Oregon State University

2018 NASA SL Team

104 Kerr Admin Bldg. # 1011

Corvallis, OR 97331

Critical Design Review

January 11th, 2019

Contents

List of Tables

List of Figures

Acronym Dictionary

9DOF Nine Degree of Freedom. 16, 83

AARD Advanced Retention Release Device. 16, 54

ABS Acrylonitrile Butadiene Styrene. 126, 127

AGL Above Ground Level. 15, 16, 48, 52, 54, 60, 169, 182, 186, 187

AIAA American Institute of Aeronautics and Astronautics. 14, 215

APCP Ammonium Perchlorate Composite Propellant. 184

ARRD Advanced Retention and Release Device. 15, 17, 26, 28, 49, 51, 60, 61, 68, 80, 81, 111, 141, 143, 144, 147, 151, 152, 167, 168, 174, 177, 186, 187

ASL Above Sea Level. 49, 57

ATI Allegheny Technologies Incorporated. 215

ATU Avionics Telemetry Unit. 17, 29, 30, 49, 64–66, 83, 84, 86, 87, 157–160, 172, 176

BEAVS Blade Extending Apogee Variance System. 4, 9, 19, 21, 29, 30, 44, 45, 69, 71, 96, 107, 232–234

CAD Computer-Aided Design. 141

CAM Computer-Aided Manufacturing. 45

CAR Canadian Association of Rocketry. 184

CDR Critical Design Review. 141, 179, 180, 185

CEMF Counter Electromotive Force. 148

CNC Computer Numerical Control. 45

CV Computer Vision. 18, 134

DC Direct Current. 124

DDM Design Decision Matrix. 5, 60, 61, 141, 150

DLM Data Logging Module. 83, 84

EMI Electromagnetic Interference. 148

FAA Federal Aviation Administration. 183, 196

FEA Finite Element Analysis. 8, 29, 116–118, 132

FHP Fore Hard Point. 4, 8, 9, 141, 144, 149, 150, 153, 236–242

FMEA Failure Mode Effects Analysis. 5, 102–119, 195, 211

FN Foreign National. 179

FRR Flight Readiness Review. 180, 185, 186, 192

GLONASS Global Navigation Satellite System. 64

GPIO General Purpose Inputs and Outputs. 136

GPS Global Positioning System. 18, 20, 46, 49, 64, 66, 83, 84, 86, 87, 134, 135, 137, 140, 158, 159, 172, 176, 204

HPR High Powered Rocketry. 80, 84, 85, 199

HRIT Horizontal Rotary Indexing Tool. 32, 35, 36

IC Integrated Circuit. 84, 87, 158–160

ICE Innovative Composite Engineering. 20, 215

IMU Inertial Measurement Unit. 16, 83

JHA Job Hazard Analysis. 32, 33, 35, 193, 210, 212

LDO Low Drop Out Regulators. 83, 84

LED Light Emitting Diode. 135, 136, 212

LiPo Lithium Polymer. 66, 83, 86, 87, 135, 158, 212

LRR Launch Readiness Review. 192

MPRL Machine Product and Realization Laboratory. 38, 42–45, 52, 193, 200, 210

MSDS Material Safety Data Sheet. 195

NAR National Association of Rocketry. 88, 94, 107, 184, 196, 199, 211

NASA National Aeronautics and Space Administration. 155, 180, 183, 185, 196, 215

NEMA National Electrical Manufacturers Association. 30

NTS Not To Scale. 7, 67, 68

OROC Oregon Rocketry. 196

OSGC Oregon Space Grant Consortium. 6, 8, 18, 215, 216

OSRT Oregon State Rocketry Team. 7, 14–18, 21, 23, 27–30, 48, 49, 51, 52, 54, 55, 57–64, 66, 69, 75, 86, 93, 94, 102, 107, 114, 120, 141, 144, 153, 154, 158, 163, 166, 172, 179–181, 193, 194, 196–200, 202, 204, 215, 217

OSU Oregon State University. 52, 60, 102, 156, 185, 193, 210, 211, 215

PCB Printed Circuit Board. 8, 17, 66, 83–87, 148, 149

PDR Preliminary Design Review. 17–20, 49, 60–62, 122, 141, 145, 150, 153, 179, 182

PEARS Payload Ejection and Retention System. 3, 4, 6, 8, 9, 18, 25, 71, 101, 119, 127, 141–143, 145, 148–153, 166, 167, 172, 174, 177, 208, 235–242

PID Proportional-Integral-Derivative. 30

PLA Polylactic Acid. 23, 25, 26, 42–44, 129–132

PLEC Payload Ejection Controller. 8, 9, 64, 101, 119, 136, 141, 143–153, 173, 241

PPE Personal Protective Equipment. 30–33, 35, 37, 38, 40–45, 83–86, 88, 91, 94, 155–157, 170, 175, 177, 194, 212

PWM Pulse Width Modulation. 134, 135

RDO Rover Deployment Officer. 141

RF Radio-Frequency. 17, 18, 20, 21, 23, 26, 27, 64–66, 86, 87, 134, 135, 147, 148, 159, 160

RPM Revolutions per Minute. 32, 35, 36, 125, 127

RRC3 Rocket Recovery Controller 3. 7, 46–48, 60, 164, 165, 188

RSO Range Safety Officer. 92, 184, 186, 194, 196

RX Receive. 64

SCAR Soil Collection and Retention. 3–6, 20, 100, 128, 130, 132, 133, 140, 243–248

SL Student Launch. 155

SMA Sub-Miniature Version A Connector. 84

SO Safety Officer. 210, 211

SPDT Single Pole Double Throw. 18, 141, 144, 145, 150, 152, 153, 175

SPI Serial Peripheral Interface. 65, 66, 87

STEM Science, Technology, Engineering and Mathematics. 179, 180

TI Texas Instruments. 17, 65, 86, 87

TRA Tripoli Rocketry Association, Inc.. 184, 196, 199, 211

UART Universal Asynchronous Receiver-Transmitter. 65, 66

USLI University Student Launch Initiative. 16, 59, 184

VMC Vertical Milling Center. 37–39, 42–45

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

1.1.1 Team Members and Organization

The Oregon State Rocketry Team (OSRT) consists of 37 members from the schools of Mechanical Engineering, Electrical Engineering, and Computer Science. The team strives to involve members of the campus American Institute of Aeronautics and Astronautics (AIAA) chapter.

Due to the multifaceted nature of this project, it has been broken up into three sub-teams according to technical design, with the following team descriptions:

Structures - Responsible for design and fabrication of the airframe and all internal components necessary for a successful launch and payload recovery. This team will also be in charge of implementing a proper motor while considering safety and handling before and after each launch. Key responsibilities include mass and stress analysis to ensure altitude precision, understanding key propulsive features to ensure reliability, and monitoring of the effects of design improvements.

Aerodynamics & Recovery - Responsible for the electronics behind aerodynamic stability, all parachute systems for recovery systems, and design of stability measures. Key requirements are to ensure a safe landing, monitor kinetic energy requirements, and fabricate electrical and mechanical hardware to ensure aerodynamic flight.

Payload - Responsible for the design, fabrication, and testing of a rover capable of traveling at least ten feet from the launch vehicle and collecting soil samples. Key responsibilities include meeting all customer requirements, designing a rover that reliably functions, and rigorous testing prior to the final launch.

The team consists of a team lead with three sub-teams. Each sub-team lead oversees a project team and additional testing project teams. The additional project teams include developing a test-bed for recovery ejection methods, implementing data-logging features to the airframe, creating a test method for ejection of the rover, and rapidly developing a rover prototype. The team construction can be seen in Figure 1.

Figure 1: Team Organization

1.2 Vehicle Summary

The major vehicle characteristics are shown in Table 2. The launch vehicle will reach an apogee altitude of 4,500 ft. The airframe is a 6.25 in. inner diameter fiberglass tube. The nosecone is a 5:1 ogive and attached to the base are three trapezoidal fins. Both the nosecone and fins are fiberglass. 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 12 ft rail at 84.6 ft/s. The motor to be used is a Cesaroni L2375-WT motor.

Table 2: Launch Vehicle Characteristics

Length	Weight	Motor
125 in.	52.4 lbf	L2375-WT

1.2.1 Size and Weight

The launch vehicle will have a length of 125 in. The weight of the launch vehicle will be 52.4 lbf.

1.2.2 Final Motor Choice

The motor to be used by the OSRT is the Cesaroni L2375-WT.

1.2.3 Target Altitude

The target apogee altitude is 4,500 ft.

1.2.4 Recovery System

The OSRT has decided that the launch vehicle will be recovered in two independent sections. The aft section will hold the motor, and the fore section will hold the payload. At apogee, the launch vehicle will have two separation events: the aft will separate from the fore section with black powder charges and release the drogue parachute, and the nosecone will separate from the fore section and release the drogue parachute. At 700 ft AGL, a Tender Descender and Advanced Retention Release Device (AARD) connected in series will release the main parachute in both the fore and aft section of the launch vehicle. The OSRT has decided to use 1.5 ft cruciform drogue parachute for both the fore and aft sections of the airframe and a 8 ft diameter toroidal parachutes for both recovered sections.

1.2.5 Rail Size

The launch rail will be a 1515 rail, that is 12 ft long.

1.2.6 Milestone Review Flysheet

1.3 Payload Summary

The OSRT has chosen to complete option two for the University Student Launch Initiative (USLI) payload: a deployable rover. 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, and a Nine Degree 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

2.1.1 Aerodynamics and Recovery

The OSRT will use a 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 advisers instead of the folding method recommended by the parachute manufacturer. This will allow both main parachutes to inflate quicker 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 an ARRD and Tender Descender. 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.

The launch vehicle will use three fins instead of the four fins proposed during the Preliminary Design Review (PDR) stage. Fin dimensions were adjusted accordingly to maintain a similar stability margin of 2.1 calibers, three fins weigh 0.22 lbf less than four fins. At the time of PDR, four fins was the leading alternative for ease of manufacturing 90° angles. Manufacturing plans have been updated to include an additive manufactured fixture which will be able to perfectly align 120° angles.

The primary design change for the Avionics Telemetry Unit (ATU) is the redesign and replacement of the old custom 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.

2.1.2 Structures

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 XX.XX in. longer than originally proposed in PDR. All of this length change is reflected in the body tube. The aft section has increased by XX.XX in. The fore section has increased by XX.XX in.

The camera system has significantly changed since the Preliminary Design Review. Originally, this system used five cameras all filming in unison to create a 360° video. Due to weight constraints of the launch vehicle, the OSRT has changed the camera system to now have only one camera inside the airframe. This will save weight and still allow for an on-board camera to film the flight of the launch vehicle. If weight is cut from the launch vehicle elsewhere, the additional four cameras may be used reintroduced into the system for full 360° video capabilities.

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.

The bulkheads remain the same except for how they are assembled into the airframe. To conserve weight and ease assembly, radial screws will secure the bulkheads to the inside the airframe instead of a threaded rod.

2.2 Changes Made to Payload Criteria

The chassis of the rover has been simplified to one solid piece, removing the modular components from the original design. The new drive motor was selected for the rover drivetrain. 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 drivetrain also had a change in bearing selection, which forced a minor redesign of its drive shaft. A team effort to cut weight involved changing the wheel to an open design. The functionality of the Payload Ejection and Retention System (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.

A goal has been added to the scope of the payload to navigate to a scientific base station and deposit the soil sample. An RF transceiver was introduced to receive the Global Positioning System (GPS) coordinates of the base station. A GPS module was added to navigate close enough to the base station for Computer Vision (CV) to take over navigation.

2.3 Changes Made to Project Plan

Since PDR, 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.

The primary change to the project schedule since PDR was a delay in launches. The subscale launch was delayed two times due to inclement weather conditions at the launch site and over the mountain passes. The subscale launch was completed on December 8th, 2018. Additionally, delays to the Blade Extending Apogee Variance System (BEAVS) test launches occurred because the control system was still being finalized. The BEAVS test launches will now be conducted in parallel with the full scale launches.

3 Vehicle Criteria

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

3.1.2 Final Design Alternatives

3.1.2.1 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 was increased from Proposal to around 6 in. Both tubes will be donated by Innovative Composite Engineering (ICE) and based on their manufacturing specifications and spindle sizes, the inner diameter was chosen to be 6.25 in., consistently across both body tubes. Material options for both tubes will be carbon fiber and fiberglass, with an option to transition from one material to the next within the same body tube. 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 information out of the airframe. The dimensional drawing can be seen on Figure 56.

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 devise 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. After analysis, this portion was deemed to small to provide any sort of benefit from the carbon fiber. For ease of manufacturing, the body tube will no longer contain a transition.

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 all located. There will be 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

3.1.2.2 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. Many alternatives were suggested for material and shape selection but the final choices were based on 2 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 6.42 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 3.1.3.2 and the dimensional drawing can be seen on Figure 58.

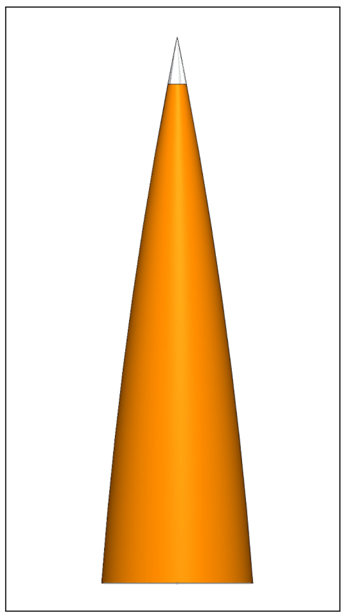

Figure 2: Nosecone Assembly

3.1.2.3 Fins

The chosen fin shape is trapezoidal clipped delta fins. The fin shape was chosen for its aerodynamic performance and ease of manufacturing. Many different fin dimensions were tested using OpenRocket to maximize apogee altitude while maintaining a stability margin of 2.1 calibers. 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 three 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 three in. location was selected from many combinations of trailing edge location and sweep length of the trapezoidal fins to maximize projected altitude while maintaining a 40° 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 40° 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 40° minimum angle. The optimal dimensions of the trapezoidal fins can be seen in Figure 59.

To maintain precise manufacturability, OSRT has decided to utilize solid carbon fiber fins. More information on material selection can be seen in Section 3.1.4.2. Utilizing 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.

3.1.2.4 Motor

The motor selected by OSRT is the Cesaroni L2375-WT. The high thrust-to-weight ratio of 11.18 will help counter weather-cocking during ascent. The launch vehicle will exit the rail at 85 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 achive an apogee altitude of 4856 ft.

3.1.2.5 Fore Avionics

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 and creating it through additive manufacturing will make manufacturing more simple. 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 two screws through the nosecone bulkhead limit rotational movement. Below the bulkhead are two eye bolts to provide a mounting point for the parachutes. These bolts are held in place with locknuts. Washers are used to help to disperse the forces more evenly throughout the bulkhead. Figure 3 shows the 3D model of the fore avionics bay with transparent nosecone.

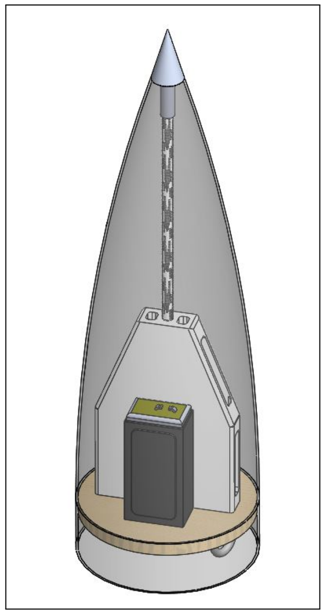

Figure 3: Fore Avionics Bay

To minimize the ejection charge size needed, a pressure seal is formed at the bulkhead. To create this seal, a flat piece of rubber is compressed into the main bulkhead by another bulkhead that has been cut out to the edges. There are six 1/4-20 bolts that are tightened to compress the rubber so that it presses against the inner wall of the airframe. The total weight of the fore avionics bay is 0.65 lbf. Figure 4 shows a representation of the seal with some recovery components attached.

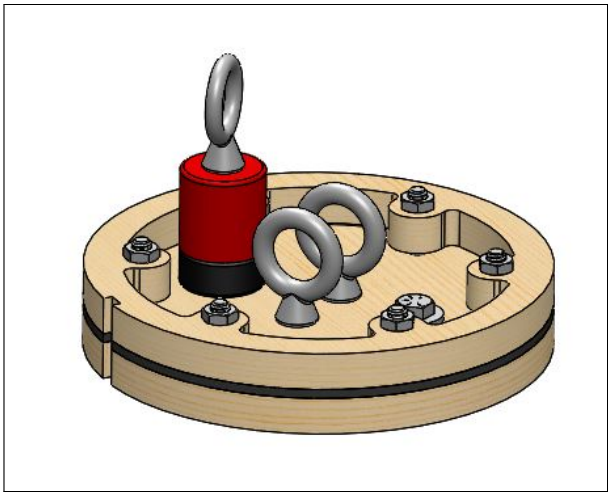

Figure 4: Removable Seal

3.1.2.6 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 accent and decent of the launch vehicle and are used to fire the ejection charges at the correct time. An additive manufactured PLA block, similar to the fore avionics, sits within the bay to provide mounting points for the altimeters and other electrical components. Figure 5 shows the fully assembled bay and Figure 6 displays the bay with a transparent body.

