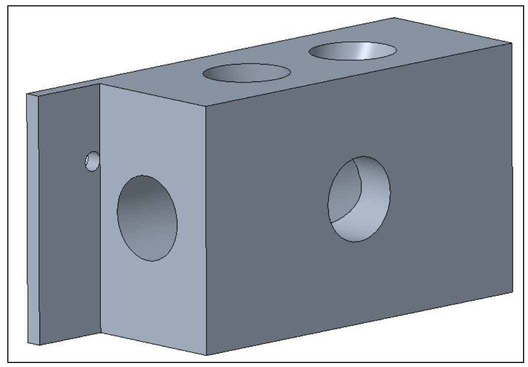

Figure 46: Stabilizing Block

A list of components with weights is shown in Table 29.

Table 29: Chassis Assembly Weight

Component	Expected Unit Weight (lbf)	Quantity	Expected Total Weight (lbf)
Chassis Block 1	0.025	4	0.100
Chassis Block 2	0.028	10	0.280
Chassis Block 3	0.036	4	0.144
Short Chassis Rod	0.007	14	0.092
Medium Chassis Rod	0.010	16	0.155
Long Chassis Rod	0.012	8	0.093
Tail	0.050	1	0.050
Stabilizer	0.050	1	0.050
Torsion Spring	0.020	2	0.040
Subsystem Total			**1.004 lbf**

5.2.2 Drivetrain

The rover will employ two coaxial, non-steerable, independently driven wheels. Each will be at one end of the chassis, perpendicular to its long axis. As such, it will have two drivetrain assemblies that are identical but mirrored across the chassis' midpoint.

What follows is a detailed description of each component of one half of the drivetrain, roughly in order from the innermost to outermost. The assembled drivetrain can be seen in Figure 47 and an exploded view is shown in Figure 48. Every part will have an identical counterpart on the other half of the rover.

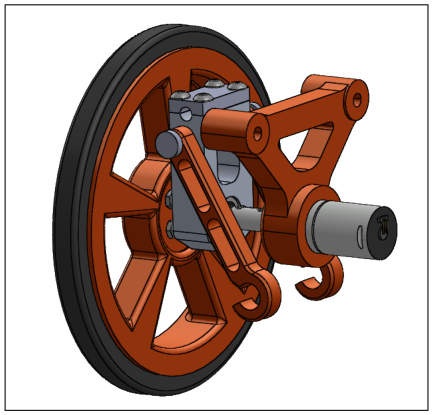

Figure 47: Drivetrain Assembly

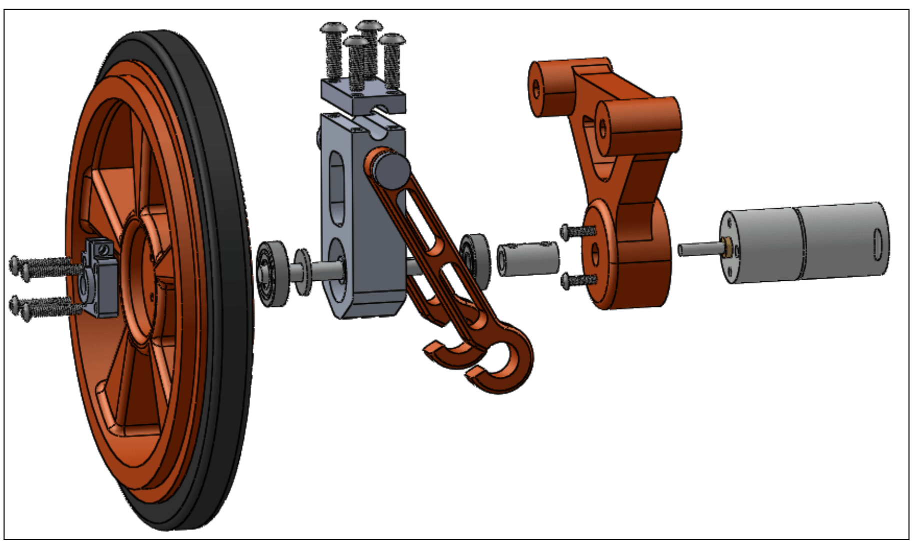

Figure 48: Drivetrain Assembly Exploded View

The team selected brushed Direct Current (DC) electric motors because of their ubiquity, low weight, relatively small form factor, and affordability. The motor chosen must be powerful enough to allow the rover to meet the team's performance goals, but should not be so powerful that it adds unnecessary weight and takes up valuable space within the chassis. For motor selection, the performance goals in Table 30 were considered.

Table 30: Rover Performance Goals

Performance Goal	Value
Maximum Velocity	1.0 ft/s
Acceleration Time	2.0 s
Maximum Slope Climb	30°

A free body diagram of the rover on a slope allowed the team to calculate the total necessary torque to meet these goals. Equation 13 was used for this purpose, where T is torque, m is the rover's mass, r is the wheel radius, a is the desired acceleration, g is the gravitational constant, and β is the slope angle.

$$T = mr[a + gsin(\beta)] \tag{13}$$

The rover's weight is 5.73 lbf and it has wheels with a 3.375 in. effective radius (see Wheel and Tire subsection for details). With the assumptions that the slope is perfectly smooth and free of obstructions and that there are no losses in power transmission, the rover needs 159.5 oz-in of torque to meet the criteria. The design has two motors so each needs to supply only half of this amount, or 79.77 oz-in. However, since there will be losses in the system and the ground surface during the mission will not be smooth, using a significant safety factor is advisable. Therefore, the team selected ServoCity's 170 RPM Econ Gear Motor, which has a stall torque of 306.09 oz-in, as the rover's drive motors. This gives a safety factor of about 3.8, making sure that it is unlikely that the drive motors will reach their stall current, even on somewhat steeper slopes. This motor's specifications can be seen in Table 31.

Table 31: Drive Motor Specifications

Specification	Value
Stall Torque	306.09 oz-in
No-Load RPM	170 RPM
Operating Voltage	6-18 V
Stall Current	3.8 A
Gear Ratio	57:1
Weight	0.203 lbf
Length	2.866 in.

The motor requires support to sustain linearity of the assembly and to rotate the wheel with respect to the chassis. To achieve this, the team will use a mount which attaches permanently to two lengthwise members of the chassis and seats the drive motor in the appropriate position below, with the motor terminals exposed for wiring purposes. The team will use additive manufacturing with ABS to achieve the complex shape.

Since the drive motor has a 4 mm diameter output shaft and the adjacent end of the drive shaft is 0.250 in., a coupling is necessary. ServoCity offers stainless steel set screw shaft couplings, which the team will use for this purpose.

The 2.2625 in. long 6061 aluminum drive shaft will transmit torque from the drive motor to the wheel to move the rover. It is 0.245 in. in diameter nearest the motor, with a D-shaped end to accommodate the set screw shaft coupling. It then steps up to 0.370 in. to fit the outer ball bearing, then back down to 0.245 in. to interface with the 0.250 in. bore clamping hub on the opposite side of the wheel.

The mounting block assembly is made of 6061 aluminum and is the main interface between the rover's drivetrain and chassis. The lower core of this assembly clamps onto a cross member of the chassis using an upper plate and four #10-32 UNF screws. The drive shaft runs through this component, which also houses three bearings. It has two press-fit extension pieces which are where the connecting rods will attach. A closer look at this assembly is in Figure 49.

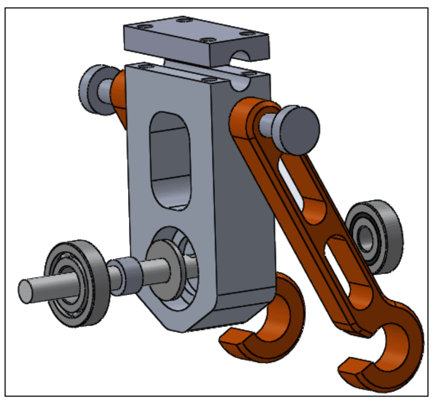

Figure 49: Drivetrain mounting block assembly.

The mounting block assembly houses a three-piece bearing assembly. These components are described from inside to outside in Table 32. The purpose of the ball bearings is to allow unrestricted rotation of the drive shaft while eliminating moment transmitted to the motor. The iron-copper thrust washer is included to mitigate the effect of large axial loads in the assembly. Both ball bearings will be press fit into the mounting block assembly and slip fit over the drive shaft.

Table 32: The bearing specifications.

Component	Inner Diameter (in.)	Outer Diameter (in.)	Dynamic Radial Load Rating (lbf)	Dynamic Thrust Load Rating (lbf)
Inner Ball Bearing	0.250	0.750	520	N/A
Thrust Bearing	0.252	0.625	N/A	980 @ 120 RPM
Outer Ball Bearing	0.375	0.875	590	N/A

The drive shaft passes through the wheel and is clamped with a 0.250 in. bore clamping hub at its end. The clamping hub has four threaded holes which match those in the wheel. The assembly is fastened together with matching locknuts. It can be disassembled easily, if necessary.

The wheel itself will be produced using additive manufacturing with ABS. It has a diameter of 6.00 in. and is 0.75 in. thick. It is an open spoke design, to save weight, with a channel along its circumference to accommodate a foam tread. This 0.50 in. PORON foam tread is compressed within a fiberglass wrap while packed inside the 6.25 in. airframe. With a bulkhead pressing against the wheel, the foam applies pressure radially to form a seal around its perimeter that will enable PEARS' black powder ejection after the airframe lands. During rover ejection, the wrap is shed and the foam is allowed to expand, giving the rover a ground clearance benefit with a new effective wheel diameter of 6.75 in.

A summary of the drivetrain components' weights is shown in Table 33.

Table 33: Drivetrain Assembly Weight

No.	Component	Expected Unit Weight (lbf)	Quantity	Expected Total Weight (lbf)
06-201	Clamping Hub	0.016	2	0.032
06-202	Wheel	0.435	2	0.870
06-203	Tire	0.096	2	0.192
06-204	Drive Shaft	0.012	2	0.024
06-205	Mounting Block Bottom	0.190	2	0.380
06-206	Mounting Block Top	0.022	2	0.044
06-207	Mounting Block Extension	0.006	4	0.024
06-208	Outer Ball Bearing	0.020	2	0.040
06-209	Thrust Washer	0.005	2	0.010
06-210	Inner Ball Bearing	0.020	2	0.040
06-211	Connecting Rod	0.018	4	0.072
06-212	Shaft Coupling	0.022	2	0.044
06-213	170 RPM Econ Gear Motor	0.203	2	0.406
06-214	Motor Mount	0.123	2	0.246
06-215	6-32 UNC Screw	0.006	8	0.044
06-216	M3-0.5 Screw	0.002	4	0.007
06-217	10-32 UNF Screw	0.007	8	0.054
06-218	6-32 Locknut	0.002	8	0.016
			Subsystem Total	**2.545 lbf**

5.2.3 SCAR

The SCAR design contained two sets of alternative designs. One set determined the type of soil collection device and the other determined the type of soil retention method. Shown in Table 34 is a summary of the final design decisions.

Table 34: SCAR Final Design Decisions

Subsystem	Final Decision Chosen	Reasoning
Collection	Auger	Lightweight, compact, breaks up soil, and reliable.
Retention	Center-pivot doors	Compact, less torque to operate, and a reversible process.

5.2.3.1 Soil Collection

The Soil Collection system will use an auger assembly to collect and transport the soil from the ground to the soil retention container. This design was chosen for its compact, lightweight, and reliable characteristics. The auger can also break apart large clumps of soil if needed. The full soil collection assembly is shown in Figure 50.

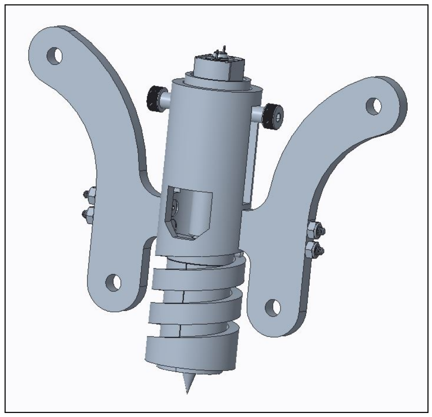

Figure 50: Soil collection assembly.

The basic components for the soil collection system are the auger, auger bar, coupler, and motor, displayed in Figure 51. The auger is displayed as a transparent component to allow the auger bar to be clearly visible within it. The purpose of the auger bar is to provide an extended arm to interact with the auger tube. The auger will be created by additive manufacturing and made of PLA plastic, allowing it to be lightweight but durable enough to dig into and break apart soil. Not shown in the figure, a carbon fiber tube will surround the auger to prevent soil from falling out during the collection process.

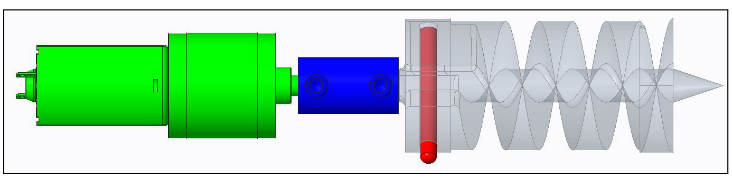

Figure 51: Soil collection basic components.

Surrounding the motor is a motor enclosure. This component mounts to the front of the motor and contains two threaded holes located on both sides. Screws will be placed in these holes and interact with the auger tube. The motor enclosure and screws are shown in Figure 52. This component is made of aluminum to be lightweight while also retaining the ability to have threaded holes.

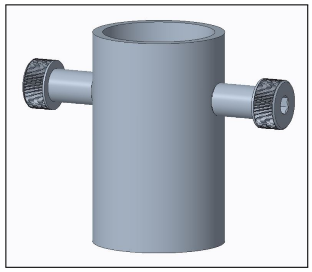

Figure 52: Motor enclosure and bolts for the soil collection assembly.

The auger tube determines the travel path for the auger and motor. The auger bar interacts with the bottom of the auger tube to only allow the auger to extend and retract in a helical motion from the tube. The motor enclosure screws interact with the top of the auger tube to only allow a linear and non-rotational path for the motor. This design allows the motor rotation speed to determine the feed rate of the auger. The pitch at the bottom of the auger tube allows the rotation per distance of the auger to be controlled. The direction of linear motion is determined by the rotational direction of the motor. This design is also used to reduce the amount of space taken by the SCAR within the rover chassis. Within the interior of the auger tube, there are two counterbored holes on each side used to prevent the screws for the auger mount from interfering with the linear motion of the auger and motor. Shown in Figure 53 is the auger tube (colored blue) surrounding the other soil collection components, excluding the mounting fixtures. This component will be made of PLA to remain lightweight, be manufacturable, and reduce costs.

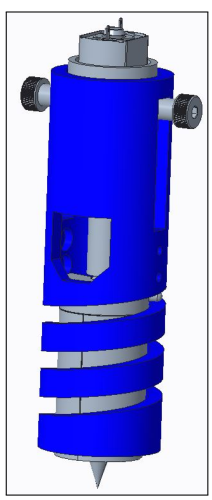

Figure 53: Auger tube surrounding the soil collection basic components.

The soil collection system is mounted to the chassis using a mounting fixture (colored blue) shown in Figure 54. The fixtures are attached to the auger tube using bolts and nuts. The chassis cross rods are placed within each of the mounting holes, allowing the soil collection system to be connected to the rover in four locations and distribute the applied forces during mission operations. This component will be made of PLA plastic to reduce weight but continue to be durable enough for the ejection and landing of the rover.

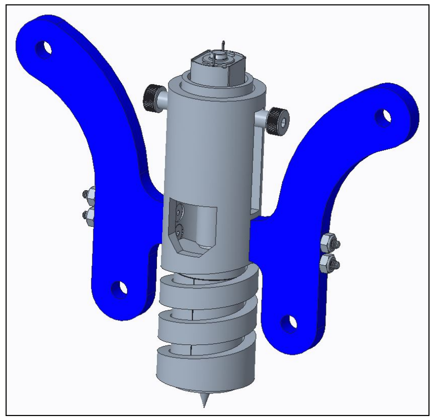

Figure 54: Mounting fixture for the Soil Collection system

The mounting fixtures are expected to experience the greatest stresses within the SCAR system due to their direct connection to the chassis, their shape, and their material. FEA was performed to determine the maximum force that could be applied to the component at its yield stress point. The component was analyzed with a force acting at a 45° angle at each front-facing mounting hole. The FEA determined the largest force that could act on each hole was 900 lbf, or 3,600 lbf for all four holes combined. This is more than the expected 2,546 lbf, derived from an estimated pressure of 83 psi caused by rover ejection charges. The FEA with the two 900 lbf is shown in Figure 55 with the stress indicated next to the component in psi. The yield strength of PLA plastic is 8,840 psi.

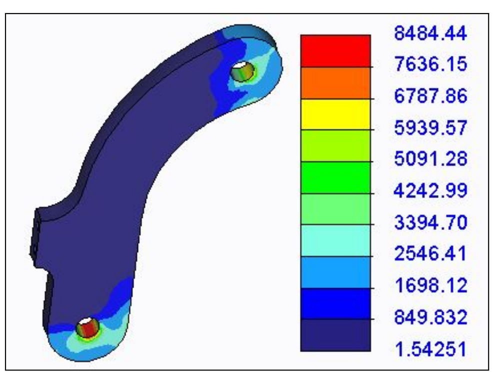

Figure 55: FEA for a mounting fixture. Units are stress in psi.

5.2.3.2 Soil Retention

The soil retention system is shown in Figure 56. It consists of two sets of door, rods, couplers, and motors, with a single soil container and motor mount. Two doors, one on top and another on bottom, will allow for soil to be deposited into the top and then released from the bottom. This provides an option for an additional scientific experiment to be performed on the soil after collection and retention has been completed successfully. The container will be built using additive manufacturing and be made of PLA plastic. The holes within the container will be used to attach the soil retention system to the chassis.

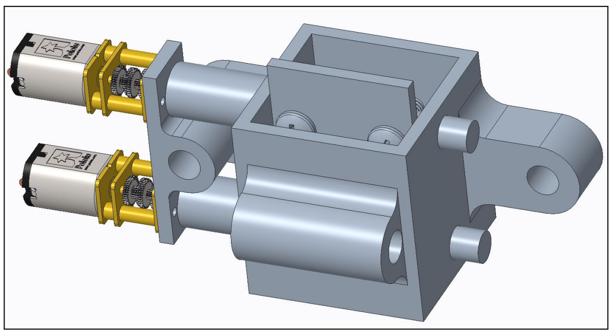

Figure 56: The soil retention assembly.

A completed list of the SCAR components with weights is shown in Table 35.

Table 35: SCAR Assembly Weight

Component	Expected Unit Weight (lbf)	Quantity	Expected Total Weight (lbf)
Auger Bar	0.004	1	0.004
Carbon Fiber Wrap - Auger	0.004	1	0.004
Motor Enclosure	0.039	1	0.039
Set Screw Shaft Coupler	0.020	3	0.060
Soil Collection Motor	0.100	1	0.100
Motor Mount Screw	0.011	2	0.022
Auger Tube	0.075	1	0.075
Container Door	0.012	2	0.024
Container Shaft	0.026	2	0.052
Container Screw	0.004	4	0.016
Auger	0.033	1	0.033
Soil Retention Motor	0.023	2	0.046
Soil Retention Container	0.055	1	0.055
Auger Mount Screw	0.001	1	0.004
Auger Mount Locknut	0.000	1	0.000
Auger Mount	0.035	2	0.070
Soil Retention Motor Mount	0.006	1	0.006
Subsystem Total		**0.610 lbf**	

5.3 Rover Electrical

Figure 57 is a high level block diagram which describes how the electrical components interface with each other. Each of the sensors, shown on the left of the diagram, output data to our chosen microcontroller, the Teensy 3.6. The microcontroller will process this information and control the drive motors accordingly.

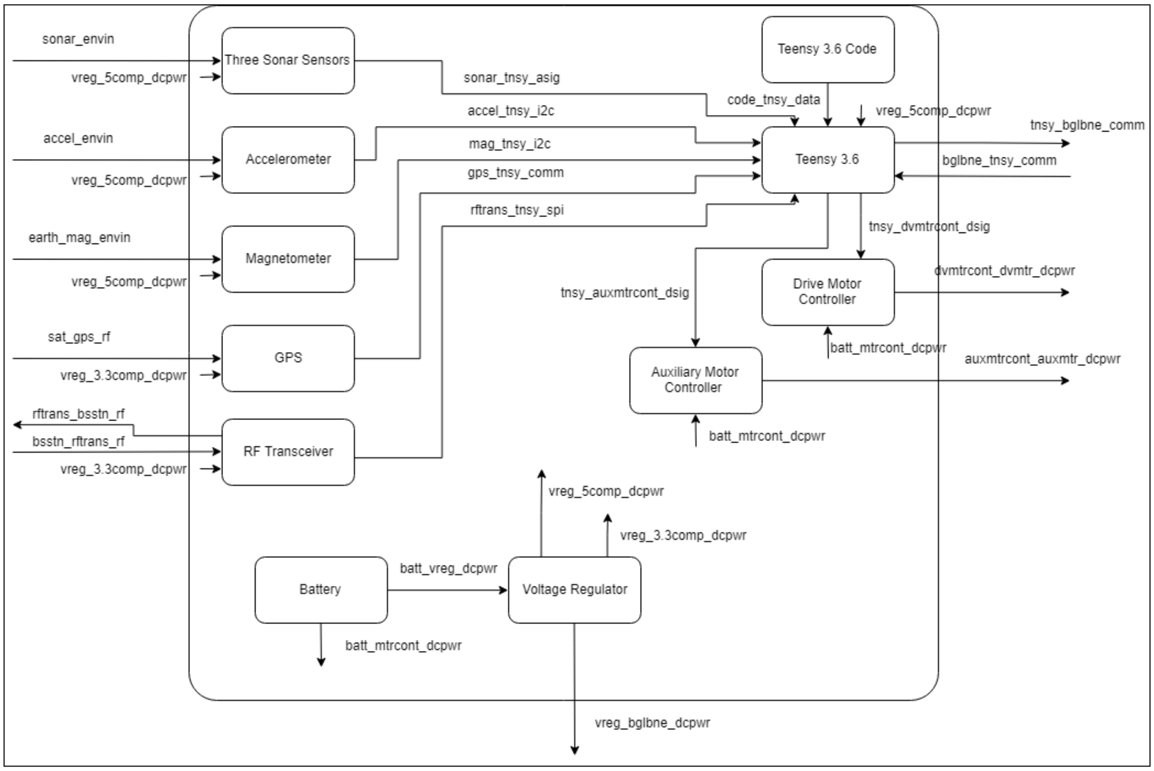

Figure 57: Payload Electrical Block Diagram

5.3.1 Component Decisions

The Teensy 3.6 microcontroller has been chosen based primarily on I/O capacity and processing power in a small form factor. Each of the components in the electrical subsystem is connected to the microcontroller with the exception of the computer vision camera, which will be outputting data to the BeagleBone Black, discussed in section 5.4. Serial communication is used to send interrupts to the Teensy when specific conditions are encountered by the CV system. The Teensy 3.6 sends digital and Pulse Width Modulation (PWM) signals to the drive and auxiliary motors to control speed and direction. It also receives input from each of the sensor and communication components including sonar sensors, accelerometer, magnetometer, GPS, and RF transceiver.

The Cytron 10 A Dual Channel DC Motor Driver was selected to control both drive motors. The 10 A continuous current rating is above the stall current for the chosen drive motors. Two digital signals are received from the microcontroller to control the direction of each drive motor. Two PWM signals are also received to control the speed of each of the drive motors.

Two TB6612FNG Dual Motor Drivers are used to control all of the non-drive motors on the rover. One motor driver is used to control the auger motor to collect soil from the ground. Another two are used to control the top and bottom of the soil retention container.

The LSM303DLHC triple axis accelerometer and magnetometer are used to determine the orientation of the rover. The magnetometer is useful while navigating with GPS to orient the rover in the correct direction. The accelerometer is used to determine if the rover is oriented correctly, with the auger pointing towards the ground, to allow for soil collection to occur.

Three sonar sensors are used within the rover for collision detection and avoidance. The MB1230 sonar sensor was chosen based on its minimum and maximum readable ranges and it's narrow detection field. The narrow detection field allows for limited detection of the ground beneath the rover. Two sensors are oriented nearly parallel with the ground and facing slightly outward to scan a wider field of view. The remaining sonar module is centered and facing slightly upward to allow for taller objects to be detected.

Voltage regulation is needed within the rover to step down the battery voltage to the appropriate input voltage for each component. The TPS5438 was chosen as it supplies two different voltages. 5 V is supplied to the accelerometer, Teensy 3.6, camera, Beaglebone Black, and the sonar sensors. 3.3 V is supplied to the transceiver and the GPS module.

A MAX-M8 U-Blox GPS is used to track the location of the rover. This module was selected for its reliability. A heartbeat Light Emitting Diode (LED) will indicate when GPS coordinates are being determined.

The XBee-PRO 900HP transceiver module is used to receive the GPS coordinates of the base station via an RF transmission. The XBee transmits and receives RF signals at frequencies ranging from 902MHz to 928MHz. An LED is used to display when transmissions are being received.

The Turnigy Graphene 1300 mAh battery has been chosen based on it's continuous current rating and the power budget shown in Table 36. The sum of the final column represents the expected current draw from the battery adjusted for expected duty cycle of each component. The battery has a capacity of 1300 mAh and the expected current draw is 735 mA, resulting in an expected operational time of 105 minutes, well above our specified mission time of 45 minutes. An analog pin on the microcontroller is dedicated to keeping track of the cross terminal voltage of the battery. LiPo batteries have a predictable voltage curve which will allow for remaining battery capacity to be estimated. This reading is used to determine when a critical voltage LED is lit.

Table 36: Power Budget

Component	Quality	Current (mA)	Voltage (V)	Battery Current (mA)	Duty Cycle	Adjusted Battery Current
LSM303 Accelerometer	1	0.11	5.00	0.05	1	0.05
Teensy 3.6	1	50.00	5.00	22.52	1	22.52
Logitech C310 Camera	1	80.00	5.00	36.04	1	36.04
Beaglebone Black	1	500.00	5.00	226.23	1	226.23
Drive Motors	2	500.00	11.10	500.00	0.7	350.00
XBee Pro Transceiver	1	215.00	3.30	63.92	0.1	6.39
Auxiliary Motors	3	300.00	11.10	300.00	0.2	60.00
MAX-M8 GPS Module	1	67.00	3.30	19.92	1	19.92
MB1230 XL-MaxSonar-EZ3	3	34.00	5.00	15.32	1	15.32
	Total	**1746.11**		**1182.99**		**735.46**

5.3.2 Switches and Indicators

A master power switch is located on the upper-right portion of the rover; this allows for the rover to be easily turned on and off. In series with this switch is an electromagnetic relay which will remain open while the payload is within the airframe. The relay is held open by voltage from the rover battery connected to the relay input after being inverted. The voltage to the inverter is delivered through a wire which is physically connected to the PLEC bulkhead.

Each of the indicator LED's have a forward bias max current rating of 20 mA and voltage of 2.0 V. To regulate the current through each LED to 15 mA to stay well below the max rated current of the LEDs. The Teensy 3.6 has a rated voltage of 3.3 V on each General Purpose Inputs and Outputs (GPIO) pin. As a result a 100 Ω resistor is used in series with each LED. Each indicator LED will therefore consume 43 mW of power while on. The limited duty cycle of these LED's will, however, make the overall power draw from the battery negligible.

5.4 Rover Software

The software of the rover will consist of a Teensy micro controller with many different external sensors, along with a BeagleBone Black connected to the Teensy for serial communication. The Teensy will control the general rover movement and communication to all peripheral devices and sensors, while the BeagleBone will operate the CV and instruct the Teensy to perform specific routines based on the input being received by CV. Each command given by the BeagleBone will interrupt the Teensy in order to run a pre-programmed routine located on the Teensy.

5.4.1 Teensy State Diagram

The software for the rover will be split up into two separate state diagrams that will work together in order to complete the task given. The Teensy will be fit with the ability to carry out a basic mission, to collect the soil sample, without use of the CV. This is to limit the risk of a mission failure if the CV became damaged. Minimizing risk becomes increasingly important with the extreme G forces during flight and deployment.

As shown below, the Teensy has two phases. The first phase, the smaller of the two, has a primary objective of moving the rover outside the range of the payload. This will be done by moving and constantly checking the GPS coordinates with that of the rockets. When the rover is 15 meters or more away from the rocket body, it will proceed to check the gyroscope in order to see if it is on level ground. After the rover is both far enough away from the rocket and within operating ranges of the gyroscope, the rover can begin the auger drilling routine and log the location of the sample collected. After drilling, the soil sample will be sealed and the USLI stated mission is completed.

The second phase is used to repeatedly collect soil samples and deposit them at the scientific base station to complete the OSRT additional mission. After collecting the soil sample, the rover will wait for an RF transmission holding the number of soil samples to obtain and the coordinates of the base station. Using GPS, the rover will travel in the general direction of the base station and avoid objects along the path using both CV and sonar. When close enough to the base station, the CV will interrupt the Teensy. Once a green triangle located on the base station is found, the CV will take over the docking procedure. Once docked, the soil sample will be released and the rover is ready for another trip. Shown in figure 58 are the first and second phase loops which demonstrate the control over the rover.

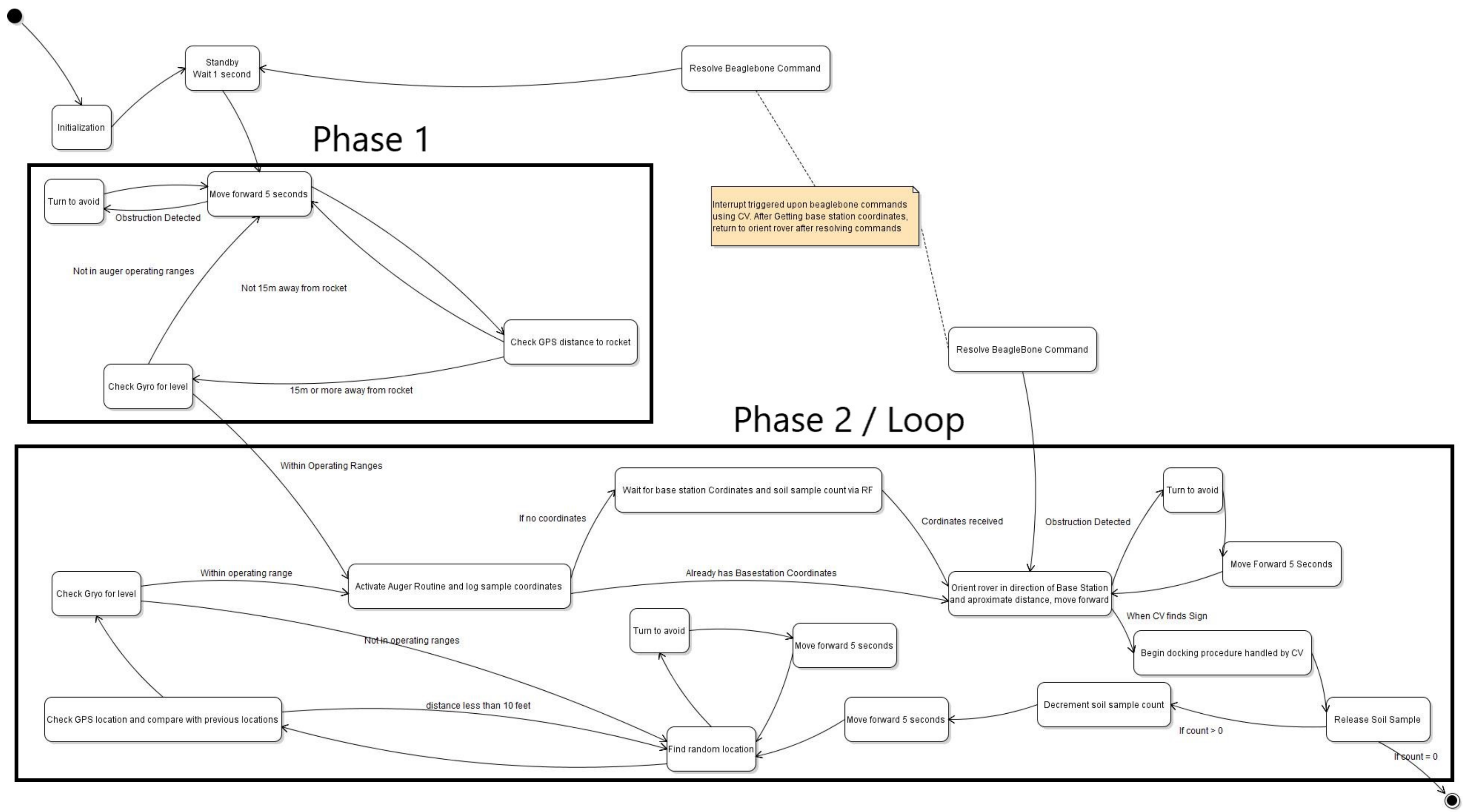

Figure 58: Rover Teensy State Diagram

Continuing from phase 2, after the soil sample has been deposited, the rover decrements the soil sample count given through the RF transmission. To collect another sample, the rover will move forward, through the flag with the green triangle. Object avoidance must be disabled at this time. After clearing the flag, the rover will find a random location that is not within 10 feet of another sample collected. The location found will be the next spot a soil sample is collected from. The rover then navigates back to the base station and docks releasing another soil sample. This process is then repeated for each sample being collected.

5.4.2 BeagleBone State Diagram

During the operation of the Teensy, the BeagleBone will constantly be processing information in front of the rover using CV. The BeagleBone is used primarily to implement redundancy and docking the rover. It functions by issuing interrupts that will stop the Teensy and perform a specific routine whenever a certain event occurs. Shown in Figure 59 is the state diagram for BeagleBone operations.

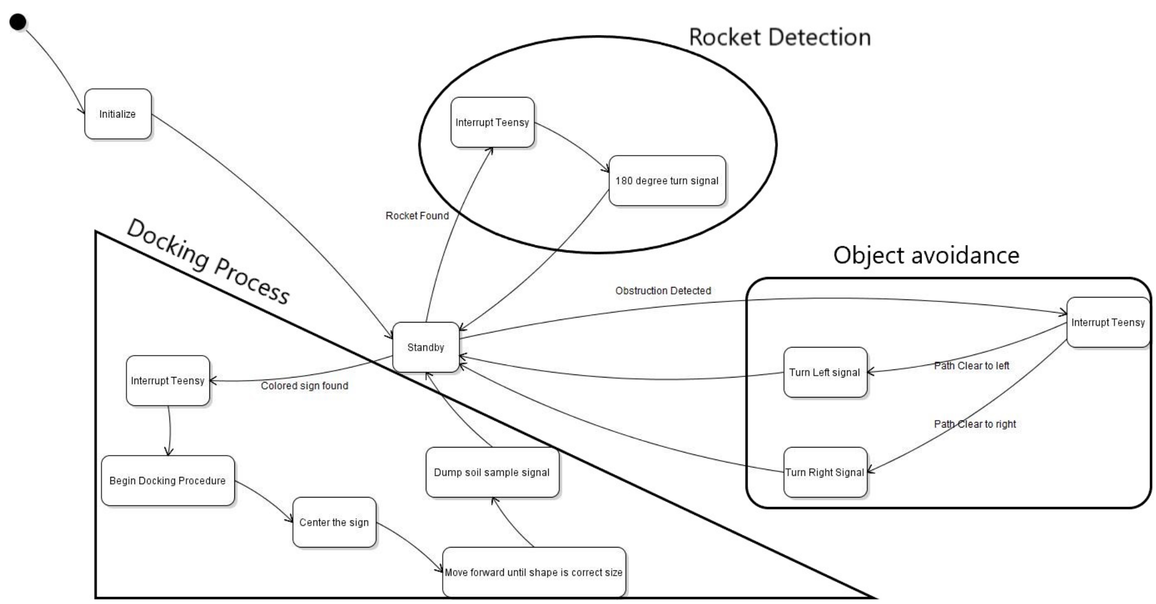

Figure 59: Rover BeagleBone State Diagram

The BeagleBone has 3 separate routines that are called to assist the Teensy and are listed as follows:

1) The first is the rocket detection. The OSRT will train the BeagleBone to recognize the rocket and turn away if found, this will implement redundancy for our task of moving away from the rocket before soil collection.
2) The second routine performed is for object detection. This will give our rover redundancy for objects that may need to be avoided. If any objects are detected, the BeagleBone will send instructions to the Teensy on how they can be avoided.

3) Lastly, we have a routine for docking that will activate when the green triangle located on the scientific base station is seen and will give the Teensy commands in order to move the rover square facing the green triangle shown. After this docking process has been completed, a signal to dump the soil sample will be issued and control will be passed back to the Teensy.

5.4.3 Scientific Base Station

After the rover has taken multiple samples, we can then collect a text file from the Teensy that contains every sample GPS location in order. This data can be used to label each sample, or create a map of each collection point around the area. Combining location information with pH information determined at the base station, we can create a map of the pH at locations surrounding the scientific base station.

5.5 Rover Overall Design

5.5.1 Rover Design Completeness

Shown in Figure 60 is the completed rover assembly. The drivetrain is displayed in orange, the chassis in blue, and the SCAR in red. The electrical components will be attached inside the chassis to prevent them from becoming damaged during mission operations. Overall, the rover weighs 5.73 lbf and is 14.5 in. in length.

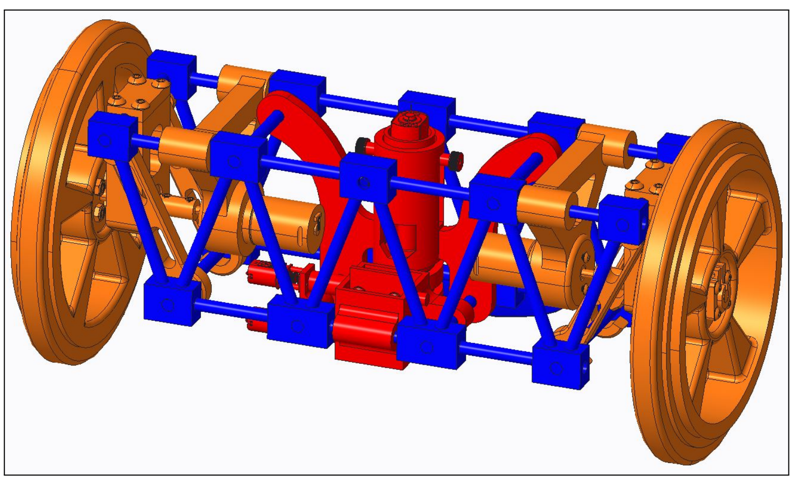

Figure 60: Completed Rover Assembly

5.6 Payload Ejection and Retention

As stated within the mission profile, the launch vehicle will descend in two separate sections after apogee, with the payload contained in the fore section. The coupler will descend with the aft motor section, leaving an open end in the fore section. The rover will be retained in the payload bay by a Kevlar harness connected to retention devices which can be released after landing. Following a safe landing, and once given clearance from the Rover Deployment Officer (RDO), a signal is sent to the payload bay which will release the retention devices, subsequently ejecting the rover from the open end of the airframe by igniting a black powder charge ignited with an e-match.

In OSRT's PDR submission, several design alternatives were evaluated for each subsystem required for successful retention, ejection and arming of the electrical systems. These designs were evaluated each with their own DDM. The final design chosen for Critical Design Review (CDR) is the system which scored the highest points. These final decisions are summarized in Table 37.

Table 37: PEARS Final Design Decisions

Subsystem	**Final Decision Chosen**	**Reasoning**
Retention	Tender Descenders and ARRD connected to Kevlar harness	Reliable, strong, lightweight, simple integration
Ejection	Black powder change	Reliable, lightweight, adjustable, simple
Arming	SPDT switch with access hole	Low impact on airframe structures, safe, easy integration

The combination of these systems is referred to as the PEARS. The PEARS is integrated into the fore airframe using a permanent series of bulkheads called the FHP. A complete CAD mockup of the PEARS and FHP can be referenced in Figure 61. The PEARS system can be broken up into three subassemblies as discussed in the following sections: rover housing, retention and ejection, and the PLEC.

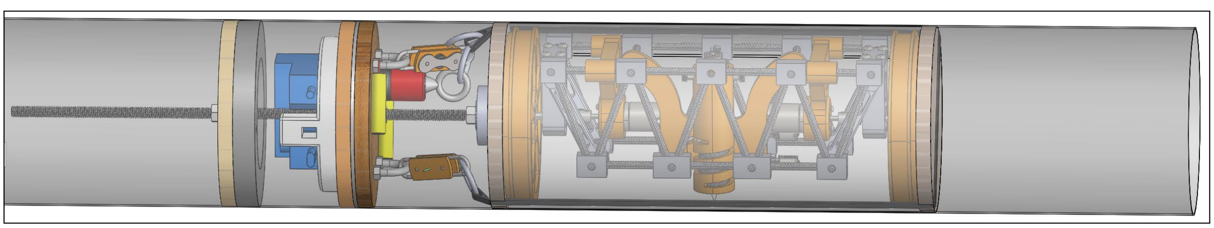

Figure 61: The fully integrated PEARS in the fore airframe

5.6.1 Rover Housing

The rover housing can be seen in Figure 62 and is comprised of five components:

1) Aft payload bulkhead
2) Fiberglass wrap
3) Fore payload bulkhead

4) Kevlar harness
5) Steel links x3

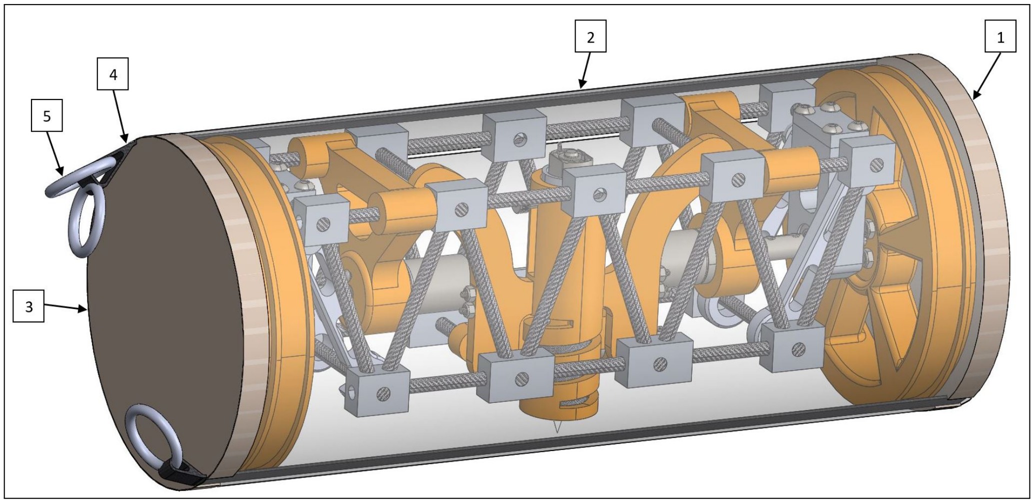

Figure 62: Wrapped rover housing subassembly with reference component numbers

The purpose of this subassembly is to wrap and protect the rover, keeping it immobile within the airframe during launch. The fiberglass wrap compresses the foam tires of the rover during integration into the airframe, and the foam subsequently pushes the wrap against the inside of the airframe, providing a pressure seal and keeping the rover in place with friction. The bulkheads protect the ends of the rover, and have a slot for the Kevlar harness to wrap around. The quick links on the ends of the harness connect to two Tender Descenders and an ARRD, which are part of the retention and ejection subsystem discussed below. In order to keep the rover in a low power mode until it is ejected, wires will be permanently attached to the inside of the fiberglass wrap. These wires will plug into ports of the body of the rover which close a circuit keeping it in low power. Upon ejection, due to the natural state of the fiberglass wanting to flatten, the wrap will open up and fall away, pulling the wires off the rover, powering it up for its mission.

5.6.2 Retention and Ejection

The retention and ejection subassembly can be seen in Figure 63, and is comprised of 11 different components:

1) Rod end cap
2) Threaded aluminum rod, $\frac{3}{8}$-16
3) PEARS bulkhead
4) Rubber seal
5) PLEC mount

6) PLEC
7) ARRD
8) Tender Descender x2
9) Ejection charges x2
10) U-bolt, 1/4-20 x2
11) Steel nut, 3/8-16 x5
12) Steel washer x5

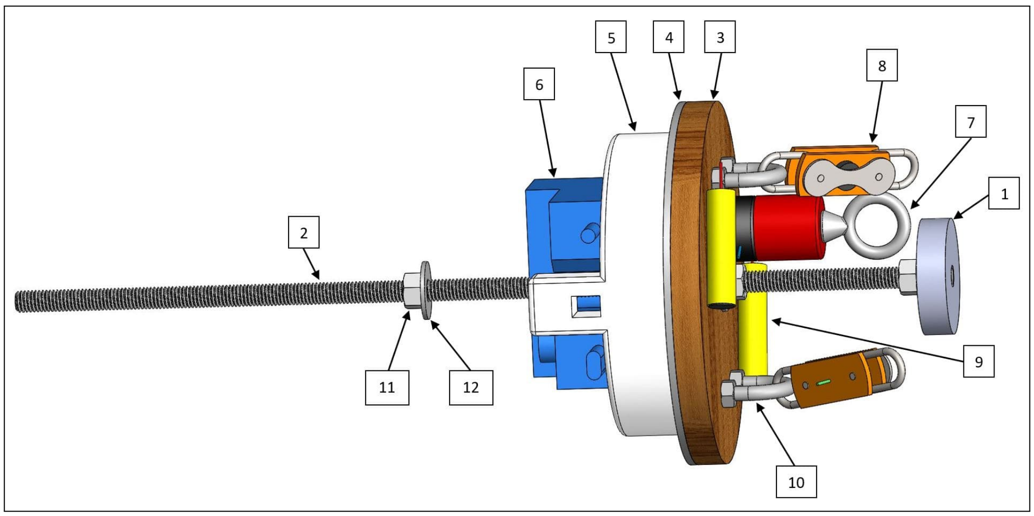

Figure 63: Retention and ejection subassembly with reference component numbers

The threaded rod serves to both keep the subassembly together, as well as to attach this system into the airframe via the FHP. During assembly, this system is fully removed from the airframe, and the rover housing assembly is attached via the Tender Descenders and ARRD. The fore payload bulkhead sits against the rod end cap to keep space between the ejection charges and the payload. The rubber seal will create a removable pressure seal against the pass through bulkhead in the fore hard point subassembly to allow the ejection charges to project the full rover housing assembly out of the airframe. The charges are made from 4F black powder, surgical tubing, santoprene plugs, zip ties, and an e-match. The PLEC mount will serve to separate the PLEC from the bulkhead's hardware, mount a locking SPDT switch, and provide a guiding hole for integration orientation.

While the mass of black powder for ejection will be chosen based on ground testing, a mass of 5 g will be used to start. A simple state diagram and analysis were conducted to evaluate the needed pressure on the wrapped assembly to eject it from the airframe. From this calculated pressure a 4F black powder charge size was determined using the charge properties and the volume of pressure sealed compartment. While this analysis yielded a charge size of 6.2 g, testing will begin at 5 g for safety purposes and to avoid damaging the testing equipment with too large a charge. Last year's OSRT used a 5.5 g primary charge to eject the payload in a similar fashion, but used a smaller airframe. The final mass will be determined through incremental size testing in the same manner conducted for recovery testing.

5.6.3 Payload Ejection Controller

In order to remotely activate the retention devices and ejection charge, the PEARS must include a controller, referred to as the PLEC. The functionality and electrical design of the PLEC has not changed since the PDR except for the final decision to include a SPDT locking switch to shunt to dissipate any charge built up upon integration. The top level view of the PLEC can be seen in Figure 64.

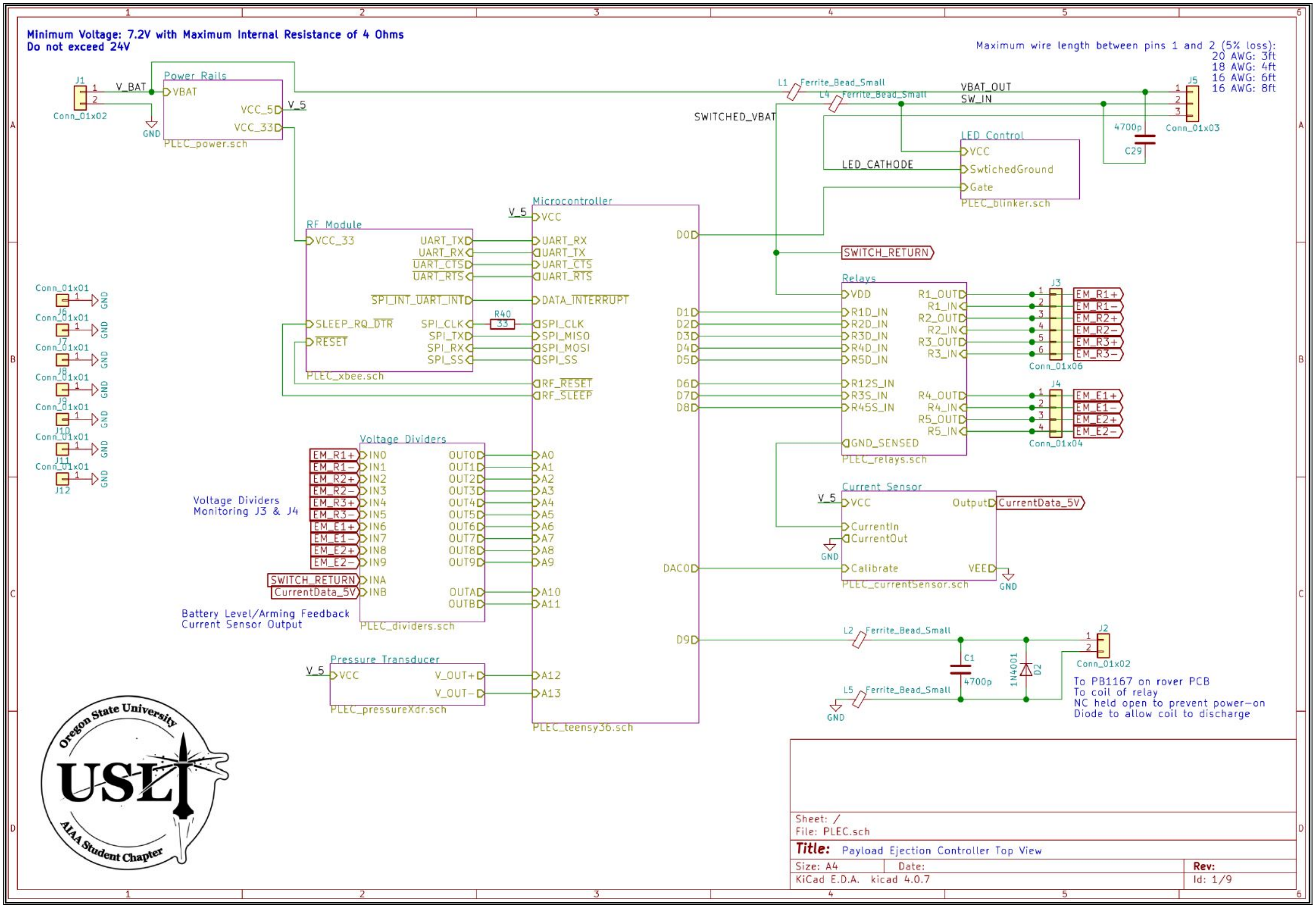

Figure 64: Top level view of PLEC

The PLEC has a Teensy 3.6 hub which communicates with the RF ground station through an XBee Pro 900HP. The XBee transmits and receives with a bandwidth of 26 MHz centered at 915 MHz. The Teensy has several digital outputs which control ignition of the retention and release devices discussed earlier.

A separate e-match is used to ignite each black powder charge. A total of five ignition channels are needed on the PLEC: three retention devices and two ejection devices. Because the ARRD is a backup device, and the two Tender Descenders are the primary devices, a more redundant circuit was used for the ARRD due to an extra channel in the power relay. The Tender Descenders and ejection devices all rely on the same relay circuit. Figure 65 shows the difference in these two circuits. Channels 1 and 2 connect to the Tender Descender e-matches, and channel 3 connects to the ARRD e-match. Channels 4 and 5 connect to the primary and backup ejection charges, and are functionally identical to channels 1 and 2.

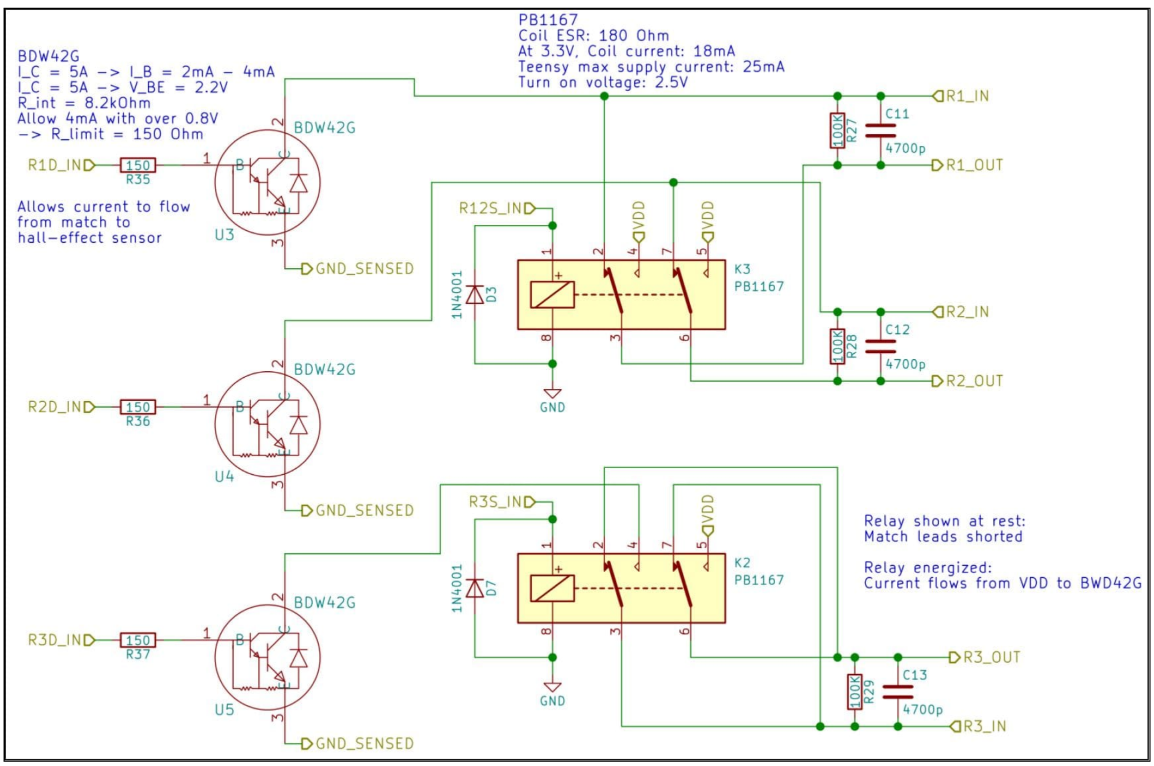

Figure 65: Three of the five relay circuits (4 and 5 are identical to 1 and 2)

Each ignition channel requires two signals to arrive from the microcontroller in order to send current to its respective e-match: one to a PB1167 electromechanical relay, and one to a BDW42G NPN Darlington pair transistor chip. The Darlington pair prevents current from flowing to electrical ground, and the relay performs multiple functions. In the rest position, the PB1167 relay shorts the leads of each e-match together, so no voltage can be generated across it. When the relay is energized, one lead of the e-match is pulled to electrical high, and the other is left to float until the Darlington pair pulls it low. Channel 3 has an added safety feature, where even if one relay contact vibrates to a floating position, the second channel continues to short the leads together until both contacts are energized. A resistor-capacitor filter is also present at the terminal block of each channel to absorb Electromagnetic Interference (EMI) over long periods of time. Each electromechanical relay has a fly back diode to mitigate Counter Electromotive Force (CEMF).

Due to the mechanical design of the rover retention, it is extremely important that the charges are ignited in the correct order; simultaneous ignition would be a very dangerous event. If the retention devices are holding the rover in place when the ejection charges are activated, the rover will suffer catastrophic damage. Therefore, the microcontroller has an array of sensors to detect the ignition of each e-match:

- HXS 20-NP current sensor to measure current
- E-match 13-bit differential voltage sensors to measure voltage of each terminal
- Software integration of voltage times current over time to calculate energy to e-match
- NBPMANN150 pressure sensor to detect rising chamber pressure

All of these devices are conditioned to output a 3 V analog signal to the microcontroller for software control. With these sensors, the microcontroller can calculate with high certainty whether the retention devices were activated properly, and proceed to eject the rover.

The PLEC communicates with the base station over a 918 MHz RF transmission through an XBee module. The XBee transmits and receives over a 50 Ω shielded transmission line to an antenna on on the PLEC The fore section of airframe is fiberglass for RF transparency. The PLEC will be encased in a sheet aluminum Faraday cage, and the openings for other wires will be back filled with grommets and putty to protect from black powder residue. This protection is important because even though the electrical components are on the other side of a pressure seal from the black powder when ignited, during launch vehicle disassembly and cleaning powder residue could come in contact with the PLEC.

Figure 66 shows a the printed circuit board (with power planes hidden). The PCB will be fitted to the fore side of the PEARS bulkhead. A slot is removed from the center to accommodate the threaded rod and corresponding washer and nut that attach to the bulkhead.

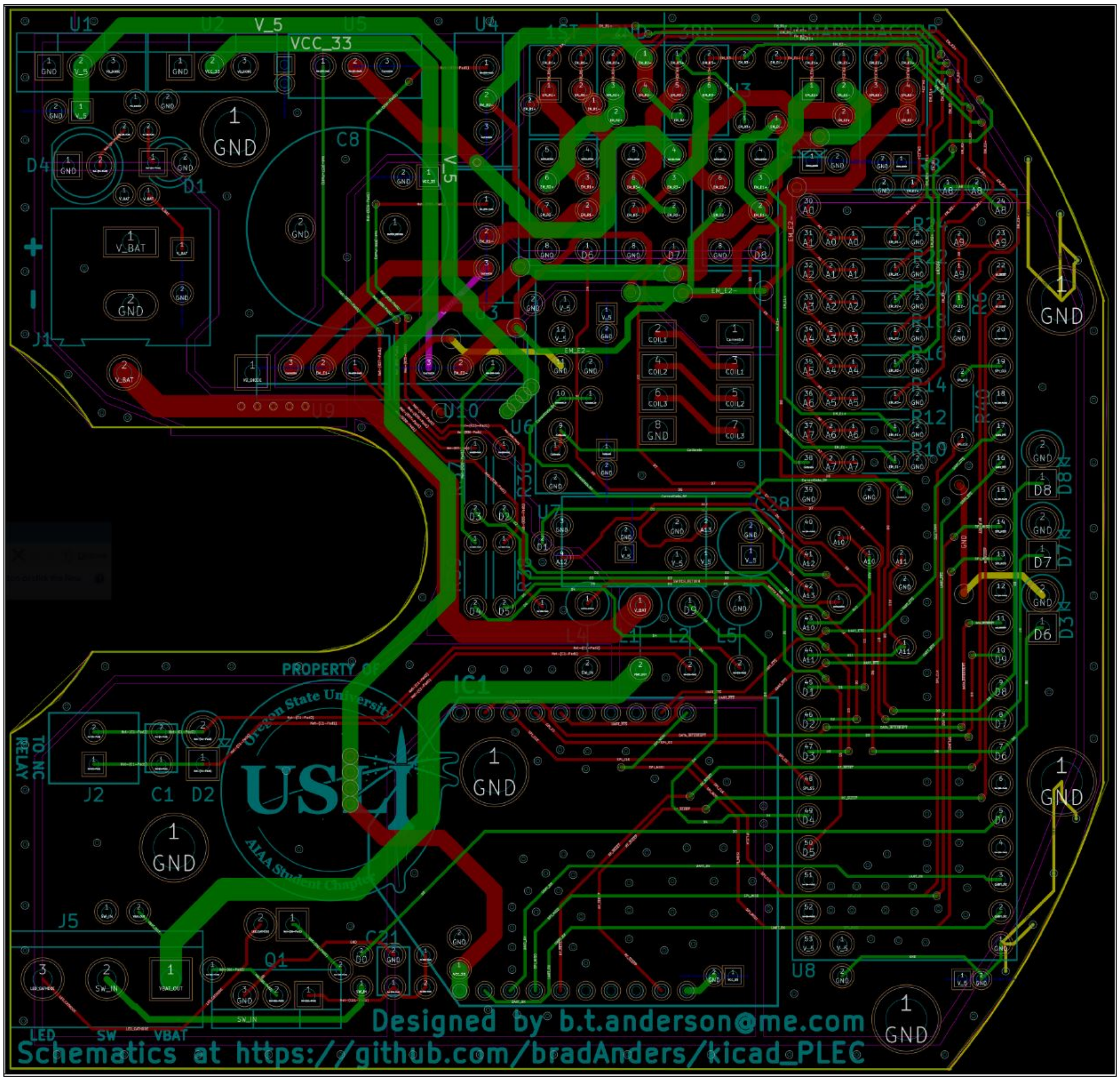

Figure 66: Ordered PLEC PCB

5.6.4 Fore Hard Point

In order to secure the PEARS within the airframe and create a pressure seal, the three component FHP subassembly will be used as seen in Figure 67. The three components are:

1) Pass-through bulkhead
2) Guiding funnel
3) Main bulkhead

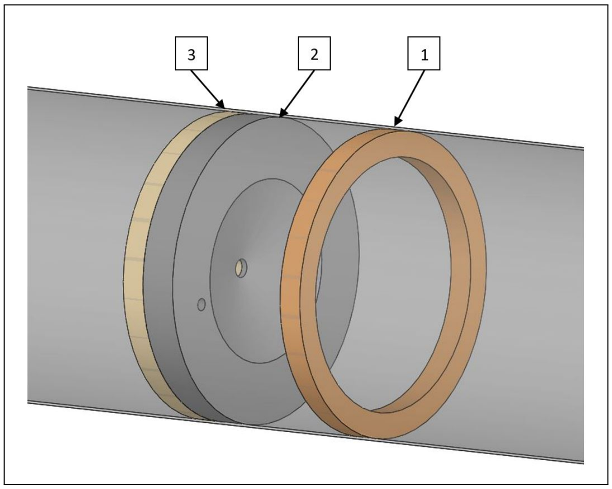

Figure 67: FHP permanently fixed in fore airframe section

All FHP components will be epoxied into the airframe. The pass-through bulkhead will provide a pressure seal when the PEARS is fully integrated, the rubber seal is compressed, and the PLEC mount has passed through the bulkhead. The funnel is solely to ease integration of the systems as the long threaded rod must pass through the center of the main bulkhead. Once passed through, the threaded rod will be retained against the main bulkhead using a nut and washer. Both the main bulkhead and guiding funnel have a through hole feature aligns the PEARS in the proper orientation, ensuring the SPDT switch on the PLEC is accessible through a single, small hole in the airframe.

5.6.5 PEARS Design Completeness

While the overall subsystems within PEARS were decided based on PDR DDMs, component level decisions were based on trying to minimize weight while keeping adequate strength within the systems. All structural components were analyzed and iterated to withstand a minimum of 50 g of acceleration during launch and recovery. The analysis procedure can be seen in Section 6.2.5. Table 38 shows the results of calculating the accelerations each component is able to experience without failure.

Table 38: PEARS Component Strength

Component	Weight on Component (lbf)	Rated Strength (lbf)	Accelerations Able to Withstand (g)
Kevlar Harness	8.08	550.00	68.07
Quick Link	4.14	500.00	120.77
Threaded Rod	8.28	4,417.86	533.56
PEARS Bulkhead	8.28	51,539.25	6,224.55
ARRD	2.07	2,000.00	966.18
Tender Descender	4.14	2,000.00	483.09
U Bolt	4.14	425.00	102.66
Nut 3/8 - 16"	10.86	9,300.00	856.35
Fore Hard Point Bulkhead	10.86	186,504.00	17,173.48

As seen from the results, all loaded components can withstand accelerations well above 50 g, which was determined to be a reasonable safety factor above atypical flight forces in the worst case scenarios, and based on team mentor suggestion. The weakest component was found to be the Kevlar harness, assuming the rover acts as a point load directly in the center of the harness. While this system will be tested further when physically built, the analysis conducted shows that the payload retention system will not fail due to structural reasons. Based on the electrical design, if a failure is to occur within PLEC, the system will keep the rover fully retained and refrain from firing the ejection charges. The final component weight breakdown can be seen in Table 39, with a total weight of the system at 3.54 lbf excluding the rover itself.

Table 39: PEARS Assembly Weight

Component	Unit Weight (lbf)	Quantity	Total Weight (lbf)
Aft Payload Bulkhead	0.34	1	0.34
Fiberglass Wrap	0.276	1	0.276
Fore Payload Bulkhead	0.34	1	0.34
Kevlar Harness	0.1	1	0.1
Quick Link	0.0344	3	0.1032
Rod End Cap	0.15	1	0.15
Threaded Rod $\frac{3}{8}$-16	0.164	1	0.164
PEARS Bulkhead	0.34	1	0.34
Rubber Seal	0.027	1	0.027
PLEC Mount	0.35	1	0.35
ARRD	0.354	1	0.354
Tender Descender	0.112	2	0.224
Ejection Charges	0.05	2	0.1
U-Bolt $\frac{1}{4}$-20	0.07	2	0.14
Kevlar Thread	0	1	0
Nut $\frac{3}{8}$-16	0.0156	5	0.078
Washer	0.0088	5	0.044
PLEC	0.25	1	0.25
PLEC Battery	0.15	1	0.15
PLEC SPDT Switch	0.01	1	0.01
		Subsystem Total	**3.54 lbf**

The process for assembling and integrating the rover into the PEARS and into the airframe is as follows:

1) Assemble ARRD, Tender Descenders and ejection charges based on their respective assembly procedure following all safety precautions.
2) Place assembled rover with charged batteries on the fiberglass wrap with bulkheads on ether wheel, and Kevlar harness in slots.
3) Begin folding wrap around rover, connecting the wire to keep the rover in low power mode until ejected.
4) Compress foam tires and zip tie wrap closed
5) Ensure PLEC is powered off and wires do not read a voltage.
6) Attach ARRD, Tender Descenders and ejection charges to the ejection and retention assembly.
7) Connect wrapped payload to ARRD, Tender Descenders.
8) Insert alignment rod into PLEC mount via fore section of airframe.
9) Ensure SPDT switch is still in the off/shunting position.
10) Begin inserting assembly into airframe, adding cellulose insulation wadding around charges.
11) Cut zip-ties around wrap as assembly is inserted.

12) Push PEARS fully into airframe until rubber seal is pressed against the pass-though bulkhead of the FHP
13) Secure with washer and nut from fore end of airframe.
14) Ensure that the SPDT switch is accessible through the airframe hole.
15) Once on the launch rail, arm PLEC by turning on the SPDT switch through the access hole.

5.7 Scientific Experiment

The OSRT is attempting to perform an additional scientific experiment. At the PDR milestone, the OSRT planned for an x-ray fluorescence experiment which could determine the chemical composition of the soil sample. The experiment design was completed for x-ray fluorescence; however, it has been modified due to safety concerns about the experiment.

The x-ray fluorescence experiment design consists of three main elements: an x-ray source, a sample to absorb the x-rays, and a detector to detect the x-rays emitted from the sample. To achieve this, the OSRT designed the experiment as shown in Figure 68.

A U-shaped channel (blue item in Figure 68) is lined with 1/2 in. thick acrylic, which is capable of attenuating beta particle emissions. Above and below the channel is also lined with 1/2 in. thick acrylic. Acrylic was chosen based on a paper titled ”EM50 Strontium-90 Source Handling and Storage” authored by Hoppe, Brown, and Burns as work instructions at Marshall Space Flight Center. Figure 69 displays a closer view of the U channel.

- A strontium-90 radioactive isotope is placed in the bottom left corner of the channel shown in Figure 69.
- A lead block is placed in the corner of the U which is adjacent to the strontium-90 sample, shown in red in Figure 69.
- The soil sample is deposited in the corner of the U which is displayed as a purple square in Figure 69.
- A detector, composed of silicon doped with lithium, is placed in the opposite end of the U-shaped channel from the Strontium-90 sample, in the bottom right corner of Figure 69.

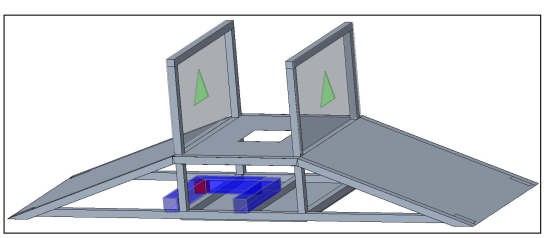

Figure 68: X-ray fluorescence assembly in the scientific base station.

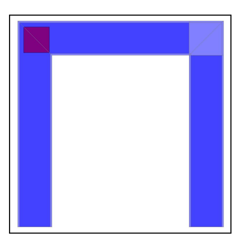

Figure 69: Top view of the x-ray fluorescence channel.

Once all of the pieces of the experiment are in place, the following process happens:

1) Beta particles are emitted in a random direction from the strontium-90 source.
2) Some beta particles will be incident with a lead block. Due to the high atomic mass of the lead, the kinetic energy of the beta particles decreases as they are redirected by the atoms' nuclei. Due to conservation of energy, the kinetic energy loss is converted to x-rays in a process called Bremsstrahlung. The x-rays are emitted from the lead block in a random direction.
3) Some of the x-rays emitted from the lead source collide with the soil sample. These x-rays are absorbed by the atoms within the soil by exciting electrons to higher energy states. When the electron changes energy states, an x-ray of quantized wavelength is emitted, which is unique to the atom. These quantized x-rays are emitted in a random direction, only some of the x-rays will head towards the detector. Due to the shielding, only the quantized x-rays emitted from the soil sample are capable of reaching the silicon doped with lithium.
4) The silicon doped with lithium detects the wavelength of the x-rays which collide with it.
5) The wavelength of the x-rays and the frequencies with which they collide with the Si(Li) detector are used to determine the chemical composition of the soil.

After designing the experiment as described above, OSRT began researching safe handling and shielding practices for the materials required. The experiment is shielded with 1/2 in. acrylic to attenuate the beta particle emissions, and x-rays should only be produced when the lead block is present. However, without anyone on OSRT having experience or training handling radioactive materials, the team decided the risks were too high to perform the experiment. Instead, the experiment will be conducted as a mock experiment. Neither the strontium-90 source nor the lead block will be handled for the purposes of this experiment. Therefore, what will be present on the scientific base station is an experimental setup which could be quickly and easily converted to an actual x-ray fluorescence experiment. The rover will deposit the soil in an area prepared for the x-ray fluorescence experiment. However, no data will be collected.

While OSRT determined the risk of performing the x-ray fluorescence experiment was unnecessary, the team still would like to conduct a real scientific experiment on the soil. This provides the opportunity to demonstrate the feasibility of the x-ray fluorescence, without the risk. For the secondary experiment, the team chose to perform a pH experiment. The pH sensors necessary to perform this experiment are cost effective, easy to implement, and present no hazards to the team or environment.

Due to the relative simplicity of the pH experiment, OSRT has widened the scope of the scientific base station. The rover will now dock with the base station and deposit the soil sample into a fluid to develop a mixture which the pH sensor can measure. The layout for the pH experiment on the scientific base station can be seen in Figures 70 and 71. The rover will then leave from the scientific base station by driving off the opposite end and collect a new soil sample, while logging the GPS coordinates. The old soil sample is discarded by activating a motor to move the part shown in green, and the pH sensor is cleaned when a small pump directed at the sensor is turned on. The rover will return to the scientific base station and deposit the new sample. The pH and GPS coordinates will be broadcast back to the ground station. This will create a map of the pH of the soil in the area. The purpose of creating the pH map is to scale up the experiment to extraterrestrial missions. A similar map could be made to gain information about potential landing sites for future missions, or additional places to explore and experiment.

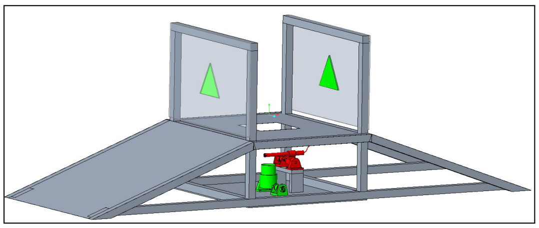

Figure 70: The pH experiment assembly on the scientific base station.