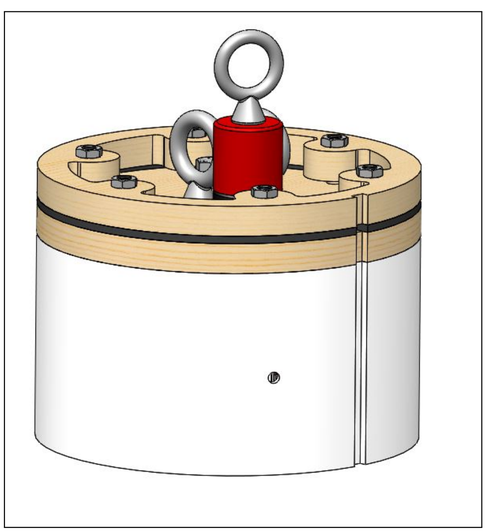

Figure 5: Fore Ejection Bay Assembly

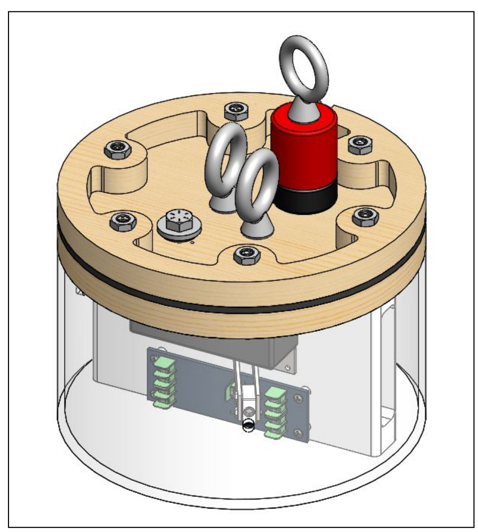

Figure 6: Fore Ejection Bay Transparent

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 bulkheads that cap the bay. The conductive spray paint does not allow RF signals through and creates a shielded bay.

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 nearly impossible due to its extremely tight fit. However, it is critical that the holes for the altimeter switches in the body wall are aligned rotationally with the holes in the airframe. To simplify integration, a rail will be placed 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.

To create a pressure seal on the fore end of the bay, the same method as the fore avionics is used. Six bolts tighten two bulkheads together, compressing a rubber piece against the inner wall of the airframe. This allows for a removable seal that is simple to integrate, while still maintaining its strength. Figure 4 shows only the seal, which can be detached from the rest of the bay in case of repair or for ejection testing.

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

3.1.2.7 Aft Electronic 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 five in. and is capped by an additive manufactured bulkhead just like the bottom bulkhead in the fore ejection bay. Along the side of the bay is a key way. 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 avionics and fore ejection bay is used here as well. Figure 7 shows the aft ejection bay assembly and Figure 8 shows how the altimeters are avionics are kept separate.

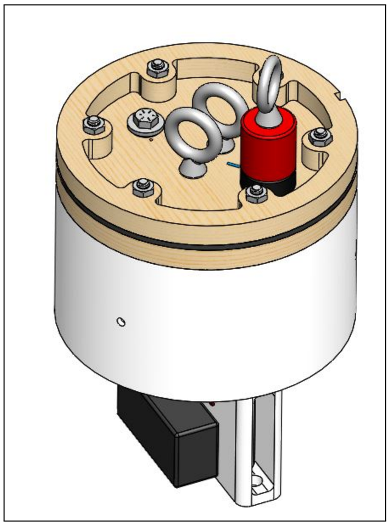

Figure 7: Aft Ejection Bay Assembly

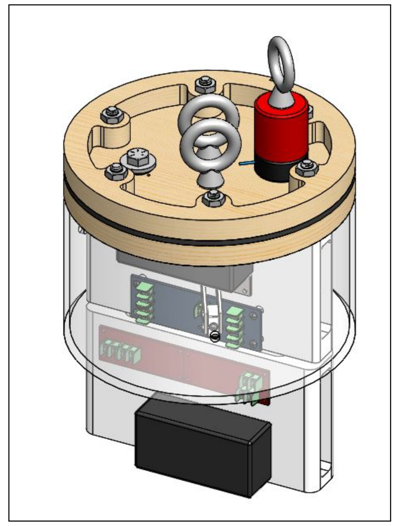

Figure 8: Aft Ejection Bay Transparent

3.1.2.8 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 10 in. in length and will be laid up in house to ensure a proper fit into the nosecone and fore airframe. 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 80

Instead of a traditional coupler, the OSRT decided to implement the canister for the aft coupler. This component connects the fore and aft airframes and also eases assembly of the launch vehicle. Four components will be preassembled into the canister and then the canister will be assembled into the airframe. The canister is 26 in. in length 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 9. This includes all components except for the packed parachutes.

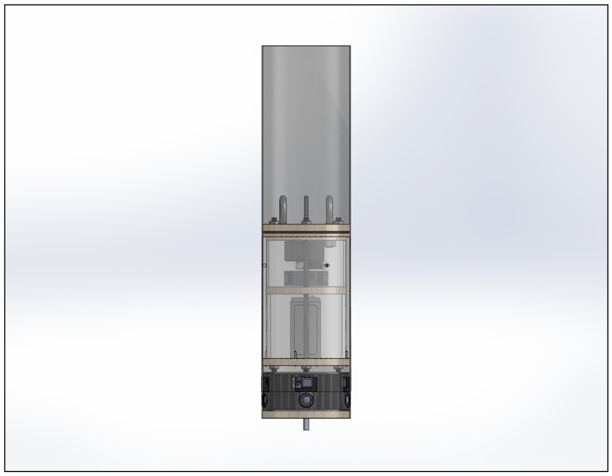

Figure 9: Assembled Canister

The bulkhead with all recovery components attached to it, ARRD and eyebolts, is mounted using three 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.

3.1.2.9 Camera System

3.1.2.10 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 onto the end of a G12 fiberglass motor tube, manufactured by Madcow Rocketry, with G5000 RocketPoxy. 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.

3.1.2.11 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 easily accessible to the OSRT. This simple bulkhead design was chosen over more complex materials for these reasons as well as the ease of manufacturing of plywood.

Bulkheads will be secured into the airframe using four 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.

3.1.2.12 BEAVS Mechanical System

The linear guide rail was selected to be a 7 mm (convert) with linear guide blocks rated for operation at a moment of 0.29 kg-m. 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 that 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 10.8 kg per blade.

The drag coefficient with blades retracted is 0.5375, while the drag coefficient with blades extended is estimated at 0.688. 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.

$F_D = {}^1\!/_2 * C_D * \rho * v^2 * A$

This provides a force of 154.6 N with blades extended and 94.3 N with the blades retracted. This is a force of 15.1 N per blade, providing a safety factor of 7.03 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. The are made of 0.125 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.

3.1.2.13 BEAVS Electrical System

The electrical system consists of the OSRT designed ATU. A third ATU will be used which will collect data for the control system and perform the motor actuation. For more details about the ATU, see section **??**. 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. Shown in Figure **??** is a diagram which displays properties of the motor provided by the manufacturer, Lynxmotion. The hall effect encoder and gear reduction is included from the manufacturer.

3.1.2.14 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 with respect to altitude. The state was defined 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 iterative process involved simulating the flight given initial conditions 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.

3.1.3 Manufacturing Plans

3.1.3.1 Composites

The following procedure is a guide on how to handle composites.Personal Protective Equipment (PPE)

Table 3: Composites Manufacturing Plan

Materials Required	Tools Required	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: 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.
- 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.

3.1.3.2 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 4: 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.

1) Begin by marking the nosecone with a reference line indicating where it will be cut by inserting the centering ring through the tip until it sits tightly on the outer surface of the nosecone.
2) Adjust the centering 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 2 surfaces come in contact.
4) Mark a circular line around the nosecone where the 2 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 4 radial set screws.
9) Clamp wide end of nosecone into Horizontal Rotary Indexing Tool
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 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 0.25 in. end mill and Revolutions per Minute (RPM) set to 1,500, cut into the nosecone, slowly rotating, leaving a 0.25 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.

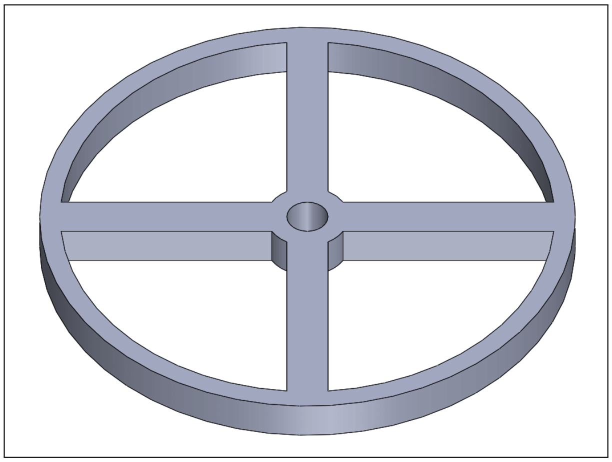

Figure 10: Nosecone Fixture Insert

3.1.3.3 Fins

A 6061 Aluminum fixture plate will be utilized to precisely manufacture all three fins. The fixture consists of four sections, one for achieving each necessary cut. The method of using all of these sections in the correct order is outlined below.

Table 5: Fin Manufacturing Plan

Materials Required	**Tools Required**	**PPE Required**
36x36x0.125 in. Carbon Fiber Sheet	Fadal VMC 4525	Nitrile Gloves
24x24x0.25 in. 6061 Aluminum Sheet	Machine Clamps	Certified Safety Goggles
Toggle Clamps	Machine Tools	Respirator
Bolts	Table Saw	Close Toed Shoes
	Slotted Diamond Blade	Long Sleeves
	0.500 in. End Mill	Long Pants

- 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 JHA has been filled out and signed by a safety officer prior to manufacturing.

1) Manufacture fixture for cutting the final fin shape
   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 fixture plate

f) Remove fixture plate from Fadal VMC 4525

g) Mount all toggle clamps to the fixture plate

2) Clamp down each corner of the finished fixture plate

3) Manufacture fins

a. Use each corner of the 36x36x0.125 in. Carbon Fiber as perpendicular datum planes

b. Mark each corner with the letter (R) for reference

c. Rough cut height of each fin from bottom datum plane with slotted diamond blade on table saw

d. Rough cut root cord length of each fin from side datum plane with slotted diamond blade on table saw

e. Place the datum corner (R) into corner (A) on the fixture, as seen in Figure 11

f. Clamp down toggle clamps

g. Check to make sure carbon fiber stock is properly secured

h. Run the appropriate program for the slot (A) cut

i. Repeat Steps f-i three more times changing (A) to (B) to (C) and finally to (D)

j. Sand down each edge of fin with 1000 grit sand paper

k. Keep fourth fin as an extra

l. Store excess carbon fiber

4) Manufacture fin alignment fixture with additive manufacturing process

figures/FinShapeFixture.pdf

Figure 11: Fin Shape Fixture

3.1.3.4 Fin Slots

A 6061 Aluminum fixture plate will be utilized to precisely manufacture all three fin slots and can be seen below in Figure 12. 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 Horizontal Rotary Indexing Tool.

Table 6: Fin Slot Manufacturing Plan

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

- 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 JHA has been filled out and signed by a safety officer prior to manufacturing.

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 fixture plate
   f. Remove fixture plate from Fadal VMC 4525
2) Manufacture fin slots
   a. Clamp down HRIT to Bridgeport Vertical Mill work table
   b. Insert fore end of aft body tube through 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

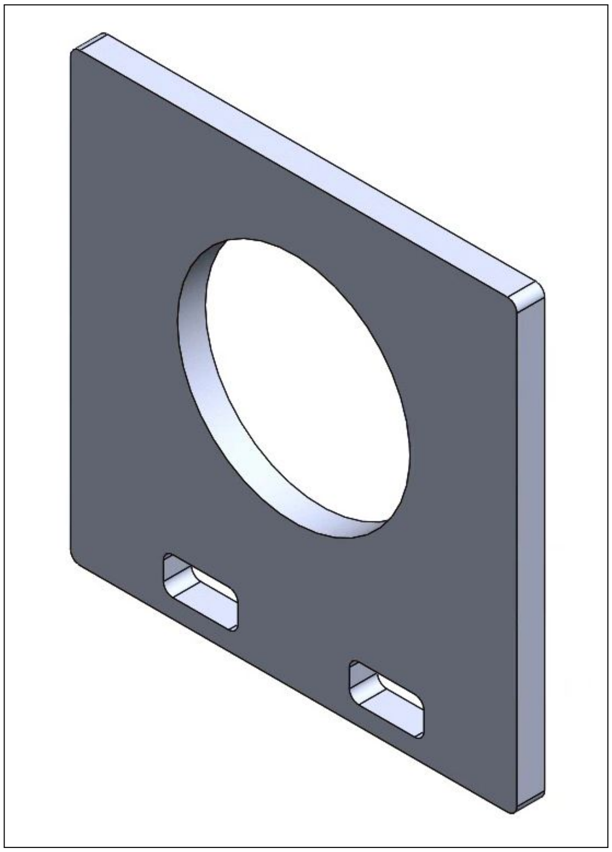

Figure 12: Fin Slot Fixture

3.1.3.5 Bulkheads

The Oregon State University machine shop will be used to manufacture bulkheads. The manufacturing plans for these components can be seen below.

Table 7: Bulkhead Manufacturing Plan

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

Manufacturing Instructions:

1) Safety Consideration: To enter the shop and use the equipment, all team members must be wearing safety glasses, have closed toed shoes, have tied back loose clothing and be wearing certification name tag.
2) Safety Consideration: The rotary table is very heavy. Dropping it could injure the user, others, and damage the rotary table.
3) Use table saw to cut plywood into 6.5x6.5 in. squares.
4) Mount plywood square into VMC.
5) Use VMC edge finder tool to properly align plywood square.
6) Cut 3/8 in. hole into center of plywood square.
7) Remove plywood square from VMC.
8) Clean glsVMC.
9) Mount Z-axis rotary fixture to VMC.
10) Mount plywood square into into Z-axis rotary fixture on the VMC.
11) Use VMC edge finder tool to properly align plywood square.
12) 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.
13) Use Z-axis rotary fixture and VMC to cut plywood square into a 6.25 in. diameter disk.
14) Use calipers to check the diameter of the bulkhead.
15) Note: Do not alter the thickness of the plywood. This needs to remain at 1/2 in.
16) Remove bulkhead from Z-axis rotary fixture.
17) Remove Z-axis rotary fixture from VMC.
18) Clean VMC and work area.

3.1.3.6 Centering Rings

The Machine Product and Realization Laboratory (MPRL) will be used to manufacture Centering Rings. The manufacturing plans for this components can be seen below.

Table 8: Centering Rings Manufacturing Plan

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

Manufacturing Instructions:

1) Safety Consideration: To enter the shop and use the equipment there, all team members must be wearing safety glasses, have closed toed shoes, have tied back loose clothing and be wearing certification name tag.
2) Safety Consideration: The rotary table is very heavy. Dropping it could damage the user, others, and the rotary table.
3) Use table saw to cut plywood into 6.5x6.5 in. squares .
4) mount plywood square into VMC.
5) Use VMC edge finder tool to properly align plywood square.
6) Cut 3/8 in. hole into center of plywood square.
7) Remove plywood square from VMC.
8) Clean VMC.
9) Mount Z-axis rotary fixture to VMC.
10) Mount plywood square into into Z-axis rotary fixture on the VMC.
11) Use VMC edge finder tool to properly align plywood square.
12) 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.
13) Use Z-axis rotary fixture and VMC to cut plywood square into a 6.25 in. diameter disk.
14) Use calipers to check the outer diameter of the centering ring.
15) Note: Do not alter the thickness of the plywood. This needs to remain at 1/2 in.
16) Remove centering ring from Z-axis rotary fixture.
17) Remove Z-axis rotary fixture from VMC.
18) Clean VMC
19) Mount centering ring into VMC
20) Use VMC edge finder tool to properly align centering ring.
21) Use VMC to cut 3.1 in. diameter hole into the center of centering ring.
22) Use calipers to check inner diameter of centering ring.
23) Remove centering ring from VMC.
24) Clean VMC and work area.

3.1.3.7 Epoxy

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

Table 9: Epoxy Manufacturing Plan

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

Safety Consideration: Gloves must be worn to prevent skin contact when working with epoxy to avoid rash or other skin damage.

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 sandpaper to rough up the surfaces for epoxy.
5) Wipe all dust created by sanding off of the surfaces.
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 best and easiest to apply soon after mixing.
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 applying more epoxy.

3.1.3.8 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 10: 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: Gloves must be worn when working with epoxy to avoid skin damage.