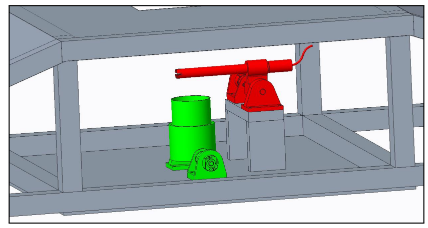

Figure 71: Closer view of the pH sensor and beaker assemblies.

6 Project Plan

6.1 Testing Procedures

6.1.1 Fully Integrated Weight

Testing the fully integrated weight of the launch vehicle is necessary to validate the overall weight and the location of the center of gravity of the launch vehicle. If the launch vehicle is manufactured heavier than anticipated, the launch vehicle is in danger of not achieving an apogee of 4,500 ft. If the launch vehicle is manufactured lighter than anticipated, the altitude will likely be overshot. If the location of the actual center of gravity is different than the location of the simulated center of gravity, the launch vehicle could be unstable as it leaves the launch rail. If the center of gravity is in a different location than designed for, ballast within amount allowed by the USLI handbook may be added to correct the offset and maintain a stability margin of 2.1 calibers.

Test Objective: Test the fully integrated weight of the launch vehicle in order to verify accuracy of simulations.

Success Criteria: The fully integrated launch vehicle will be no more than 54 lbf, and no less than 43.1 lbf. A launch vehicle above 54 lbf will fail the maximum landing kinetic energy requirement. A launch vehicle below 43.1 lbf is simulated to reach an apogee altitude above 6,000 ft.

Testing Variable: Weight of fully integrated launch vehicle.

Test Materials Required:

- Fully assembled launch vehicle with payload
- 2 ft rope
- Spring scale

Testing Procedure:

1) Ensure appropriate PPE is being worn by all participants.
2) Mark simulated location of center of gravity and center of pressure on outside of airframe.
3) Fully assemble and integrate launch vehicle and payload following assembly checklist procedures, including motor assembly with propellant.
    - Safety Consideration: Do not tighten enclosures on motor assembly during integration.
4) Place fully assembled launch vehicle on ground or table.
5) Tie loop in rope to place around the circumference of launch vehicle at simulated center of gravity.
6) Attach spring scale to rope.
7) Lift the launch vehicle from the spring scale.

- Safety consideration: Ensure appropriate number of people assist in lifting procedure to avoid injury. Use proper lifting techniques and appropriate equipment to prevent injury.

8) Adjust rope as necessary until launch vehicle balances from one point.
9) Mark balance point as center of gravity and record fully loaded weight from spring scale.
10) Measure distance between center of pressure mark and tested center of gravity.
11) Calculate stability in calibers by dividing the distance between the center of pressure and center of gravity by the diameter of the airframe.

Results: The test has not yet been conducted.

6.1.2 Radial Bolt Testing

Test Objective: Determine the number of machine screws needed to retain the recovery attachment bulkhead in the airframe.

Success Criteria: The bulkhead withstands the 50 g estimate of the worst case forces experienced during launch. The aft section, after full motor burn, weighs 23.1 lbs, meaning that the max expected force is 1,155 lbf.

Testing Variables: Number of machine screws, size of machine screws, and what material they are mounted into.

Test Procedure:

- Safety Consideration: Ensure proper PPE is worn by all participants
- Safety Consideration: Ensure all proper safety considerations are taken for machining carbon fiber. Proper PPE including respirators, gloves, and safety glasses should be worn by all members within the vicinity. Machining carbon fiber should only be done in areas with proper air filtration systems.

1) Cut small section of excess airframe for destructive testing.
2) Machine radial bolt holes in airframe test section.
3) Assemble bulkhead into airframe test section with six machine screws, equally spaced radially along the bulkhead.
4) Prepare Instron machine.
5) Mount assembly into Instron machine. Pictured in Figure 75.
   - Safety Consideration: Ensure all body parts and loose clothing or jewelry are secure and away from Instron machine.
6) Compression test using the Instron machine to measure the force required to cause failure in any component present in the system (airframe, bulkhead, retention ring, or machine screws).
7) Record maximum force data.

8) If the force required to cause failure is less than the worst case expected recovery force of 50 g, the test is considered a failure. Modifications of the design must be made and tested again.

Results and Necessary Modifications:

The first method that was tested used six radially mounted #8-32 bolts, that were 3/4 in. long, around the body tube of the launch vehicle. These bolts were mounted into a 1/2 in. marine grade plywood bulkhead. This test was unsuccessful, as the bolts were mounted in such a way that the plies began to separate at a mere 519.81 lbf, as seen below in Figure 72 and Figure 77. The airframe and bolts had no visual defects from the test.

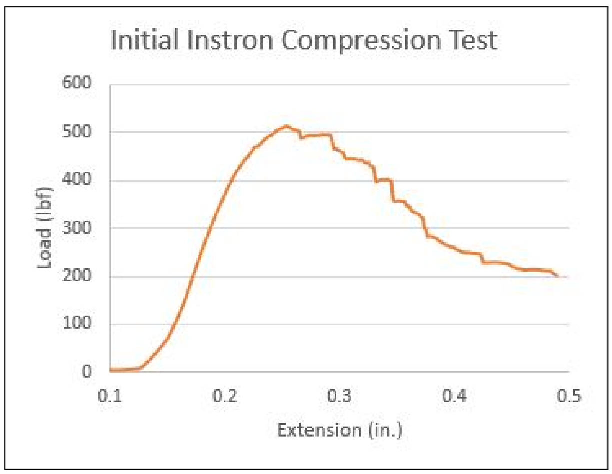

Figure 72: Plywood Bulkhead Failure due to Splitting

A second method was tested that implemented an aluminum ring mounted on the face of the plywood bulkhead. With this strategy, the force on the plywood is spread out more evenly across the ring and bulkhead. Additionally, the force will be truly compressing the bulkhead rather than attempting to separate the glue. The ring measured 3/8 in. thick with an outer diameter of 6.25 in. and an inner diameter of 5.00 in. Six bolts were utilized again, but this time they were sized up to 10-24 and were 3/4 in. long. Simulating the forces that the plywood bulkhead would see during recovery, this method held up to 2,212.79 lbf. As seen below in Figure 73, one can see each ply's breaking point. The results show that a bulkhead can withstand up to 95 g applied force, which is well above the requirement of 75 g.

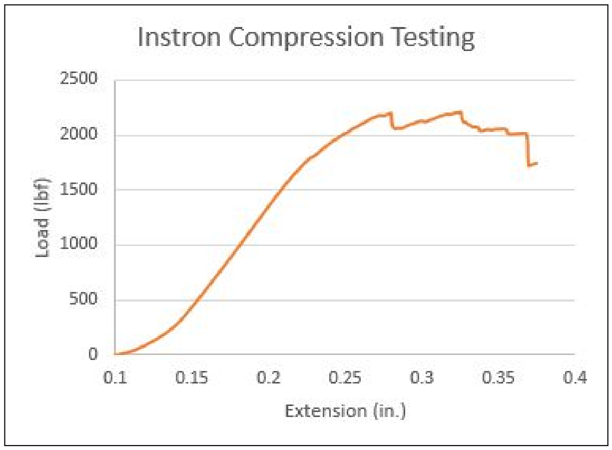

Figure 73: Plywood Bulkhead Failure

Lastly, the airframe was tested to failure. The whole aluminum ring was pushed on, instead of just the center of the plywood. This test resulted in the bolts tearing through the carbon fiber section at an applied force of 3,524.41 lbf. The results of this test can be seen in Figure 74 and Figure 76. Both of the tests with the aluminum ring show that this method will hold up to the worst case expected forces during recovery.

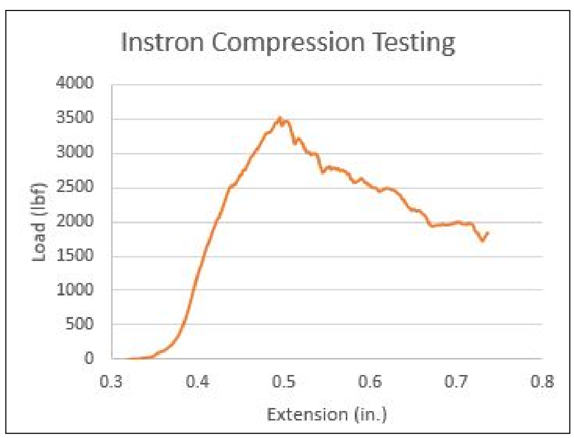

Figure 74: Carbon Fiber Airframe Failure

Figure 75: Instron Test

Figure 76: Body Tube Failure

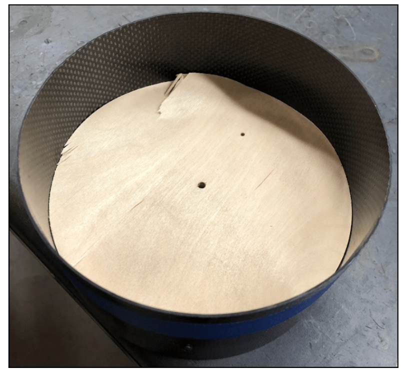

Figure 77: Bulkhead Failure

6.1.3 Battery Life Test

Due to the indeterminate duration the ATU will be required to operate, the system must have a significant uptime capability. The ATU will be armed during launch preparation, flight, and recovery - sufficient power reserves must be available so data logging and transmission operate correctly for the entire duration. Each ATU should be capable of 8 hours of concurrent operational time, with 10 being the ideal target.

Test Objective: Test fully operational uptime of ATUs to verify power delivery is sufficient for mission profile requirements.

Success Criteria: ATU remains powered on for 8 hours while system is in fully operational standard configurations (900 MHz at 250 mW to start with).

Testing Variable: Operational duration of ATU batteries.

Test Materials Required:

- ATU
- Ground station
- LiPo batteries for ground station and ATU

Testing Procedure:

- Safety Consideration: LiPo batteries can be damaged through overcharging. Use of smart charger should prevent this.
- Safety Consideration: Make sure that battery leads on ATU are not touched to any other electrically live or conductive components to prevent shorting. Do not touch leads together in case of electric shock.
- Safety Consideration: ATU Data logs should be cleared or moved before this test.

1) Charge battery packs for both units to full capacity using smart charger.

2) Check and verify that the battery voltage of each ATU is > 7.7 V.
   - Safety Consideration: Do not continue the test if voltages aren't within acceptable range.
3) Follow ATU Preparation Checklist in Section 4.1.6 up to plugging in the battery to prepare units for testing.
4) Plug battery into ATU and record time (for ease of data analysis), ensure that GPS unit displays red light and Teensy 3.6 displays flashing orange light. GPS unit will switch to blinking red light when lock is acquired.
5) Leave ATU on until lights on both ICs cease, record stop time.
6) Unplug ATU from battery.
7) Remove micro-SD cards from ATU and transfer data to computer.
8) Compare timestamps between first lock (and recorded start time) and record termination (and recorded end time) and determine total operational time.

Results and Necessary Modifications: Test has been completed successfully for 900 MHz configuration during subscale launch, demonstrating over 9 hours of concurrent operation at a full charge. Testing still needs to be performed on 433 MHz system.

6.1.4 Continuous Transmission Test

The RF communication needs to demonstrate regular, long-range, consistent continuous transmission. Continuous tracking can be defined as providing accurate tracking data in intervals no greater than 5 seconds.

Test Objective: To ensure that the hardware being implemented on the avionics system can remain in constant contact with the ground station.

Success Criteria: At least 1 packet arrives every five seconds for the duration of the test.

Testing Variable: Packet arrival frequency.

Test Materials Required:

- ATU
- Ground station
- LiPo batteries for ground station and ATU

Testing Procedure:

- Safety Consideration: Weather conditions must be good to ensure circuit safety. Do not perform test in poor weather such as rain, snow, or even fog.

- Safety Consideration: Walking tester must be alert and aware of potential hazards or obstructions such as traffic.
- Safety Consideration: Battery leads must not be touched to ensure circuits don't short.
- Safety Consideration: Ground station operator should be careful not to touch any exposed circuitry or ICs during operation in case of damaging equipment.

1) Configure RF transceiver on ATU to communicate with base station at minimum rate of 5 Hz, gain GPS lock on flight unit.
2) Hold ATU 10 ft away without visual obstruction and confirm that flight unit is communicating with ground station.
3) Once an RF link is confirmed, begin walking away from the ground station at a steady pace (about 3 mph) until the flight unit and ground station are 1 mi apart.
4) Turn off flight unit and ground station, pull SD card from ground station.
5) Transfer data from SD card to computer.
6) Verify that a packet was received from the flight unit at least every 5 seconds.

Results and Necessary Modifications: Test successful on existing 900 MHz ATU. Test to be repeated with ATU featuring 433 MHz transmission frequency.

6.1.5 Transmission Range Test

The ATU must be able to communicate with the ground station at a significant range to allow for tracking of the launch vehicle after flight. According to the SL handbook, the maximum allowable drift radius of the launch vehicle is 2500 ft.

Test Objective: To determine the effective reliable distances for the ATU.

Success Criteria: A reliable operating range (at least 1 packet arrives every five seconds for the duration of the test) of at least 1 mi.

Testing Variable: Transmission range.

Test Materials Required:

- ATU
- Ground station
- LiPo batteries for ground station and ATU

Testing Procedure:

- Safety Consideration: Weather conditions must be good to ensure circuit safety. Do not perform test in poor weather such as rain, snow, or even fog.

- Safety Consideration: Walking tester must be alert and aware of potential hazards or obstructions such as traffic.
- Safety Consideration: Battery leads must not be touched to ensure circuits don't short.
- Safety Consideration: Ground station operator should be careful not to touch any exposed circuitry or ICs during operation in case of damaging equipment.

1) Configure RF transceiver on ATU to communicate with ground station at minimum rate of 5 Hz, gain GPS lock on flight unit.
2) Hold flight unit 10 ft away from ground station without visual obstruction and confirm that flight unit is communicating with ground station.
3) Once RF link is confirmed, begin walking away from ground station and continue until flight unit and ground station are 1 mi apart, wait 30 seconds, then continue until flight unit and ground station are 2 mi apart.
4) Unplug flight unit and return to ground station.
5) Remove SD card, transfer data to PC, rename and save.
6) Reinsert SD card and power flight unit back up. Repeat steps 2-5 until 5 iterations of the test have been performed.
7) Analyze data to determine effective transmission ranges.

Results and Necessary Modifications: Test successful on the existing 900 MHz ATU. Test to be repeated with ATU featuring 433 MHz transmission frequency.

6.1.6 Rover Weight Test

Test Objective: The objective of this test is to find the final rover weight, which is very important for verifying stability and simulations of the launch vehicle flight.

Demonstration Description: A scale rated for the weight of the rover will be used to measure the weight of the rover. The weight of the rover will be compared to the weight used in simulations. Significant discrepancies will result in further investigation of component weights.

Success Criteria: Rover is within the mass margin allowed for the fore section.

Results: Test not yet conducted.

6.1.7 Soil Collection Test

The soil collection must be able to collect a soil sample in a variety of soil conditions in order to ensure mission success. To test this, a soil collection testbed has been developed.

Success Criteria: At least 10 mL of soil is measured within the soil retention container.

Testing Variable: Soil types and conditions.

Test Materials Required:

- Soil collection assembly without the mounting components
- Soil collection testbed
- Different types of soil
- Timer

Test Procedural Steps:

1) Place the soil collection assembly into the testbed.
2) Place the testbed on the testing soil.
3) Power-on the soil collection assembly to start collecting soil. Begin timer.
4) Move the testbed to different sections of the test soil as necessary, simulating the rover moving to different locations during operation.
5) Power-off the soil collection assembly once 10 mL has been collected (record the time on the timer) or five minutes have elapsed.
6) Repeat the test using different types of soil.

Results and Necessary Modifications: The test has yet to be performed.

6.2 Analysis Procedures

6.2.1 Rail Exit Velocity Analysis

The launch vehicle rail exit velocity is determined through an OpenRocket simulation. The minimum exit velocity from the rail is 52 $^{ft}/_{s}$

Analysis Inputs

- Motor thrust curve
- All internal component weight and lengths
- Rail size

Analysis Outputs

- Velocity off rail

Analysis Description

1) Input each weight and length of internal components into simulation program.
2) Select desired motor thrust curve.
3) Simulate velocity of launch vehicle throughout the flight.

Results The analysis performed used the motor characteristics of a Cesaroni L2375-WT. When located on the launch rail, the launch vehicle will weigh 48.9 lbf. The launch rail to be used is 144 in. long. Inputting these factors into OpenRocket, the launch vehicle will exit the 12 ft rail at 88.8 ft/s. The total allowable weight of the launch vehicle to remain above the minimum 52 ft/s was calculated next. The launch vehicle can increase by 74 lbf before dropping below the minimum rail exit velocity. OSRT is in no danger of having a rail exit velocity below 52 ft/s.

6.2.2 Static Stability Analysis

The launch vehicle static stability is determined through OpenRocket and RockSim simulations. The static stability will be above 2.0 calibers to ensure stability, and below 3.5 calibers to prevent over-stability.

Analysis Inputs

- All internal component weight and lengths
- Fin shape and dimensions
- Nosecone shape and dimensions

Analysis Outputs

- Center of gravity
- Center of pressure
- Static stability

Analysis Description

1) Input each weight and length of internal components into simulation program.
2) Design fin dimensions to locate the center of pressure 13.125 in. aft of the center of gravity location.
3) Simulate stability calculation with max ballast amount in fore ballast bay.

Results: The designed center of gravity and center of pressure locations are similar between the OpenRocket simulation and the RockSim simulation (see Section 3.4.2). The static stability margin was designed to be 2.1 calibers. This equals a center of pressure location 13.125 in. aft of the center of gravity. The similar stability margins from the two software's ensure the launch vehicle will have a safe static stability margin. The maximum ballast of the launch vehicle is 10% of the total launch vehicle weight. To ensure that the launch vehicle will be below the 3.5 caliber over-stable criteria, the maximum ballast value was input into the fore ballast bay. This locates the center of gravity towards the nosecone, while maintaining the same center of pressure location. The static stability margin therefore increases, but only to 2.58 calibers. The launch vehicle will not be over-stable during flight, limiting weather-cocking.

6.2.3 Descent Trajectory Analysis

In order to determine the landing kinetic energy, descent time, and drift radius, a simulation must be created and ran. The OSRT decided to create the simulation in MATLAB. The simulation will use specification of the launch vehicle and flight predictions to analyze the descent. In the simulation done by the OSRT, the change in air density due to altitude was taken into consideration.

Analysis Inputs

- Launch vehicle weight by section
- Launch vehicle size by section
- Predicted apogee
- Parachute diameter
- Parachute coefficient of drag
- Wind Speed

Analysis Outputs

- Landing kinetic energy
- Drift radius
- Descent time

Analysis Description: The general steps to create and complete this simulation are given below: **Note:** This simulation does not account for weather cocking

1) Calculate the cross sectional area of both the drogue and main parachutes for each section of the launch vehicle.
2) Calculate the force acting on each launch vehicle section by considering the force of gravity and the drag force due to the parachutes with respect to time for the drogue parachute.
3) Calculate the acceleration of each launch vehicle section with respect to time for the drogue parachute.
4) Use the time difference to calculate the descent velocity for each section of the launch vehicle at a given time.
5) Use the predicted apogee to determine when the launch vehicle will reach the main parachute deployment height.
6) Repeat these steps for the main parachute starting with the time of the main parachute deployment.
7) Use this information to determine when the launch vehicle will reach the ground.
8) Calculate the kinetic energy at landing using the mass and final velocity of each launch vehicle section.

9) To calculate the descent time, add the time needed for the launch vehicle to reach the main deployment height under the drogue to the time needed for the launch vehicle to reach the ground under the main.
10) To calculate the drift radius, multiply the descent time by the given wind speed.

Use this simulation to determine the size of parachutes needed. This simulation can be updated easily to account for changed to the launch vehicle by updating those inputs. Alter the parachute size and/or types until all requirements are met.

Results: The analysis was performed and the OSRT decided to use a 8 ft toroidal parachute for the fore and aft main parachutes and a 1.5 ft cruciform parachute for the fore and aft drogue parachutes. These parachutes will result in a landing kinetic energy of 71.680 ft-lbf and 67.754 ft-lbf for the fore and aft sections, respectively. These are both under the maximum allowable landing kinetic energy of 75 ft-lbf. Using these parachutes, the OSRT can add 0.5 lbf to the fore section and 1.19 lbf to the aft section and still stay below the maximum landing kinetic energy. The drift radius at 20 mph is 2,048.050 ft and 2,119.338 ft for the fore and aft sections respectively. This is the maximum wind velocity that the OSRT will launch in, so these values will be the largest drift radius. Both these values are under the maximum drift radius of 2,500 ft. The simulation yielded a descent time of 69.82 seconds and 72.25 seconds for the fore and aft sections, respectively. Both these values are under the maximum allowable descent time of 90 seconds.

6.2.4 Static Port Hole Sizing Analysis

Two different mission critical altimeters are being flown in the full scale launch vehicle: RRC3 and StratoLoggerCF. Both of these altimeters manuals' describe an appropriate static port hole sizing procedure.

Analysis Inputs

- Bay radius
- Bay length

Analysis Outputs

- Diameter of the static port hole(s)

Missile Works RRC3

1) Calculate the altimeter bay volume with Equation 14

$$Volume = \pi R^2 L \tag{14}$$

Where R is the radius of the bay in $in.$ and L is the length of the bay in $in.$.

2) If one port is being used, calculate the diameter using Equation 15 if $Volume \leq 100\ in^3$ or Equation 16 if $Volume \geq 100\ in^3$.

$$D = \frac{Volume}{400} \tag{15}$$

$$D = 2\sqrt{\frac{Volume}{6397.71}} \tag{16}$$

Where D is the single port hole diameter in $in.$.

3) If multiple ports are going to be used, calculate the area of the single port with the diameter calculated in step two with Equation 17.

$$Area = \pi(\frac{D}{2})^2 \tag{17}$$

4) Lastly, calculate the diameter of each port with Equation 18

$$D_{multi-port} = 2\sqrt{\frac{Area/N}{\pi}} \tag{18}$$

PerfectFlite StratoLoggerCF

The StratoLoggerCF manual lists a table of values for recommended diameter of static port holes given airframe inner diameter and av bay length. Using values from this table and calculating the diameter of holes with the RRC3 method, the RRC3 values are slightly higher. The StratoLoggerCF values are listed in Table 40.

Table 40: StratoLoggerCF Values

AV Bay Diameter	AV Bay Length	Single Port Hole Size	Four Port Hole Size
1.6	6	0.032	0.02
2.1	6	0.048	0.025
3.0	8	0.113	0.057
3.0	12	0.170	0.085
3.9	8	0.202	0.101
3.9	12	0.302	0.151
5.5	12	—	0.286
7.5	12	—	0.5

The single port diameter can be calculated with Equation 19

$$D = \frac{D_{AvBay}^2 L}{.0016} \tag{19}$$

The four port diameters can be calculated with Equation 20

$$D = \frac{D_{AvBay}^2 L}{.0008} \tag{20}$$

Use this analysis to appropriately size the static port holes for altimeter bays.

Results: Three static port holes will be used for both altimeter bays. Based off the calculations, each static port hole will be sized to 0.216 in. in diameter. The closest drill bit sizes are a #3 or a 7/32 in. drill bit.

6.2.5 PEARS Component Strength Analysis

Analysis Objective

The objective of this analysis is to determine the strength of the structural components within the PEARS. All components must be able to withstand over 50 g of acceleration in order for OSRT to use the component in full scale launches.

Analysis Description

The first step of the analysis is determining the force that acts on each component before launch, in other words, the force at 1 g acceleration. These values are based on how the rover weight is distributed though the system via each linking component.

The next step is finding the rated strength of each component. These values are all based on product specifications and and material properties. The PEARS bulkhead and Fore Hard Point Bulkhead listed strengths are based on the shear strength of the high strength epoxy, and the surface area for each bulkhead. The Fore Hard Point Bulkhead takes into account both the plywood bulkhead as well as the funnel bulkhead.

Finally, g acceleration rating is found by dividing the rated strength of a component by the applied force.

Results

The results can be seen in Table 41. All loaded components can withstand accelerations well above 50 g, which was determined to be a reasonable safety factor above atypical flight forces in the worst case scenarios. The weakest component was found to be the Kevlar harness, assuming the rover acts as a point load directly in the center of the harness. While this system will be tested further when physically built, the analysis conducted shows that the payload retention system will not fail due to structural reasons.

Table 41: PEARS Component Strength

Component	Weight on Component (lbf)	Rated Strength (lbf)	Acceleration Able to Withstand (g)
Kevlar Harness	8.08	550.00	68.07
Quick Link	4.14	500.00	120.77
Threaded Rod	8.28	4,417.86	533.56
PEARS Bulkhead	8.28	51,539.25	6,224.55
ARRD	2.07	2,000.00	966.18
Tender Descender	4.14	2,000.00	483.09
U Bolt	4.14	425.00	102.66
Nut 3/8 - 16"	10.86	9,300.00	856.35
Fore Hard Point Bulkhead	10.86	186,504.00	17,173.48

6.3 Demonstration Procedures

6.3.1 Full Scale Flight Demonstration

Demonstration Objective: The full scale launch vehicle will be assembled and flown in the exact configuration intended for flight at the USLI competition.

Demonstration Description: The launch vehicle will be flown, carrying the payload, on the Cesaroni L2375-WT (or a comparable motor) that is intended for use at the USLI competition.

Success Criteria: The launch vehicle:

- Is prepared within 2 hours of the time the Federal Aviation Administration (FAA) waiver opens.
- Is launched off of a standard 12 V DC ignition system.
- Flies to an apogee altitude between 3500 ft and 6000 ft.
- Lands with a safe kinetic energy, under 75 ft-lbs.
- Lands within the allowed drift radius, 2500 ft from the launch pad.
- Can be launched again with no repairs necessary.

Results: Demonstration not yet conducted.

6.3.2 Launch Vehicle Integration Demonstration

Demonstration Objective: The full scale launch vehicle should be capable of being quickly assembled and prepared for flight on launch day.

Demonstration Description: The full scale launch vehicle assembly procedures will be conducted according to checklists within a time of 2 hours. No energetics should be used. Instead, mock ejection charges should be created with no black powder.

Success Criteria: All checklists in Section 4.1 are executed by assigned primary or backup assembler with an inspector observing assembly process. The launch vehicle and payload should be completely integrated and ready to put on the launch rail.

Results: Demonstration not yet conducted.

6.3.3 Altimeter Battery Life Demonstration

Demonstration Objective: The purpose of this demonstration is to show that the altimeters are capable of firing ejection charges after waiting to be launched for lengths up to two hours.

Demonstration Description: The altimeters should be wired to a brand new 9 V battery with an e-match attached to the drogue and main ports. The altimeter needs to be located in a safe place in the event the e-matches fire. The switch should be turned to armed and a timer started for 2 hours. After two hours, perform the altimeter pressure reading demonstration in Section 6.3.7.

Success Criteria: If the altimeter pressure reading demonstration is completed successfully 2 or more hours after the altimeter has been armed, the demonstration passes.

6.3.4 Parachute Staging Demonstration

Demonstration Objective: This procedure is to demonstrate the staging of recovery systems, with a drogue parachute being deployed at apogee and a main parachute being deployed at a lower altitude.

Demonstration Description: The full scale launch vehicle will be assembled according to checklists. The full scale launch vehicle will be flown, including a substitute for the payload mass and size if the payload is not ready for flight. At apogee, the altimeters will cause separation, deploying the drogue parachute. The altimeters will be set to have a delay of 0 seconds. The main parachute will be retained in the airframe by two Tender Descenders in series until a lower altitude. At a minimum of 500 ft, the altimeters will fire e-matches, releasing the Tender Descenders, which releases the main parachute.

Success Criteria: The drogue parachute will deploy at apogee. The main parachute will deploy at a specified, lower altitude.

Results: Two subscale launches demonstrated the recovery components. On the first subscale launch, both the drogue and main parachute deployed at apogee. The OSRT team redesigned the recovery harness to better retain the main parachute. On the second subscale launch, the drogue parachute deployed at apogee, and the main parachute failed to deploy because of high friction between the deployment bag and the airframe. The OSRT added additional ejection charges to prevent this from happening in the future.

The altimeters performed correctly on both launches. With the additional ejection charges the OSRT is confident the drogue parachute will be deployed at apogee and the main parachute will be deployed at a lower altitude.

6.3.5 Recovery Analysis Demonstration

Demonstration Objective: This procedure is used to verify that the simulations used to model the descent trajectory of the launch vehicle is accurate.

Demonstration Description: Compare the Recovery Descent Trajectory analysis to match the specifications and flight predictions of the subscale launch vehicle. Determine the descent trajectory of the subscale launch vehicle and compare them to the actual data of the launch.

For preparation and launch procedures of subscale, reference section 4.1.3

Success Criteria: The subscale launch data matches that of the analysis to a reasonable degree, as discussed in Section 3.2.4.3.

Results: The simulations predicted an apogee of 3,867 ft. The apogee altitudes AGL were 3,423 ft and 3250 ft. These match to a reasonable degree. The simulation predicted a landing kinetic energy of 67.529 ft-lbf, the actual landing kinetic energy was between 50 and 53 ft-lbf. This number are different, but the actual value is lower than the theoretical value. This verifies that by using this MATLAB simulation, the OSRT ensures that the landing kinetic energy will be lower than 75 ft-lbf. The simulation predicted a descent time of 64.620 seconds. both launches need to be used to verify this number. By using the time taken from apogee to the altitude the main is deployed from the second launch and the time taken from the altitude the main is deployed to ground level of the first launch, the total descent time can be estimated. This descent time was 86.8 seconds. This shows that the descent is actually 34% slower. By combining data from both flights, the assumption is made that the main parachute deploys and expands instantaneously. However, including that 34% error in the full scale descent models, both sections of the airframe land in under 90 seconds.

6.3.6 Recovery Integration Order Demonstration

Demonstration Objective: This procedure is used to verify that the chosen recovery harness layout will result in the desired extraction of all recovery components.

Demonstration Description: Set up the recovery harness with all components excluding live charges. Ensure the Tender Descender is not attached to the harness. Ensure all components have been appropriately packed into the airframe. Pull on the butterfly knot the drogue parachute is attached to until the deployment bag has left the airframe. Continue pulling until the main parachute is completely extracted from the deployment bag.

Success Criteria: All recovery components are extracted untangled, and in the desired order. The force required to extract components should not exceed a reasonable force the drogue parachute can provide.

Results and Necessary Modifications: The recovery integration order demonstration was completed for the first and second subscale launch. For further discussion, see Section 3.2.4.2. The results of the recovery integration order demonstration were not conclusive for the first subscale flight, while the second subscale flight appeared to pass with the previous success criteria. Based on the results of the second subscale flight, the recovery integration order demonstration must include a reasonable force criterion.

6.3.7 Altimeter Pressure Reading Demonstration

Demonstration Objective: This demonstration is used to show that the barometric altimeters are reading a pressure change and ignite the ejection charges at the desired altitude.

Demonstration Description: Mark each e-match with a piece of tape, saying primary drogue, secondary drogue, primary main, and secondary main. Wire e-matches through the electronic bay bulkhead. Connect each e-match to the appropriate altimeter ports. Place the altimeters in the airframe as they would be during a launch. Arm the altimeters. Use a shop vacuum on the end of the airframe with the altimeters to pull air out of the airframe. Do this until the drogue e-matches ignite. Shut the shop vac off and remove the hose end from the airframe. As the airframe re-pressurizes, the main e-matches should ignite. Ensure all the charges ignite at the correct time. Pull the altimeters out of the airframe and extract the data from them. Ensure that the altimeter data shows the altimeters ignited the e-matches at the desired altitude. Ensure the drogue parachutes e-matches were ignited at the highest altitude sensed. Ensure the main parachute e-matches were ignited near 700 ft AGL (if not near, ensure the altitude was higher than 500 ft AGL.

Success Criteria: The correct e-matches ignite at the expected times, and the altimeter data shows the charges were ignited at apogee and the expected main parachute release altitude.

Results: E-matches were ignited in the correct sequence at the expected times during this demonstration for subscale. This is incomplete for full scale.

6.3.8 E-match Resistance Demonstration

Demonstration Objective: Verify that all e-matches read the correct resistance before use during ejection testing or a flight.

Demonstration Description: A multimeter, box of e-matches, and alligator clips are needed. Grab an e-match and pull the black wire-protector off the end. Pull the two leads away from each other, tearing the plastic shielding. Plug the alligator clips into the multimeter, and turn the multimeter on. Set it to the correct ohms setting. Attach the alligator clips to the wire leads. Ensure the resistance is between 1.2 and 1.7 Ohms. Repeat for all e-matches needed.

Success Criteria: The e-match reads the nominal resistance rating of 1.3-1.7 Ω.

Results: All e-matches which OSRT have used have fallen within the nominal resistance rating except one. The e-match falling outside nominal resistance rating was clearly marked with the resistance rating and disposed of.

6.3.9 Ejection Demonstration

Demonstration Objective:

This demonstration is associated with recovery integration. It is necessary to ensure that only the drogue section of the recovery harness leaves the airframe. It is also necessary to prove that the ejection charges are sized correctly and that an airtight seal is formed in the recovery bays. These requirements are are necessary to successfully separate the launch vehicle sections at apogee.

Demonstration Description:

Listed below is the procedure which should be followed when performing this demonstration:

- Safety consideration: Ensure appropriate PPE and clothing are being worn by ALL participants

1) Connect all recovery components to the eye bolts and Tender Descender on the electronics bay bulkhead.
2) Wire the e-match connected to a black powder charge through the electronics bay bulkhead. Leave about 15 in. of the e-match wire on the fore end of the bulkhead. Reach into the airframe and thread the e-match wires through the static port hole in the airframe.
   - Safety consideration: Handle the charge with care. Static electricity can set off a charge.
3) Slide the electronics bay into airframe. Attach bulkhead to the airframe with radial screws.
4) Tighten all six pressure sealing bolts to create a pressure seal against the inner wall of the airframe.
5) Attach extension leads to the e-match leads.
6) Follow recovery integration procedure in Section 4.1.9 to ensure the assembly is integrated correctly.
7) Slide the coupler into the airframe and put nylon shear pins in place.
8) Strap down the airframe with ratchet straps to cinder blocks.
   - **Note:** It is important for the fin section to be immobile during this demonstration.

9) Move appropriate distance away from airframe.
10) Ensure the ignition system is in the off position.
11) Plug extension into the ignition system.
12) Attach a 9 V battery to the ignition system.
    - Safety Consideration: Ensure all participants are aware that the ignition system is ready. Announce that you are about to set off the charge. Ensure no one is within 50 ft the airframe before the charge is set off. Ensure everyone is behind a protective barrier/shield.
13) Flip the switch.
    a. If successful, repeat until 5 consecutive tests are successful.
    b. If unsuccessful, determine why: Did **zero/one** charges ignite?
       i) **Zero:** Disassemble subscale launch vehicle. Check the following potential causes in the order listed until the problem is solved: improper battery and e-match combination used, leading to a current over 6 A; charges are likely not wired correctly; the e-matches have a broken lead; the e-matches are faulty.
       ii) **One:** If one ignited, charge was sized incorrectly, or a pressure seal was not formed.
14) Inspect the recovery assembly. Ensure the deployment bag has been contained within the airframe.
    - **Note:** If the deployment bag has left the airframe, or can be pulled out of the airframe, the recovery system demonstration is considered a failure.
15) Repeat this process until five consecutive, successful tests have been performed.

Success Criteria: This demonstration is considered successful if 5 consecutive separation events are fully separate the launch vehicle sections, expel the drogue parachute, and retain the deployment bag within the airframe. The deployment bag or main should not be easily removed from the airframe by hand without unclipping or untying any section of the recovery system.

Results: Ejection demonstrations have successfully been performed to size charges and view the events which would occur at apogee on the subscale launch vehicle. Ejection demonstrations will be repeated for the full scale launch vehicle. Figure 78 displays a successful successful separation of the subscale launch vehicle sections.

Figure 78: Full separation of the launch vehicle sections caused by ignition of an ejection charge.

6.3.10 Ejection Charge Demonstration

Demonstration Objective: This demonstration will be implemented to ensure consistency in the rupturing of the ejection charges.

Demonstration Description: During all testing involving ejection charges, including flights, charges should be inspected afterwards. The rupture point should be located through the wall of the surgical tubing. If the rupture point is not located in the side of the surgical tubing, refer to checklists to ensure all steps were followed during the ejection charge assembly process.

If no errors are apparent in the checklists, ejection charge assembly procedures will be reviewed. Alternatives may be implemented to seal the end better than with zip ties.

Success Criteria: All five consecutive ejection demonstrations will involve the ejection charges rupturing through the side of the surgical tubing. Additional ejection demonstrations will be conducted until five consecutive ejection demonstrations have ejection charges which rupture through the side of the surgical tubing.

Results: All ejection charges used to date have properly detonated, causing the explosion to rupture through the wall of the surgical tube. Figure 79 displays how the charges should appear after successfully firing. Ejection charge demonstrations will be performed for all tests and launches involving ejection charges.

Figure 79: Ejection charges exploding through the wall of the surgical tubing.

6.3.11 Avionics Operation Demonstration

Demonstration Objective: This procedure is used to demonstrate successful full-system operation of the ATU including tracking of the launch vehicle during and after the flight via broadcasting GPS information from the flight units to a ground station.

Demonstration Description: ATU checklist (see Section 4.1.6) is to be completed prior to launch vehicle assembly. Ground station checklist is then completed (see Section 4.1.7); ground station can be activated and operated for demonstrating connection and reception from ATUs as soon as ATUs have a flashing red light indicating GPS lock. Live drift plots will be rendered on the computer connected to the ground station while a connection is operating. Operation and connection are verified in the same method once ATUs have been placed in aft and fore sections of launch vehicle. Ground station will continue to receive transmitted data and render drift plot as long as flight ATUs are operational.

Success Criteria: Ground station ATU renders drift plot and positional data on attached PC before, for the duration of, and after the flight. Application will crash or freeze if connection is lost; the application not freezing or closing indicates a successful full-flight tracking.

Results: The ATU has successfully tracked the subscale launch vehicle during flight. This demonstration will be repeated for all full scale launches.

6.3.12 Rover Deployment Demonstration

Demonstration Objective: The purpose of this demonstration is to verify that the rover can be deployed remotely from the internal structure of the launch vehicle after it has been successfully recovered.

Demonstration Description: The rover will be assembled in the PEARS which will be integrated into the launch vehicle. From a safe distance, OSRT will use the ground station to send the remote signal to the

PLEC which will release the retention devices and ignite the black powder charges, ejecting the rover from the airframe.

Success Criteria: If the rover is successfully deployed from the airframe from the remote signal, the demonstration is successful.

Results: Demonstration not yet conducted.

6.3.13 Rover Mobility Demonstration

Demonstration Objective: Verify the rover will travel at least 10 ft from the launch vehicle before collecting soil samples.

Demonstration Description: After ejection from the airframe, the rover will be powered-on and autonomously start driving. Using sonar sensors, the rover will avoid obstacles in its path. Once the program has finished the initial driving phase, the distance from the launch vehicle will be measured.

Success Criteria: The rover drives at least 10 ft from the launch vehicle after ejection and before collecting soil samples.

Results: Demonstration not yet conducted.

6.3.14 Soil Retention Demonstration

Demonstration Objective: Verify the soil retention system can seal at least 10 mL of soil.

Demonstration Description: Starting with the soil retention lower door closed and the upper door open, slowly place soil into the container in a manner similar to the auger. Once at least 10 mL has been placed into the container, operate the soil retention controls to close the upper door.

Success Criteria: The container properly closes and seals the soil. No soil falls from the soil container after closing.

Results: Demonstration not yet conducted.

6.3.15 Rover Deployment Demonstration

Demonstration Objective: The objective of this demonstration is to verify that the payload will be capable of remaining launch-ready on the pad for a minimum of 2 hours without losing any functionality.

Demonstration Description: The PEARS will be fully assembled without any black powder in the ARRD or Tender Descender, and without ejection charges attached. It will then be turned on and a timer started.

After two hours, the system will be tested with a multimeter to show that the system still retains enough charge to perform all retention and ejection functionality.

Success Criteria: The demonstration is considered successful if the PEARS still has functionality after being armed for 2 hours.

Results: Demonstration not yet conducted.

6.3.16 Collision Avoidance Demonstration

Demonstration Objective: This procedure will be used to ensure that our rover can actively avoid obstacles autonomously and not become stuck.

Demonstration Description: Place the rover in the middle of an area surrounded by objects and walls that will obstruct the rovers path. Conditions should be similar to the field conditions at the USLI competition. Turn the rover on.

Success Criteria: The rover detects when objects obstruct its path via sonar and reacts by changing directions to avoid these obstacles. The path may appear random.

Results: Demonstration not yet conducted.

6.3.17 Rover Low Power State Demonstration

Demonstration Objective: The objective of this demonstration is to verify that the rover will be capable of remaining in a low power state until it has been ejected.

Demonstration Description: The rover will be powered on and encased in the fiberglass wrap assembly. During assembly, the wire attached to the wrap will be inserted into the terminals on the rover. This will put it in a low power state. The system will be left in this state for 10 hours before being unwrapped and the batteries tested.

Success Criteria: The demonstration is considered successful if the rover retains functionality after 10 hours of being in the low power state.

Results: Demonstration not yet conducted.

6.4 Inspection Procedures

6.4.1 RF Shielding Inspection

Inspection Objective: All altimeter housings will block radio signals from both entering and exiting the bay when fully assembled.

Inspection Description: Use a multimeter to test the resistance across the inner walls of the altimeter bay. The walls should be highly conductive so that signals are blocked. Test the resistance at several locations. All altimeters will be placed within a bay with these characteristics to eliminate the risk of unwanted signals interfering with the readings.

Success Criteria: The inspection is successful if the resistance across any two points is below 10 ohms.

Results: Completed on subscale altimeter bay. All locations measured a resistance lower than 10 ohms. This inspection will be repeated with both full scale altimeter bays. Altimeter bay is kept separate from the rest of the components by both a physical wall and a Faraday cage.

6.4.2 Recovery Electrical Circuits Inspection

Inspection Objective: The electrical circuits for all recovery electronics will be separate from all payload circuits.

Inspection Description: Check that all recovery circuits include only: one commercially available altimeter, one SPDT switch accessible from outside of airframe which can be locked in ON position for flight, and one 9 V battery.

Success Criteria: The inspection is successful if all recovery circuits only include one commercially available altimeter, one SPDT switch, and one 9 V battery.

Results: Completed on subscale launch vehicle. Inspection to be completed on full scale launch vehicle for all launches.

Results: All charges used in all ejection demonstrations and launches have successfully ruptured through the wall of the surgical tubing. Ejection charge inspection to be repeated for all future tests involving ejection charges.

6.4.3 Avionics Inspection

Inspection Objective: Ensure that active electronic tracking devices are installed in the launch vehicle and will transmit position of any tethered or untethered (independent) component to a ground receiver. Any independent section must contain a functional, active electronic tracking device.

Inspection Description: Ensure ATU prep checklist has been completed (see Section 4.1.6) and that electrical components are all taped down and secured. Make sure that ATUs have achieved GPS lock. During integration, ensure that flight ATUs are armed and one is placed in the aft and one in the fore of the launch vehicle. Check that avionics sleds are secure inside the bays. Check components holding launch vehicle together to confirm that separation will occur as expected. Perform ground station prep checklist (see Section 4.1.7) and confirm that transmission from ATUs inside launch vehicles is operational and that data stream is stable through the launch vehicle body.

Success Criteria: One ATU placed in both fore and aft sections of the launch vehicle and transmitting to the ground station successfully. Avionics sleds are mechanically secured inside avionics bays and don't impede integration. Transmission is successful to ground station even through launch vehicle body and at a distance.

Results: The ATU has performed successfully for the subscale launches. The full scale launches will have a new ATU, which will need to transmit position of the launch vehicle sections throughout flight.

6.4.4 Heat and Pressure Effects Inspection

Inspection Objective: The objective of this inspection is to ensure the heat and pressure of ejection charges during ejection demonstrations and launches do not adversely effect sensitive component performance or ratings, such as parachute shroud lines.

Inspection Description: After conducting and ejection demonstration or after a launch, inspect all sensitive components for damage due to the heat and pressure of ejection charges. Focus should be given to the risers, shroud lines, parachute canopy, and deployment bag. If damage occurs, component should be evaluated for failure potential due to the damage. Significant damage to recovery critical components should result in replacement of component.

Success Criteria: The ejection charges do not cause noticeable damage or melting of any components.

Results: Inspection not yet conducted.

6.4.5 Rover Battery Impact Protection Inspection

Inspection Objective: The objective of this inspection is to ensure that the rover's batteries are appropriately protected from impact with the ground.

Inspection Materials:

- Assembled rover

Inspection Procedure:

1) Inspect the rover's battery mount.

Success Criteria: Batteries are contained entirely within the volume of the chassis. Batteries cannot come loose with different orientations or shaking of the rover.

Results: Inspection not yet conducted.

6.4.6 Ejection Charge Protection Inspection

Inspection Objective: The objective of this inspection is to ensure that all components within the ejection bay have not been damaged by the heat, residue, or pressure from payload ejection.

Inspection Materials: PEARS bay after ejection, payload aft bulkhead after ejection, Kevlar harness after ejection, latex gloves, safety glasses.

Inspection Procedure:

- Safety consideration: Ensure all proper PPE is being worn as components contain black powder residue.

1) Inspect PEARS bay:
   a) Clean off black powder residue and remove any extra ejection wadding
   b) Inspect PEARS bulkhead for any damage
   c) Inspect ARRD for any damage
   d) Inspect Tender Descenders for any damage
   e) Make note of, and report any, damaged components
2) Inspect ejected components:
   a) Clean off black powder residue
   b) Inspect Payload aft bulkhead for any damage
   c) Inspect Kevlar harness for any damage
   d) Make note of, and report any, damaged components

Success Criteria: The inspection procedure is successful if all components are damage free. Should there be any damaged components, replace with higher strength or heat resistant components and inspect again after the next ejection.

Results: Inspection not yet conducted.

6.4.7 Expandable Wheels Inspections

Inspection Objective: The objective of this inspection is to ensure that the rover wheels are expandable.

Inspection Materials: Assembled rover, fiberglass wrap, two large zip-ties, calipers.

Inspection Procedure:

1) Wrap the assembled payload in the fiberglass wrap.
2) Secure the fiberglass wrap with one zip-tie around it at each wheel.
3) Measure the diameter of the wheel, including the tire, using the calipers.
4) Remove fiberglass wrap and wait at least 10 seconds.
5) Measure the diameter of the wheel, including the tire, using the calipers.

Success Criteria: Rover wheels have a larger effective diameter when undisturbed than when secured with a fiberglass wrap.

Results: Inspection not yet conducted.

6.4.8 Recoverablility and Reusability Inspection

Inspection Objective: The objective of this inspection is to ensure that the launch vehicle is both recoverable and reusable.

Inspection Description: Post launch, the OSRT will attempt to recover the launch vehicle. After the launch vehicle has been recovered, it will be inspected for any defects such as cracks in the epoxy, airframe zippering, fin stability and other factors that would affect any future launches.

Success Criteria: The launch vehicle is recovered and is able to safely perform another launch without repairs or replacement of any components that are not intended to be replaced. Batteries and ejection charges are examples of components that need to be replaced every launch.

Results: To date, the subscale has not had a fully successful recovery. During the first launch, the main parachutes deployed too early and, in the second launch, the force needed to deploy the main parachutes was too large for the drogue. The launch vehicle was reusable after the first attempt, however, the high impact of the second launch was too much for the fore avionics sled to withstand. This is the only component that failed and the rest of the airframe and components are able to launch again without any repairs. The full scale inspection will take place at each full scale launch.

6.5 Requirement Compliance

The following sections summarize the methods OSRT is using to comply with all requirements in the SL handbook and all requirements which have been derived by the team.

6.5.1 Competition Requirements

6.5.1.1 General Requirements

Table 42: General Verification Matrix

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	I	Students will do all the work of the project.	Complete - to date, students have done all the work of the project so far, and will continue to do so for the remainder of the project life cycle.	N/A
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 assignments, Science, Technology, Engineering and Mathematics (STEM) engagement events, and risks and mitigations.	I	OSRT will provide and maintain a project plan throughout the project.	Complete - to date, OSRT has provided and maintained a project plan so far. A project plan will be maintained throughout the remainder of the project life cycle.	N/A

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Table 42 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
1.3	Foreign National (FN) team members must be identified by PDR and may or may not have access to certain launch week activities during launch week due to security reasons. In addition, FNs may be separated from their team during certain activities.	I	OSRT will identify FN students by PDR.	Complete - no FNs are a part of the current OSRT roster.	N/A
1.4	The team must identify all team members attending launch week by the CDR.	I	OSRT will identify all members attending launch week by CDR.	Incomplete - team members attending launch week activities will by January 30th, the extended deadline by the SL team.	N/A
1.4.1	Students actively engaged in the project throughout the entire year.	I	OSRT will identify all members attending launch week by CDR.	Incomplete - team members attending launch week activities will by January 30th, the extended deadline by the SL team.	N/A
1.4.2	One mentor (see requirement 1.13).	I	OSRT will identify all members attending launch week by CDR.	Incomplete - team members attending launch week activities will by January 30th, the extended deadline by the SL team.	N/A
1.4.3	No more than two adult educators.	I	OSRT will identify all members attending launch week by CDR.	Incomplete - team members attending launch week activities will be identified by the extended deadline by the SL team of January 30th.	N/A

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Table 42 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
1.5	The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics STEM activities, as defined in the STEM Engagement Activity Report, by FRR. To satisfy this requirement, all events must occur between project acceptance and the FRR due date and the STEM Engagement Activity Report must be submitted via email within two weeks of the completion of the event.	D	OSRT will engage a minimum of 200 participants in STEM lessons before FRR.	Complete - OSRT has engaged 1735 participants in STEM lessons.	N/A
1.6	The team will establish a social media presence to inform the public about team activities.	D	The team will establish social media presence on Facebook, Twitter, Instagram, and Snapchat.	Complete - social media presence has been established.	N/A
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 in an email, inclusion of a link to download the file will be sufficient.	D	The team will submit all deliverables appropriately.	Complete - to date, all documentation has been and will continue to be submitted appropriately.	N/A
1.8	All deliverables must be in PDF format.	I	The team will submit all deliverables appropriately.	Complete - to date, all documentation has been and will continue to be submitted appropriately.	N/A
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	I	The team will include a table of contents with all reports.	Complete - to date, a table of contents has been included on all documentation, and will be included for all future documentation.	N/A

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Table 42 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
1.10	In every report, the team will include the page number at the bottom of the page.	I	The team will include a page number on all pages.	Complete - to date, page numbers have been on all documentation, and will continue to be included for all future documentation.	N/A
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.	I	The team will use a conference room with necessary capabilities.	Complete - two conference rooms have been selected for use in teleconferences. These rooms have all necessary equipment.	N/A
1.12	All teams will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted on the field. Eight foot 1010 rails and 12 foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on launch day. The exact cant will depend on wind conditions.	I	The team will make use of a 12 foot 1515 rail for all designs.	Complete - simulations and designs account for a 12 foot 1515 rail.	N/A
1.13	Each team must identify a mentor.	I	Team will identify a mentor.	Complete - Joe Bevier has been identified as the OSRT mentor.	N/A

6.5.1.2 Launch Vehicle Requirements

Table 43: Launch Vehicle Verification Matrix

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
2.1	The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 ft AGL.	D	The motor selection is based on OpenRocket simulation to reach the required AGL range. This will be determined as the team refines the design and determines a definite weight.	Incomplete - launch vehicle has been designed to meet requirements. It is currently being manufactured for a future demonstration flight.	Section 6.3.1
2.2	Teams shall identify their target altitude goal at the PDR milestone.	I	The target AGL goal has been set during PDR.	Completed - launch vehicle has been designed to reach 4,500 ft.	N/A
2.3	The vehicle will carry one commercially available, barometric altimeter.	I	The launch vehicle will contain a commercially available barometric altimeter.	In progress - multiple commercially available altimeters have been selected. Commercially available barometric altimeters were used in the subscale launch vehicle.	Section 6.4.2
2.4	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.	I	The location of the altimeter housing will allow for each altimeter arming switch to be activated from the exterior of the launch vehicle.	In progress - arming switches will be accessible from exterior of launch vehicle. Externally armed mechanical switches will be present in all future designs.	Section 6.4.2
2.5	Each altimeter will have a dedicated power supply.	I	All altimeters will have their own dedicated power supply.	In progress - each altimeter in design has dedicated power supply in design.	Section 6.4.2
2.6	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	D	All arming switches will have a mechanical locking system.	In progress - arming switches in all designs are armed through use of hex key which maintains ON position throughout flight.	Section 6.4.2

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Table 43 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
2.7	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.	D	The launch vehicle will be designed to survive launch and recovery without needing repairs or modifications prior to an additional same day launch.	In progress - launch vehicle designs have been made to withstand all expected forces of launch and recovery. Reusability of designs will be demonstrated on full scale demonstration flight.	Section 6.3.1
2.8	The launch vehicle will have a maximum of four (4) independent sections.	I	The launch vehicle will have no more than four independent sections.	Completed - launch vehicle has been designed to have three independent sections.	N/A
2.9	The launch vehicle will be limited to a single stage.	I	The propulsion system will consist of only one motor.	Completed - only one motor will be used.	N/A
2.10	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the FAA flight waiver opens.	D	The team will perform preparation drills to practice assembling and readying the launch vehicle within two hours.	Incomplete - OSRT will demonstrate the ability to prepare the launch vehicle and payload for launch within 2 hours on the demonstration flight.	Section 6.3.2
2.11	The launch vehicle 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.	T, D	The team will perform testing for leakage current in order to optimize energy usage of all electrical systems.	In progress - all batteries were chosen to be capable of maintaining functionality for more than 2 hours. Testing will be conducted with all systems prior to full scale launch.	Sections 6.1.3 and 6.3.3
2.12	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.	D	The launch vehicle will have a separate launch system that is powered by an external 12-volt system.	Incomplete - standard igniters which can be ignited with a 12 V DC firing system will be used to ignite the Cesaroni L2375-WT on demonstration flight.	Section 6.3.1

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Table 43 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
2.13	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch.	I	All electrical systems will run autonomously and wait for launch, internally. Acceleration sensors will inform the control systems of launch.	Completed - no external circuitry will be used.	N/A
2.14	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant Ammonium Perchlorate Composite Propellant (APCP) which is approved and certified by NAR, Tripoli Rocketry Association, Inc. (TRA), Canadian Association of Rocketry (CAR).	I	The launch vehicle will be designed to use a commercially available motor that is approved and certified by the NAR, TRA, and/or the CAR.	Completed - The Cesaroni L2375-WT meets these requirements.	N/A
2.15	Pressure vessels on the vehicle will be approved by the RSO and will meet the provided criteria.	I	Pressure vessels will not be integrated into the launch vehicle.	Completed - no pressure vessels are used in current designs.	N/A
2.16	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	I	The motor selection will be limited to using a L-class or lower as to not exceed 5,120 Newton-seconds of impulse.	Completed - the Cesaroni L2375-WT is 4905 N-s according to the manufacturer.	N/A
2.17	The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit.	A	Update weights and dimensions of in OpenRocket simulation for design changes. Modify fin shape to control stability until the time of manufacture. After manufacture, maintain any minor stability changes through adjusting ballast masses.	In progress - static stability has been determined in simulations and in design. Measured center of gravity will be compared to simulated center of gravity.	Section 6.1.1
2.18	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	A, D	The selected motor will be simulated to achieve over 52 fps off of a 12 ft rail provided by USLI.	Incomplete - rail exit velocity has been simulated and will be confirmed with the demonstration flight.	Section 6.2.1 and 6.3.1

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Table 43 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
2.19	All teams will successfully launch and recover a subscale model of their launch vehicle prior to CDR. Subscales are not required to be high power rockets.	T	The team will successfully create, launch, and recover a subscale launch vehicle prior to submitting the CDR.	Completed - the subscale launch vehicle was flown twice, on 12/8 and 1/4.	N/A
2.20	All teams will complete demonstration flights.	D	The team will launch a subscale and full scale launch vehicle with retained payload included in the full scale, eliminating the need of a simulation mass. Both vehicles will be built with resources available at OSU, fully equipped with chutes and avionics. Information recovered from the flight will reported on the FRR. The launch vehicle will not be modified at this point. If re-flight is necessary, proper documentation will be filed for an extension which would be done before the FRR deadline.	Incomplete - will be completed by each of the specified deadlines.	Section 6.3.1
2.21	An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR.	D	If the team fails to complete a Payload Demonstration Flight prior to the FRR, the team will follow the proper procedure for re-launch.	Incomplete - will be completed by specified deadline if necessary.	Section 6.3.1
2.22	Any structural protuberance on the launch vehicle will be located aft of the burnout center of gravity.	A	Any structural protuberances will be located behind the burnout center of gravity.	Completed - analyses have been conducted to show all protuberances in design are aft of center of gravity.	Section 3.1.14.1

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Table 43 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
2.23	The team name and launch day contact information will be in or on the launch vehicle airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe.	I	There will be sufficient and obvious contact information on each section of the launch vehicle.	Incomplete - contact information will be labeled during manufacture of the launch vehicle.	N/A

6.5.1.3 Recovery Requirements

Table 44: Recovery System Verification Matrix

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
3.1	The 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.	D	Demonstrations will be performed to ensure staging events occur in the correct order and at the correct time.	In progress - This concept was tested in a successful subscale launch, but will be complete in a full scale launch prior to the FRR submission.	Section 6.3.4

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Table 44 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
3.1.1	The main parachute shall be deployed no lower than 500 feet.	D	Demonstrated during both subscale flights that the Tender Descender separated at the aaltitude expected (700 ft AGL)	Incomplete - In a subscale launch, the barometric altimeters successfully ignited the black powder in the Tender Descender and ARRD at 700 ft AGL, however the main parachute did not deploy at the desired altitude. This is discussed in section 6.3.1	Section 6.3.4
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	D	Demonstrated during both subscale flights that both altimeters fired the drogue ejection charges within two seconds of sensing apogee. Demonstrated that the delay on both altimeters were set to less than two seconds.	Complete - Primary charge ignition will occur with no delay and secondary charge ignition will occur with one second delay. This was successfully tested in the subscale launch.	Section 6.3.4
3.2	Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.	D	Ground ejection tests were performed with the subscale launch vehicle to demonstrate proper ejection of drogue and main parachutes.	In Progress - Ejection testing has been complete for all subscale launches and will be complete prior to all full scale launches.	Section 6.3.9
3.3	At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	A, D	It was demonstrated during the first subscale launch that each launch vehicle section will land under with a kinetic energy under 75 ft-lbf.	Complete - Parachute sizes have been selected based off analyses which have been verified through the results of a subscale launch.	Section 6.2.3 & 6.3.5
3.4	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	I	Each recovery circuit will be inspected to ensure they are separate from all payload circuits.	Complete - The final full scale launch vehicle design has accounted for completely independent circuits for payload and recovery.	Section 6.4.2

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Table 44 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
3.5	All recovery electronics will be powered by commercially available batteries.	I	Recovery electronics will be inspected to ensure they are powered by commercially available batteries.	Complete - All batteries have been purchased through reputable vendors.	N/A
3.6	The recovery system will contain redundant, commercially available altimeters. The term ”altimeters” includes both simple altimeters and more sophisticated flight computers.	I	Each altimeter bay will be inspected to ensure it contains redundant altimeters.	Complete - Redundant, commercially available altimeters have been selected and were tested on the subscale flight.	6.4.2
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	I	The motor and motor retainer will be inspected to ensure the motor will not be ejected during recovery.	Complete - The motor will not be used for ejection during the flight.	N/A
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	I	Once the full scale launch vehicle has been fully assembled, the vehicle will be inspected to ensure it is held together with removable shear pins. Ensure nylon shear pins are used at separation points.	Complete - all couplers include 3x 2-56 nylon shear pins. These shear pins were successfully used on the subscale ejection demonstrations and launches.	N/A
3.9	Recovery area will be limited to a 2,500 ft radius from the launch pads.	A, D	Demonstrated in subscale flights and simulations for maximum drift radius in ideal scenarios.	Complete - Multiple simulations have been performed which demonstrate recovery of all sections will fall within 2,500 ft radius. A combination of the results from the subscale launches verified these simulations.	Section 6.2.3 & 6.3.5
3.10	Descent time will be limited to 90 seconds (apogee to touch down).	A, D	Demonstrated in simulations for ideal scenarios and both subscale flights.	Complete - Multiple simulations have been performed which demonstrate recovery of all sections within 90 seconds. A combination of the results from both subscale launches verified these simulations.	Section 6.2.3 & 6.3.5 & 6.3.1

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Table 44 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
3.11	An electronic 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.	I	While the fore and aft avionics bays are being assembled, an inspection will be performed to ensure the tracking system locks onto the ground receiver.	Complete - Design has accounted for the inclusion of tracking systems in the fore and aft sections of the launch vehicle.	Section 6.4.3
3.11.1	Any launch vehicle section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.	I	While assembling the launch vehicle, an inspection will ensure a tracking device is placed in each section that will land independently of the rest of the launch vehicle.	Complete - Design includes one avionics systems on each independently recovered section of the launch vehicle.	Section 6.4.3
3.11.2	The electronic tracking device(s) will be fully functional during the official flight on launch day.	D	Demonstrated on launch day by turning tracking systems on and ensuring they lock onto the ground receiver.	In Progress - This was completed for the subscale launch and will be completed prior to the full scale launch pending further launch testing.	Section 6.3.11
3.12	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	I	An inspection will be performed to ensure recovery electronics are properly shielded from any electronics which may adversely affect them.	Complete - design has accounted for appropriate shielding and protection of electronics.	Section 6.4.1
3.12.1	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.	I	An inspection will be performed during the full scale launch vehicle assembly to ensure recovery system altimeters are located in a separate compartment from all other radio frequency transmitting devices and/or magnetic wave producing devices.	Complete - design has accounted for appropriate shielding and protection of electronics.	Section 6.4.1
3.12.2	The recovery system electronics will be shielded from all on-board transmitting devices to avoid inadvertent excitation of the recovery system electronics.	I	an inspection will be performed to ensure recovery system electronics are properly shielded from all on-board transmitting devices.	Complete - design has accounted for appropriate shielding and protection of electronics.	Section 6.4.1

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Table 44 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
3.12.3	The recovery system electronics will be shielded from all on-board devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	I	An inspection wil be performed to ensure all recovery components are properly shielded from all on-board devices which may generate magnetic waves.	Complete - design has accounted for appropriate shielding and protection of electronics.	Section 6.4.1
3.12.4	The recovery system electronics will be shielded from any other on-board devices which may adversely affect the proper operation of the recovery system electronics.	I	An inspection will be performed to ensure the recovery system electronics are properly shielded from any other on-board devices which may adversely affect the proper operation of the recovery system electronics.	Complete - design has accounted for appropriate shielding and protection of electronics.	Section 6.4.1

6.5.1.4 Payload Requirements

Table 45: Payload Verification Matrix

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
4.3.1	The team's custom rover must deploy from the internal structure of its launch vehicle.	D	Demonstration is conducted by showing that the rover can be fully contained within and ejected from the internal structure of the launch vehicle.	Incomplete - Demonstration to be conducted once full scale launch vehicle and payload are built prior to first launch.	Section 6.3.12
4.3.2	The team's launch vehicle will feature a fail-safe active retention system to maintain control of the payload, even under atypical flight forces.	A	An analysis of all structural components was conducted to verify that even under atypical flight forces the system would not release the payload.	Complete - Analysis was conducted based on final system components chosen.	Section 6.2.5

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Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
4.3.3	Once on the ground, the team's rover must be deployed remotely.	D	Demonstration is conducted by showing that the rover can be deployed remotely from a signal from the ground station.	Incomplete - Demonstration will be conducted once full scale launch vehicle and payload are built prior to first launch.	Section 6.3.12
4.3.4	The team's rover must travel at least 10 ft from its launch vehicle before collecting a soil sample.	D	Demonstration is conducted showing the rover will drive itself away from the launch vehicle after ejection from the airframe.	Incomplete - Demonstration will be conducted once full scale launch vehicle and payload are built prior to first launch.	Section 6.3.13
4.3.5	The collected sample must be greater than or equal to 10 mL in volume.	T	Tests will be performed using a testbed and test assembly to assess the auger system.	Incomplete - Testbed and test assembly have been designed are in the manufacturing phase.	Section 6.1.7
4.3.6	The soil sample must be stored in a compartment that can be closed to prevent contamination.	D	Demonstration is conducted by showing the soil retention container is sealed.	Incomplete - Demonstration will be conducted once payload is built prior to first launch.	Section 6.3.14
4.3.7	All rover batteries must be protected from impact with the ground.	I	Battery module will be contained within the chassis.	Incomplete - Batteries will be mounted such that they are retained entirely within the chassis.	Section 6.4.5
4.3.8	All rover batteries must be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts.	I	Battery modules will be marked with colored electrical tape.	Incomplete - Batteries will be marked or colored appropriately once purchased.	N/A

6.5.1.5 Safety Requirements

Table 46: Safety Verification Matrix

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	I	Each subteam will create a checklist of their required items. Checklists will be compiled and verified by the Safety Officer. All team members will verify checklists and comply with them at launch.	In progress - subscale checklists are under development. Full scale checklists will be under development as the team begins manufacture and assembly of full scale launch vehicle and payload.	
5.2	Each team must identify a student safety officer who will be responsible I for all items in section 5.3.	I	The team Safety Officer has been selected.	Complete - the team Safety Officer is Jon Verbiest.	
5.3	The role and responsibilities of each safety officer will include, but not limited to:	I	Safety Officer will manage all roles outlined within requirement section 5.3. There are two additional safety officers for the launch vehicle and payload. These two sub-team safety officers report to the Safety Officer and are responsible for maintaining safe practice in the case that the Safety Officer cannot be at the event	In progress - the safety officer is currently, and will continue to be responsible for team safety in all aspects.	
5.3.1	Monitor team activities with an emphasis on Safety during:	I	Lead Safety Officer or sub-team Safety Officer will be present during all team activities which pose a safety risk.	In progress - Safety Officers will be present when necessary through all of manufacturing and testing phase.	

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Table 46 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
5.3.1.1	Design of vehicle and payload	I	The Lead Safety Officer or one of the sub-team Safety Officers will be at all internal design reviews to make sure all design decisions follow all safety requirements. The Safety Officer has final say over a design when the safety of a design is in question.	In progress - Safety Officers are present at all design reviews to provide safety input when necessary.	
5.3.1.2	Construction of vehicle and payload	I	Before construction begins, the Safety Officer will inform all team members of potential hazards and mitigation plans. The Safety Officer will make sure that JHA forms are filled out prior to any manufacturing. One of the Safety Officers will stand by to assist in fulfilling safety protocols. Manufacturing safety rules are set in place by the OSU MPRL	Complete - Safety Officers have given safety briefings to team and taught a lesson on filling out JHA forms.	
5.3.1.3	Assembly of vehicle and payload	I	Before assembly begins, Safety Officer will inform all team members of potential hazards and mitigation plans. One of the Safety Officers will stand by to provide assistance in fulfilling safety protocols. One of the safety Officers will verify checklists with their respective sub-team leads before assembly.	In progress - all checklists require a signature from safety officer to verify proper assembly procedures have occurred. Checklist development is still not complete, but all checklists will follow the same format.	
5.3.1.4	Ground testing of vehicle and payload	I	Before ground testing begins the Safety Officer will inform all involved team members on potential hazards and mitigation plans. The lead Safety Officer or one of the sub-team Safety Officers will stand by to provide assistance in fulfilling safety protocols.	Incomplete - OSRT has not begun ground testing of vehicle or payload.	

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Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
5.3.1.5	Subscale launch test(s)	I	During launch assembly, the Safety Officer will be responsible for monitoring checklists, PPE, and troubleshooting steps. The Officer ensured that the team was in compliance with safety restrictions set by the RSO.	Incomplete - OSRT has not launched the subscale launch vehicle.	
5.3.1.6	Full-scale launch test(s)	I	Before full-scale launch the Safety Officer will complete a checklist for launch with the help of the members taking part of the launch. The Safety Officer swill inform all members on the rules and regulation of the launch site and each members' role during the launch. A final check off of all components will then be carried out by the Safety Officer.	Incomplete - OSRT has not launched the full-scale launch vehicle.	
5.3.1.7	Launch day	I	Before Launch Day, the Safety Officer will complete a checklist for launch with the help of the members taking part if the launch. The Safety Officer will inform all members on the rules and regulation of the launch site and each members role during the launch. A final check off of all components will then be carried out by the Safety Officer. Lead Safety Officer or one of the sub-team Safety Officers will stand by to make sure all safety regulations are followed throughout the duration of the launch activities.	Incomplete - no launch days have occurred yet.	
5.3.1.8	Recovery activities	I	The Safety Officer will work closely with the appropriate range officers to determine the appropriate time to collect the launch vehicle. The Safety Officer will inform all team members of potential hazards and mitigation plans.	Incomplete - no recovery activities have occurred yet.	

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Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
5.3.1.9	Educational Engagement Activities	I	Safety Officer will approve all engagement activities for safety.	In progress - Safety Officer has been present for engagement activities and approved lesson plans.	
5.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	I	The Safety Officer will verify all checklists and make sure all team members are informed of them. The Safety Officer will be in charge of making sure all checklists are followed.	In progress - procedures have been developed and will continue to be developed as necessary.	
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and Material Safety Data Sheet (MSDS)/chemical inventory data.	I	The Safety Officer will collect all required forms and analyses and make sure that they are available to all team members. New versions will replace older editions	In progress - Safety Officer is managing and maintaining current hazard analyses and FMEAs.	
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	I	The Safety Officer will be in charge of collecting, compiling and reviewing all hazard analyses, failure mode analyses and procedures.	In progress - Safety Officer assists and reviews all hazard analyses and FMEAs.	

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Table 46 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
5.4	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	I	The team will communicate with the RSO for all test launches. The Safety Officer will work closely with the RSO and any concerns from the RSO will either be addressed before launch or the launch rescheduled to allow for more time to address them. The team understands that the decisions of the RSO are final and the RSO has the power to postpone or cancel any launch activities. NASA gives no authority regarding any test launches completed by the OSRT.	In progress - team has been briefed on Oregon Rocketry (OROC) launch site rules. The team will work with the OROC RSO for all launches and review launch site rules prior to all launches.	
5.5	Teams will abide by all rules set forth by the FAA.	I	The team has knowledge of all appropriate FAA regulations and will abide by them. The Safety Officer is responsible for verification that regulations are adhered to and will be assisted by the sub-team Safety Officers.	In progress - the team will abide by FAA rules for all launches.	