1) **Note:** Refer to Epoxy 3.1.3.7 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.
   - **In this same step**
8) Fillet motor tube and epoxy upper centering to the airframe with blind fillet below.
9) Place lower airframe into fin fixture.
10) Place generous amount of epoxy on motor tube where fin will mount
11) Press fin through slot in airframe and into the pre-applied epoxy
12) Press fin down and forward to ensure fin is properly in place
13) Create fillet on either side of fin along the motor tube by sliding glove covered finger down the length of fin
14) Press remaining fins through the remaining slots
15) Press fin alignment fixture into place, holding all fins in place
16) Epoxy the fins to the body tube both on the inside of the body tube and outside of the body tube.
    - **In this same step**
17) Fillet the inside and the outside of fin-body tube joint.
18) Place epoxy along back ends of fins.
19) Place epoxy along inside of the airframe and outside of the motor tube where the last centering ring

will be placed.

20) Slide in centering ring until it contacts and lays flat against the fin ends.
21) Make epoxy fillets on the outside of the last centering ring, along the body tube and motor tube to centering ring contact points.
22) Epoxy on motor retainer making sure inner stop makes contact with the edge of the motor tube.
23) Clean off any excess epoxy with a rag.

3.1.3.9 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) Convert the model into a high resolution stl file.
3) Use slicer to convert the stl file into G-code.
4) Upload the G-code into the 3D printer.
5) Check the print for defects.

The bulkheads will be manufactured primarily according to Section 3.1.3.5, with several additional holes placed for eyebolts and sealing bolts using a vertical mill. The bulkheads will be manufactured according to the following process:

Table 11: 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: Use caution when working with a VMC. Hands should be kept a safe distance from the rotating end mill. Hair should be tied up and no loose clothing worn. 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 Appendix X to determine placement and sizing of holes.
4) Drill all holes in the aluminum using peck drill method.

5) Remove the bulkhead plate from the Haas vice.
6) Repeat steps 1-5 using the drawing Appendix Y to determine placement and hole sizing.

3.1.3.10 Fore Ejection Bay

The fore ejection bay has many more parts, however, all of the additive manufactured components are made the same way as the fore avionics and of the same material, PLA. Parts in this section consist of the fore altimeters mount, fore body, switch mount obtuse, switch mount acute, and fore bottom bulkhead. For all of these parts, the manufacturing process is the same and is as follows:

1) Create a 3D model of the part.
2) Convert the model into a high resolution stl file.
3) Use slicer to convert the stl file into G-code.
4) Upload the G-code into the 3D printer.
5) Check the print for defects.

Along with the additive manufactured parts are two bulkheads that are used to create a pressure seal against the inner wall of the airframe and to provide a mounting point for the fore parachutes. The bulkheads will be manufactured primarily according to Section 3.1.3.5, with several additional holes placed for eyebolts and sealing bolts using a vertical mill. The bulkheads will be manufactured according to the following process:

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

Safety Consideration: Use caution when working with a VMC. Hands should be kept a safe distance from the rotating end mill. Hair should be tied up and no loose clothing worn. 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 Appendix X to determine placement and sizing of holes.
4) Drill all holes in the aluminum using peck drill method.
5) Remove the bulkhead plate from the Haas vice.
6) Repeat steps 1-5 using the drawing Appendix Y to determine placement and hole sizing.

3.1.3.11 Aft Electronic Bay

The aft electronic bay consists of many components that are created through an additive manufacturing process and are composed of PLA. The parts in this section are the aft altimeters mount, the aft avionics mount, the aft body, switch mount obtuse, switch mount acute, aft inner bulkhead, and aft bottom bulkhead. For all of these parts, the manufacturing process is the same and is as follows.

1) Create a 3D model of the part.
2) Convert the model into a high resolution stl file.
3) Use slicer to convert the stl file into G-code.
4) Upload the G-code into the 3D printer.
5) Check the print for defects.

In addition to the additive manufactured parts, there are two bulkheads that are used to create a pressure seal and provide mounting points for the aft parachutes. The bulkheads will be manufactured primarily according to Section 3.1.3.5, with several additional holes placed for eyebolts and sealing bolts using a vertical mill. The bulkheads will be manufactured according to the following process:

Table 12: 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: Use caution when working with a VMC. Hands should be kept a safe distance from the rotating end mill. Hair should be tied up and no loose clothing worn. 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 Appendix X to determine placement and sizing of holes.
4) Drill all holes in the aluminum using peck drill method.
5) Remove the bulkhead plate from the Haas vice.
6) Repeat steps 1-5 using the drawing Appendix Y to determine placement and hole sizing.

3.1.3.12 BEAVS

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 3.1.3.5, 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:

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: Use caution when working with a VMC. Hands should be kept a safe distance from the rotating end mill. Hair should be tied up and no loose clothing worn. 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 Appendix X 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 Appendix X.
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.

3.1.4 Integrity of Design

3.1.4.1 Fin Suitability

3.1.4.2 Material Choice

3.1.4.3 Final Mass of Rocket and Subsystems

3.1.5 Component Justifications

3.2 Subscale Flight Results

3.2.1 Flight Data

For the first 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. 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.

3.2.1.1 PerfectFlite StratoLoggerCF Data

Shown in Figure 13 is the flight data the PerfectFlite StratoLoggerCF altimeter recorded during the first subscale launch.

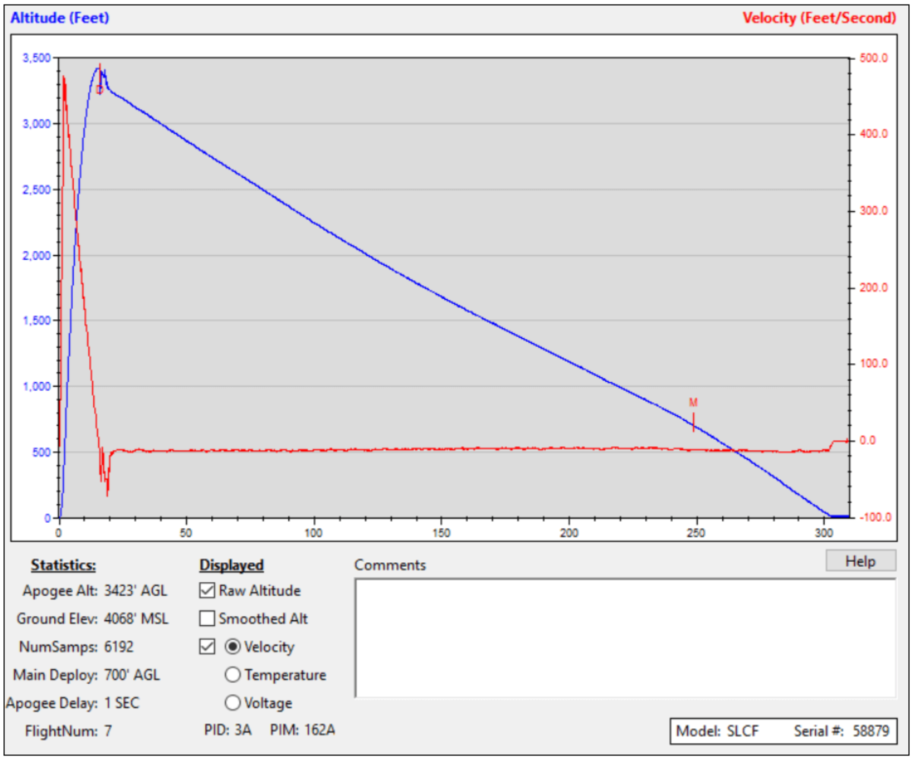

Figure 13: StratoLoggerCF Altimeter Flight Data

Shown in Table 13 are the recorded maximum altitude, impact velocity, impact Kinetic energy, and total descent time for the StratoLoggerCF altimeter.

Table 13: StratoLogger Subscale Relevant Data

Maximum Altitude [ft]	Impact Velocity [ft/s]	Impact Kinetic Energy [ft-lbf]	Total Descent Time [s]
3423	13.2	52.26	287.25

3.2.1.2 Missile Works RRC3 Data

Shown in Figure 14 is the flight data the Missile Works RRC3 altimeter recorded during the first subscale launch.

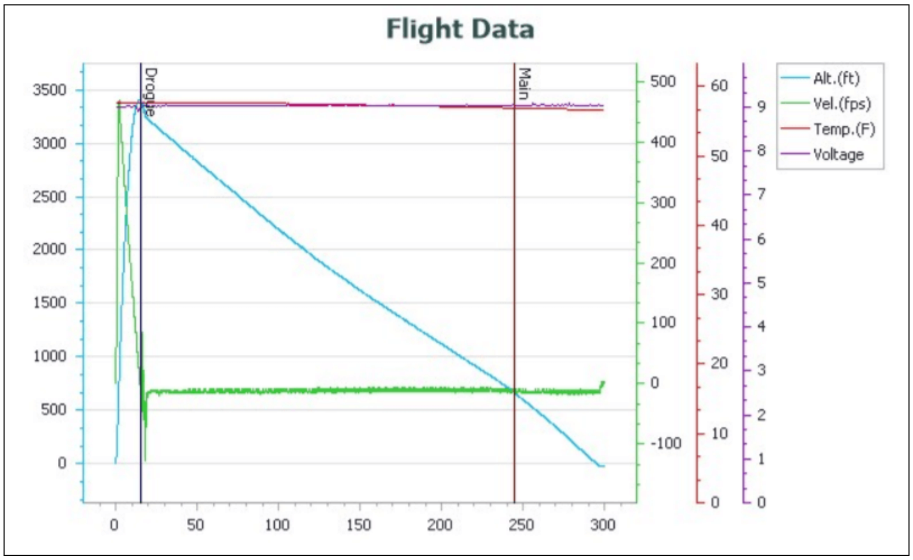

Figure 14: RRC3 Altimeter Flight Data

Shown in Table 14 are the recorded maximum altitude, impact velocity, impact Kinetic energy, and total descent time for the RRC3 altimeter.

Table 14: StratoLogger Subscale Relevant Data

Maximum Altitude [ft]	Impact Velocity [ft/s]	Impact Kinetic Energy [ft-lbf]	Total Descent Time [s]
3402	13.0	50.5	281.25

3.2.1.3 Discussion

At apogee, when the launch vehicle sections separated, the main parachute was pulled out of the airframe (see Section 3.2.4.2 for more detail). The main parachute deploying at apogee is what caused the total descent time to be nearly five minutes. This is also evident in both Figures 13 and 14, as the slopes are shallow 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 13 and 14. 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.

Currently. OSRT is planning a second subscale launch to verify a new recovery integration design. This new design has been demonstrated with an ejection demonstration, as well as forceful shaking of the main parachute in the deployment bag trying to dislodge it from the airframe. OSRT is confident that this method will provide a successful dual deployment launch.

3.2.1.4 Avionics Data

The ATU ground station malfunctioned and was nonoperational during the launch due to time constraints. The data gathered and plotted by the ground station is actually a subset of the total GPS data which is recorded and stored in its entirety in the SD cards on-board the flight ATUs. Recovery and manual analysis of the 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. This gives a concurrent uptime of more than 9 hours per ATU, with a total uptime of over 10 hours per ATU. Calculations using GPS coordinates - while accounting for their relative inaccuracy - indicate a drift radius of roughly 1 mi.

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. Since PDR, the final design was selected as three trapezoidal fins due to weight savings, however three trapezoidal fins should not present significantly different performance as long as it is properly accounted for in simulations.

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. A 7 ft toroidal parachute was used to match the drag coefficient of the full scale launch vehicle, though a 8 fttoroidal parachute was chosen for the fore section and a 8 fttoroidal parachute was chosen for the aft section.

3.2.3 Launch Day Conditions Simulation

The 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 inHg. Inserting these factors into OpenRocket, the simulated apogee altitude is 3,877 ft for the subscale launch.

3.2.4 Subscale Flight Analysis

3.2.4.1 Parachute Analysis

The parachutes 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 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. [DESCENT TIME DISCUSSION AFTER NEXT LAUNCH]

3.2.4.2 Recovery Integration

Shown in Figure 15 was the intended subscale recovery integration design. [Include image of system that was planned for use]

figures/RecoveryIntegration/InitialSubscaleRecoveryIntegrationDesign.PNG

Figure 15: Initial Subscale Recovery Integration Design

The aft bulkhead has two eye bolts and an ARRD bolted to it with a nyloc nut. Two e-matches were threaded through the bulkhead and placed on the bulkhead with some slack. 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.

At the launch site, OSRT asked for advice from one of the team's mentors, Joe Bevier. 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 16.

[upload a figure of the recovery integration system for subscale]

figures/RecoveryIntegration/SubscaleRecoveryIntegration.PNG

Figure 16: 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 17 is the result of the ejection demonstration.

Figure 17: Subscale Ejection Demonstration

The deployment bag is hanging halfway outside of the airframe and the parachute is partially outside of the deployment bag. Assuming the launch happened the same way as the ejection demonstration, 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 redesigned several times, until OSRT found a design they are confident in.

3.2.4.3 Flight Profile Analysis

The projected altitude of the subscale rocket with launch day conditions was 3,877 ft AGL. The actual subscale rocket achieved an apogee altitude of 3,423 ft AGL. This is a significant undershoot between the projected altitude and the actual altitude. The weight of the subscale rocket was determined after integration testing in the MPRL at Oregon State University (OSU). The weight of the rocket was not measured after assembly at the launch site. The final weight and center of gravity should have been measured after assembling the rocket, right before placing the rocket on the launch rail.

3.2.5 Changes to Full Scale Based on Subscale Flight

Based on the undershoot that the subscale rocket experienced, the full scale projected altitude may need to be increased to avoid undershoot of 4,500 ft. More info after second subscale launch.

3.2.5.1 Structures Changes

3.2.5.2 Parachute Changes

3.2.5.3 Recovery Integration Changes

Shown in Figure 18 is the planned recovery integration system for the second subscale launch. If this launch is 100% successful, this will be the system integrated into the full scale launch vehicle.

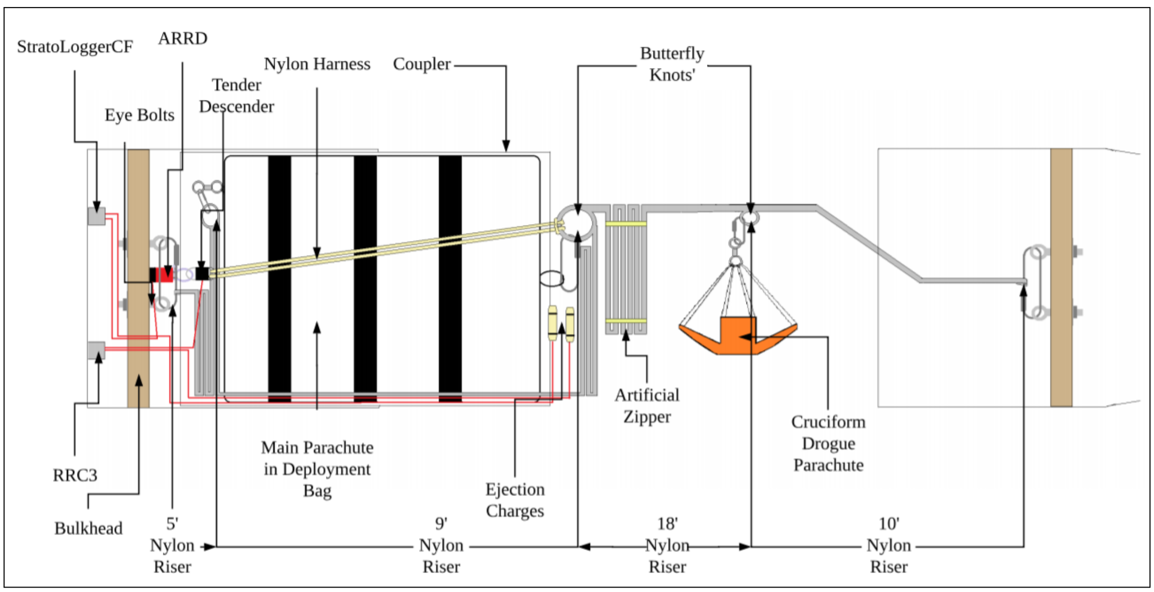

Figure 18: Full Scale Recovery Integration Design

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 rise 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 18

Nothing will be changed with the bulkhead attachment points. Ejection charges will be wired through the bulkhead and sealed in the same way, but these charges will be extended to the edge of the coupler. The eye bolt will still have an extra wide quick link attached to it. The aft loop of the riser will be hooked to this quick link. The main parachute swivel will be attached to a butterfly knot 5 ft down the riser with a quick link. 9 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 18 ft down the riser, and the drogue swivel is attached to this loop with a quick link. The end of the riser is 10 ft further down the riser. This end is attached the fore bulkhead in the same manner as the previous design.

3.2.5.4 Flight Profile Changes

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 a Tender Descender and AARD connected in series. 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.