6.5.2 *Team Derived Requirements*

6.5.2.1 Launch Vehicle Team Derived Requirements

Table 47: Launch Vehicle Team Derived Verification Matrix

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
LV-1	All components will be able to withstand the heat and pressure from ejection charges.	The heat and pressure from ejection charges could potentially harm components located within the parachute bays. Any component not capable of handling the heat or pressure should be shielded with kevlar or other protective material.	I	All components will be inspected after ground tests are completed for damage or burning.	In progress - ejection demonstrations and launches of the subscale launch vehicle did not damage any sensitive components.	Section 6.4.4
LV-2	Launch vehicle will not be over stable or susceptible to weather cocking.	A stability which is too high will result in more significant weather cocking, reducing consistency of launches.	A	Static stability will be limited to maximum of 3.5 calibers.	Complete - OpenRocket simulations have shown static stability to be 2.1 calibers. The simulations will be updated to account for future design changes.	Section 6.2.2
LV-3	Motor will provide a 10 to 1 thrust to weight of the launch vehicle ratio.	A high thrust to weight ratio helps prevent weather cocking during the ascension of the launch vehicle. A high thrust from the motor quickly accelerates the launch vehicle, creating a high rail exit velocity.	A	Using OpenRocket simulations, OSRT will be able to test the thrust output of the motor acting on the launch vehicle.	Completed - L2375-WT has been selected based on OpenRocket simulations.	Section 3.1.5

Table 47 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
LV-4	The launch vehicle will accommodate the payload and avionics systems.	All components and systems should be able to be integrated within the launch vehicle. Additionally, the launch vehicle needs to accommodate avionics for RF transparency where necessary.	D	Launch vehicle will have specific areas to accommodate the payload and avionics system in the payload bay and avionics bay, respectively. Both the payload and avionics system will be designed within the constraints of the interior dimensions or their respective bay. The payload and avionics system will be verified upon demonstration flight of the full scale launch vehicle.	Incomplete - will be completed with the demonstration flight of the full scale launch vehicle.	Section 6.3.1
LV-5	MATLAB scripts will be used in conjunction with all OpenRocket simulations.	Redundant simulations will ensure descent velocities, descent trajectory, and landing energy of the launch vehicle will maintain safe values.	A	Descent velocities, descent trajectory, and landing energy will be calculated using MATLAB scripts. All simulations will be checked to ensure no values disagree by more than 15%.	In progress - MATLAB code has been developed for necessary calculations thus far.	Section 6.2.3
LV-6	Bulkheads will be able to withstand up to 75 g applied force with respect to the maximum pressure forces experienced during separation.	The bulkheads provide the mounting points for the parachutes. In the case that a bulkhead were to dislodge from the launch vehicle, there would be nothing to slow the descent of the airframe. It is important that the bulkheads are able to withstand forces at least twice the expected forces.	T	Maximum pressure forces and stress on the bulkheads and at the bulkhead/airframe bond will be calculated and compared to the epoxy's bond strength.	Incomplete - will be accounted for and completed in final design.	Section 6.1.2

Table 47 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
LV-7	Radial bolts will withstand the worst case scenario anomalous recovery forces of 50 g.	Failure of the radial bolts would result in the parachutes separating from the launch vehicle. Therefore, radial bolts need to be directly tested for their maximum holding capacity.	T	An Instron compression test was used to determine the failure mode and maximum force a bulkhead retained with radial bolts in a small section of excess airframe.	Complete - the compression testing first resulted of the bulkhead at 2200 lbf followed by the airframe at 3500 lbf.	Section 6.1.2
LV-8	All threaded attachments have a length greater than 1.5 times the minimum shear length of the selected threads.	This will prevent any failure of threaded rods at attachment points.	I	All purchased threaded components will be compliant, all manufactured components will be compliant.	Incomplete - will be accounted for and completed in final design.	N/A

6.5.2.2 Recovery Team Derived Requirements

Table 48: Team Derived Recovery Verification Matrix

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Recovery - 1	Ejection charges will separate launch vehicle and eject the drogue parachute a minimum of five consecutive times during testing.	This verification ensures the correct ejection charge size will reliably separate the launch vehicle and eject the drogue parachute to avoid the launch vehicle landing ballistic. Reliability will be confirmed through five consecutive tests at one size.	D	Ejection demonstrations were performed prior to both subscale launches.	In Progress - Ejection testing was completed prior to subscale launch and will be completed prior to all full scale launches.	Section 6.3.9
Recovery - 2	Recovery system will allow for the payload to be deployed from the airframe.	Having an open end available will simplify payload ejection and allow for minimal obstacles upon ejection.	D	It will be demonstrated that the open end of the launch vehicle allows the payload to be deployed.	Complete - Recovery system design allows for the payload to be deployed from the aft end of the fore airframe.	Section 6.3.7
Recovery - 3	Avionics will be able to track the launch vehicle during and after the flight, broadcasting GPS information to a ground station.	The avionics communicating GPS coordinates to the ground station is critical to being able to locate the launch vehicle after landing.	T, D	Tested and demonstrated prior to and during both subscale launches.	Completed - The avionics system was partially successfully tested on the first subscale flight, and completely successfully tested on the second flight. It will be tested on the full scale launches.	Sections 6.1.4 & 6.3.11
Recovery - 4	Avionics will have enough transmission power to communicate with the ground station through the entirety of the flight.	This verification ensures that the launch vehicle will be tracked throughout the entirety of the flight and continue transmitting upon landing.	T	The avionics system will be sufficiently ground tested to be capable of communicating with the ground station at maximum drift radius.	In Progress - The avionics system was partially successfully tested on the subscale flight and will be tested on the full scale launches.	Section 6.1.5

Table 48 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Recovery - 5	Avionics system will have a minimum of four hours of battery life to transmit to the ground station after being armed.	Ensuring the avionics communicate with the ground station for a minimum of four hours will allow the launch vehicle to stay armed on the rail for a maximum of two hours, while allowing an additional two hours of recovery time after landing. This is critical to being able to locate the launch vehicle after landing.	T	The battery life of the system will be tested.	Complete - Battery life was successfully tested during the subscale flight.	Section 6.1.3
Recovery - 6	Recovery system will have appropriately sized static port holes.	This verification ensures the altimeters will correctly sense the pressure outside of the launch vehicle. Under or oversized static port holes will cause early or late separation events respectively.	A	Analyses will be performed to determine the correct sizing and number of static port holes.	Complete - The port hole calculations have been performed.	Section 6.2.4
Recovery - 7	E-match wires will have a resistance within nominal range.	E-matches with an incorrect wire resistance will deliver incorrect current to the igniter leads, raising the chance for the lead to not ignite. Ensuring the resistance is in the nominal range will allow for the highest chance to ignite ejection charges.	D	Demonstrated prio to all ejection testing and launches. Only e-matches verified to be within the nominal operating range have been used for testing and launches.	Complete - Ejection charge manufacturing process includes verification of e-match resistance.	Section 6.3.8

Table 48 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Recovery - 8	Altimeters will be verified to be pressure sensitive prior to each launch.	The team determined it was necessary to verify that the altimeters would react to a change in pressure prior to being used.	D	Demonstrations proving the altimeters that are going to be flown are pressure sensitive will be performed prior to all launches.	Complete - This process is included in the altimeter demonstration procedures.	Section 6.3.7
Recovery - 9	Altimeters will be verified to be capable of firing e-matches.	The altimeters used should be capable of firing e-matches for the drogue and main parachutes. Without this capability, the launch vehicle will never operate safely.	D	The altimeters will be verified to be capable of firing drogue and main e-matches by firing both drogue and main e-matches on the ground during a vacuum test.	Complete - This process is included in the altimeter demonstration procedures.	Section 6.3.7
Recovery - 10	Pack method will allow components to be ejected in correct order.	The team determined it is necessary to verify that any new pack method and recovery configuration will result in an untangled and ordered ejection for reliability and safety of recovery components.	D	The recovery section will be separated by hand by pulling on the shock cord to ensure the components come out in the correct order, without tangles.	Complete.	Section 6.3.6
Recovery - 11	Ejection charges will consistently rupture through surgical tubing, not through the santoprene end.	This will ensure consistency in the ejection charges, as the material properties of the surgical tubing will be more consistent than the force of the zip tie and santoprene ends.	I	Photograph the failure point of all ejection charges during ejection testing. If rupture does not occur through the surgical tubing, consider new packing methods for the ejection charges.	Complete - Rupture points in all ejection tests have been through the surgical tubing. All future ejection charges will be inspected to determine if changes are necessary.	Section 6.3.10

6.5.2.3 Payload Team Derived Requirements

Table 49: Team Derived Payload Verification Matrix

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Payload - 1	The payload will be an adequate weight for both flight trajectory and payload mission.	The team needs the payload to be reasonably light to reach its target altitude with the selected motor. However, the rover must be robust enough to survive flight and ejection stresses and heavy enough to be able to use its auger reliably.	T	Design weight will be based upon ideal flight simulations. A test will occur prior to test launches and payload test missions.	In Progress - Designs have been modeled with expected weights. Manufacturing is beginning, and the test will be conducted after manufacture is complete and rover is fully assembled.	Section 6.1.6
Payload - 2	The 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 components.	It is a requirement that the launch vehicle be able to sit on the launch pad for a minimum of 2 hours, and because the PEARS will be armed at the same time as the launch vehicle, it must also be able to last as long.	D	Demonstration is conducted by showing that all Payload systems are still functioning after being armed for a minimum of 2 hours.	Incomplete - Demonstration will take place once full scale payload systems are fully built.	Section 6.3.15
Payload - 3	All components will withstand heat and pressure from ejection charges.	The team wants to use durable components that will last for years in the future. This will require all components to be able to withstand the effects of ejection charges without any ware.	I	After each ejection, all components in the ejection bay will be inspected. If any damage is found from the heat, residue, or pressure, the component will be replaced with one of higher quality.	Incomplete - Inspection will occur after each ejection test, both in ground testing and full scale launch ejections.	Section 6.4.6

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Table 49 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Payload - 4	The payload will have on-board sensors to provide a means of collision avoidance.	Collisions have the potential to cause the rover to become stuck. In order to proactively avoid such a scenario, collisions must be avoided.	D	The rover will have three sonar sensors mounted to its front, facing in slightly different directions to scan a wide field of view. Range information will be displayed to a serial monitor during testing to allow for verification that detected distances are sufficiently accurate. The rover will demonstrate the ability to steer to avoid an object in its path.	Incomplete - An algorithm has been developed and implemented for the rover to read data from sonar modules and determine if steering is necessary to avoid collisions.	Section 6.3.16
Payload - 5	The rover will have expandable wheels that form a pressure seal against the airframe.	A pressure seal is necessary for the team's black powder ejection to be successful.	I	The rover's tires will be shown to expand upon release of radial pressure.	Incomplete - System has been designed to meet this criterion and will be inspected upon manufacture of rover.	Section 6.4.7
Payload - 6	The rover's batteries will provide enough power to supply all of its electrical systems for at least 45 minutes.	The mission, including the requirements set forth by NASA and those created by the team, may take up to 45 minutes to complete.	T	The rover will operate for 45 minutes while performing the tasks required for competition.	Incomplete - Component specifications have been determined and testing will occur once components are purchased.	N/A
Payload - 7	The rover will remain in a low power state until it has been ejected.	Because the amount of time the payload will sit integrated on the launch pad, the rover will need to be in a low power state to avoid the need for large batteries.	D	Demonstration is conducted by showing that the rover can remain in a low power state while wrapped in the fiberglass.	Incomplete - The demonstration will take place once the rover and electronics are fully built.	Section 6.3.17

6.5.2.4 Safety Team Derived Requirements

Table 50: Team Derived Safety Verification Matrix

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Safety - 1	All team members that use the manufacturing and machining facilities at OSU will have appropriate certification.	OSU requires all students to obtain the appropriate certification before using any machine on campus. This minimizes the risk of injury due to improper use or an unknowledgable user.	I	All team members who need to use the OSU, MPRL, the woodshop, or the composites manufacturing lab will receive appropriate certification from the administrator of said lab before use.	In Progress - Necessary certifications will be obtained as they are required.	N/A
Safety - 2	Additional team members will assist the SO in explicitly promoting team safety and the preparation of safety documents.	Promoting safety requires cooperation from the full team. Two other team members outside of the SO have been identified to make the safety team. Having a subteam dedicated to safety will help to keep safety paramount and minimize the risk of injury.	I	Two additional safety officers, a Launch Vehicle Safety Officer and a Payload Safety Officer will assist the Team Safety Officer. JHA form developed for internal use when completing hazardous tasks.	Completed - Two team members volunteered for Launch Vehicle Safety Officer and Payload Safety Officer.	Section **??**
Safety - 3	The team will secure all hazardous material so only certified personnel can access them.	When working with a hazardous material, the risks are substantially heightened. Securing all hazardous materials separately from other materials will decrease the chance of injury due to improper material handling.	I	Hazardous materials will be kept in a separate area of the team workspace secured with a lock. Only team leaders, SO, and team mentors will have access to the hazardous materials.	Completed - Hazardous materials have been locked away in cabinets.	Section **??**

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Table 50 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Safety - 4	The team will follow all safety rules and guidelines set by the NAR, TRA, and OSU.	The rules and guidelines set by NAR, TRA, and OSU are made to protect all individuals involved. Following these rules is beneficial for all parties involved.	D	The SO will understand both NAR/TRA safety regulations, OSU safety codes and will ensure team members abide by all rules. Team members are also expected to be familiar with all safety regulations.	In Progress - All team members have followed all safety regulations so far.	Section **??**
Safety - 5	The team will have written checklists with instructions on how to safely assemble the rover, recovery systems, and launch vehicle.	Written checklists ensure that all safety considerations are taken into account and that all steps are followed when assembling components. Correct assembly is crucial and can easily go wrong if the checklist is not followed. Additionally, the checklists mean that the assembler must work with a qualified partner, further promoting safety.	I	Each team member or sub-team responsible for designing a part on any assembly pertaining to the launch vehicle or payload will write a formal checklist to ensure that any team member can assemble the part without the presence of the designer of the part. All checklists will be verified by assembler, inspector, and safety officer.	Incomplete - Will be implemented when assembly processes are developed.	Section 4.1.15
Safety - 6	The team will create a comprehensive list of FMEAs for each subsystem of the project, to mitigate as many of the failure modes as the team can.	FMEAs help the team identify potential failure points. If possible, the failure point will be completely eliminated. If elimination is not possible, steps will be taken to minimize the risk of the failure mode.	I	Each team member will write a FMEA for each and every part of the project they are working on. These will be organized by sub-team and subsystem so they can be easily referenced.	Complete - FMEAs for all parts have been created.	Section **??**

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Table 50 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Safety - 7	The team will charge all LiPo batteries with a smart charger to prevent nonuniform or over charging of the batteries.	Properly charging the batteries is important so that the avionics are capable of running for up to two hours. If the batteries charge poorly, GPS tracking could fail.	D	The team will agree to only buy smart chargers, so that non-smart chargers are never used for charging the batteries.	Incomplete - Will be implemented when team buys chargers.	Section **??**
Safety - 8	The team will not short circuit any of the batteries while installing them into systems requiring batteries.	Short circuiting a battery could result in damage to the avionics or the battery itself.	D	A formal procedure will be written with instructions explaining how to safely install the batteries into the rover.	Incomplete - Will be implemented when team reaches that point.	Section **??**
Safety - 9	The team will use appropriate PPE when handling and machining composite materials.	Improper PPE will result in injury to the user. Using the correct PPE will minimize this risk.	D	Safety briefings will be conducted, JHAs will be filled out as necessary.	In Progress - appropriate PPE has been used up to this point.	Section **??**
Safety - 10	There will be no sharp edges on the payload.	Sharp edges on the payload could cause damage to the airframe or other components. More importantly, a sharp edge could cause an injury.	I	Any sharp edges on payload will be machined off or will be completely encased in a safe container. See Section 5.2.3 for auger encasing.	Incomplete - Will be implemented when team reaches that point.	Section **??**
Safety - 11	There will be a light to indicate the payload ejection charges are armed.	It is important to know if the ejection charges are armed so that extra precautions can be taken. All present individuals should be aware of armed charges.	I	Blinking LED indicator will be installed, connected to payload ejection controller. LED blinking will be visible upon arming vehicle.	Incomplete - Will be implemented when team reaches that point.	Section **??**

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Table 50 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Safety - 12	The payload ejection controller will have an arming switch.	Being able to arm the payload ejection charges from a distance will minimize the risk of injury due to premature ejection charge firing.	I	Turn the switch to verify the LED is blinking to indicate armed status.	Incomplete - Will be implemented when team reaches that point.	Section **??**
Safety - 13	The Mentor and Educational Advisor will have a final say in safety decisions on all activities and designs.	The Mentor and Educational Advisor have much more experience than the rest of the team and are more qualified to assess the risk involved. If either of these individuals is insecure about a method or component, their opinion should be accounted for.	I	If the safety of an event or activity is disputed, whatever the Mentor or Advisor decides will be the final decision.	Complete - All team members have agreed to follow this rule should this issue arise.	Section **??**
Safety - 14	All team members must remain attentive and at safe distances from the launch area during subscale and full scale launches.	The majority of injuries are due to neglect or obliviousness to one's surroundings. If all individuals are aware of potential hazards before, during, and post launch, the risk of injury is substantially decreased.	I	Each team member will be responsible for having awareness of their surroundings during all launch related activities. All three safety officers will oversee team members' safety.	Incomplete - Will be implemented at first launch event and maintained through all future launches.	Section **??**

6.6 Budgeting and Timeline

6.6.1 Budget

Tables, 51, 52, and 53 are itemized lists of components and materials necessary to realize this design. These tables represent a breakdown of components and raw materials which OSRT plans to use in the manufacture and launching of the launch vehicle and payload. Item identifiers may not be sequential because design changes have eliminated the need for some components.

Section codes correspond to the physical location of the component within the launch vehicle and are as follows:

- 01: Motor
- 02: BEAVS
- 03: GoPro Cameras
- 04: Aft Avionics/Ejection
- 05: Recovery
- 06: Payload
- 07: Fore Hard Point
- 08: Fore Avionics/Ejection
- 09: Nosecone
- 10: Fins
- 11: Aft Airframe
- 12: Fore Airframe

The team has access to some items at no cost, either because they are already part of its resources or are being supplied as part of a sponsorship or partnership. The values of these items are noted, but not considered to be a team expenditure.

As a general rule, purchases made by Oregon residents (in-state or online) are not subject to sales tax.

Table 51: Structures Bill of Materials

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
01	Structures	01-001	Cesaroni L2375-WT	3	$331.99	$995.97	Wildman	PR75-4G-WT	
01	Structures	01-002	Motor Casing	1	$415.22	$415.22	Apogee Rockets	71043	
01	Structures	01-003	75 mm Fore Closure	1	$70.99	$70.99	Wildman	P75-CL	
01	Structures	01-004	75 mm Retainer	1	$48.89	$48.89	Apogee Rockets	24054	
01	Structures	01-005	Centering Ring	3	$0.54	$0.54	Spaeth Lumber	-	
01	Structures	01-006	Fiberglass Motor Tube	1	$111.99	$111.99	Apogee Rockets	-	
03	Cameras	03-001	Top Camera Case	1	n/a	n/a	Club Resources		$5.00
03	Cameras	03-002	Bottom Camera Case	1	n/a	n/a	Club Resources		$5.00
03	Cameras	03-003	GoPro Camera	5	$50.00	$250.00	Various (Secondhand)		
03	Cameras	03-004	Threaded Rod	1	$6.80	$6.80			
03	Cameras	03-005	Notched Bulkhead	2	$5.00	$10.00			
04	Structures	04-001	Aft Marine Grade Plywood Blkhd	1	$0.54	$0.54	Spaeth Lumber	-	
04	Structures	04-002	Aft Body Wall	1	n/a	n/a	Club Resources	-	$1.25
04	Structures	04-003	Altimeters Mount	2	n/a	n/a	Club Resources	-	$0.87
04	Structures	04-004	Switch Mount Obtuse	1	n/a	n/a	Club Resources	-	$0.12
04	Structures	04-005	Switch Mount Acute	1	n/a	n/a	Club Resources	-	$0.12
04	Structures	04-006	Battery Casing	2	$1.69	$3.38	LEDSupply	BH-9V-SWITCH	
04	Structures	04-007	Spacer	12	$0.07	$0.84	Alliedelec	901-605	
04	Structures	04-008	9V Battery, 4 ct.	1	$12.96	$12.96	Walmart	MN16RT4Z	
04	Structures	04-009	Board Screws, 100 ct.	1	$5.29	$5.29	McMaster-Carr	91772A081	

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Table 51 – continued from previous page

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
04	Structures	04-010	Battery Screws, 100 ct.	1	$5.82	$5.82	McMaster-Carr	90471A215	
04	Structures	04-011	Sealing Washer, 10 ct.	1	$8.58	$8.58	McMaster-Carr	93303A102	
08	Structures	08-001	Battery Casing	2	$1.69	$3.38	LEDSupply	BH-9V-SWITCH	
08	Structures	08-002	Spacer	8	$0.07	$0.56	Alliedelec	901-605	
08	Structures	08-003	9V Battery	2	n/a	n/a	Club Resources	MN16RT4Z	
08	Structures	08-004	Sealing Washer, 10 ct.	1	n/a	n/a	Club Resources	93303A102	
08	Structures	08-005	Seal Washer Bolt, 50 ct.	1	n/a	n/a	Club Resources	92620A564	
09	Structures	11-001	Nosecone	1	$184.95	$184.95	Madcow Rocketry	-	
10	Structures	12-001	3 x 3 ft Carbon Fiber Fin Stock	1	$295.00	$295.00	Tim McAmis Performance Parts	TMC-1290-0125	
11	Structures	13-001	Aft Body Tube	1	n/a	n/a	Innovative Composite Engineering	-	$1,500.00
11	Structures	13-002	RocketPoxy (2 pints)	1	n/a	n/a	Club Resources		$43.75
11	Structures	13-003	6.25 in. OD Canister	1	n/a	n/a	Club Resources	-	$100.00
12	Structures	14-001	Fore Body Tube	1	n/a	n/a	Innovative Composite Engineering	-	$1,500.00
12	Structures	14-002	Fore Coupler	1	$	$	Club Resources	-	$50.00
12	Structures	14-003	Prepreg 7781 E-Glass (5 yd roll)	1	n/a	n/a	Fiberglast		$241.95
			Structures Subtotal		$ 2,431.70				
			10% Contingency		$ 243.17				
			STRUCTURES TOTAL		**$ 2,674.87**				

Table 52: Aerodynamics and Recovery Bill of Materials

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
02	Mech. BEAVS	02-001	1/8 in. Aluminum Plate (2 x 24 in.)	1	$11.08	$11.08	McMaster-Carr		
02	Mech. BEAVS	02-002	1/4-20 Fasteners	4	$0.19	$0.76	McMaster-Carr		
02	Mech. BEAVS	02-003	Aft Marine Grade Plywood Blkhd	1	$0.54	$0.54	Spaeth Lumber		
02	Mech. BEAVS	02-004	PLA 3D Printer Filament (1 kg)	1	$19.99	$19.99	Amazon		
02	Mech. BEAVS	02-005	M2 Fasteners, 100 ct.	1	$13.26	$13.26	McMaster-Carr		
02	Mech. BEAVS	02-006	7 mm Linear Guide Block/Rail	4	$14.99	$59.96	McMaster-Carr		
02	Electrical BEAVS	02-007	SparkFun Venus GPS	1	$49.95	$49.95	SparkFun		
02	Electrical BEAVS	02-008	Teensy 3.6	1	$31.25	$31.25	Digi-Key		
02	Electrical BEAVS	02-009	MPL3115 Barometer	1	$4.87	$4.87	Mouser		
02	Electrical BEAVS	02-010	BNO055 9DOF IMU	1	$34.95	$34.95	Adafruit		
02	Electrical BEAVS	02-011	Turnigy 2200mAh LiPo	1	$10.99	$10.99	HobbyKing		
02	Electrical BEAVS	02-012	OSRT Designed PCB	1	$92.90	$92.90	DFRobot		
02	Electrical BEAVS	02-013	Xbee Pro 900hp	1	$39.00	$39.00	Digi-Key		
02	Electrical BEAVS	02-014	7 in. RPSMA Whip Antenna	1	$4.29	$4.29	Amazon		
02	Mech. BEAVS	02-015	Retention Ring	1	n/a	n/a	Club Resources		$0.10
02	Mech. BEAVS	02-016	Retention Link	4	n/a	n/a	Club Resources		$0.40
02	Mech. BEAVS	02-017	3/8 in. 4-40 Bolt	8	$0.30	$2.40	McMaster-Carr		
02	Mech. BEAVS	02-018	24 Pitch 14.5 deg Pressure Angle	1	$19.22	$19.22	Amazon		
02	Mech. BEAVS	02-019	Lynxmotion 5.2:1 Brushed DC Motor	1	$45.92	$45.92	RobotShop		
04	Recovery	04-012	MissileWorks RRC3 Sport Altimeter	2	$69.95	$139.90	MissileWorks	90905	
04	Recovery	04-013	PerfectFlite StratoLogger CF	4	$57.50	$230.00	PerfectFlite	-	
04	Recovery	04-014	4f Black Powder (1 lb)	1	$36.54	$36.54	Graf and Sons	SC4FG	
04	Recovery	04-015	Santoprene (1 ft)	5	$2.43	$12.15	McMaster-Carr	-	
04	Recovery	04-016	Surgical Tubing (10 ft)	2	$36.00	$72.00	McMaster-Carr	88210	
04	Recovery	04-017	E-Match	80	$0.75	$60.00	Australian Rocketry	-	
05	Recovery	05-001	Main Parachute	2	$404.00	$808.00	FruityChutes	IFC-96-S	

Continued on next page

Table 52 – continued from previous page

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
05	Recovery	05-002	Drogue Parachute	2	$19.99	$39.98	Top Flight Recovery	XTPAR-18	
05	Recovery	05-003	Eye Bolt	6	$6.65	$39.90	Grainger - Ken Forging	35Z511	
05	Recovery	05-004	Nyloc	6	$5.67	$34.02	Zoro	G5360591	
05	Recovery	05-005	Nylon Shock Cord	2	$34.60	$69.20	FruityChutes	SCN-1000	
05	Recovery	05-006	Quick Links	7	$4.10	$28.70	Apogee Rockets	29621	
05	Recovery	05-007	Swivel	4	$9.00	$36.00	FruityChutes	SWIV-3000	
05	Recovery	05-008	Nylon Harness	2	$18.00	$36.00	FruityChutes		
05	Recovery	05-009	Kevlar Sleeve	4	$28.75	$115.00	BlackCat Rocketry	HK-S-250	
05	Recovery	05-010	Deployment Bag	2	$43.00	$86.00	FruityChutes	CDB-4	
05	Recovery	05-011	Tender Descender	4	$81.43	$325.72	TinderRocketry	-	
05	Recovery	05-012	Wide Mouth Quick Link	5	$4.76	$23.80	McMaster-Carr	3711T23	
05	Recovery	05-013	Shear Pins	3	$3.22	$9.66	Apogee Rockets	29615	
05	Recovery	05-014	Cellulose Insulation	-	$n/a	$n/a	Club Resources	-	
05	Recovery	05-015	Parachute Blast Protector	4	$11.95	$47.80	Madcow Rocketry	NB-9	
			Aerodynamics and Recovery Subtotal			$2,691.69			
			10% Contingency			$269.17			
			AERODYNAMICS AND RECOVERY TOTAL			**$2,960.86**			

Table 53: Payload Bill of Materials

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
06	PEARS	06-001	Threaded Rod	1	$8.44	$8.44	McMaster-Carr		
06	PEARS	06-002	Aft PEARS Bulkhead - Loose	1	$0.92	$0.92	Club Resources		
06	PEARS	06-003	Rod Cap - Spacer	1	n/a	n/a	Club Resources		$3.00
06	WRAP	06-004	Aft Payload Bulkhead	1	$0.92	$0.92	Club Resources		
06	WRAP	06-005	Fore Payload Bulkhead	1	$0.92	$0.92	Club Resources		
06	WRAP	06-006	Kevlar Harness	1	$11.67	$11.67	Giant Leap Rocketry		
06	PEARS	06-007	Advanced Retention Release Device	1	n/a	n/a	Club Resources		$119.00
06	PEARS	06-008	Tender Descender	2	n/a	n/a	Club Resources		$158.00
06	Soil Collection	06-009	Auger	1	n/a	n/a	Club Resources		$3.00
06	Drivetrain	06-010	Clamping Hub (0.25 in. bore)	2	$5.99	$11.98	ServoCity		
06	PEARS	06-011	Ejection Charge	2	n/a	n/a	Club Resources	-	
06	Soil Collection	06-012	High-Strength 1045 Carbon Steel Rod	1	$6.60	$6.60	McMaster-Carr	8279T16	
06	Soil Collection	06-013	Carbon Fiber Auger Wrap	1	n/a	n/a	Club Resources	-	$10.00
06	SCAR	06-014	Set Screw Shaft Coupler	3	$4.99	$14.97	ServoCity	625118	
06	SCAR	06-015	26 RPM Mini Econ Gear Motor	1	$9.99	$9.99	ServoCity	638830	
06	Soil Collection	06-016	Short-Thread Alloy Steel Shoulder Screw	2	$4.10	$8.20	McMaster-Carr	94361A112	
06	Soil Collection	06-017	Auger Tube	1	$5.00	$5.00	McMaster-Carr	89955K919	
06	Soil Retention	06-018	Low-Carbon Steel Rod	2	$1.20	$2.40	McMaster-Carr	8920K115	
06	Soil Retention	06-019	Psvtd 18-8 SS Pan Head Phillips Screw, 100 ct.	1	$7.54	$7.54	McMaster-Carr	91772A194	
06	Chassis	06-020	Carbon Fiber Tail	1	n/a	n/a	Club Resources		$10.00
06	Chassis	06-021	Torsion Spring	1	n/a	n/a	Club Resources		$1.00
06	Chassis	06-022	Aluminum Tail Mount	1	n/a	n/a	Club Resources		$3.00
06	Drivetrain	06-023	Wheel	2	n/a	n/a	Club Resources	-	$20.66

Continued on next page

Table 53 – continued from previous page

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
06	Drivetrain	06-024	Urethane Foam Strip	2	n/a	n/a	Club Resources	-	$20.00
06	Drivetrain	06-025	.25 x .75 x 12 in. 6061 Aluminum Bar	1	$2.14	$2.14	McMaster-Carr	8975K594	
06	Drivetrain	06-026	.75 x 1.5 x 12 in. 6061 Aluminum Bar	1	$11.42	$11.42	McMaster-Carr	8975K45	
06	Drivetrain	06-027	.5 in. dia, 1 ft. 6061 Aluminum Rod	1	$2.66	$2.66	McMaster-Carr	8974K28	
06	Drivetrain	06-028	1.125 in. dia, 6 in. Aluminum Rod	1	$5.86	$5.86	McMaster-Carr	8974K15	
06	Drivetrain	06-029	Connecting Rod	4	n/a	n/a	Club Resources	-	$1.52
06	PEARS	06-030	PLEC Mount	1	n/a	n/a	Club Resources	-	$4.00
06	PEARS	06-031	SPDT Switch	7	$10.00	$70.00	McMaster-Carr		
06	PEARS	06-032	1" Steel Ring	3	$1.20	$3.60	McMaster-Carr		
06	PEARS	06-033	Santoprene Rubber (12 x 24 x 1/16 in.)	1	$23.80	$23.80	McMaster-Carr		
06	PEARS	06-034	U Bolt	2	$0.80	$1.60	McMaster-Carr		
06	PEARS	06-035	Nylon Locknut	5	n/a	n/a	Club Resources		$2.00
06	PEARS	06-036	Sealing Washer	5	n/a	n/a	Club Resources		$2.00
06	Electrical	06-037	Teensy 3.6 Development Board	1	$29.25	$29.25	SparkFun		
06	Electrical	06-038	Solid-Core Wire Spool (25 ft, 22 AWG)	1	$2.95	$2.95	Adafruit		
06	PEARS	06-039	Quick Link	3	$1.20	$3.60	McMaster-Carr		
06	PEARS	06-040	Kevlar Thread	10	$0.34	$3.40	Giant Leap Rocketry		
06	Drivetrain	06-041	3/8" Ball Bearing	2	$16.94	$33.88	McMaster-Carr	4648K5	
06	Drivetrain	06-042	1/4" Ball Bearing	2	$12.13	$24.26	McMaster-Carr	2342K164	
06	Drivetrain	06-043	1/4" High Load Fe-Cu Thrust Bearing	2	$2.02	$4.04	McMaster-Carr	3750K1	
06	Drivetrain	06-044	Steel Shaft Coupling (0.25 in. to 4 mm)	2	$4.99	$9.98	ServoCity	625118	
06	Drivetrain	06-045	170 RPM Econ Gear Motor	2	$14.99	$29.98	ServoCity	638354	

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Table 53 – continued from previous page

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
06	Drivetrain	06-046	Motor Mount	2	n/a	n/a	Club Resources	-	$8.00
06	Drivetrain	06-047	6-32 UNC Screw, 50 ct.	1	$10.60	$10.60	McMaster-Carr	97763A144	
06	Drivetrain	06-048	M3-0.5 Screw, 100 ct.	1	$8.38	$8.38	McMaster-Carr	92095A182	
06	Drivetrain	06-049	10-32 UNF Screw, 100 ct.	1	$7.55	$7.55	McMaster-Carr	92949A267	
06	Drivetrain	06-050	6-32 Locknut, 100 ct.	1	$7.54	$7.54	McMaster-Carr	90101A007	
06	Soil Collection	06-051	1 in. OD Mirror-Like 6061 Al Round Tube	1	$21.32	$21.32	McMaster-Carr	7785T11	
06	Soil Retention	06-052	3 x 3/32 in. 6061 Aluminum Sheet	2	$4.35	$8.70	McMaster-Carr	8975K343	
06	Soil Retention	06-053	1000:1 Micro Metal Gearmotor HPCB 12V	2	$24.95	$49.90	Pololu	3046	
06	Soil Retention	06-054	Soil Retention Container	1	n/a	n/a	Club Resources	-	$3.00
06	Soil Collection	06-055	Blk-Ox Steel Hex Drive Flat Head Screw, 10 ct.	1	$7.36	$7.36	McMaster-Carr	91253A119	
06	Soil Collection	06-056	LS Steel Nylon-Insert Locknut, 100 ct.	1	$2.79	$2.79	McMaster-Carr	90631A005	
06	Soil Collection	06-057	Auger Mount	2	n/a	n/a	Club Resources	-	$3.00
06	Soil Retention	06-058	Soil Retention Motor Mount	1	n/a	n/a	Club Resources	-	$2.00
06	Electronics	06-059	PLEC	1	n/a	n/a	Club Resources	-	$35.00
06	Electronics	06-060	PLEC Battery	1	n/a	n/a	Club Resources	-	$5.00
06	Electronics	06-061	PLEC SPDT Switch	1	n/a	n/a	Club Resources	-	$5.00
06	Electronics	06-062	Dual Channel DC Motor Driver	1	$19.25	$19.25	RobotShop	RB-Cyt-153	
06	Electronics	06-063	2200mAh LiPo Battery Pack	1	$15.01	$15.01	HobbyKing	T2200.3S.40	
06	Electronics	06-064	Dual Motor Driver Carrier	1	$2.11	$2.11	Digi-Key	TB6612FNG	
06	Electronics	06-065	Voltage Regulator	1	$2.73	$2.73	Mouser	595-TPS54383PWP	
06	Electronics	06-066	Accelerometer/Magnetometer	1	$14.95	$14.95	Adafruit	LSM303	
06	Electronics	06-067	RF Transceiver	1	$39.00	$39.00	Symmetry Electronics	XBP9B-DMST-002	
06	Electronics	06-068	Logitech HD Webcam	1	$27.84	$27.84	Amazon	960-000585	

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Table 53 – continued from previous page

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
06	Electronics	06-069	Relay	1	$8.57	$8.57	Digi-Key	RV2H-2G-D12-C1D2	
06	Electronics	06-070	Sonar Module	3	$39.95	$119.85	MaxBotix	MB1230	
06	Electronics	06-071	GPS Module	1	$27.00	$27.00	Digi-Key	MAX-M8W-0	
06	Electronics	06-072	Antenna	1	$5.10	$5.10	Taoglas	GP.1575.18-4.A.02	
06	Chassis	06-073	1/4 in. dia, 2 ft Carbon Fiber Rod	10	$14.09	$140.90	McMaster-Carr	2153T52	
06	Chassis	06-074	0.5 in. x 0.75 in. x 6 ft 6061 Aluminum Bar	1	$16.32	$16.32	McMaster-Carr	8975K618	
07	Fore Hard Point	07-001	Fore Bulkhead	1	n/a	n/a	Club Resources	-	$0.35
07	Fore Hard Point	07-002	Fore Funnel	1	n/a	n/a	Club Resources	-	$5.00
07	Fore Hard Point	07-003	Pass-Through Bulkhead	1	n/a	n/a	Club Resources	-	$0.35
			Payload Subtotal		$ 914.74				
			10% Contingency		$ 91.47				
			PAYLOAD TOTAL		**$ 1,006.21**				

6.6.2 Funding

The OSRT is supported in part through NASA/OSGC, grant NNX15AJ14H. OSGC is sponsoring the OSRT with $11,000 through the OSGC Undergraduate Team Experience Award at a 1.5:1 matching rate. This means that, for every $1 that OSGC provides the OSRT, the team must supply $1.50, a total of $16,500 of matching funds. This sponsorship makes up the majority of the funding for the team. The remaining cost share that must be matched will be done through sponsorships, discounts, and materials donations from other companies and resources. Table 54 shows the funding plan. The OSU chapter of American Institute of Aeronautics and Astronautics (AIAA), OSGC, and ICE represent the primary funding sources for OSRT.