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 19

Figure 19: Fruity Chutes Toroidal Parachute

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 20

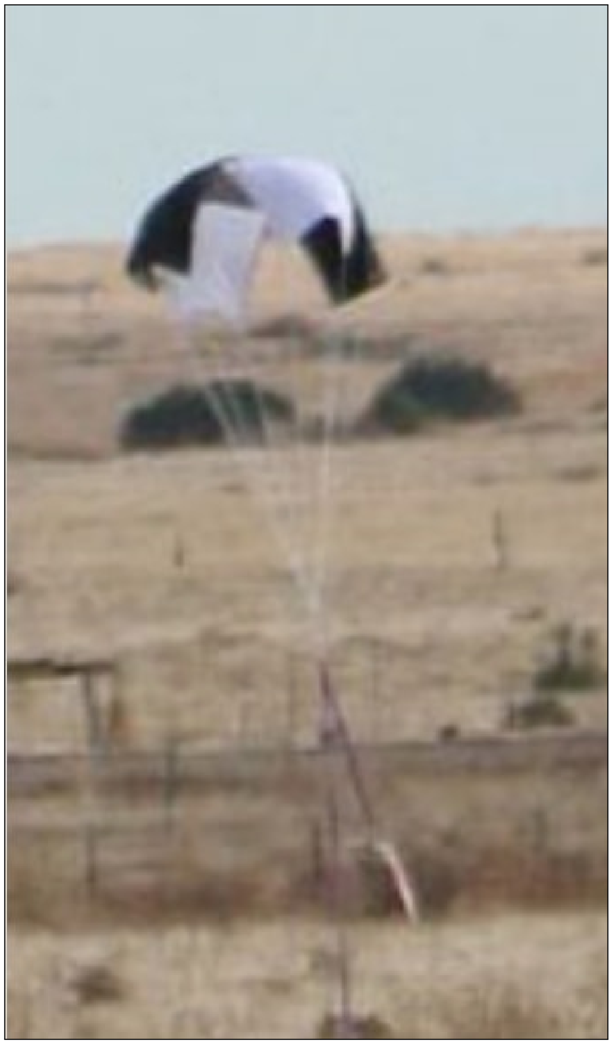

Figure 20: Top Flight Recovery Cruciform Parachute

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 15.

Table 15: 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. 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:

$$\rho = \rho_b[\frac{T_b}{T_b + L_b(h - h_0)}]^(1 + \frac{g_0 M}{R^* L_b}) \tag{2}$$

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 ($b = 0, h < 36,089ft$).

$$KE = \frac{1}{2}mv^2 \tag{3}$$

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

$$D = \frac{1}{2}C_d \rho_{air} v^2 A_r \tag{4}$$

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.

$$A_r = \frac{1}{4}\pi(d_o^2 - d_i^2) \tag{5}$$

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:

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

Plugging equation 6 into equation 4 and solving for the outer diameter gives:

$$d_o = \sqrt{\frac{25W_{lv}}{3\pi \rho_{air} C_d v^2}} \tag{7}$$

To calculate the reference area of the drogue parachutes, Equation 8 was used.

$$A_{xform} = 2DW - W^2 \tag{8}$$

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 torodial and cruciform parachutes that are readily available online, the OSRT decided use a 10 ft toroidal main parachute and a 1.5 ft cruciform drogue parachute for the fore section, and an 8 fttoroidal 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 21.

Figure 21: 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 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. Four altimeters capable of igniting ejection charges will be contained in the launch vehicle: two in the fore section and two in the aft section. A fifth 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 of each will be located in both the fore and aft sections. The fifth altimeter will be a Jolly Logic AltimeterThree.

Missile Works RRC3 has a proven track record at OSU. 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 at OSU 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 foot increments.

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. OSRT is in possession of one of these altimeters, and it will be strapped down in 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.

The StratoLoggerCF 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 StratoLoggerCF altimeters will be connected to the primary ejection charges and the ARRDs. The RRC3 altimeters will be connected to the secondary ejection charges and the Tender Descenders.

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 16 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 16: 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 eye bolt or other attachment point, an ARRD just requires a nut and a hole in the bulkhead. One Tender Descender in series with one ARRD is what has been used in the subscale launch and is what will be used in full scale launches.

3.3.1.9 Reduction of Zippering Chance

In OSRTs PDR submission, it was decided that to reduce the chance the airframe is zippered when the drogue parachute is ejected, an artificial zipper would be implemented. 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 22, 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 22: Artificial Zipper

[Information about how ICE is strengthening the edge of all airframes to reduce the chance of zippering]

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.

3.3.1.11 Ejection Charge Sizing

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

$$BlackPowder(g) = (CompartmentDiameter)^2 * CompartmentLength * 0.006 + 1 \tag{9}$$

$$BlackPowderAft(g) = (6.107in.)^2 * (13.5in.) * 0.006 + 1 = 4.021grams \tag{10}$$

$$BlackPowderAft(g) = (6.107in.)^2 * (14.5in.) * 0.006 + 1 = 4.245grams \tag{11}$$

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 three successful ejection tests are completed in a row.

3.3.1.12 E-matches

Every ejection charge will be ignited with an electric match, otherwise known 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. According to our mentor, Joe Bevier, any 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 bored through 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.

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 serious design considerations 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, omni-directional 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.

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 23 shows the expected flight of the full scale vehicle.

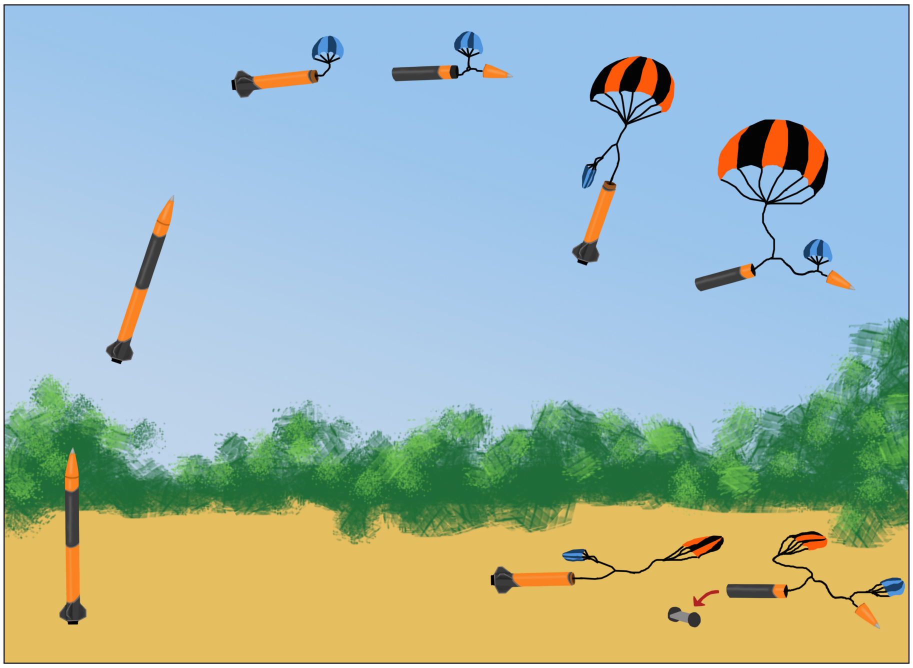

Figure 23: Recovery Separation Events (Not To Scale (NTS))

The two dual deployment systems are nearly identical. The fore system is shown in Figure 24, and the aft system is shown in Figure 25.

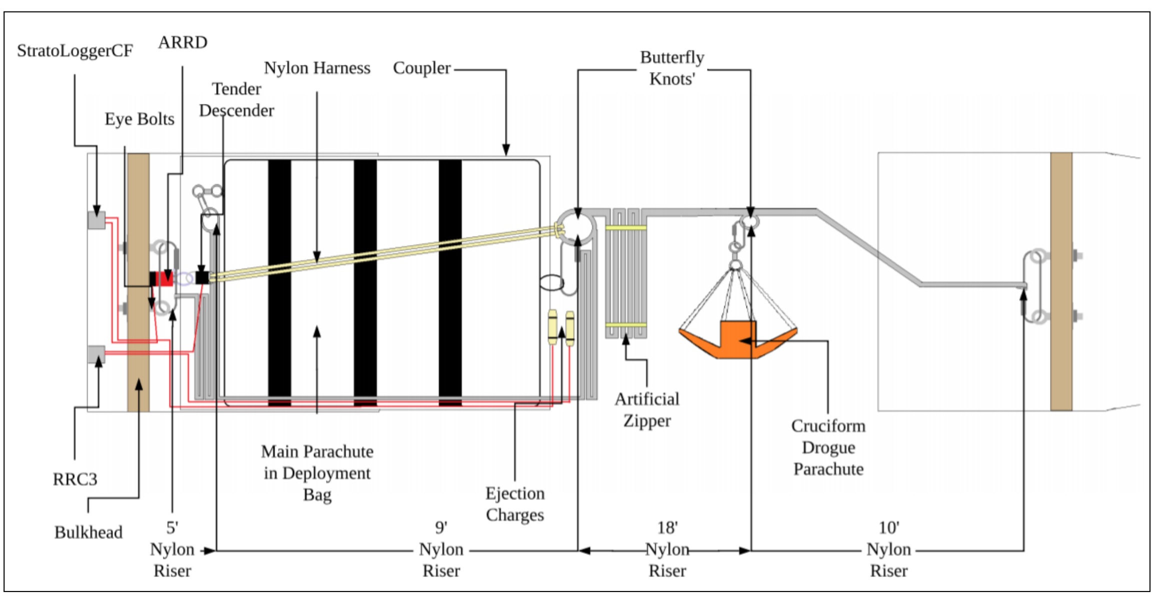

Figure 24: Fore Recovery Integration (NTS)

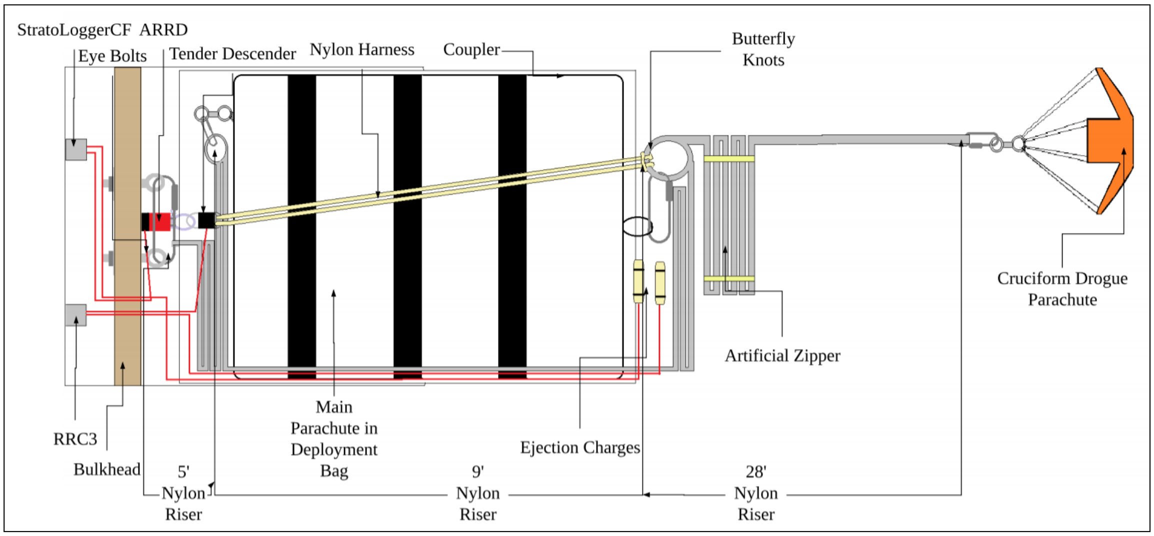

Figure 25: Aft Recovery Integration (NTS)

In the fore recovery system, the aft bulkhead has two eye bolts and an ARRD bolted to it with nylocs. The eye bolts are aligned and located along the center of the bulkhead. The ARRD is offset 90°between the eye bolts. Two e-matches are threaded through the bulkhead and attached to the ARRD and Tender Descender. Two more e-matches attached to ejection charges are threaded through the bulkhead and have one ft of slack. 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. A Tender Descender is attached to the ARRD, and 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 5 ft down the riser with a quick link. 9 ft down the riser 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, which is folded in half, with a cow hitch. The other end of this riser is attached to the Tender Descender. Just past this knot is a nomex heat shield. 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 18 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 10 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 last butterfly is not tied into the riser. Instead, the parachute is attached to the end loop with a standard quick link.

[This section isn't finished and will be subject to change upon the results of the next subscale launch]

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 4856 ftwith no wind. Upon exit of the twelve ft rail, the launch vehicle will be traveling 85.2 ft/s. The launch vehicle will reach apogee in 17.4 s. The 1.5 ftdrogue parachute will deploy at apogee for both the fore and aft sections The 8 ftmain parachute for the fore section and the 8 ftmain parachute for the aft section deploying at 700 ft during descent. With 0 mph winds, both sections will return to the ground 79.5 s after separating at apogee for a total flight time of 96.9 s. With no wind, both sections will hit the ground at 10.2 ft/s. The OpenRocket model can be seen in Figure 26.

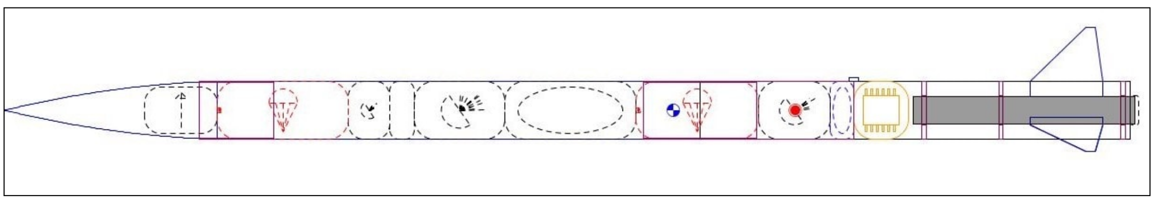

Figure 26: OpenRocket of OSRT Launch Vehicle

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 . The projected altitudes for each of the wind speeds can be seen in Table 17. 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.

Table 17: Altitude Predictions with Varying Wind Speeds

Wind Speed (mph)	Projected Altitude (ft)
0	4856
5	4851
10	4843
15	4812
20	4782

3.4.1.3 Motor Thrust Curve

The motor thrust curve of the Cesaroni L2375-WTused in the OpenRocket simulations can be seen in Figure 27.

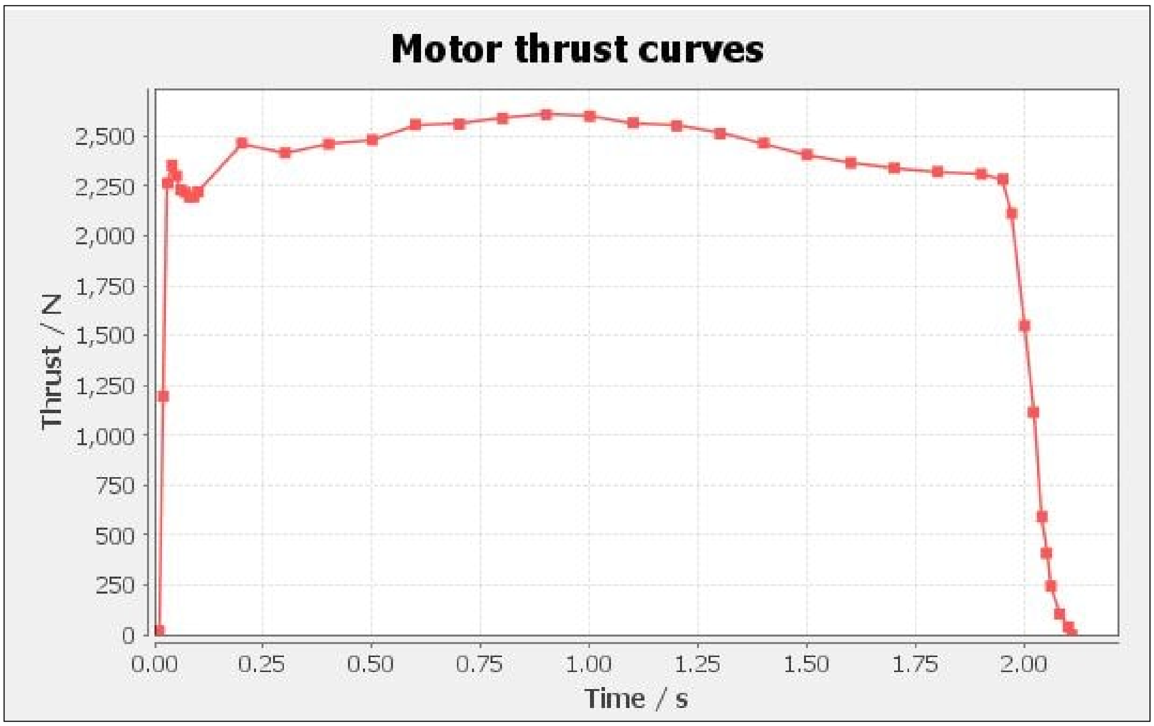

Figure 27: Motor Thrust Curve of Cesaroni L2375-WT

3.4.1.4 Component Weights

The component weights can be seen in Table 18. The components are divided 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	10.81
BEAVS	Mechanical System, Aft Ballast, Electrical System	2.68
Camera	Camera, Fixture, Electronics	0.50
Aft Avionics/Ejection Bay	Avionics, Altimeters, Fixture, Charges	2.33
Aft Parachutes	Drogue Parachute, Main Parachute, Shock Chord, Deployment Bag, Blankets, Connection Hardware	4.20
Payload	Rover, PEARS	8.86
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	4.38
Fore Avionics Bay	Avionics, Fixture	0.65
Nosecone	Fiberglass Nosecone, Aluminum Nosecone Tip	1.54
Fins	Fins, Epoxy	0.96
Aft Airframe	Fiberglass and Carbon Fiber Tube, Fore/Aft Coupler	6.36
Fore Airframe	Fiberglass Tube, Fore/Nosecone Coupler	6.48

3.4.2 Stability Margins

Fins were designed to achieve a stability margin of 2.1 caliberswith the component weights given in Table 18. The OpenRocket model with each component weight and length input gives a center of gravity at 73.83 in. aft of the nosecone tip. Using the optimal fin dimensions (see Figure) to achieve a stability of 2.1, the center of pressure is located 87.30 in. aft of the nosecone tip. The center of gravity can be seen as the blue dot in Figure 26. The center of pressure is represented by the red dot in Figure 26.

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)	22.3	22.7	2.2
Velocity with Main and Drogue Deployed(ft/s)	14.4	13.8	14.4
Kinetic Energy with Main and Drogue Deployed (ft-lbf)	71.7	67.8	7.0
Velocity with Only Drogue Deployed (ft/s)	111.0	105.0	111.0
Kinetic Energy with Only Drogue Deployed (ft-lbf)	4,269.9	3,889.3	421.2
Velocity with no Parachutes Deployed (ft/s)	115.0	112.0	115.0
Kinetic Energy with no Parachutes Deployed (ft-lbf)	4,583.1	4,425.1	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 ftcruciform drogue parachute and a 8 fttoroidal 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 28. It can be seen that both sections land in under 90 s. The exact descent time can be seen in Table 20.

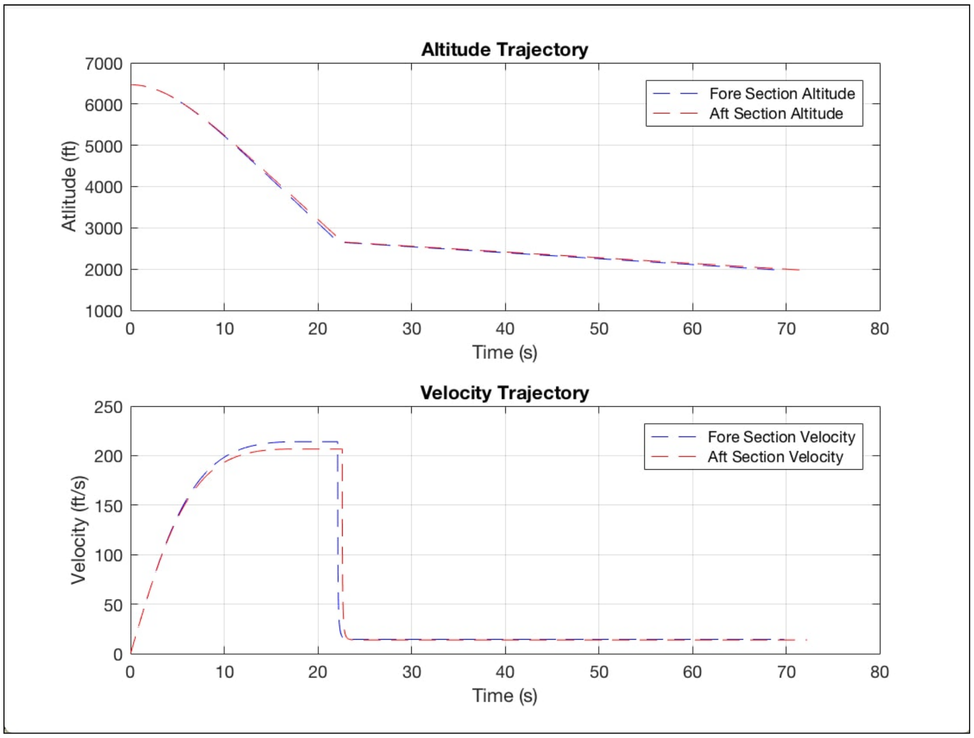

Figure 28: Descent Trajectory

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	512	1,024	1,536	2,046	70
Drift of the Aft Section (ft)	0	520	1,060	1,590	2,119	72
OpenRocket Simulation (ft)	00	00	00	00	00	00

All sections stay within the maximum drift radius of 2,500 ft

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; 5x Jolly Logics; Fore ATU LiPo; Aft ATU LiPo; 2x balance chargers; multimeter; 5x USB hubs; 5x 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. Safety Officer must sign off on 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.
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) Check nosecone coupler for shear pins and remove any found.
11) Inspect BEAVS for any cracks or bends.
12) Inspect motor casing for any marks, dents, or other visible damage.
13) Charge all batteries:
    - 5x Jolly Logic
    - Fore ATU LiPo and record voltage
    - Aft ATU LiPo and record voltage
    - Camera batteries

4.1.2 Pre-flight Inspection

- **Necessary Items:** aft section; fore section; nosecone; coupler; motor casing; motor retainer; de-natured alchohol; paper towels

- Safety Consideration: Remove all objects not related to pre 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 Pre Flight 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 motor retainer for cracks or bends
5) Inspect airframe for dirt and clean
6) Check airframe 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) Check nosecone coupler for shear pins and remove any found
10) Inspect motor casing for any marks, dents, or other visible damage

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:** two 18 in. X-form drogue parachutes, two swivels, and masking tape.
- Safety Consideration: Ensure all sharp objects and flammable materials are removed from workspace. Workspace should be clear of any items not related to harness prep. Failure to follow all steps will result in complete mission failure due to recovery failure

1) Get the 18 in. X-type 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) Make sure shroud lines are untangled
5) Inspect the shroud lines for burns or tears and ensure 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 right left 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 all bundled
   h. Secure the bundle with a piece of blue tape labeled "18 in."; place a red RBF tag under the tape
9) Ensure all masking tape is removed prior to launch. There is one piece of tape on the drogue parachute

- Safety Consideration: Check the drogue packing looks correct, and that a REMOVE BEFORE FLIGHT tag is placed under the tape holding it closed

Repeat these steps for the fore and aft drogue parachutes.

4.1.3.2 Main Parachute

- **Necessary Items:** Two 96 in. standard iris parachute, 5.5 in. by 7 in. deployment bag, masking tape, and two swivels
- Safety Consideration: Ensure all sharp objects and flammable materials are removed from workspace. Workspace should be clear of any items not related to harness prep. Failure to follow all steps will result in complete mission failure due to recovery failure

1) Grab shrouds by 2 bundles at collector
2) Lay out parachutes so that each set of shrouds is on either side of the collector
3) Separate shroud lines into a right, left and middle sections
4) Ensure there are 4 shroud lines for the left and right, and 5 shroud lines for the middle
5) Wrap tape around the right shroud lines to keep them together
6) There are 4 middle shroud lines that are not the main middle shroud line, there are 2 on top and 2 on bottom. Take 2 lines that are opposite and diagonal of each other and place them on top of each other on the middle shroud line. This is now your center line
7) Ensure that on this center line, different colored canopy sections are lined up together.

8) Pull the top middle section of the canopy down towards the bottom diameter and ensure the center line is maintained through the entire canopy
9) Take the closest gore and fold the farthest edge onto the center line. Repeat this process for one side of the canopy until there are no more gores to fold.
10) Take the closest gore on the other side and fold the farthest edge onto the center line. Repeat this process for this side of the canopy unit there are no more gores to fold.
11) Ensure that the canopy is folded in a way that divides the canopy into 2 separate, different colored sections
12) Flatten the folded canopy as much as possible by pushing out all the air
13) Fold the right side of this canopy in half by taking the furthest edge of the outside and folding it onto the center line
14) Fold the left side of this canopy in half by taking the farthest edge of the outside and folding it onto the center line
15) Fold the left side of this canopy in half by taking the farthest edge of the outside and folding it onto the center line
16) Ensure the canopy is now divided into 2 sections of different colors.
17) Make one more fold down the center line, folding one side of the canopy onto the other.
18) Ensure the canopy is folded into a long thin rectangular shape with the shroud lines and shock cord attached to the end of the thin side of the rectangle
19) Place the folded canopy into the deployment bag with the shock cord side facing out. Insert into the deployment bag by compressing the canopy until it fits. Make no more fold in the canopy.
20) Secure the blanket to the collector bridle with a 2' Kevlar cord looping through the blanket hole and the top of the swivel
21) Fold excess shroud lines into the exterior bands in the deployment bag.
22) Ensure all masking tape is removed prior to launch. There are two on the shroud lines.

- Safety Consideration: Check the drogue packing looks correct, and that a REMOVE BEFORE FLIGHT tag is placed under the tape holding it closed

Repeat these steps for the fore and aft main parachutes.

4.1.3.3 Recovery Harness

- **Necessary Items:** Two Packed 18 in. X-type drogue assemblies; masking tape; four RBF tag; two 96 in. Iris Ultra main packed in a deployment bag assembly; two 18" x 18" parachute blast protector; sharpie; two 2 ft. Kevlar cord; two 14 yd. nylon shock cord; 6 standard quick links; 3 extra wide mouth quick links; two Kevlar shock cord sleeve.

- Safety Consideration:Check the main packing looks correct, and that a REMOVE BEFORE FLIGHT tag is placed under the zip-tie holding it closed
- **Note:** If the fore or aft launch vehicle section is not specified, do the given step for both harnesses.

1) Get two 14 yd. nylon shock cords
2) Inspect the shock cord for any tearing or excessive scorching; inspect the butterfly loops (if still tied) for any stressed areas.
3) For the fore section harness, tie a single butterfly loop located 10 feet from the nosecone end loop. Ensure the Kevlar sleeve is on the longer side of the harness before the knot is tied. This loop is for the drogue. For the aft section harness, disregard this step - the end loop will be used to connect the drogue parachute.
4) Tie a single butterfly loop located 18 feet from the first drogue loop. This is for the deployment bag. For the aft harness, tie a butterfly knot 28 feet from the drogue end loop.
5) Ensure the Kevlar sleeve is between the drogue butterfly knot and the deployment bag butterfly knot.
6) Tie a single butterfly loop located 9 feet from the deployment bag loop on both harnesses. This is for the main parachute.
7) Check that there is about 5 feet left of cord between the end loop and the last butterfly knot.
8) Tape an artificial zipper along the shock cord between the drogue butterfly loop and the deployment bag butterfly loop. The artificial zipper should be 6 thicknesses of the shock cord.
9) Place drogue swivel on a standard quick-link, and put the quick-link through the drogue butterfly loop. Ensure quick link is tightened all the way down.
10) Place main swivel on a standard quick-link, and put the quick-link through the main butterfly loop. Ensure quick-link is tightened all the way down (hand tightness).
11) Ensure the other Kevlar sleeve is between the main parachute butterfly knot and the end loop.
12) Attach a wide-mouth quick link to the end loop of the harness
13) Connect a 2 ft Kevlar cord to the deployment bag butterfly knot with a cow hitch.
14) Connect a standard quick link to the deployment bag butterfly knot and the top loop of the deployment bag
15) Secure the top and bottom of both Kevlar sleeves to the bridle with blue tape
16) Place an 18 in. x 18 in. Parachute Blast Protector over the Kevlar sleeve so that it rests in between both ends of the Kevlar sleeve

4.1.4 ARRD Assembly

- **Necessary Items:** 1/4-28" nut and washer, toggle, ejection charge canister, five (5) 1/4" ball bearings, spring assembly, red body aluminum housing, 4F Black Powder, e-match, Black Powder Funnel, Small Black Powder Vial, Scale, Measuring Triangle, Wrench set.

- Safety Consideration: All steps to be carried out by High Powered Rocketry (HPR) level 1 certified team member.
- Safety Consideration: S Process includes usage of black powder, follow Black Powder Handling for proper handling procedure.
- Safety Consideration: Ensure all team members in close proximity wear safety glasses to avoid black powder contacting the eyes.
- Safety Consideration: Ensure all ignition sources have been removed from the area.
- Safety Consideration: Make sure the multimeter is set to measure Ohms before checking the charges. Failure to do so may result in injury due to premature charge ignition.
- Safety Consideration: Failure to load correct charge may result in a failed ejection of payload.

1) Unscrew base and remove toggle.
2) Place the 5 ball-bearings in red body aluminum housing.
3) Place toggle assembly into red body, push piston into body, securing toggle.
4) Measure 0.3g of 4F Black Powder using the small black powder vial.
5) If the small black powder vial is missing, ensure the scale is measuring in grams.
6) If the small black powder vial is missing, ensure the scale has been zeroed to include the measuring triangle.
7) If the small black powder vial is missing, measure 0.3g of black powder for the charge.
8) If the small black powder vial is missing, record mass.
9) Verify e-match resistance is between 1.3-1.7 Ω.
10) Record Resistance.
11) Place e-match into cartridge.
12) Pour 0.3g of 4F Black Powder into cartridge.
13) Safety Consideration: Confirm that Black Powder is sealed within the ejection canister.
14) Screw assembly base and red body housing together.
15) Physically ensure that toggle is secured to ARRD.

4.1.5 Tender Descender Assembly

- **Necessary Items:** 2 Quick Links, Aluminum Housing, Link Retainer Assembly (connected to housing by Kevlar lanyard), U-Bolt Assembly (secured to Payload fixed bulkhead), 2 e-matches (plus spares)*, 4F Black Powder*, Hot Glue Gun, Putty, Gloves, Black Powder Funnel, Small Black Powder Vial, Scale, Measuring Triangle.
- Safety Consideration: All steps to be carried out by HPR level 1 certified team member
- Safety Consideration: Process includes usage of black powder, follow Black Powder Handling for proper handling procedure.

- Safety Consideration: Ensure all team members in close proximity wear safety glasses to avoid black powder contacting the eyes.
- Safety Consideration: Ensure all ignition sources have been removed from the area.
- Safety Consideration: Make sure the multimeter is set to measure Ohms before checking the charges. Failure to do so may result in injury due to premature charge ignition.
- Safety Consideration: Failure to load correct charge may result in a failed ejection of payload.
- Safety Consideration: Confirm that Quick Links have been threaded completely closed.

1) Verify e-match resistance is between 1.3-1.7 Ω.
2) Record Resistance.
3) Thread Kevlar shock cord through one attachment Quick Link.
4) Install e-match into aluminum housing.
5) Use hot glue gun to create a pressure seal.
6) If there is no hot glue gun, use putty to create a pressure seal.
7) Safety Consideration: Use gloves when handling putty to avoid contact with skin.
8) Measure 0.3g of 4F Black Powder using the small black powder vial.
9) If the small black powder vial is missing, ensure the scale is measuring in grams.
10) If the small black powder vial is missing, ensure the scale has been zeroed to include the measuring triangle.
11) If the small black powder vial is missing, measure 0.3g of black powder for the charge.
12) If the small black powder vial is missing, record mass.
13) Pour 0.3g of 4F Black Powder into ejection canister.
14) Safety Consideration: Confirm that Black Powder is sealed within the ejection canister.
15) Set aside assembled ARRD away from all ignition sources until the payload is ready.
16) Install Quick Link with shock cord tether attachment to U-Bolt which is fixed to the bulkhead.
17) Fix alternate Quick Link to Payload Ejection Harness sewn loop.

4.1.6 Ejection Charge Assembly

The actual ejection charge assembly list will repeat the following process for all six ejection charges. As the charge sizes have not been finalized through ground testing, the following procedure has the charge sizes listed as X.X.

- **Necessary Items:** Multimeter; 6 e-matches; pre-cut Santoprene; scissors; surgical tubing; 12 long zip ties; scale; batteries for scale; measuring triangle; 1/4 container of 4F black powder; funnel; sharpie; 6 in. masking tape; spray paint.
- Safety Consideration: Ensure all team members in close proximity wear safety glasses to avoid black powder contacting the eyes.

- Safety Consideration: Ensure all ignition sources have been removed from the area.
- Safety Consideration: Make sure the multimeter is set to measure Ohms before checking the charges. Failure to do so may result in injury due to premature charge ignition.
- Safety Consideration: Failure to load correct charge may result in a failed ejection at apogee.

1) Test each e-match resistance with a multimeter.
2) Verify e-match resistance is between 1.3-1.7 Ω.
3) Record Resistance of each e-match.
4) Cover ends of e-match leads with masking tape.
5) Cut 12x pieces of Santoprene rubber rod into approximately 0.75 in. lengths using scissors.
6) Cut 6x pieces of surgical tubing into lengths of approximately 4.5 in. using diagonal cutting pliers.
7) Insert a piece of Santoprene into one end of each piece of surgical tubing.
8) Secure Santoprene in each piece of surgical tubing by tightening a long zip tie around the outside of the surgical tubing and Santoprene with pliers.

- Safety Consideration: Failure to measure in grams will result in wrong sizing of BP charges.

1) Ensure the scale is measuring in grams.
2) Ensure the scale has been zeroed to include the measuring triangle.
3) Measure X.X g of black powder for the Fore Primary charge.
4) Record Mass of Fore Primary charge.
5) Insert funnel into the open end of a surgical tubing set-up.
6) Pour approximately X.X g of black powder into the Primary surgical tubing set-up.
7) Remove funnel.
8) Slide the red covering around the tip of the e-match down the blue and white wire about 12 inches.
9) Insert the tip of the e-match into the black powder in the surgical tubing set up.
10) Insert funnel into the open end of a surgical tubing set-up, making sure the e-match is in the shaft along the neck of the funnel.
11) Pour the remaining black powder into the surgical tubing set-up.
12) Remove funnel.
13) Insert a piece of Santoprene into the open end of the Primary surgical tubing set-up, ensuring that there is no open room between the black powder and the Santoprene.