Table 54: Major funding contributions breakdown.

	Expected	With 10% Contingency	OSGC Contribution	Matching Contribution	Matching Sources
Structures	$5,879.76	$6,122.93	$2,674.87	$3,448.06	ICE, Fiberglast, Club Resources
Aerodynamics and Recovery	$2,692.19	$2,961.36	$2,960.86	$0.50	Club Resources
Payload	$1,338.62	$1,430.09	$1,006.21	$423.88	Club Resources
Outreach	$300.00	$330.00	-	$300.00	AIAA
Travel	$12,000.00	$13,200.00	-	$13,200.00	AIAA, Student Expenditure
Lodging	$6,300.00	$6,930.00	$4,358.06	$2,571.94	AIAA, Student Expenditure
Total	**$28,510.57**	**$30,974.38**	**$11,000.00**	**$19,944.38**	

The budget and finance team has reached out to many businesses about the potential of sponsoring the OSRT. Many of the companies, such as Fastenal and Concept Systems, have agreed to materials donations or discounts. Allegheny Technologies Incorporated (ATI) has agreed to a $500.00 donation. The airframe tube is being donated by ICE and is valued at $3,000.00. All of these donations and discounts will go towards the matching. Additionally, any student expenditures, such as materials purchased by team members and travel, will also be put to reach the matching amount required by OSGC.

Other companies that are contacted by more than one rocketry team at OSU will go through a special request form by the AIAA. This is to eliminate multiple teams within AIAA from reaching out to the same companies for sponsorship.

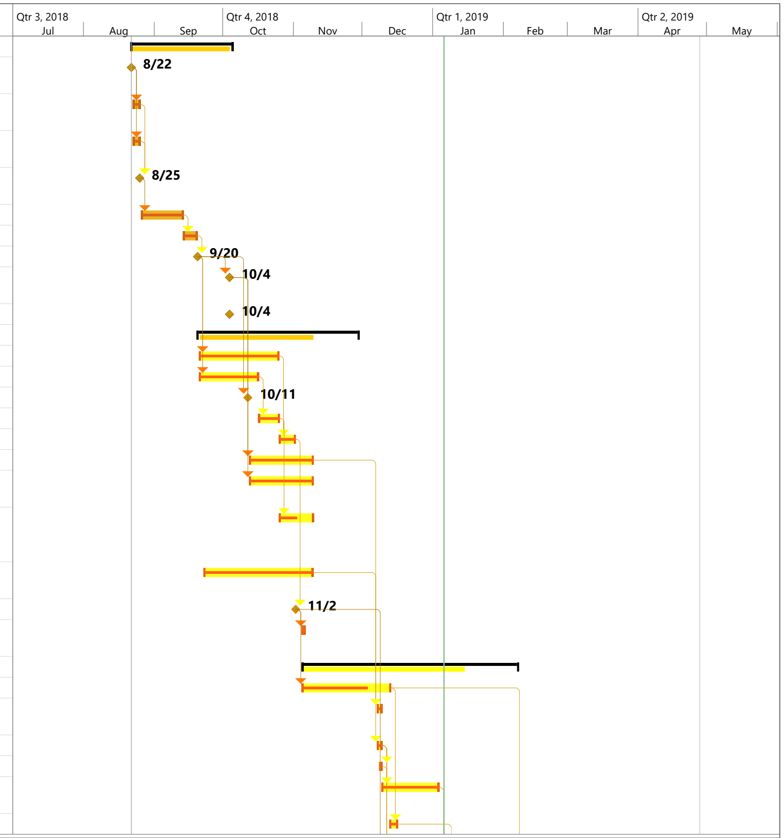
Figure 80: Special thank you to OSGC!

6.6.3 Timeline

Currently, OSRT is ending the Critical Design Phase and transitioning to the Final Readiness Phase. Some aspects of the Final Readiness Phase have already begun to allow OSRT to meet its desired launch dates. Shown in Figures 81 and 82 is the current schedule for OSRT.

The only major concern identified on the timeline is the original scheduled track of the BEAVS. Because this system is not critical for competition success, less emphasis and resources have been dedicated to the system. The team is still confident that during the Final Readiness Phase, the testing for BEAVS can occur with enough time to test it on the full scale launch vehicle.

ID	Task Name	Duration	Start	Finish	% Complete	Predecessors
1	**Proposal Phase**	**45 days**	**Wed 8/22/18**	**Fri 10/5/18**	**100%**	
2	Competition Rules Released	0 days	Wed 8/22/18	Wed 8/22/18	100%	
3	Launch Vehicle Concept Development	3 days	Thu 8/23/18	Sat 8/25/18	100%	2
4	Payload Concept Development	3 days	Thu 8/23/18	Sat 8/25/18	100%	2
5	Team Decisions and Kickoff Meeting	0 days	Sat 8/25/18	Sat 8/25/18	100%	3,4
6	Compile Proposal	18 days	Sun 8/26/18	Thu 9/13/18	100%	5
7	Edit Proposal	6 days	Fri 9/14/18	Wed 9/19/18	100%	6
8	Submit Proposal	0 days	Thu 9/20/18	Thu 9/20/18	100%	7
9	Proposal Admittance Announced	0 days	Thu 10/4/18	Thu 10/4/18	100%	8
10	AIAA Presentation	0 days	Thu 10/4/18	Thu 10/4/18	100%	
11	**Preliminary Design Phase**	**72 days**	**Thu 9/20/18**	**Thu 11/29/18**	**96%**	
12	Compile PDR	35 days	Fri 9/21/18	Thu 10/25/18	100%	8
13	Research Design Choices	26 days	Fri 9/21/18	Tue 10/16/18	100%	8
14	Kickoff and PDR Q&A	0 days	Thu 10/11/18	Thu 10/11/18	100%	8
15	Complete CAD Models	9 days	Wed 10/17/18	Thu 10/25/18	100%	13
16	Edit PDR	7 days	Fri 10/26/18	Thu 11/1/18	100%	12
17	Manufacture Subscale	28 days	Sat 10/13/18	Fri 11/9/18	100%	9
18	Ground Test Subscale Systems	28 days	Sat 10/13/18	Fri 11/9/18	100%	9
19	Manufacture BEAVS Prototype and Test Airframe Modifications	15 days	Fri 10/26/18	Fri 11/9/18	51%	15
20	Build L1/L2 Certification Rockets	48 days	Sun 9/23/18	Fri 11/9/18	100%	
21	Submit PDR	0 days	Fri 11/2/18	Fri 11/2/18	100%	16
22	PDR Video Teleconferences	1 day	Mon 11/5/18	Mon 11/5/18	100%	21
23	**Critical Design Phase**	**96 days**	**Mon 11/5/18**	**Thu 2/7/19**	**86%**	
24	Compile CDR	39 days	Mon 11/5/18	Thu 12/13/18	74%	21
25	Certification Rocket Launch Day	2 days	Sat 12/8/18	Sun 12/9/18	100%	20
26	Subscale Launch	2 days	Sat 12/8/18	Sun 12/9/18	100%	17
27	Launch Analysis	1 day	Sun 12/9/18	Sun 12/9/18	100%	26
28	Design Updates and Testing	25 days	Mon 12/10/18	Thu 1/3/19	100%	27
29	Edit CDR	3 days	Thu 12/13/18	Sun 12/16/18	100%	24



Project: CDR Schedule.mpp
Date: Sun 1/6/19

Task | Project Summary | Manual Task | Start-only | Deadline
Split | Inactive Task | Duration-only | Finish-only | Progress
Milestone | Inactive Milestone | Manual Summary Rollup | External Tasks | Manual Progress
Summary | Inactive Summary | Manual Summary | External Milestone

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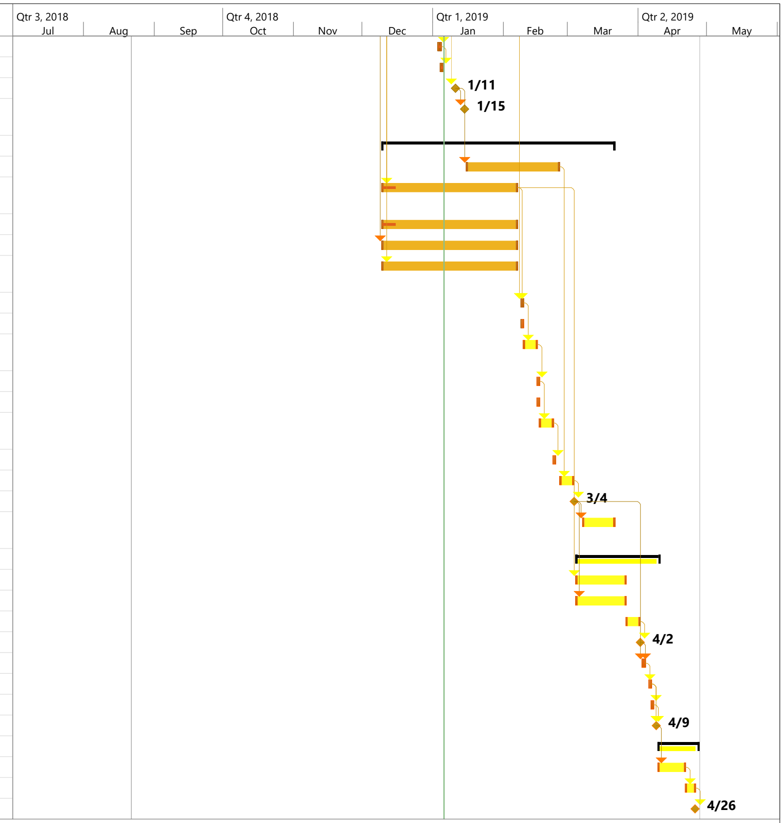
Figure 81: The OSRT project schedule (1 of 2).

ID	Task Name	Duration	Start	Finish	% Complete	Predecessors
30	Subscale Relaunch	1 day	Thu 1/3/19	Fri 1/4/19	100%	28
31	Launch Analysis	1 day	Fri 1/4/19	Sat 1/5/19	100%	30
32	Submit CDR	0 days	Fri 1/11/19	Fri 1/11/19	100%	29
33	CDR Video Teleconferences	0 days	Tue 1/15/19	Tue 1/15/19	0%	32
34	**Final Readiness Phase**	**103.5 days**	**Mon 12/10/18**	**Thu 3/21/19**	**4%**	
35	Compile FRR	41 days	Wed 1/16/19	Mon 2/25/19	0%	32
36	Manufacture Full Scale Launch Vehicle	60 days	Mon 12/10/18	Wed 2/6/19	10%	26
37	Manufacture Payload	60 days	Mon 12/10/18	Wed 2/6/19	10%	
38	Integration Testing	60 days	Mon 12/10/18	Wed 2/6/19	0%	21
39	Ground Test Full Scale Systems	60 days	Mon 12/10/18	Wed 2/6/19	0%	26
40	Full Scale Launch	1 day	Sat 2/9/19	Sat 2/9/19	0%	24,36
41	BEAVS Test Launch	1 day	Sat 2/9/19	Sat 2/9/19	0%	
42	Design Updates and Testing	6 days	Sun 2/10/19	Fri 2/15/19	0%	40
43	Full Scale Launch	1 day	Sat 2/16/19	Sat 2/16/19	0%	42
44	BEAVS Test Launch	1 day	Sat 2/16/19	Sat 2/16/19	0%	
45	Design Updates and Testing	6 days	Sun 2/17/19	Fri 2/22/19	0%	43
46	Full Scale Launch	1 day	Sat 2/23/19	Sat 2/23/19	0%	45
47	Edit FRR	6 days	Tue 2/26/19	Sun 3/3/19	0%	35
48	Submit FRR	0 days	Mon 3/4/19	Mon 3/4/19	0%	47
49	FRR Video Teleconferences	14 days	Fri 3/8/19	Thu 3/21/19	0%	48
50	**Competition Phase**	**37 days**	**Tue 3/5/19**	**Wed 4/10/19**	**0%**	
51	Paint Rocket	22 days	Tue 3/5/19	Tue 3/26/19	0%	36
52	Develop Displays	22 days	Tue 3/5/19	Tue 3/26/19	0%	48
53	Motorpool Departure	6 days	Wed 3/27/19	Mon 4/1/19	0%	
54	Arrive in Huntsville	0 days	Tue 4/2/19	Tue 4/2/19	0%	53
55	LRR	1 day	Wed 4/3/19	Wed 4/3/19	0%	54,48
56	Launch Day	1 day	Sat 4/6/19	Sat 4/6/19	0%	55
57	Backup Launch Day	1 day	Sun 4/7/19	Sun 4/7/19	0%	56
58	Depart from Huntsville	0 days	Tue 4/9/19	Tue 4/9/19	0%	57,56
59	**Post Launch Phase**	**18 days**	**Wed 4/10/19**	**Sat 4/27/19**	**0%**	
60	Compile PLAR	12 days	Wed 4/10/19	Sun 4/21/19	0%	58
61	Edit PLAR	4 days	Mon 4/22/19	Thu 4/25/19	0%	60
62	Submit PLAR	0 days	Fri 4/26/19	Fri 4/26/19	0%	61



Project: CDR Schedule.mpp
Date: Sun 1/6/19

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress

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Figure 82: The OSRT project schedule (2 of 2).

6.6.4 STEM Engagement

OSRT has completed seven events at the time of CDR submission, totaling 1,735 community members. At the time of PDR submission, two events had been completed. Since then, five more events have been completed totaling an additional 758 community members.

One of the events OSRT completed was teaching STEM activities at Veneta Elementary School for 350 elementary school kids. The STEM activities included four topics: rocketry, chemistry, engineering, and physics. The rocketry activity had students build straw rockets. Students took a section of straw, and attached duct tape fins and nosecone. Placing this straw in a small diameter straw, students could blow on the smaller diameter straw to launch their rockets. We discussed that their rockets and our rocket (on display) needed four main things: a nosecone, a body, fins, and a motor. Their motor was their own mouths. In the chemistry activity, students made slime using Borax and white glue. The engineering activity had students build gum drop and toothpick structures. OSRT members had a few display bridges and towers for the students to get started. They were able to be creative and many created tall towers and long bridges. The physics table consisted of two activities. The first activity had students go through the scientific process of estimating the weight of a steel block. Students used many different observations to predict the weight. They then used a spring scale to determine the actual weight. For the older students, a pulley demonstration with the weight was performed, showing the force applied to hold the weight can be cut in half with a pulley. The other physics activity had students roll marbles down different tracks with varying angles and roughness. OSRT discussed with the students, kinetic and potential energies, friction, and momentum.

Another STEM engagement event was with 96 high school students at Westview High School. OSRT gave a 15 minute presentation to four classes about general engineering, aerospace engineering, Oregon State, and OSRT. After the presentation, many questions were answered about engineering at Oregon State. A straw rocket activity was then done with the high school students. The activity had each student make a straw rocket, then use a compressed air launcher to launch each straw rocket. The launcher released compressed air from a tank using solenoids with an electrical signal from a control panel. Each class had a competition to see who could launch their rocket the farthest. After the first round was complete, students were then able to redesign their rockets in attempt to make them more aerodynamic for another round of the competition.

OSRT has four more events planned during the months of January and February. More teachers and community members are being contacted in attempt to schedule more events and reach more students with STEM related activities.

Appendix A

Drawings and Schematics

Contained within this appendix are dimensional drawings for unique parts that the OSRT will manufacture.

A.1 Structures

A.1.1 Body Tube

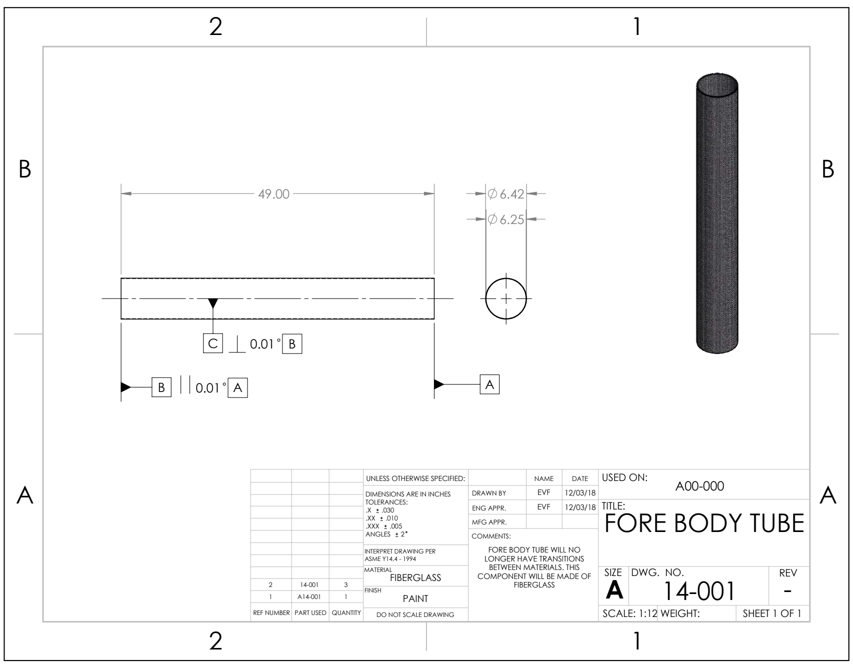


Figure 83: Fore Body Tube Drawing

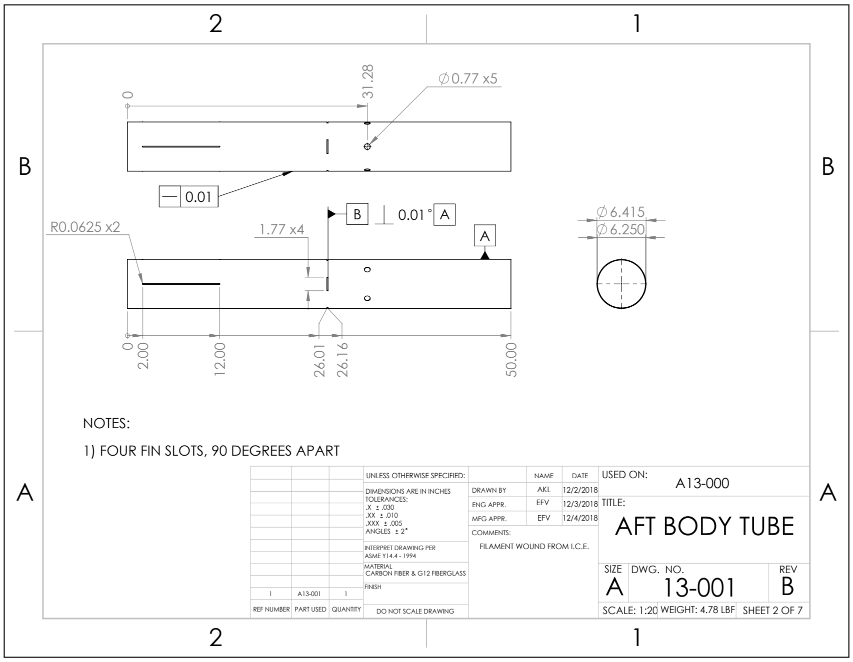


Figure 84: Aft Body Tube Drawing

A.1.2 Nosecone

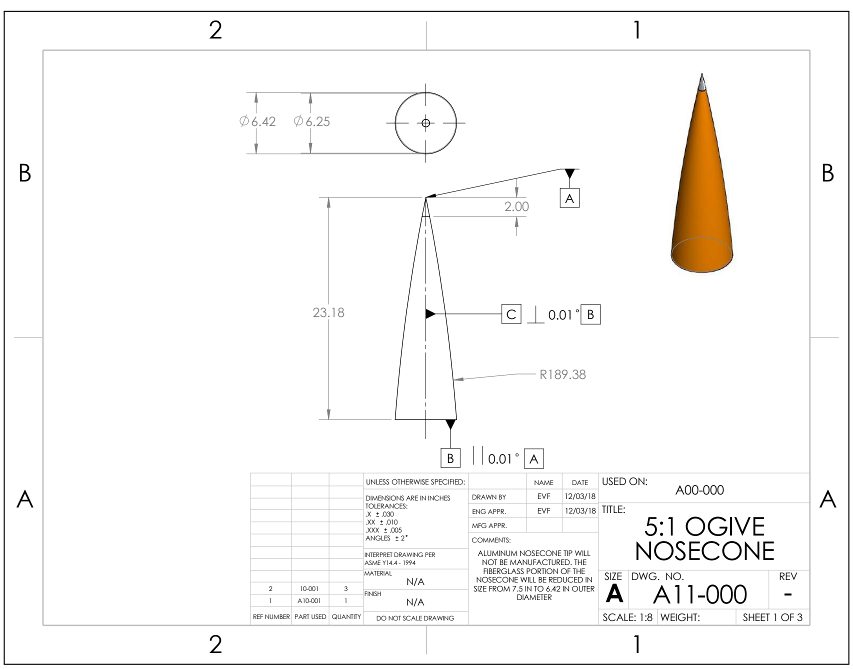


Figure 85: Nosecone Drawing

A.1.3 Fins

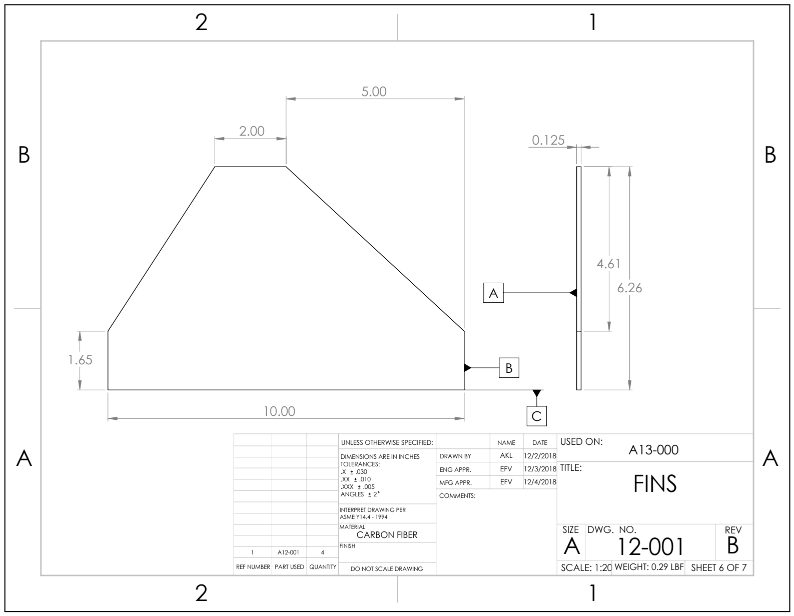


Figure 86: Fin Drawing

A.1.4 Fore Avionics

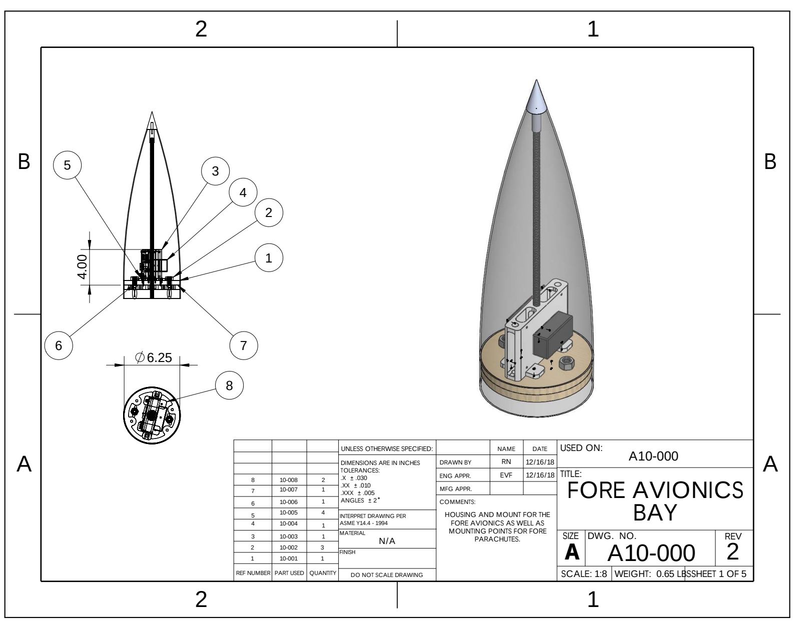


Figure 87: Fore Avionics Assembly

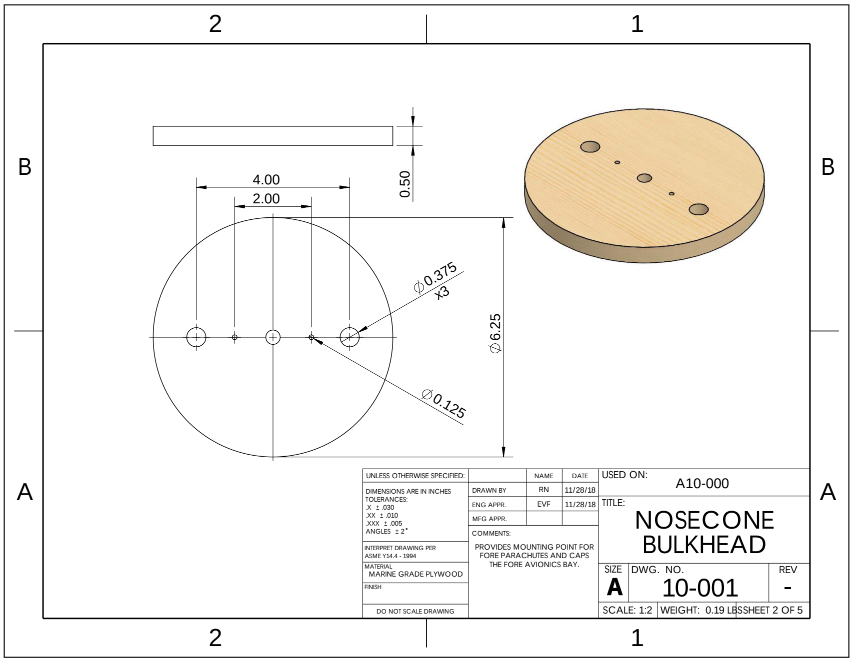


Figure 88: Nosecone Bulkhead

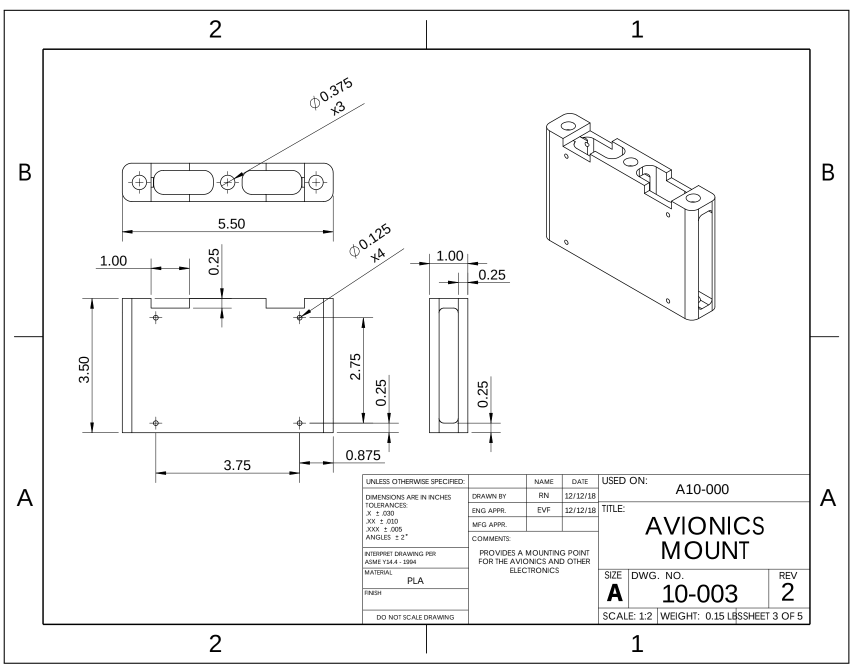


Figure 89: Avionics Mount

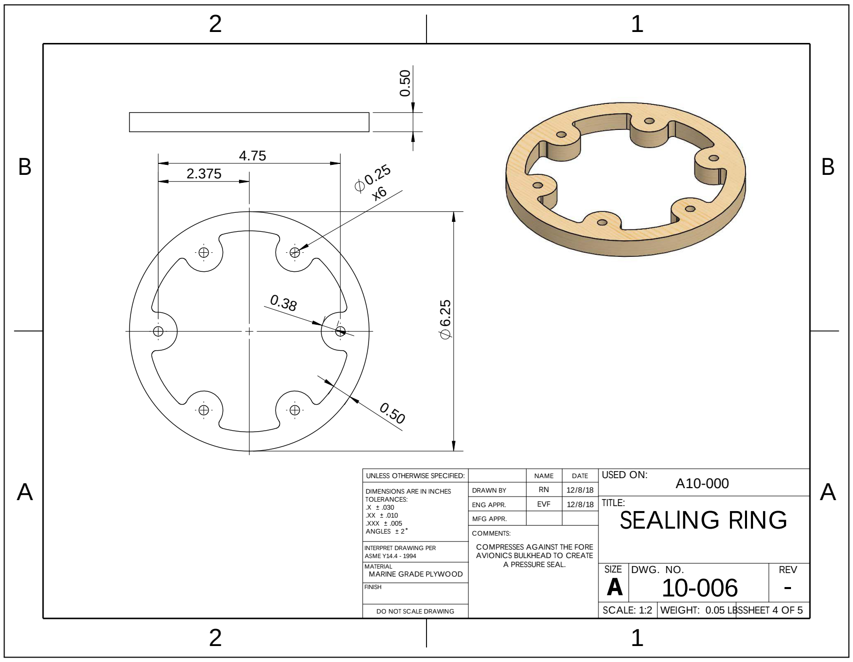


Figure 90: Sealing Ring

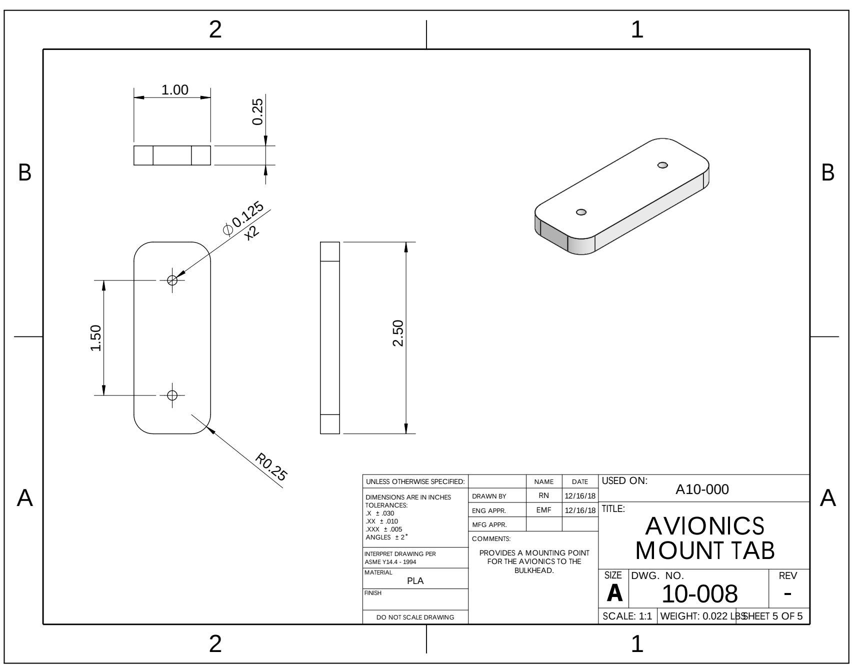


Figure 91: Avionics Mount Tab

A.1.5 Aft Electronic Bay

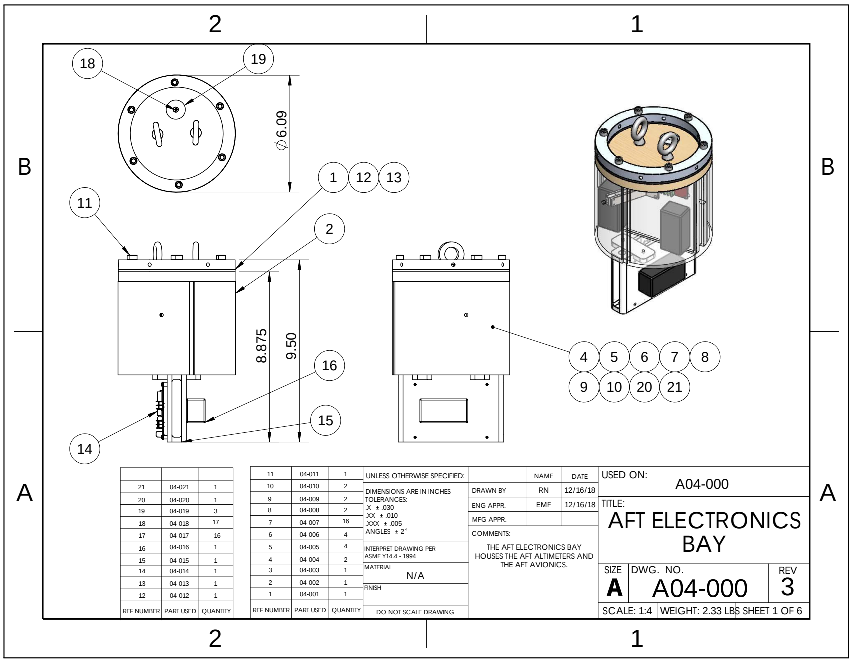


Figure 92: Fore Ejection Assembly

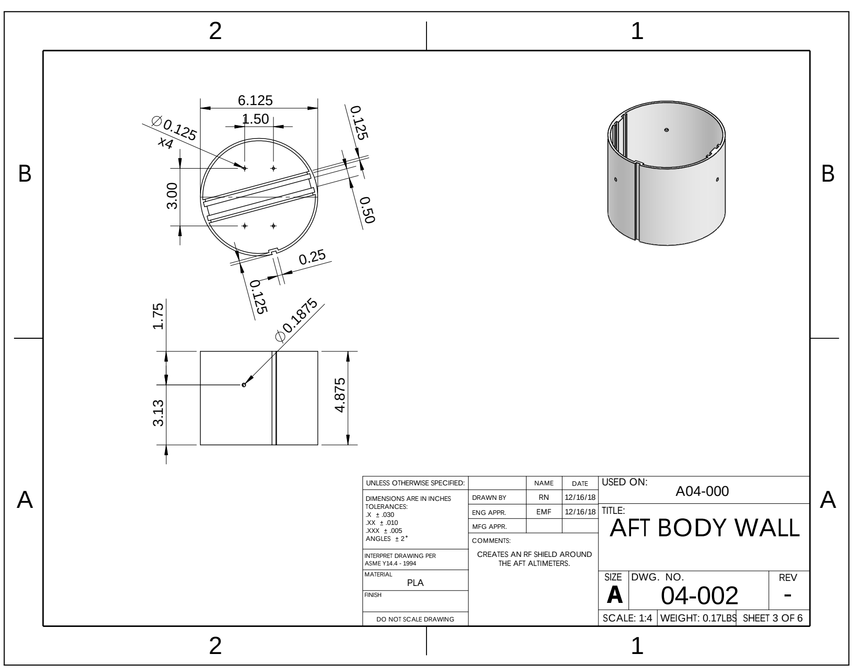


Figure 93: Aft Body Wall

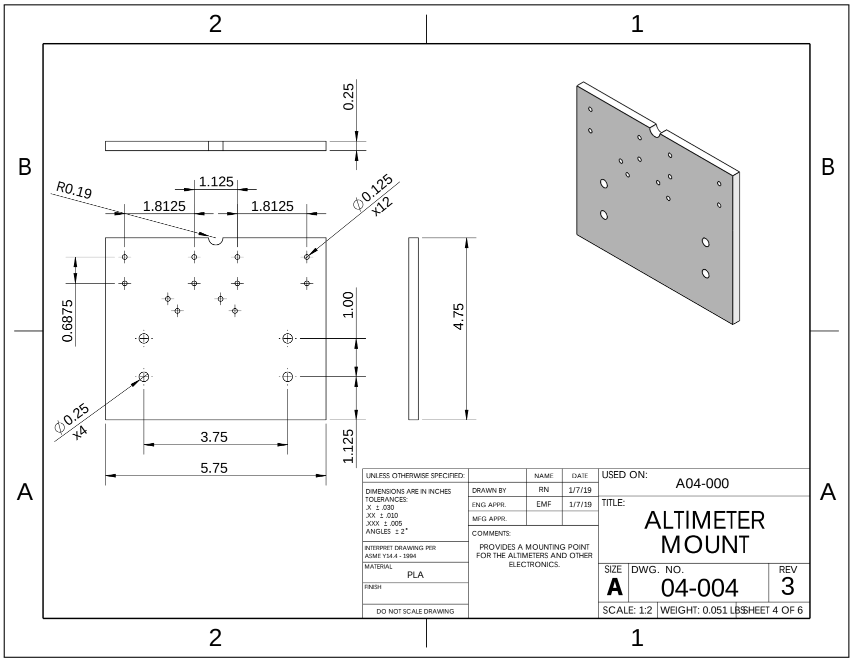


Figure 94: Altimeter Mount

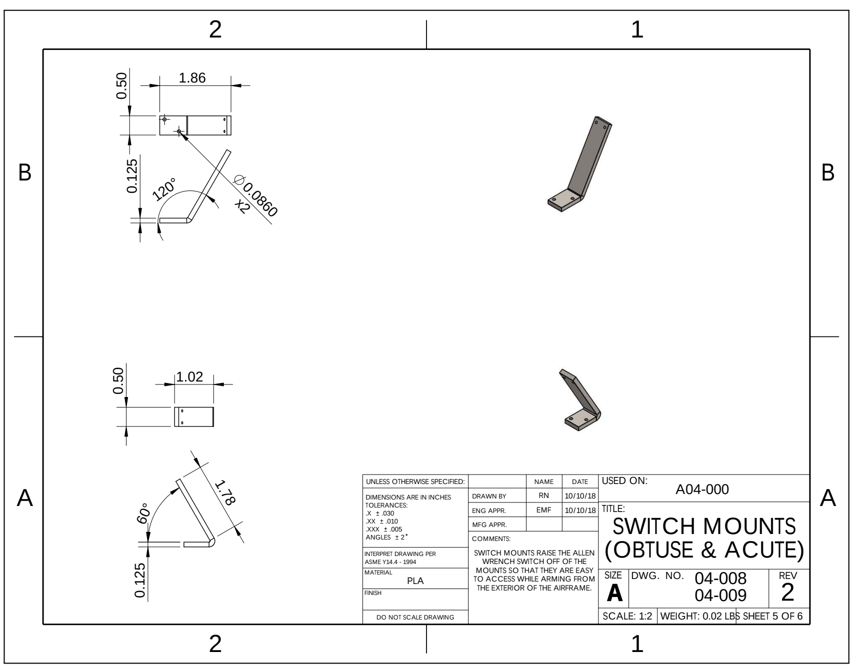


Figure 95: Switch Mount (Obtuse & Acute)