- Safety Consideration: Allowing extra room in black powder charges will result in failed ejection.

1) Ensure that there is no extra room in the charge by squeezing the outside. It will be firm if the black powder has been packed correctly.
2) If there is extra room in the charge, push the piece of Santoprene that has not been zip tied down further into the surgical tubing until the black powder is packed down.

3) Secure piece of Santoprene that has not been zip tied by tightening a long zip tie around the outside of the surgical tubing and Santoprene with pliers.

- Safety Consideration: Failure to check zip tie tightness may result in failed ejection during recovery.

1) Double check that the zip ties are secured as tightly as possible using pliers.
2) Remove zip tie tails using scissors.
3) Write "Fore Primary" with the mass of the black powder on the outside of the surgical tubing in permanent marker.
4) Twist the first 12" from the leads of the e-match wires loosely.
5) ...list continues for each additional charge

4.1.7 Fore Avionics Bay Assembly

Table 21: Fore Avionics Assembly

Materials Required	Tools Required	PPE Required
Avionics PCB	Side cutters	Fume extractor
Teensy 3.6	Leaded 60/40 solder	Anti-static grounding strap
SparkFun Venus GPS Module	Soldering iron	Safety glasses
Xbee Pro 900hp	Flux	
1x Deans connectors	Wire Strippers	
2 port terminal blocks	Small flathead screwdriver	
Female headers	Helping Hands	
High strand count 22awg wire	Isopropyl alcohol	
LM1085-5 Low Drop Out Regulators (LDO)	Anti-static work mat	
LM1085-3.3 LDO	Needle nose pliers	
MS5803		
MPL3115 Barometer		
ADXL377 Accelerometer		
MNO055 9DOF IMU		
12x 4700p ceramic disk capacitors		
7 in. RPSMA whip antenna		
Active GPS antenna		
Fore Avionics sled		
Turnigy 2200mah LiPo		
4x M2 screws and nuts		

- Safety Consideration: Before soldering, unsure safety glasses and grounding strap are worn and that fume extractor is positioned to collect any fumes that may be created when soldering.

1) Solder capacitors into respective places according to ATU/Data Logging Module (DLM) schematic and silkscreen descriptor.

2) Solder LDO's into respective places ensuring that the metal backing is in contact with the PCB according to ATU/DLM schematic and silkscreen descriptor.
3) Solder female pin headers for each breakout board that will be placed on the PCB according to ATU/DLM schematic.
4) Solder terminal blocks onto connection locations according to ATU/DLM schematic.

- Safety Consideration: After soldering clean solder joints with isopropyl alcohol.

1) Cut and crimp 5 in. of wire and insert them into the deans connectors taking care to ensure the correct connections that correspond with the correct supply rails from the batteries.
2) Insert all Integrated Circuit (IC) breakout boards into respective female header socket according to ATU/DLM schematic.
3) Screw RPSMA whip antenna onto Xbee Sub-Miniature Version A Connector (SMA) connector.
4) Screw active GPS antenna onto Venus GPS module SMA connector.
5) Fasten assembled system onto the fore avionics mounting sled according to ATU/DLM schematic using 4 M2 screws and nuts.
6) Repeat steps 1-11 to assemble second ATU/DLM.
7) Install assembled ATU/DLM on threaded rod until the sled hits the washer and locknut.
8) Install pressure sealing bulkheads into the nosecone until the seal is pressed against the avionics sled.
9) Secure the bulkheads with a locknut.
10) Tighten all six outer pressure sealing bolts to create a pressure seal.

4.1.8 Fore Ejection Bay Assembly

Table 22: Fore Ejection Bay Assembly

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

- Safety Consideration: Only members with HPR Level 1 certifications will handle black powder.
- Safety Consideration: Black powder charges should be assembled a significant distance away from any ignition 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) Back off the switches by one quarter turn.
7) Insert charge leads through the fore ejection pressure seal.
8) Cut extra leads leaving approximately two in. to connect.
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) Install the fore ejection body wall over the fore ejection bay.
13) 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.

1) Check that the altimeter switches are accessible from the exterior of the airframe through the static port hole.
2) Secure the fore ejection bay with a locknut.
3) Compress the sealing bulkheads by tightening all six sealing bolts.

4.1.9 Aft Electronic Bay Assembly

Table 23: Aft Electronic Bay Assembly

Materials Required	Tools Required	PPE Required
Aft Altimeters PCB	Multimeter	Safety glasses
2 black powder charges (primary and secondary)	Small flat-head screwdriver	
Aft altimeters sled	Phillips-head screwdriver	
Aft body wall	7/16 in. socket	
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 assembled a significant distance away from any ignition 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) Back off the switches by one quarter turn.
7) Insert charge leads through the aft ejection pressure seal.
8) Cut extra leads leaving approximately two in. to connect.
9) Insert the leads into the appropriate terminals.
10) Secure leads by tightening terminal screws.
11) Screw pressure sealing washer onto the aft side of the pressure seal. Check that all leads are sealed by the washer.
12) Install the aft ejection body wall over the aft ejection bay.
13) Secure the aft avionics to aft of the aft ejection body wall.
14) 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.

1) Check that the altimeter switches are accessible from the exterior of the airframe through the static port hole.
2) Secure the aft ejection bay with a locknut.
3) Compress the sealing bulkheads by tightening all six sealing bolts.

4.1.10 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.

1) Check battery voltage and charge of ATU LiPo, 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 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.

4.1.11 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 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.

4.1.12 Aft Section Preparation

Necessary Items: aft section; motor retainer; de-natured alchohol; 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

4.1.13 Nosecone / Fore Section Preparation

4.1.14 Recovery Integration

4.1.15 Motor Preparation

- **Necessary Items:** Propellant grains; motor casing; forward and aft closure;
- Safety Consideration: Only National Association of Rocketry (NAR) 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 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

4.1.16 Final Assembly

- **Necessary Items:** Fully assembled aft section; fully assembled fore section; 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.

1) Safety Consideration: Ensure no open flames or sparks are in the area.
2) Safety Consideration: Failure to follow all steps will result in complete mission failure due to recovery failure.
3) Safety Consideration: Recovery failure will cause hazards to nearby people and to the environment.
4) Prepare the fore section according to fore section assembly checklist.
5) Prepare aft section according to the aft section assembly checklist.
6) Press the fore section onto the aft section using marks to align.
7) 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.

8) Screw in the fore section using 3x 2-56 nylon screws.

4.1.17 Launch Pad Setup

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
4) Safety Consideration: Failure to align launch vehicle buttons with rail may cause the breaking of these components and failure in launch
5) Carefully slide launch vehicle onto launch rail, ensure co-linearity with launch rail
6) Safety Consideration: Verify specified angle of launch rail before locking in place
7) Bring launch rail to specified angle as per RSO instructions
8) Safety Consideration: Only two team members shall be present for the arming of altimeters to ensure no distractions during the process
9) All but two team members leave launch pad for arming of altimeters
10) Setup the step stool
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) 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

14) 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
15) Bring all material back to setup area

4.1.18 Igniter Installation

Instructions written down on checklist form.

4.1.19 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. Create new ejection charge with a new igniter
   e. Check new igniter resistance
3) Payload 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. Create new ejection charge with a new igniter
   e. Check new igniter resistance
4) Igniter continuity failure
   a. Use back up igniter
   b. If this one fails
      i. Disarm all active charges
      ii. Pull launch vehicle from launch pad and return to assembly area
5) Launch vehicle does not fire upon button press
   a. Wait for Range Safety Officer (RSO)
   b. Follow RSO directions for dealing with misfire
6) RSO calls off launch for safety violation
   a. Disarm all active charges
   b. Pull launch vehicle from launch pad and return to assembly area
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

4.1.20 Post-flight Inspection

4.2 Safety and Environment

4.2.1 Hazard Analysis

In Table 24 is the Hazard Analysis that OSRT has developed for the mission.

Table 24: Hazard Analysis

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Fin Breaks	Bad landing; improper parachute deployment; bad travel; high in-flight stresses.	Unpredictable flight path; no flight path; falling pieces of carbon fiber.	1C	Make fins easily replaceable; design for rigidity; secure properly.	Drop launch vehicle aft from a high location onto dirt; perform general stress/bend tests.	1D
Motor Mount fails	weak adhesion; weak retention; improper motor specification for the retention method.	Motor could destroy launch vehicle; unpredictable flight path.	2D	Use excess adhesive; use retention methods that have a low failure rate; implement extra retention.	Test thrust on a thrust stand to determine that the motor mounts will contain the motor.	2E
Bulkheads Detach	Poor application of epoxy; hard point detaches; internal components not attached.	Parachutes will have no effect on descent time; falling projectile.	1C	Application of sufficient epoxy based on manufacturer recommendations.	Compression test the epoxy with Instron machine.	1E
Ejection Charges Fire	Static charges build up due to friction against the inner wall of the airframe during integration.	The ejection charges fire during integration and present a danger to those assembling the launch vehicle.	1C	Use a single pull double throw shunting switch to the circuit to ground any static charges.	Test voltage across circuit without charges.	1E

Continued on next page

Table 24 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Fiberglass/Carbon Fiber Particle Contact	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 3.1.3.1.	4B
Launch Vehicle Fails to Lift Off from Rail	Damage to the launch rail or launch lug	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
Early Motor Ignition	Motor ignites before ignition start	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. Only qualified personnel has been identified.	2D

Continued on next page

Table 24 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Unstable Flight	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 RASAero will be used to identify center of pressure to calculate static stability margin.	2E
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

Continued on next page

Table 24 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
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 RasAero II 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
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

Continued on next page

Table 24 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
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
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

Continued on next page

Table 24 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
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 RasAero II 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 the sections of the Tender Descenders.	3D

Continued on next page

Table 24 – 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

Continued on next page

Table 24 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
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 RasAero II to ensure center of pressure location is fore of BEAVS blade deployment location.	3E
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 RasAero II 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

Continued on next page

Table 24 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
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 6.2.4.1 shows mechanical failure will not occur	2E
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 Section 4.1.6 by certified L1 members and aware from any heat or electrical source.	2E

Continued on next page

4.2.2 Failure Modes and Effects Analysis

4.2.2.1 Structures Failure Mode Effects Analysis (FMEA)

In Table 25 is the Structures FMEA that OSRT has developed for the mission.

Table 25: 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.
	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

Continued on next page

Table 25: Structures FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
	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, do 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
Fins	Fins 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 can move

Continued on next page

Table 25: Structures FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
				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 relaunchable	8	Forces experienced by the rocket create enough bending shear that the materials fail	4	3	96	Composites layed-up in directions of highest load with enough thickness to resist the loading
Bulkhead	Epoxy failure	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 stored improperly	3	6	144	Store plywood in cool, dry areas and handle with care

Continued on next page

Table 25: Structures FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
				Low quality plywood	3	8	192	Select plywood from reputable sources, select best looking plywood
	Fracture or shatter	Internal components damaged, launch vehicle unrecoverable, debris injuring spectators, debris littering property	8	Threaded rod excess force	2	2	32	Use thick plywood and large washers to be able to withstand the force
Threaded Rod	Fail 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 2 for the entire system
	Strips hardpoints	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 hardpoint mountings	2	4	72	Design the hole depth in hardpoints 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

Continued on next page

Table 25: Structures FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
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	Weak camera casing design	1	4	32	Testing will be done on the camera casing to ensure a robust design
	Not all cameras are turned on	Will not capture full 360 without all cameras on and running	7	Dead battery	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.

Continued on next page

Table 25: Structures FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
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 26, 27, and 28 are the Aerodynamics, BEAVS and Recovery Failure Mode Effects Analysis (FMEA) that OSRT has developed for the mission.

Table 26: 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 27: 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 28: 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.

Continued on next page

Table 28: 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.

Continued on next page

Table 28: 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.

Continued on next page

Table 28: 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.

Continued on next page

Table 28: 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.

Continued on next page

Table 28: 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 29 is the Payload FMEA that OSRT has developed for the mission.

Table 29: 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.

Continued on next page

Table 29: 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.

Continued on next page

Table 29: 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.

Continued on next page

Table 29: 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

Continued on next page

Table 29: 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 30 are the Environmental Hazards that OSRT have developed for the mission.

Table 30: Environmental Hazard Analysis

Hazard	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Verification**	**Post-RAC**
Shrapnel	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 3.1.3.1.	4B
c Ice Forms on Airframe Exterior	Ice forms on airframe seperation 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.	4B

Continued on next page

Table 30 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Faulty batteries	Faulty 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
Damage to electronics	Excessive moisture	Corrosion of terminals or shorted electronics	2C	Limit exposure to humid environments	All electronics will be stored in a cool, dry place when not in use; test all electronics immediately before use	2E
Damage to environment	Generation of non-degradable manufacturing waste	Contribution to greenhouse gases	3B	Purchase only necessary material; recycle waste; dispose of hazardous material properly.	Waste and excess material will be disposed of based on machine shop specifications or, if feasible, kept as stock to be reused.	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 chassis of the rover, shown in Figure 29, has a simple truss design that gives the rover strength while leaving room for hands to easily access components inside. The front and back sides of the rover are identical triangular trusses, shown in Figure 30, made out of aluminum connection blocks and 1/4 in. diameter carbon fiber rods. The front and back are connected with carbon fiber cross rods at each of the truss connection blocks. Both the truss rods and the cross rods are attached to the connection blocks by both a press fit and epoxy for solid connections.

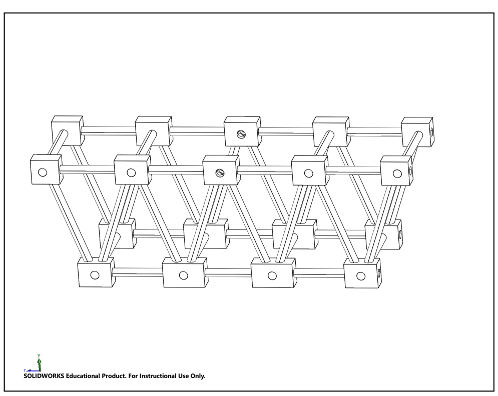

Figure 29: Chassis Assembly

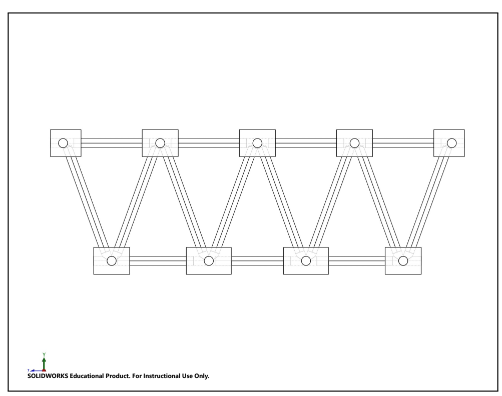

Figure 30: Side Truss Design

To minimize weight while maximizing strength, three types of connection blocks are used throughout the truss. The connection block used most is called Block 1, and it is the medium size block shown in Figure 31. The largest connection block, shown in Figure 32, is called Block 2 and it is used as extra support for the center of the truss. In the corners where only two rods meet, less support is needed so the smallest connection block, Block 3 shown in Figure 33, is used.

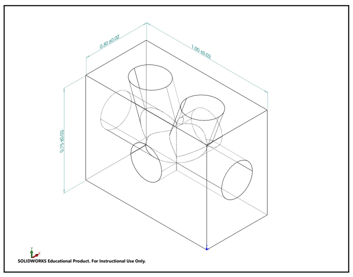

Figure 31: Connection Block 1

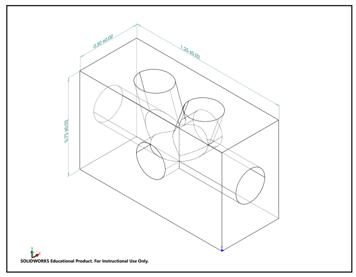

Figure 32: Connection Block 2

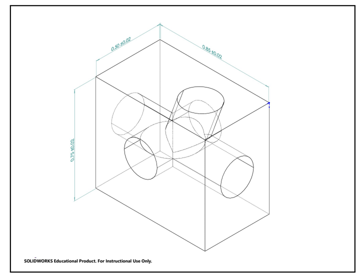

Figure 33: Connection block 3

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 34 and an exploded view is shown in Figure 35. Every part will have an identical counterpart on the other half of the rover.