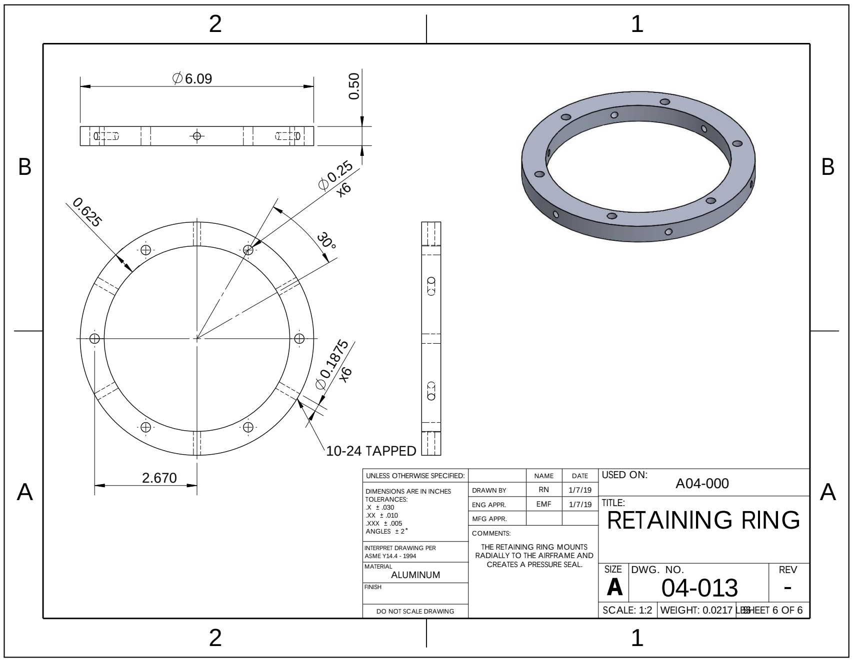


Figure 96: Retaining Ring

A.1.6 Fore Coupler

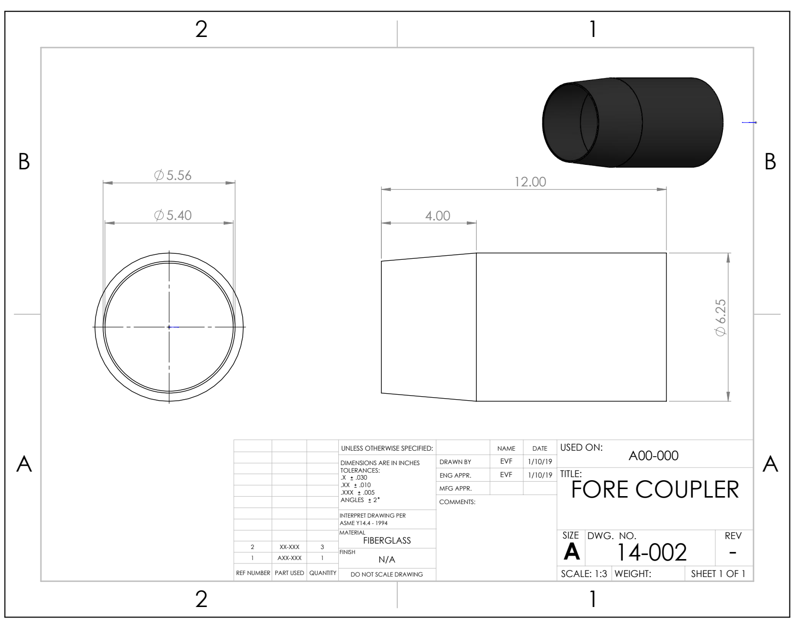


Figure 97: Fore Coupler

A.1.7 Aft Canister

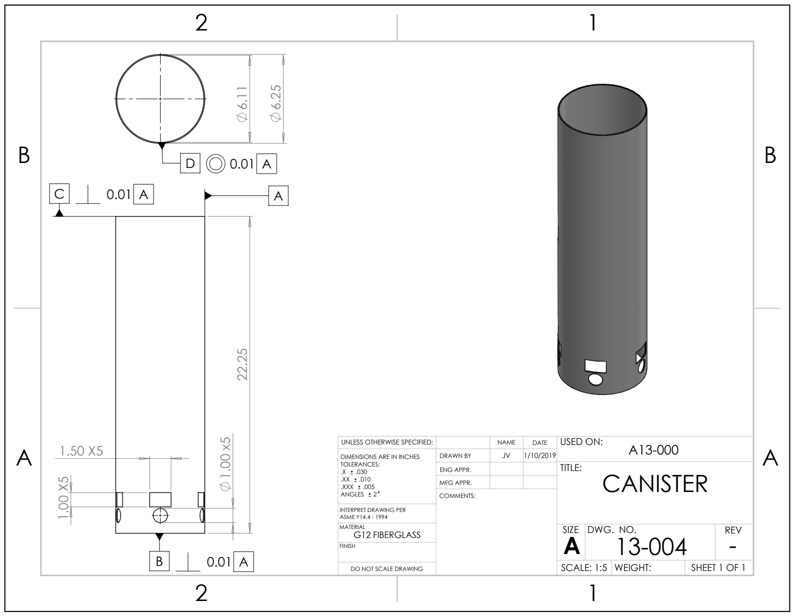


Figure 98: Canister

A.1.8 Motor Retention

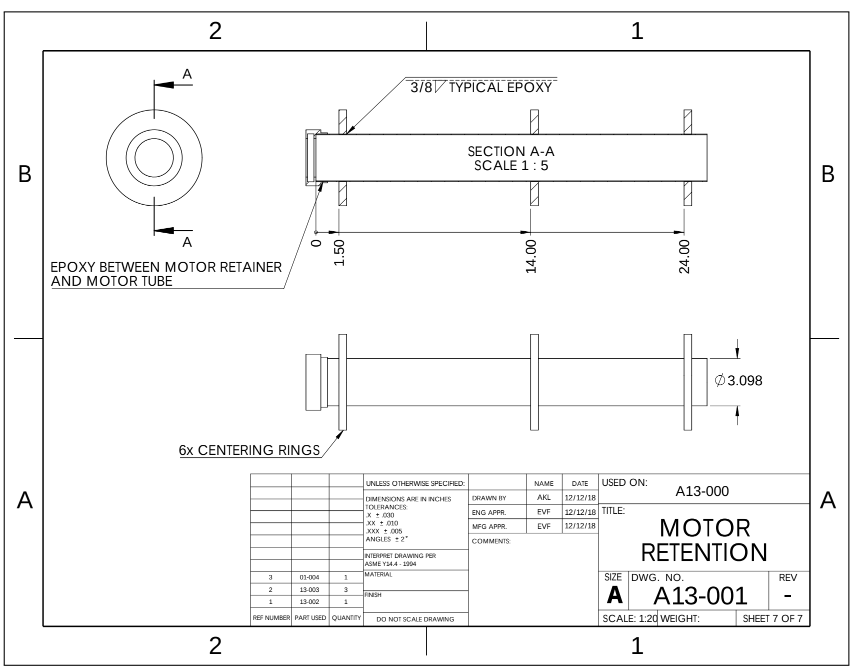


Figure 99: Motor Retention Drawing

A.1.9 Bulkheads

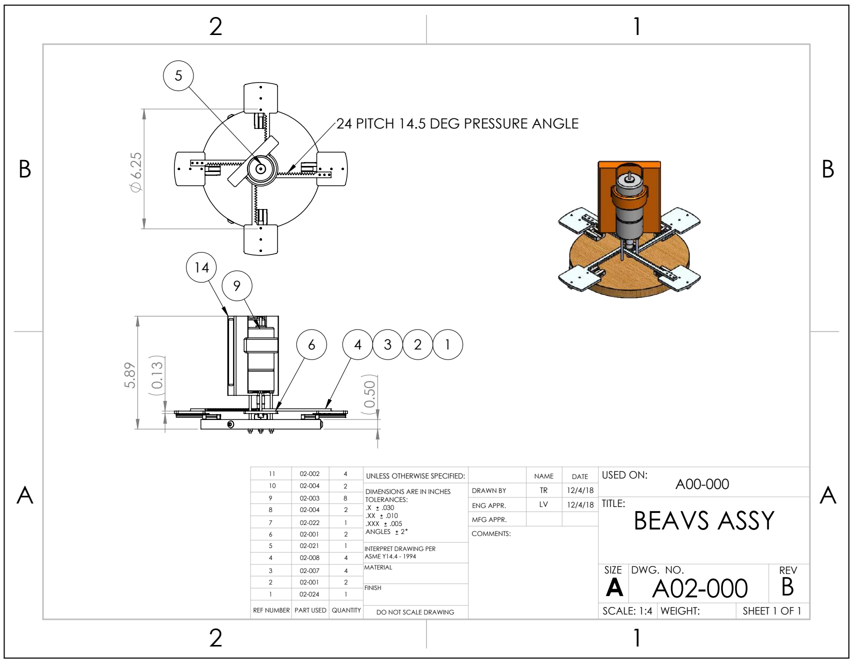


Figure 100: BEAVS Drawings

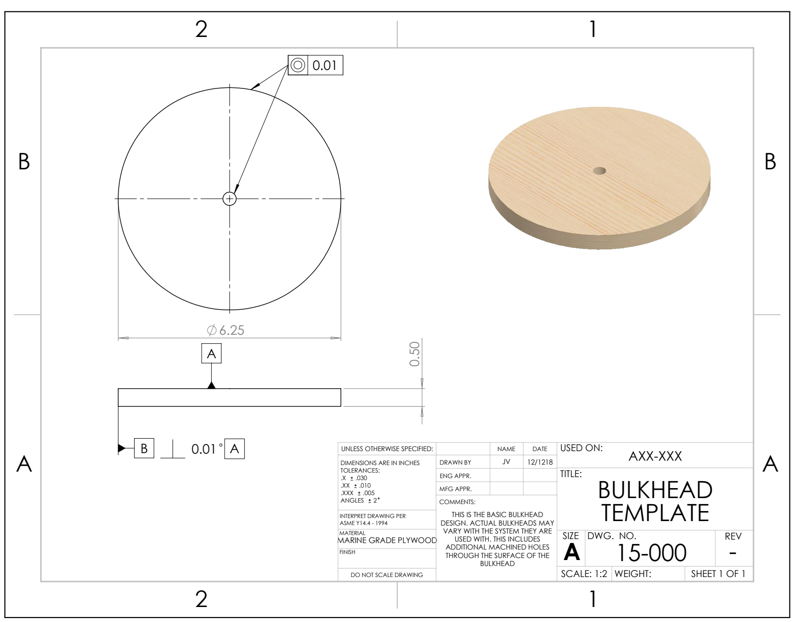


Figure 101: Standard Bulkhead

A.1.10 BEAVS

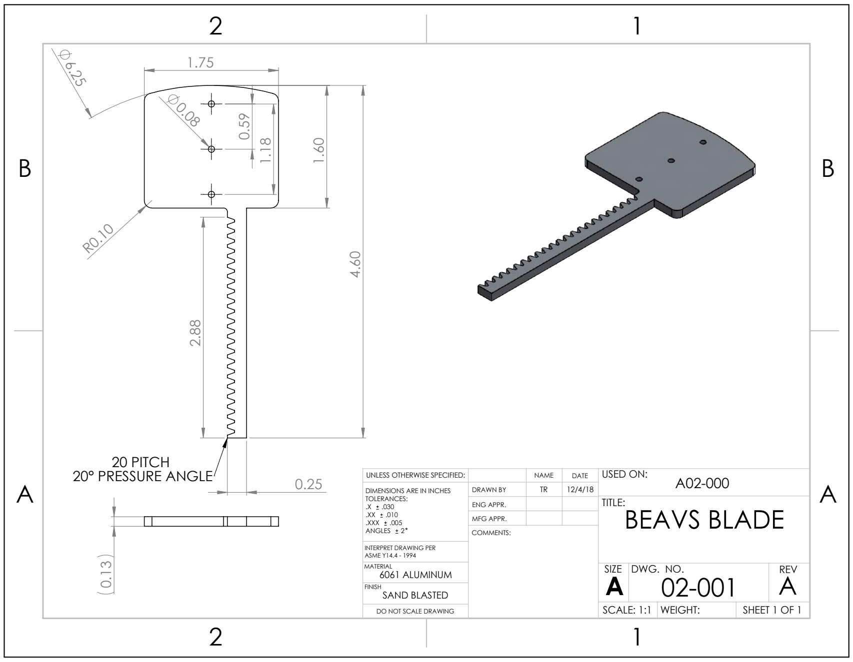


Figure 102: BEAVS Drawings

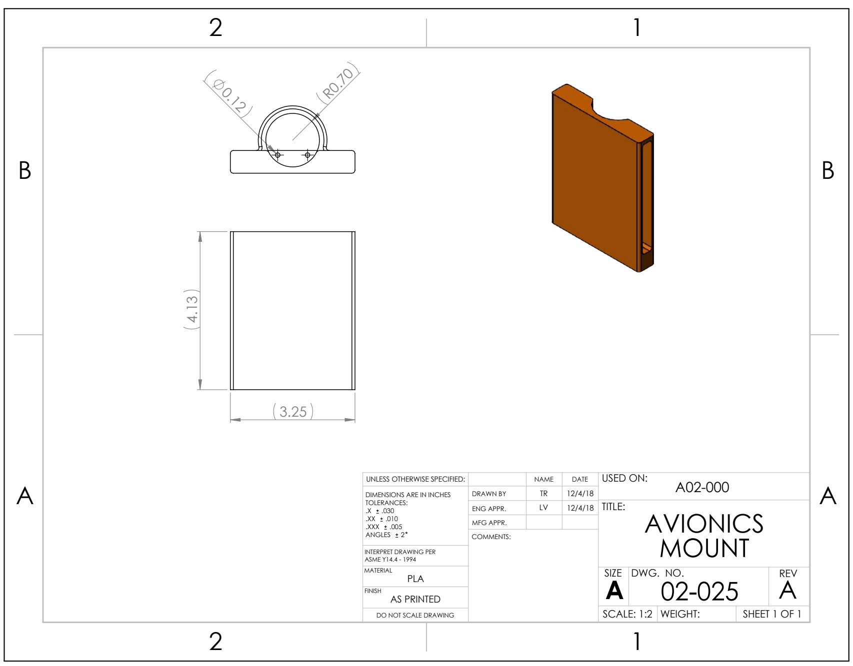


Figure 103: BEAVS Drawings

A.2 Payload

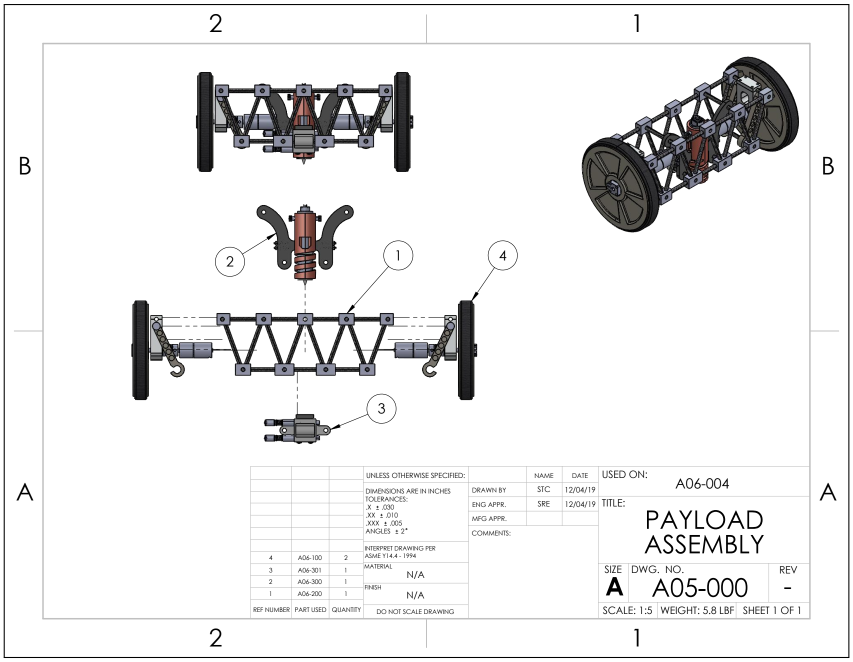


Figure 104: Rover Assembly

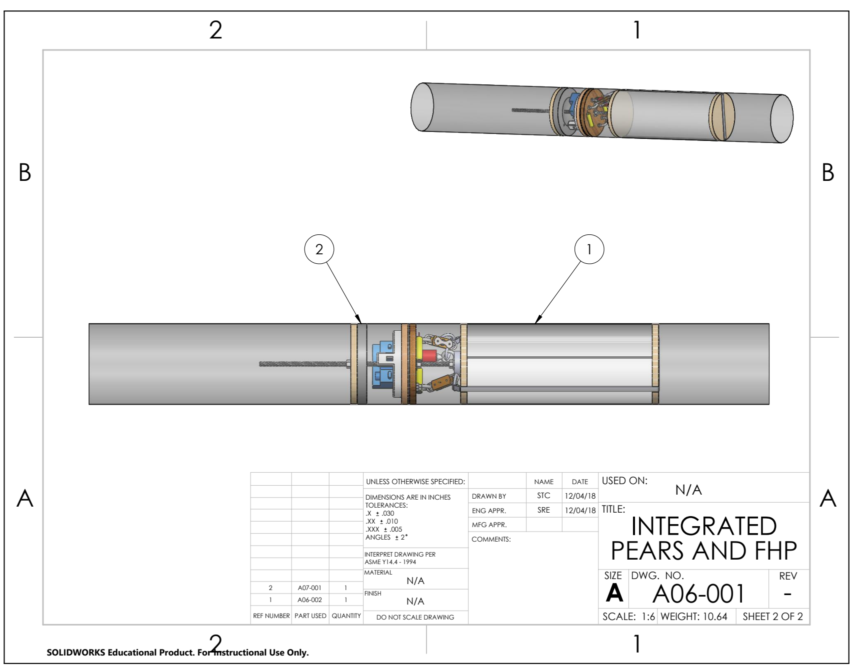


Figure 105: PEARS Integration Assembly

A.2.1 PEARS and FHP

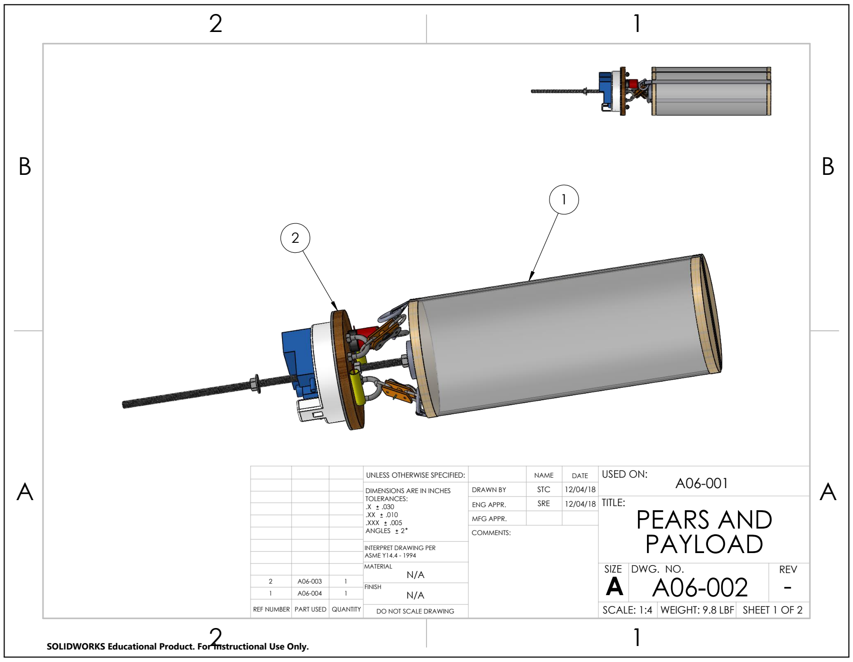


Figure 106: PEARS and Wrap Assembly

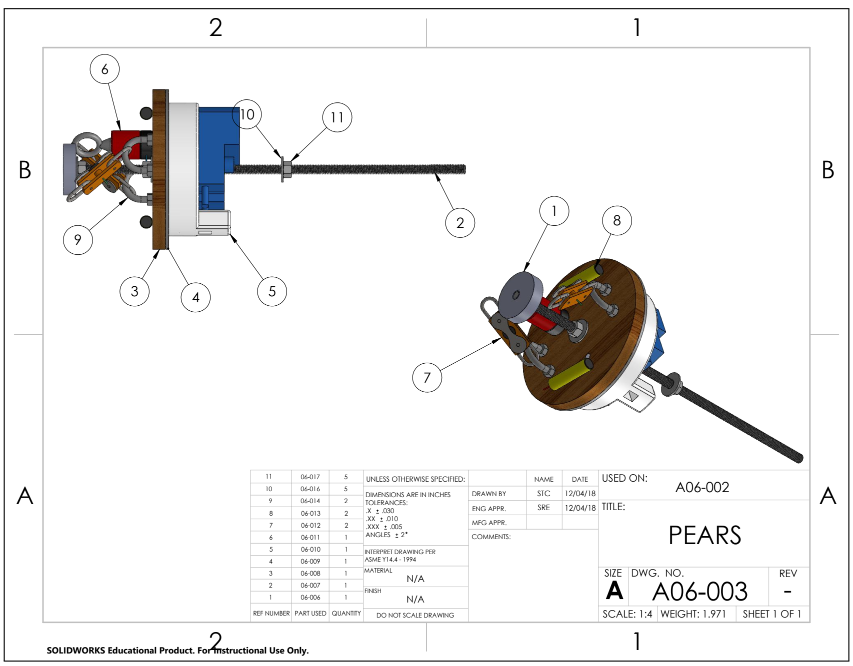


Figure 107: PEARS Assembly

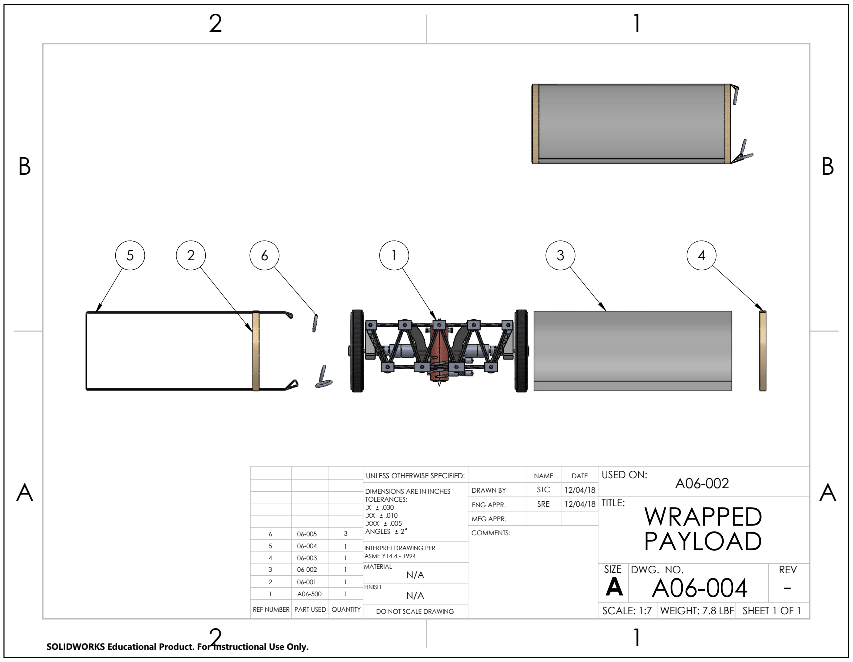


Figure 108: Wrapped Payload Assembly

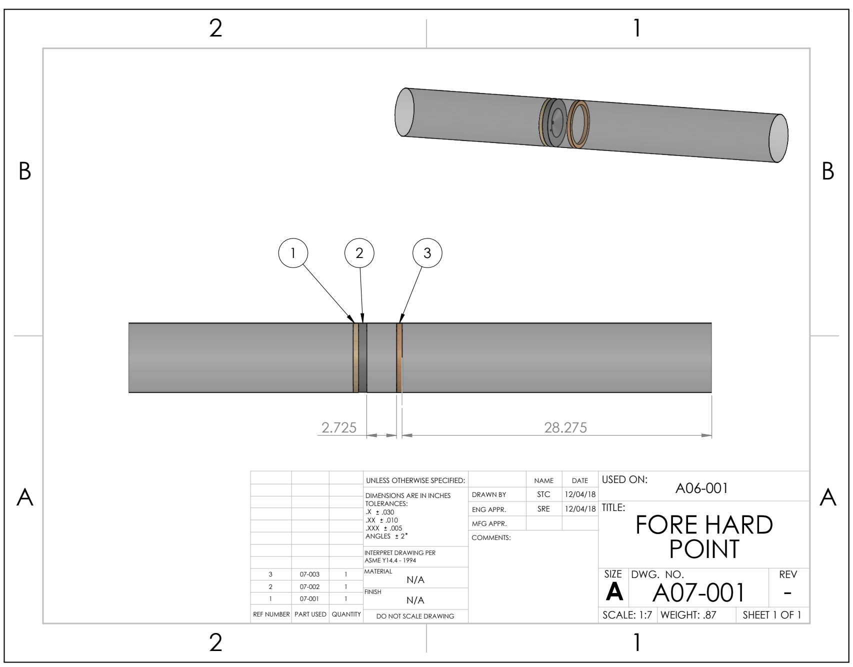


Figure 109: Fore Hard Point Assembly

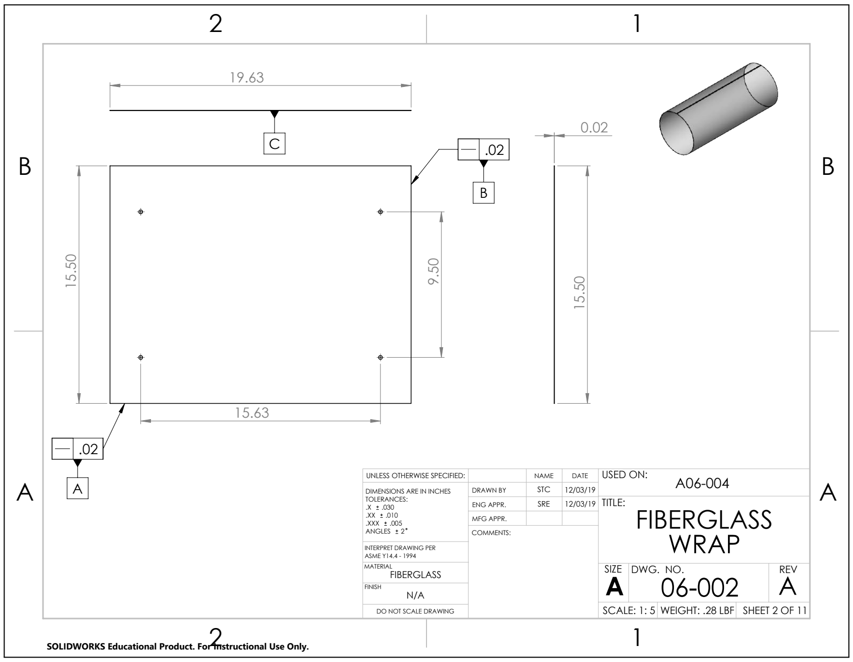


Figure 110: Fiberglass Wrap

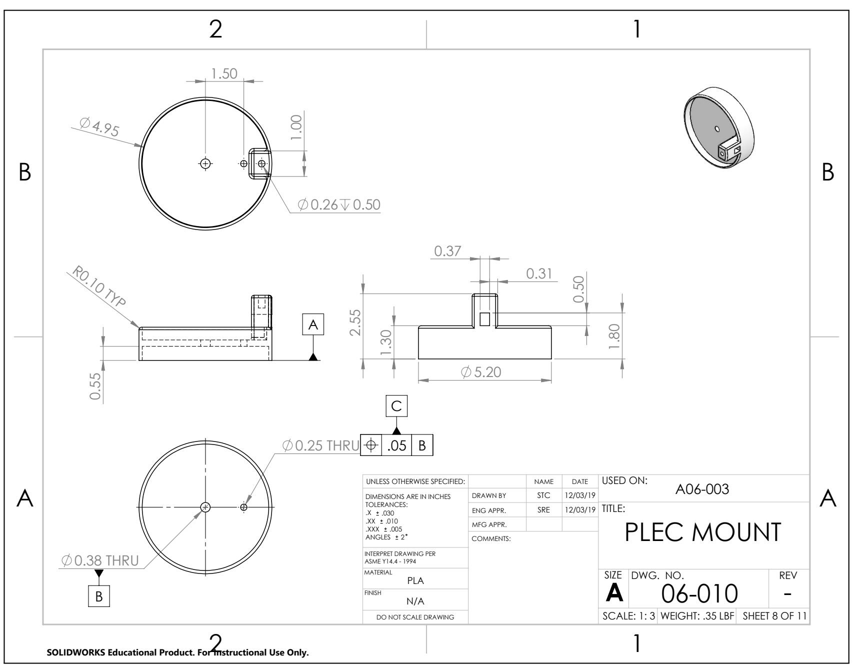


Figure 111: PLEC Mount

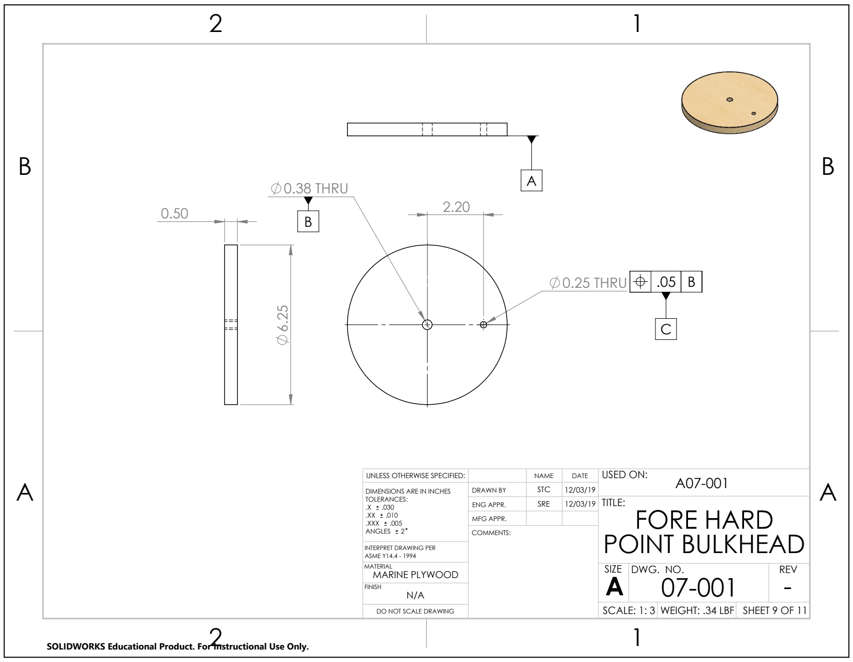


Figure 112: FHP Bulkhead

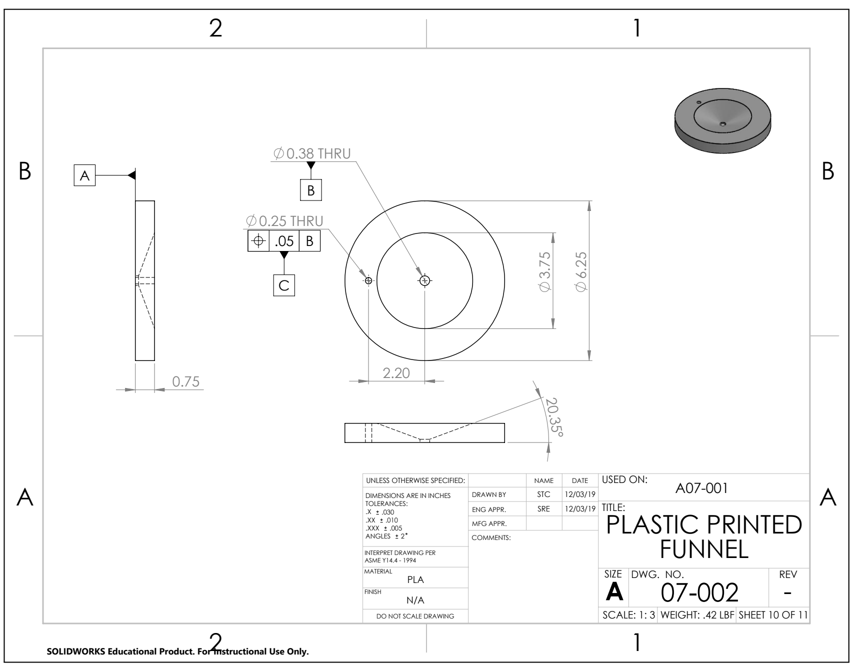


Figure 113: Plastic Printed Funnel

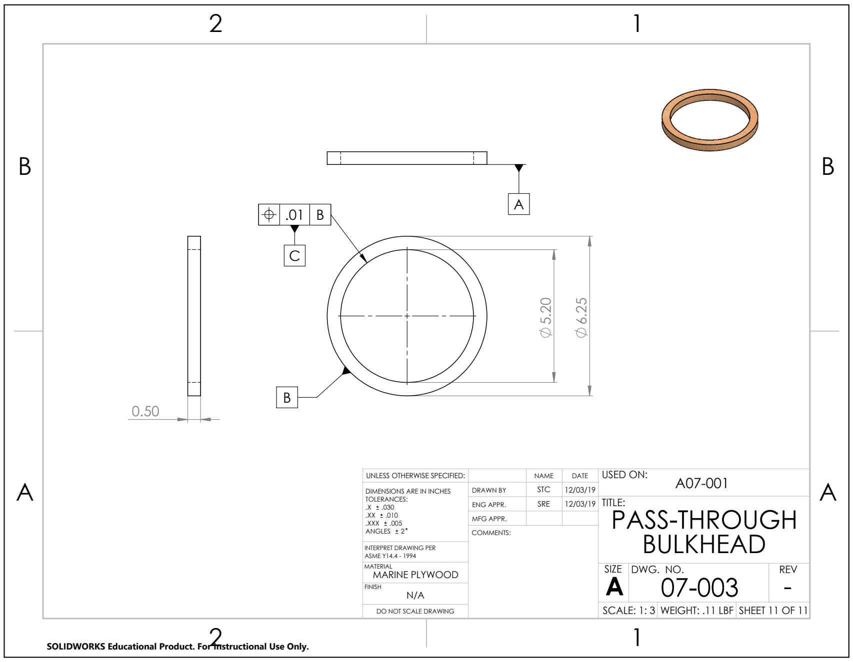


Figure 114: Pass-Though Bulkhead

A.2.2 SCAR

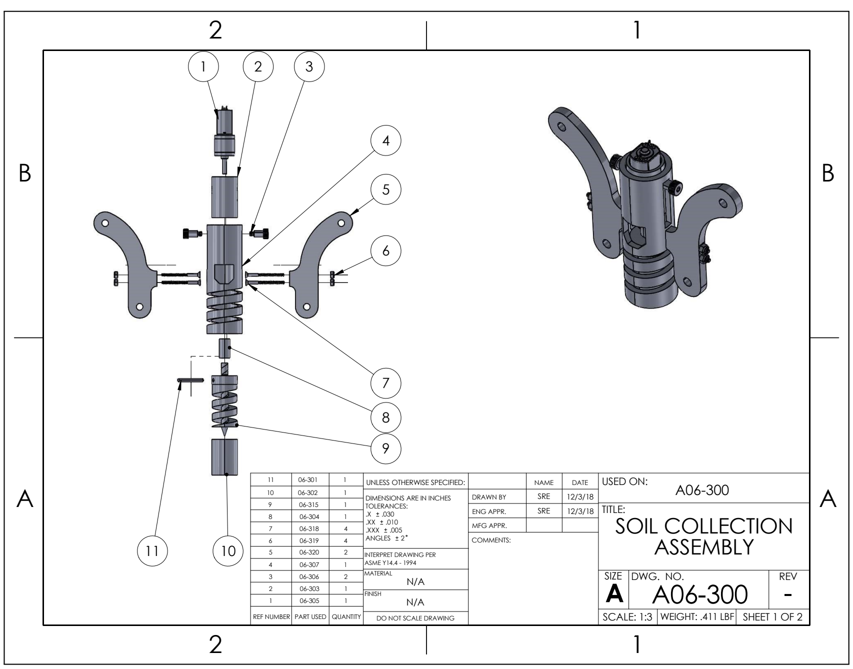
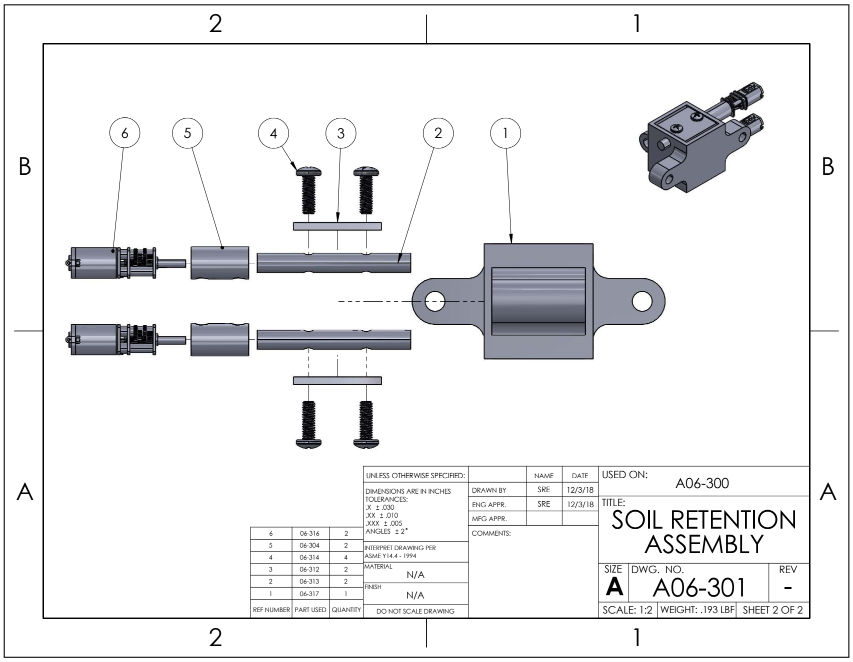


Figure 115: Soil Collection Assembly



REF NUMBER	PART USED	QUANTITY
6	06-316	2
5	06-304	2
4	06-314	4
3	06-312	2
2	06-313	2
1	06-317	1

Figure 116: Soil Retention Assembly

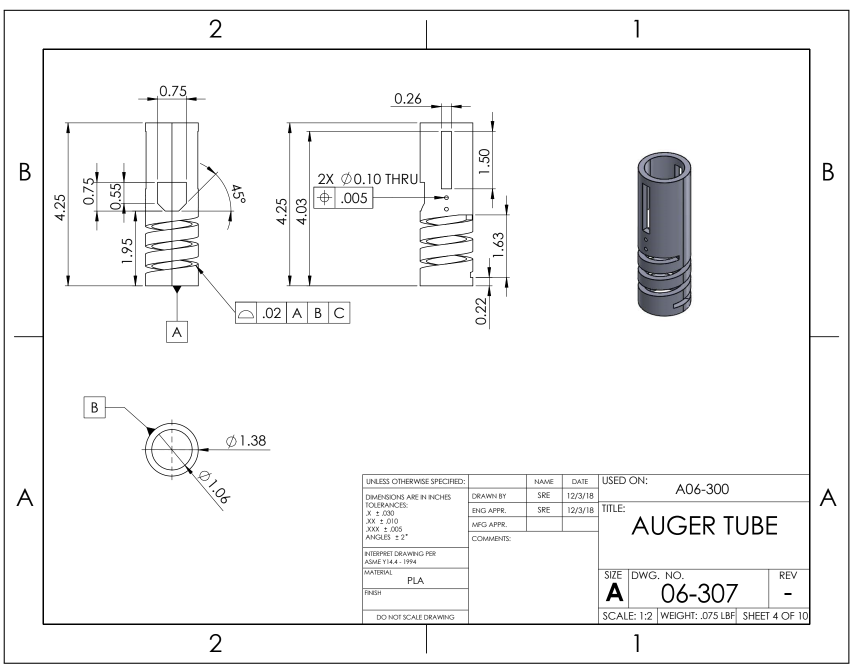


Figure 117: Auger Tube

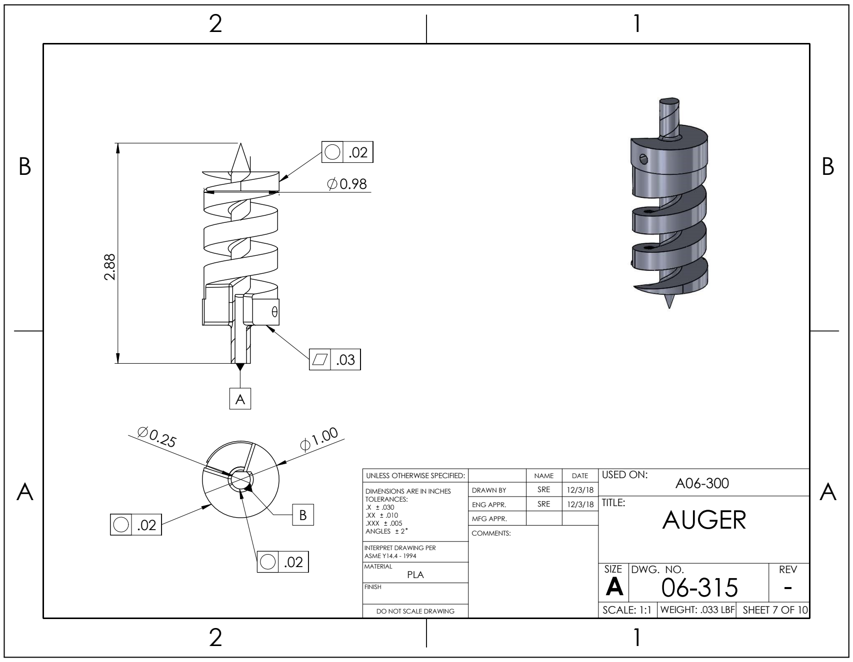


Figure 118: Auger

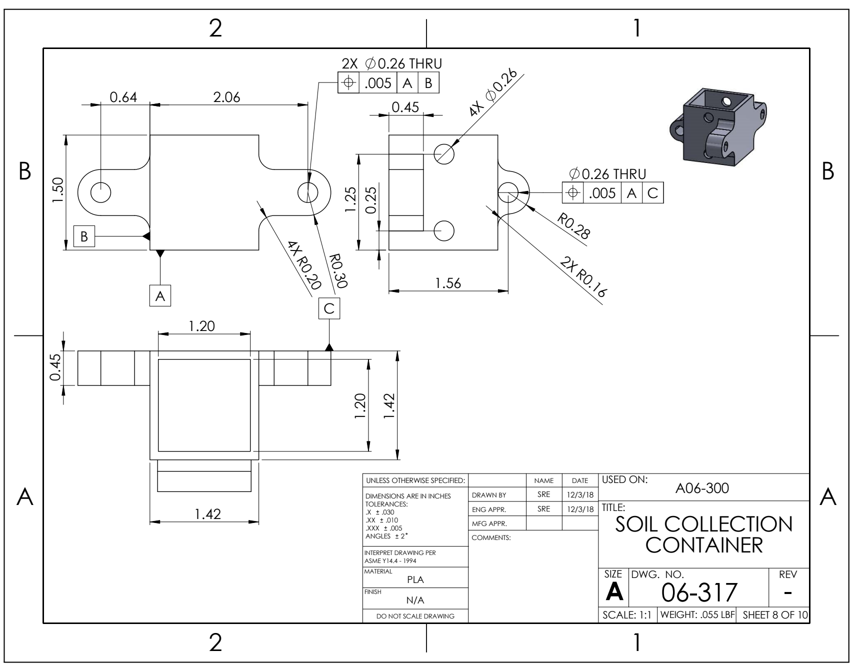


Figure 119: Soil Retention Container

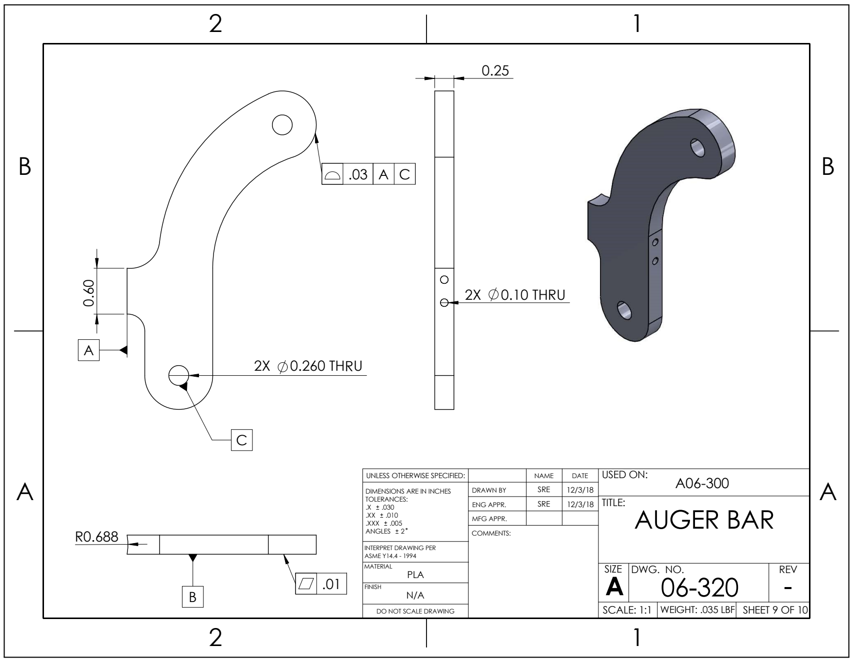


Figure 120: Auger Mount

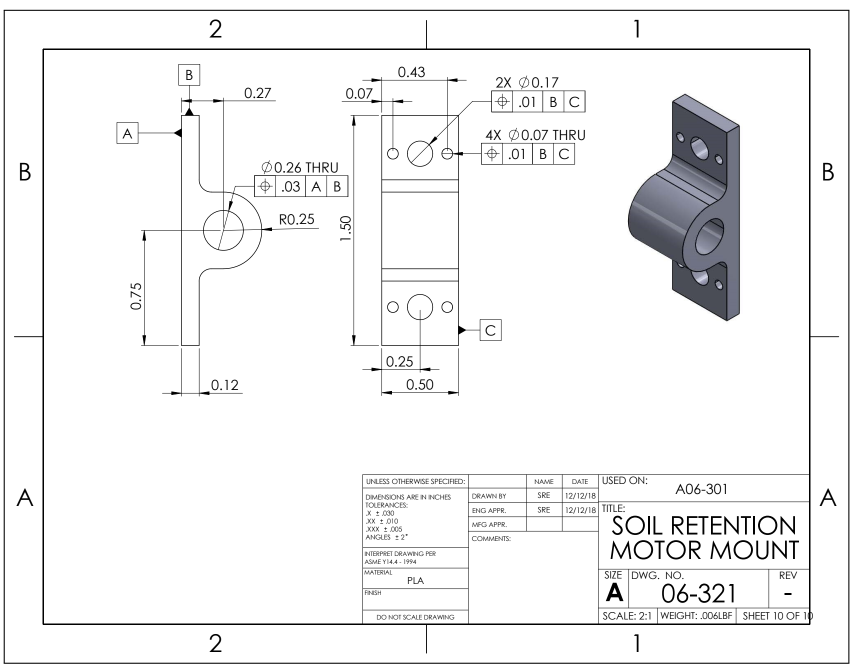


Figure 121: Soil Retention Motor Mount

A.2.3 Drivetrain

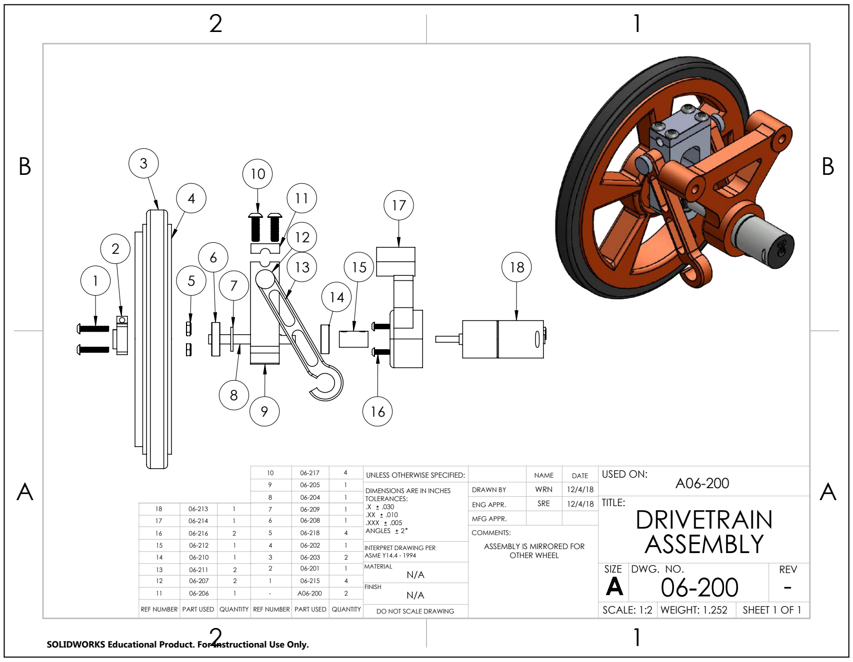


Figure 122: Drivetrain Assembly

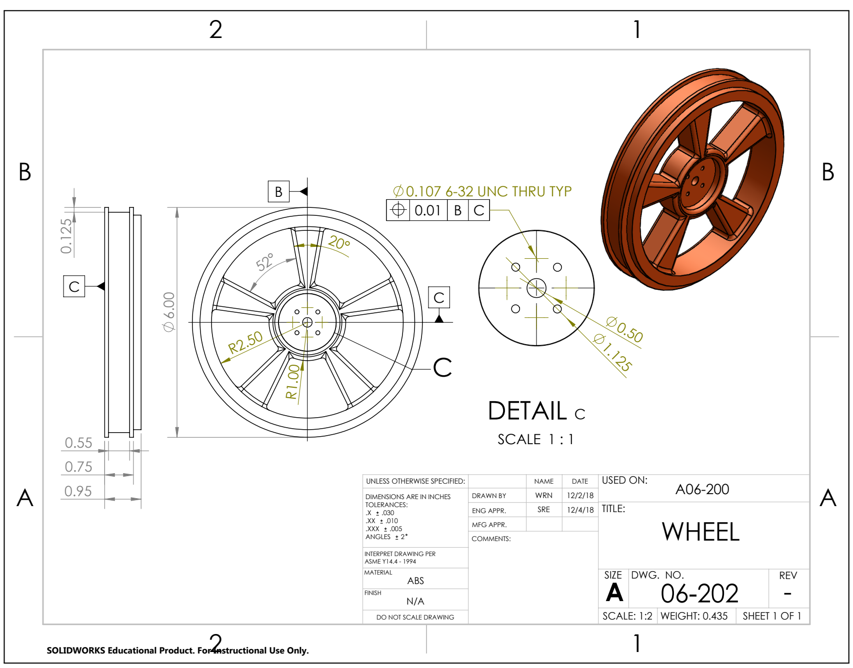


Figure 123: Wheel

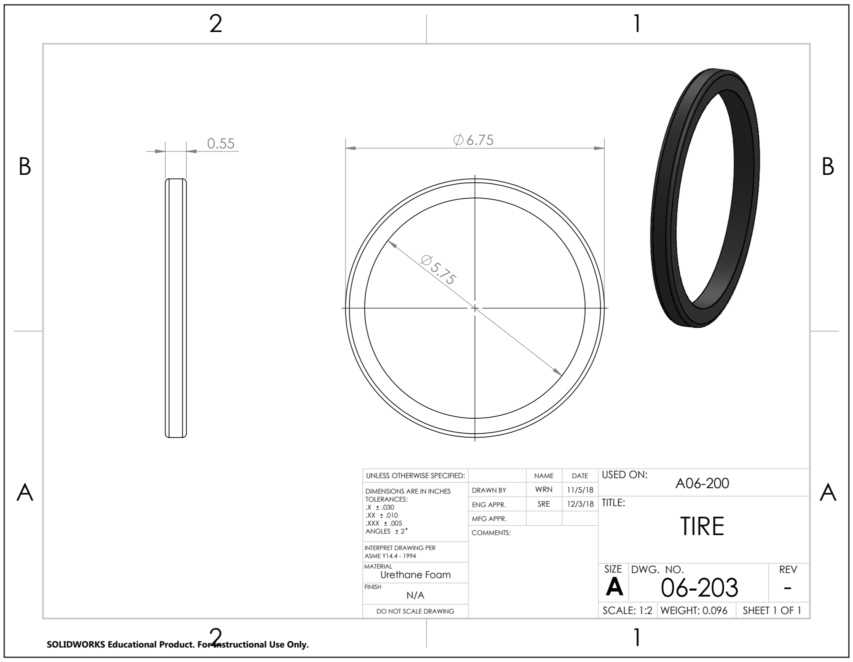


Figure 124: Tire

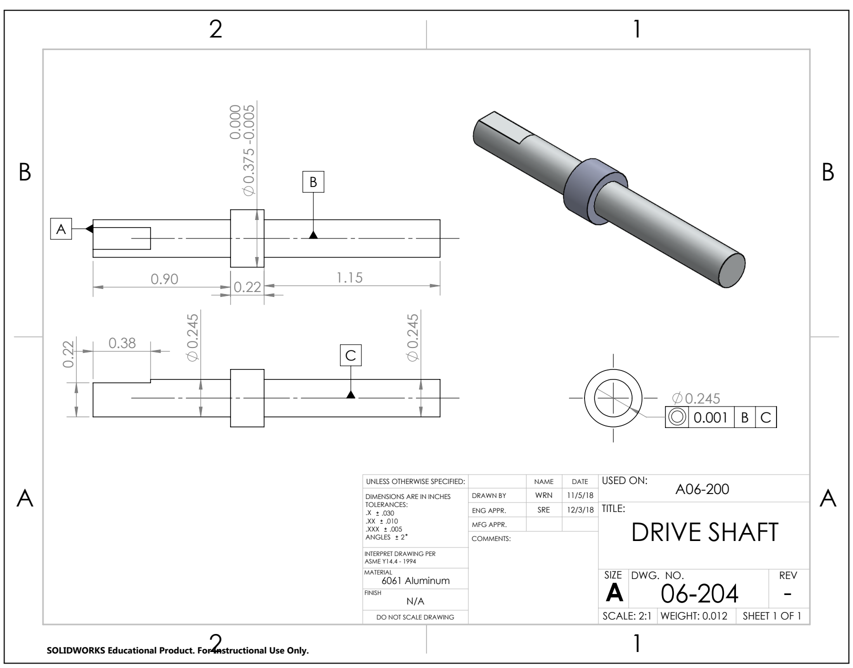


Figure 125: Drive Shaft

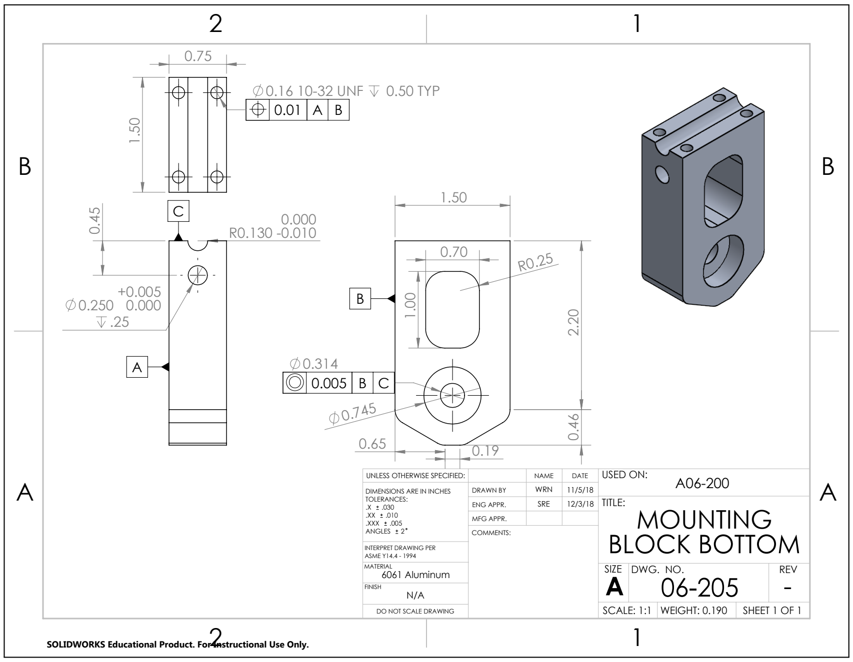


Figure 126: Mounting Block Bottom

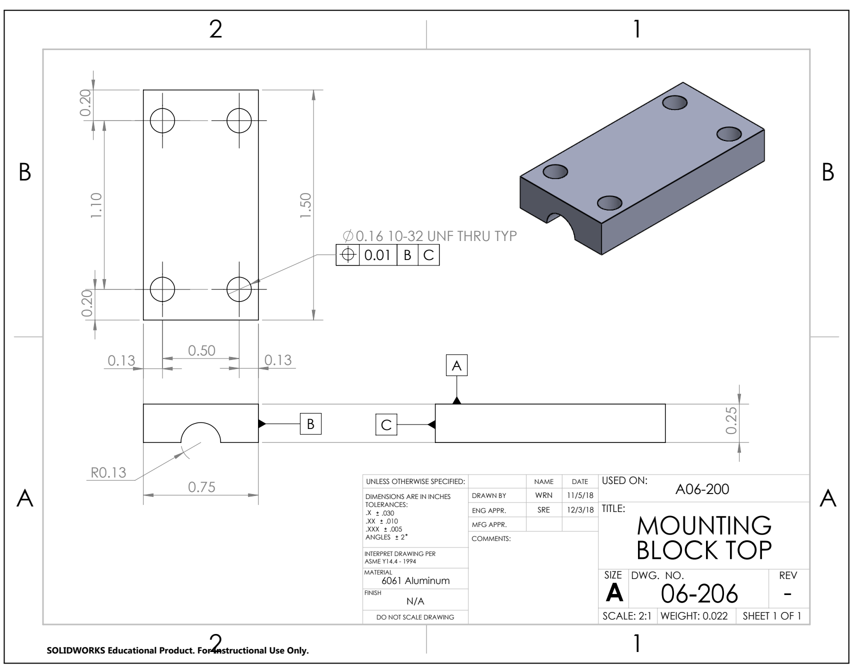


Figure 127: Mounting Block Top

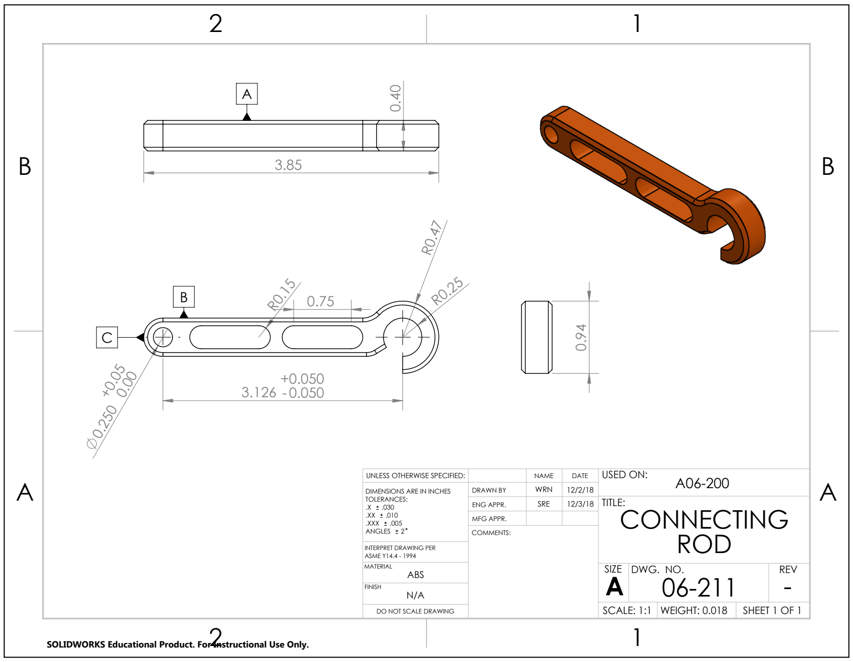


Figure 128: Connecting Rod

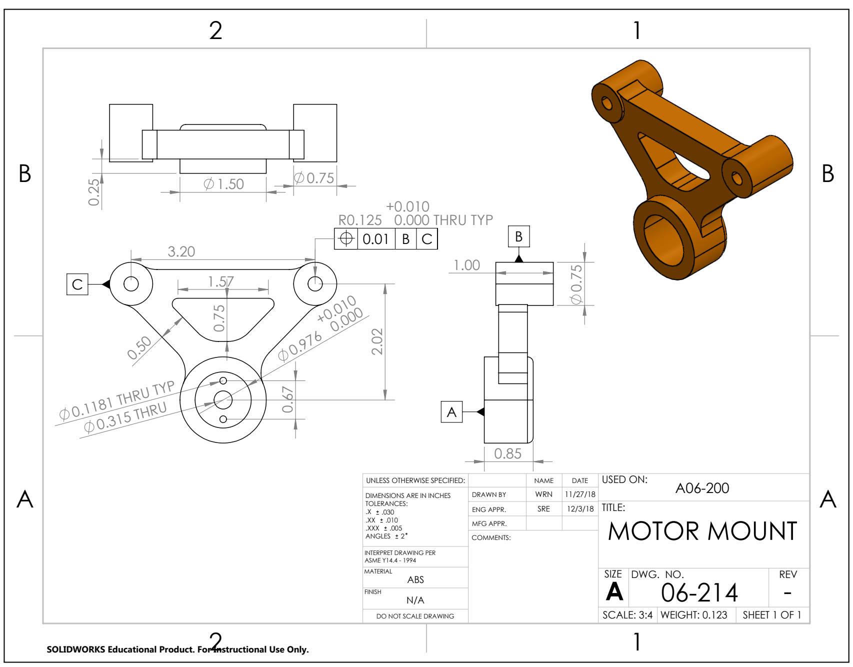


Figure 129: Motor Mount

A.2.4 Chassis

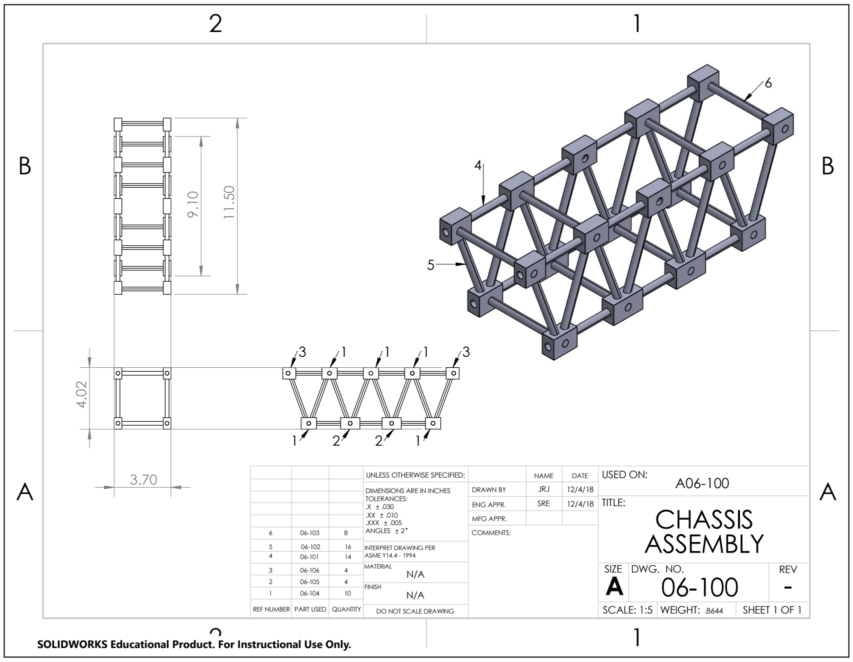


Figure 130: Chassis Full Assembly

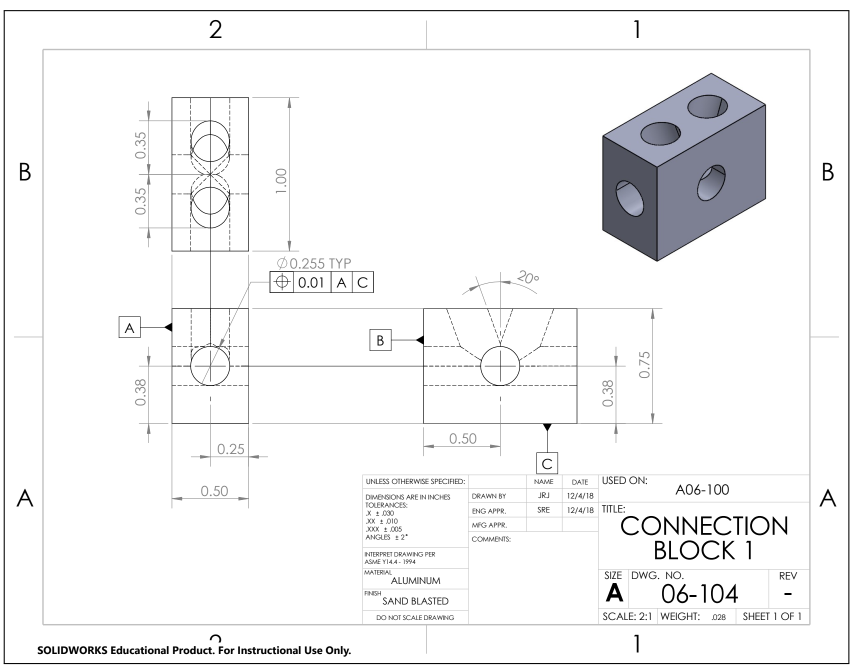


Figure 131: Connection Block

A.2.5 Payload Electrical

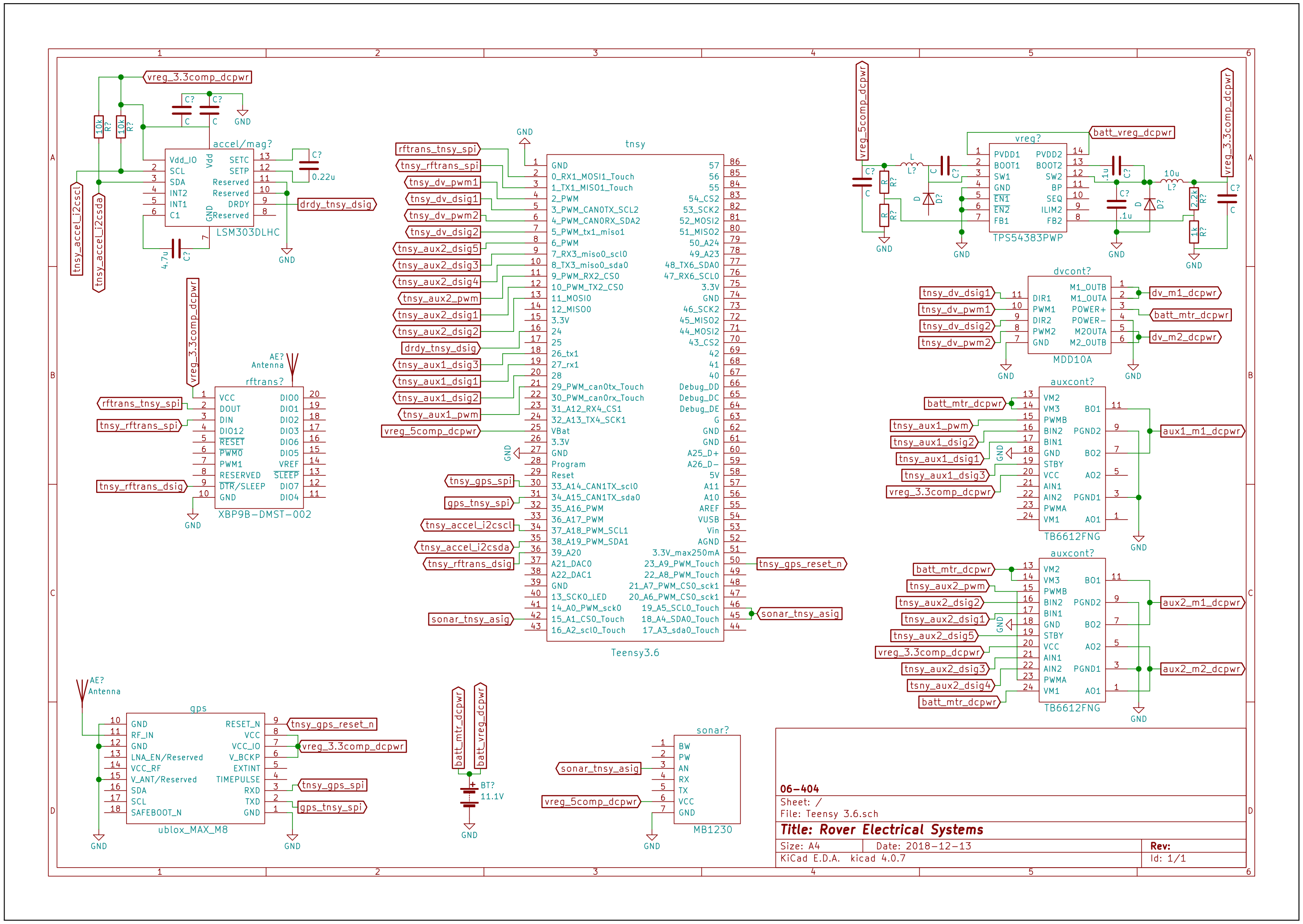


Figure 132: Schematic of Payload Electronics