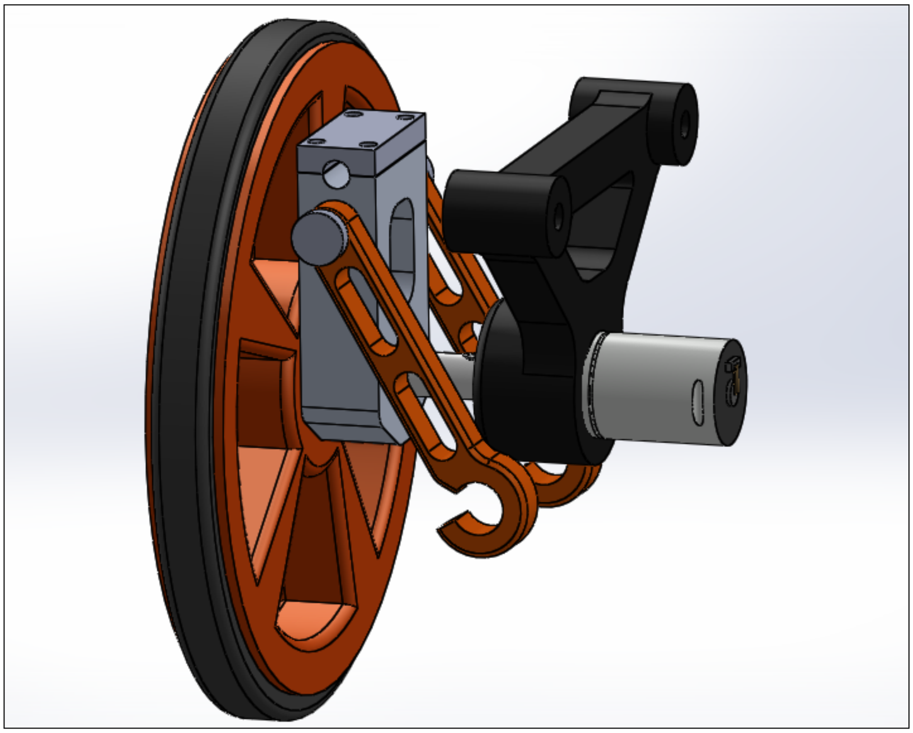

Figure 34: Drivetrain Assembly

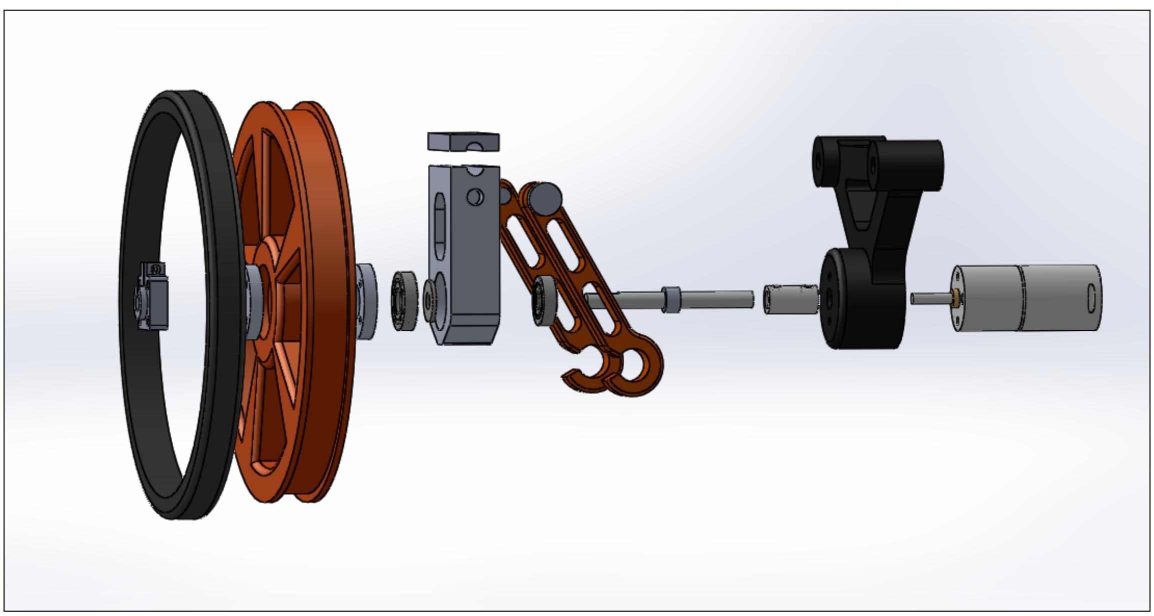

Figure 35: Drivetrain Assembly Exploded View

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 31 were considered.

Table 31: 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 12 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.

$$T = mr[a + gsin(\beta)] \tag{12}$$

The rover's weight is 5.729 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 32.

Table 32: 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 Acrylonitrile Butadiene Styrene (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 0.25 in., a coupling is necessary. ServoCity offers stainless steel set screw shaft couplings, which the team will use for this purpose.

The 2.550 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 36.

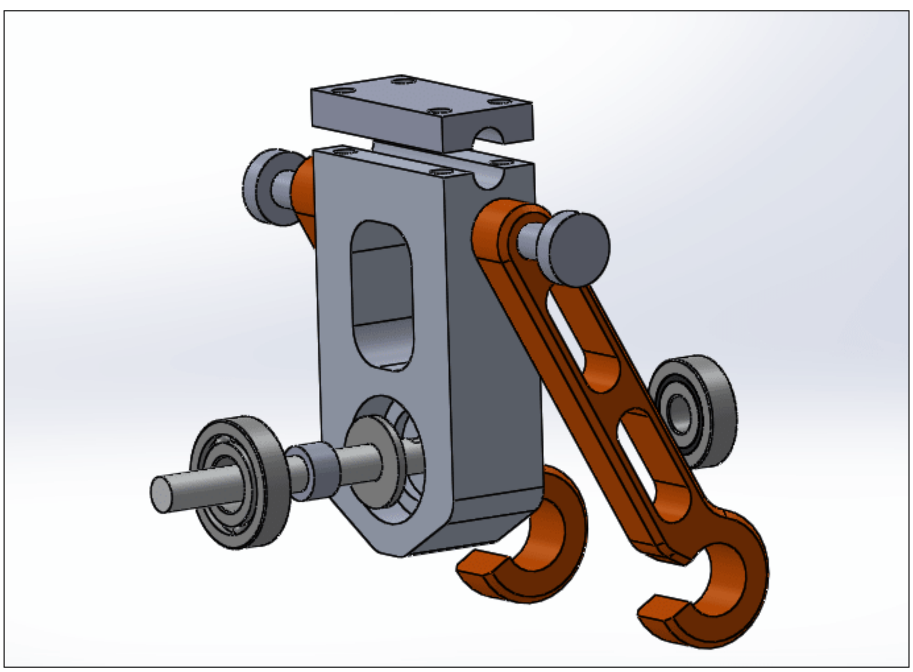

Figure 36: Drivetrain Mounting Block Assembly

The mounting block assembly houses a three-piece bearing assembly. These components are described from inside to outside in Table 33. The purpose of the ball bearings is to allow unrestricted rotation of the drive shaft. 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 33: 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 34.

Table 34: Drivetrain Assembly Weight

Component	Expected Unit Weight (lbf)	Quantity	Expected Total Weight (lbf)
170 RPM Econ Gear Motor	0.203	2	0.406
Motor Mount	0.140	2	0.280
Shaft Coupling	0.022	2	0.044
Drive Shaft	0.013	2	0.026
Mounting Block Bottom	0.190	2	0.380
Mounting Block Top	0.022	2	0.044
Mounting Block Extension	0.006	4	0.024
Connecting Rod	0.018	4	0.072
Outer Ball Bearing	0.020	2	0.040
Thrust Washer	0.005	2	0.010
Inner Ball Bearing	0.020	2	0.040
Wheel Hub Plate	0.015	4	0.060
Tire	0.096	2	0.192
Wheel	0.376	2	0.752
Clamping Hub	0.016	2	0.032
6-32 UNC Screw	0.006	8	0.044
M3-0.5 Screw	0.002	4	0.007
10-32 UNF Screw	0.007	8	0.054
6-32 Locknut	0.002	8	0.016
Subsystem Total		**2.523 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 35 is a summary of the final design decisions.

Table 35: 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 37.

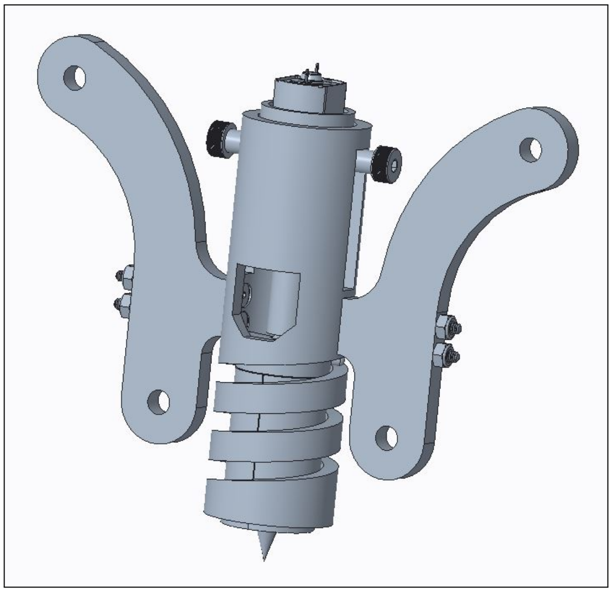

Figure 37: Soil Collection Assembly

The basic components for the Soil Collection system are the auger, auger bar, coupler, and motor, displayed in Figure 38. 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 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.

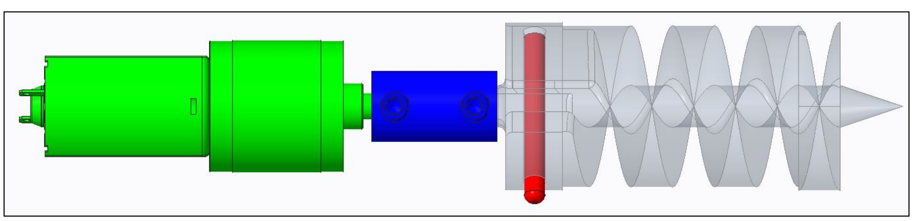

Figure 38: Soil Collection basic components

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 39. This component is made of aluminum to be lightweight while also retaining the ability to have threaded holes.

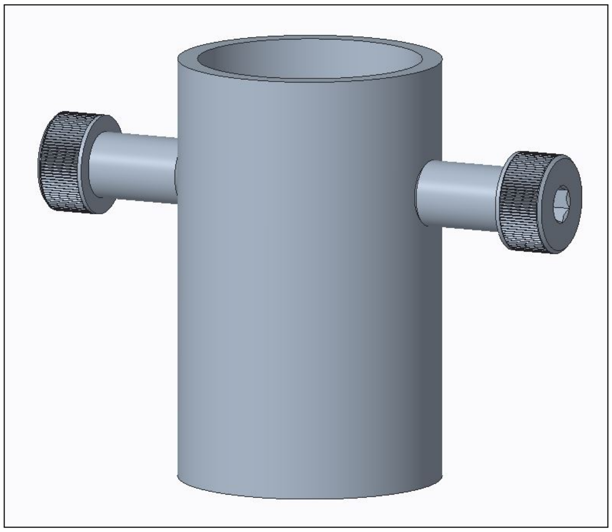

Figure 39: Motor Enclosure and bolts for the Soil Collection Assembly

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 40 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.

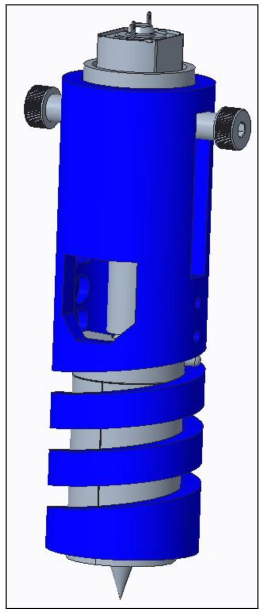

Figure 40: Auger Tube surrounding the Soil Collection basic components

The Soil Collection system is mounted to the chassis using a mounting fixture (colored blue) shown in Figure 41. 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.

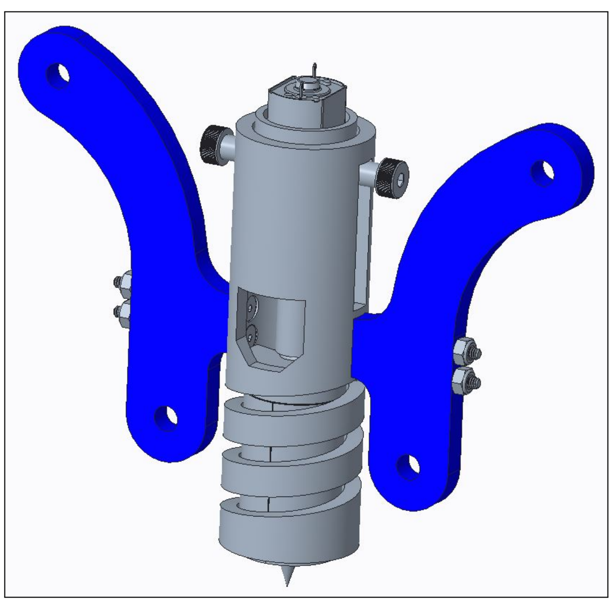

Figure 41: Mounting fixture for the Soil Collection system

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 during rover ejection. The FEA with the two 900 lbf is shown in Figure 42 with the stress indicated next to the component in psi. The yield strength of PLA plastic is 8,840 psi.

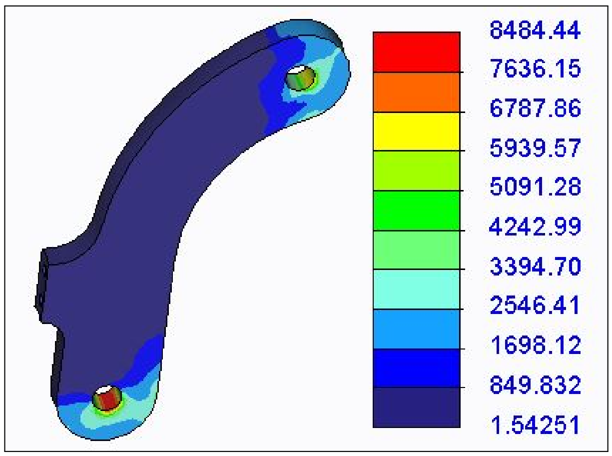

Figure 42: FEA for a mounting fixture

5.2.3.2 Soil Retention

The Soil Retention system is shown in Figure 43. 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.

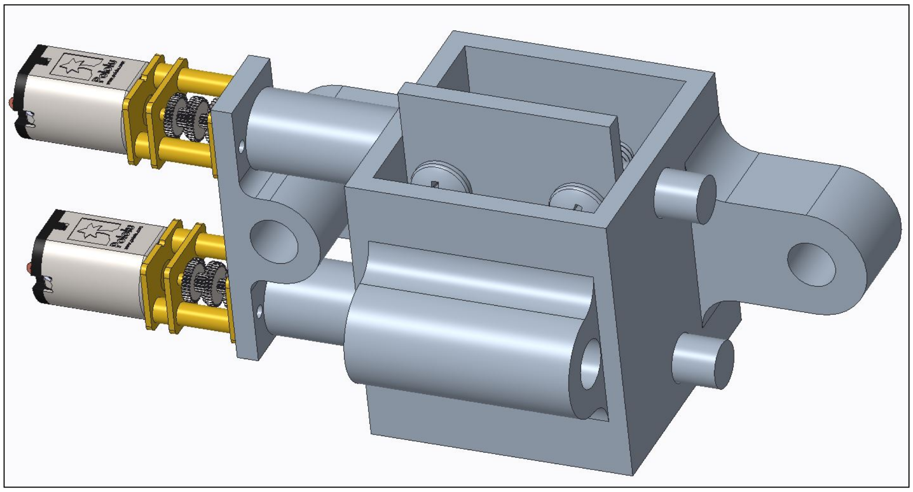

Figure 43: Soil Retention Assembly

A completed list of the SCAR components with weights is shown in Table 36.

Table 36: 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 44 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.

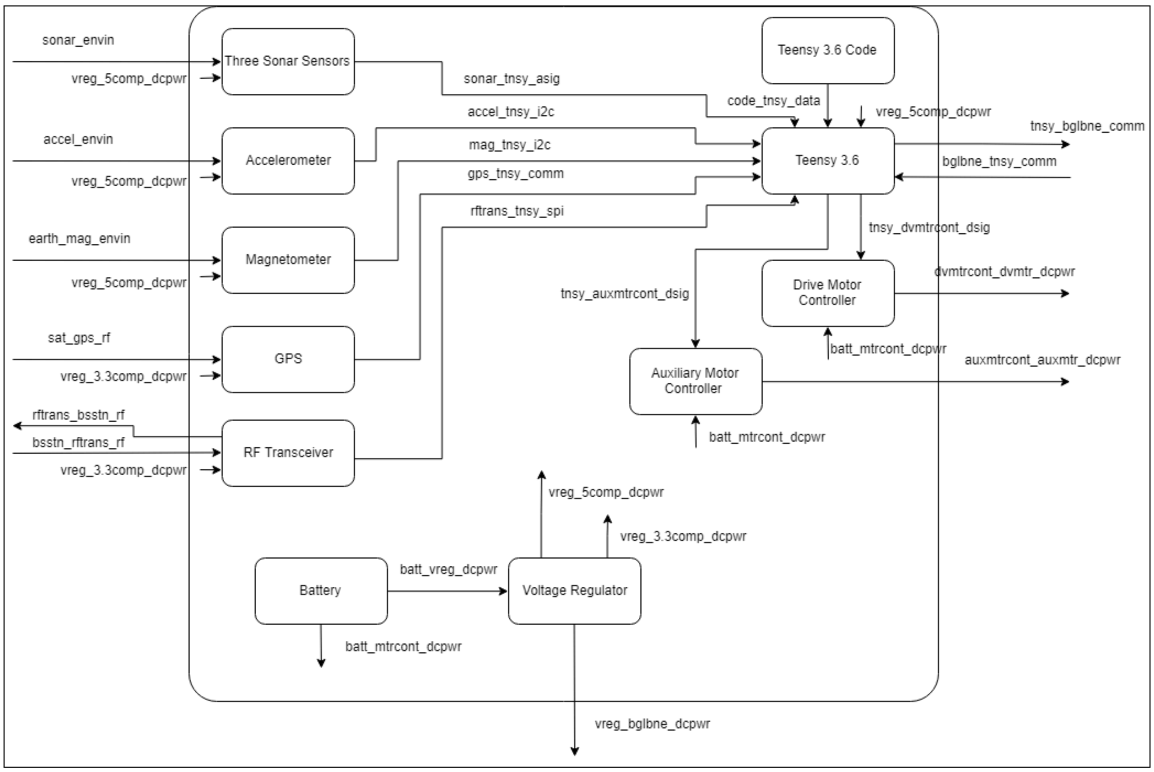

Figure 44: Payload Electrical Block Diagram

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 10A Dual Channel DC Motor Driver was selected to control both drive motors. The 10A 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. 5V is supplied to the accelerometer, Teensy 3.6, camera, Beaglebone Black, and the sonar sensors. 3.3V 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 37. 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 37: 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 Transciever	1	215.00	3.30	63.92	0.1	6.39
Auxillary 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 3.3V 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 43mW 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 Beagle Bone Black connected to the Teensy for serial communication. The Teensy will control the general robot movement and communication to all peripheral devices and sensors, while the Beagle Bone will operate the computer vision and instruct the Teensy to perform specific routines based on the input being received by CV. Each command given by the Beagle Bone 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 computer vision. This is to limit the risk of a mission failure if the computer vision 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 gyro in order to see if we are on level ground. After the rover is both far enough away from the rocket and within operating ranges of the gyroscope, we can begin the auger drilling routine and log the location of the sample collected. The second phase is used to repeatedly collect soil samples and deposit them all at the base station. After collecting the soil sample, the rover should 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 as soon as a green triangle is found and the CV will take over the docking procedure. Once docked, the soil sample will be released and the rover is ready for another trip.

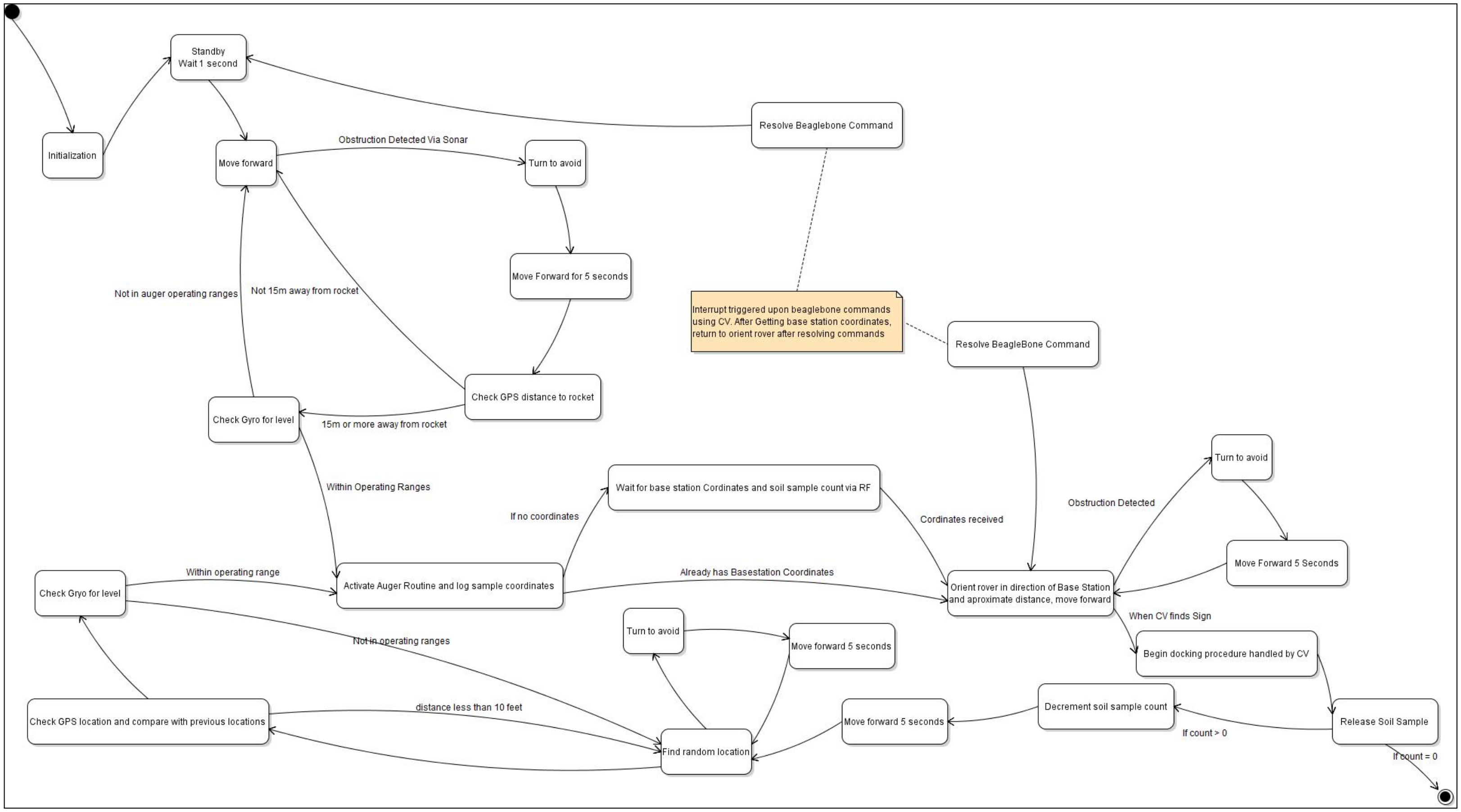

Figure 45: Rover Teensy State Diagram

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 computer vision. 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.

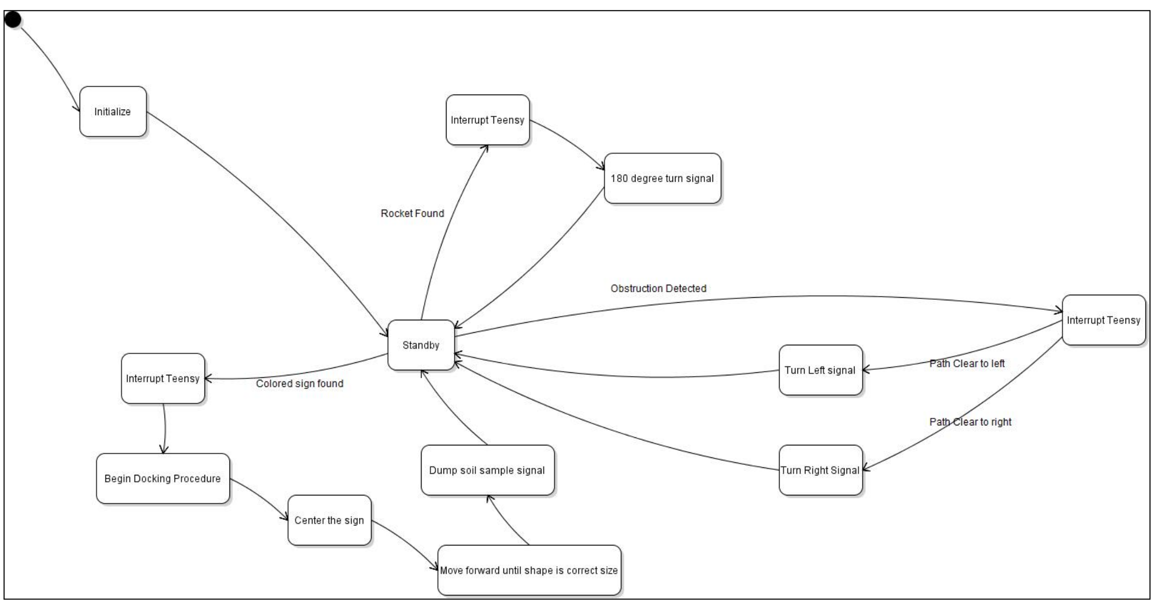

Figure 46: Rover Beaglebone State Diagram

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. We 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 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 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 heat map of each collection point around the area. Using this information, we can create a map of each location accompanied by the pH levels in each location after being tested.

5.5 Rover Overall Design

5.5.1 Rover Design Completeness

Shown in Figure 47 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 5.729 lbf and is 14.5 in. in length.

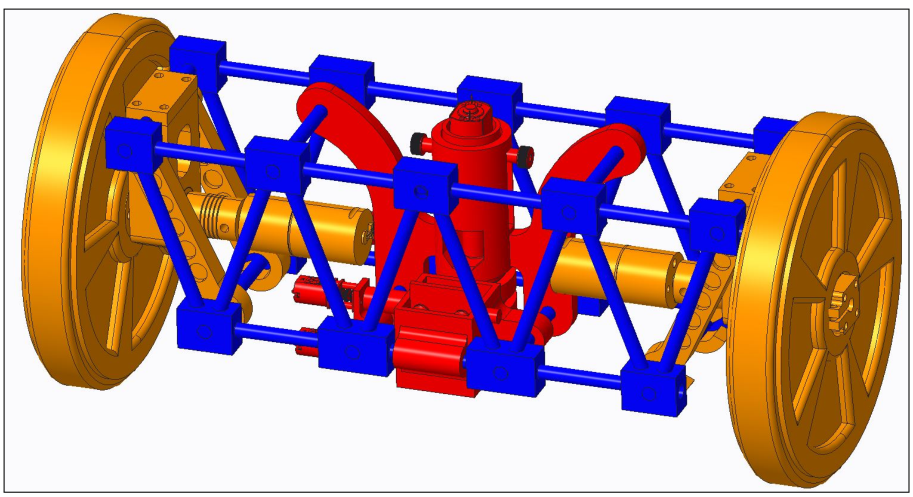

Figure 47: Completed Rover Assembly

5.5.2 Rover Justification

Many of the payload components will be made through additive manufacturing. This is to reduce the weight of the system to allow the launch vehicle to reach the target altitude. This also allows components to be rapidly prototyped and reduce costs.

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 38.

Table 38: 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 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 Fore Hard Point (FHP). A complete Computer-Aided Design (CAD) mockup of the PEARS and FHP can be referenced in Figure 48. The PEARS system can be broken up into three subassemblies as discussed in the following sections: rover housing, retention and ejection, and the PLEC.

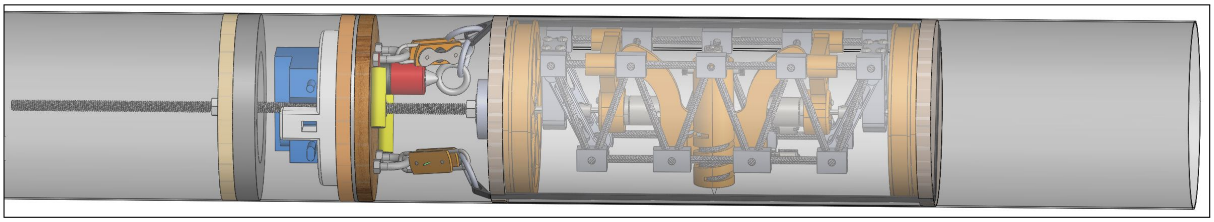

Figure 48: The fully integrated PEARS in the fore airframe

5.6.1 Rover Housing

The rover housing can be seen in Figure 49 and is comprised of five components:

1) Aft Payload Bulkhead
2) Fiberglass Wrap
3) Fore Payload Bulkhead
4) Kevlar Harness
5) Steel Links x3

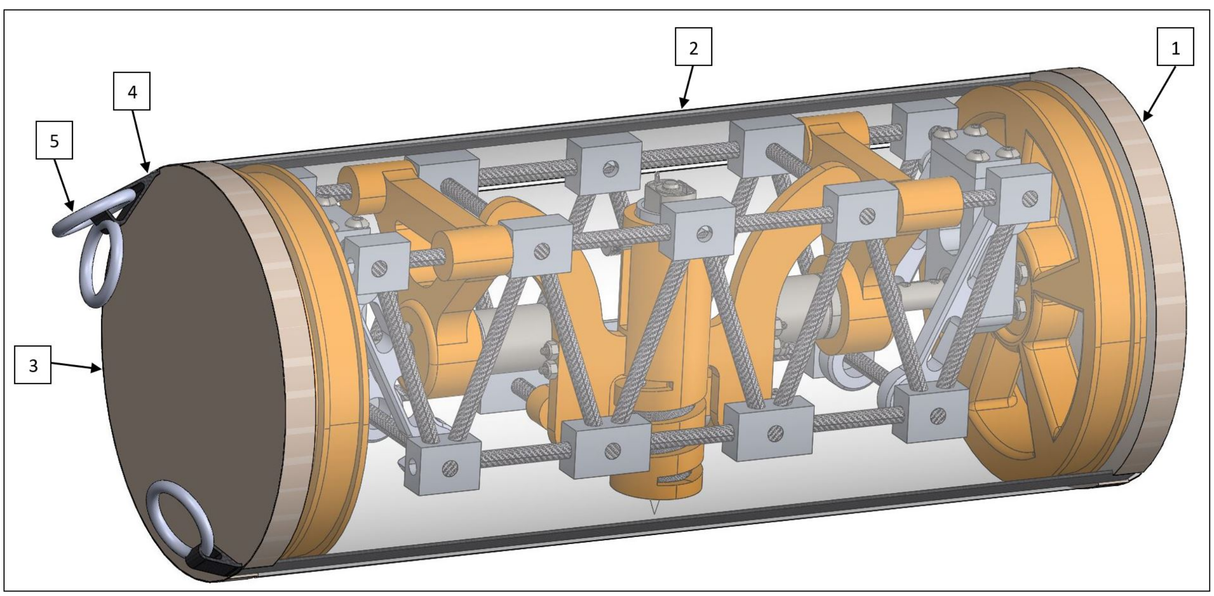

Figure 49: Wrapped rover housing subassembly with reference component numbers

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 50, 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, $\frac{1}{4}$-20 x2
11) Steel Nut, $\frac{3}{8}$-16 x5
12) Steel Washer x5

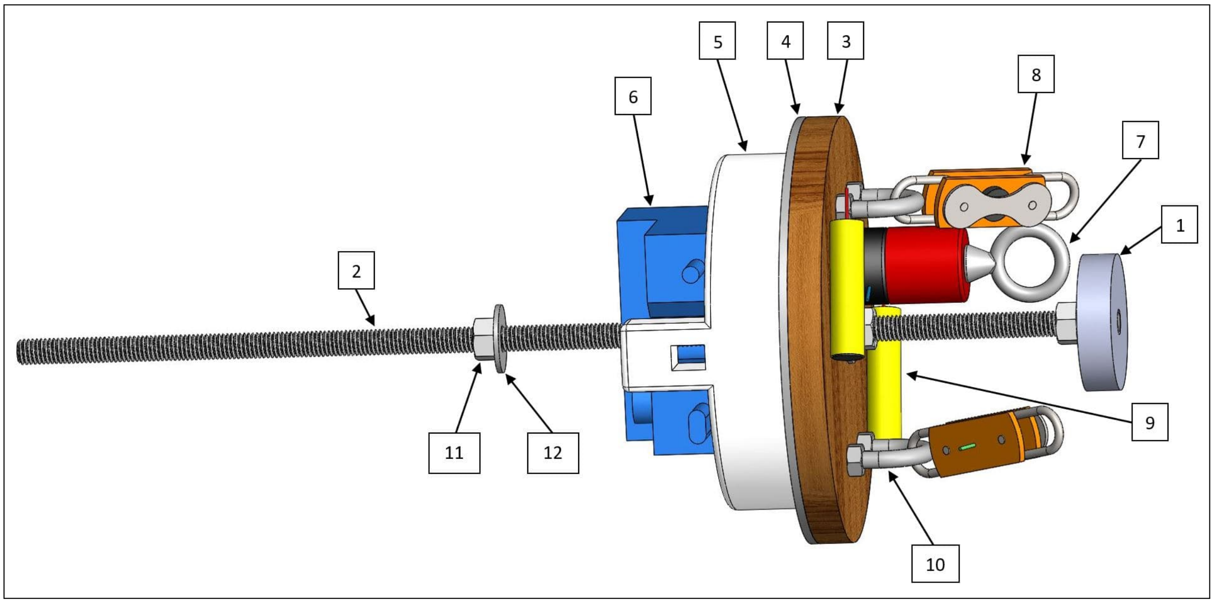

Figure 50: Retention and Ejection Subassembly with reference component numbers

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. This charge assembly can be seen in Section 4.1.6. 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 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 51.

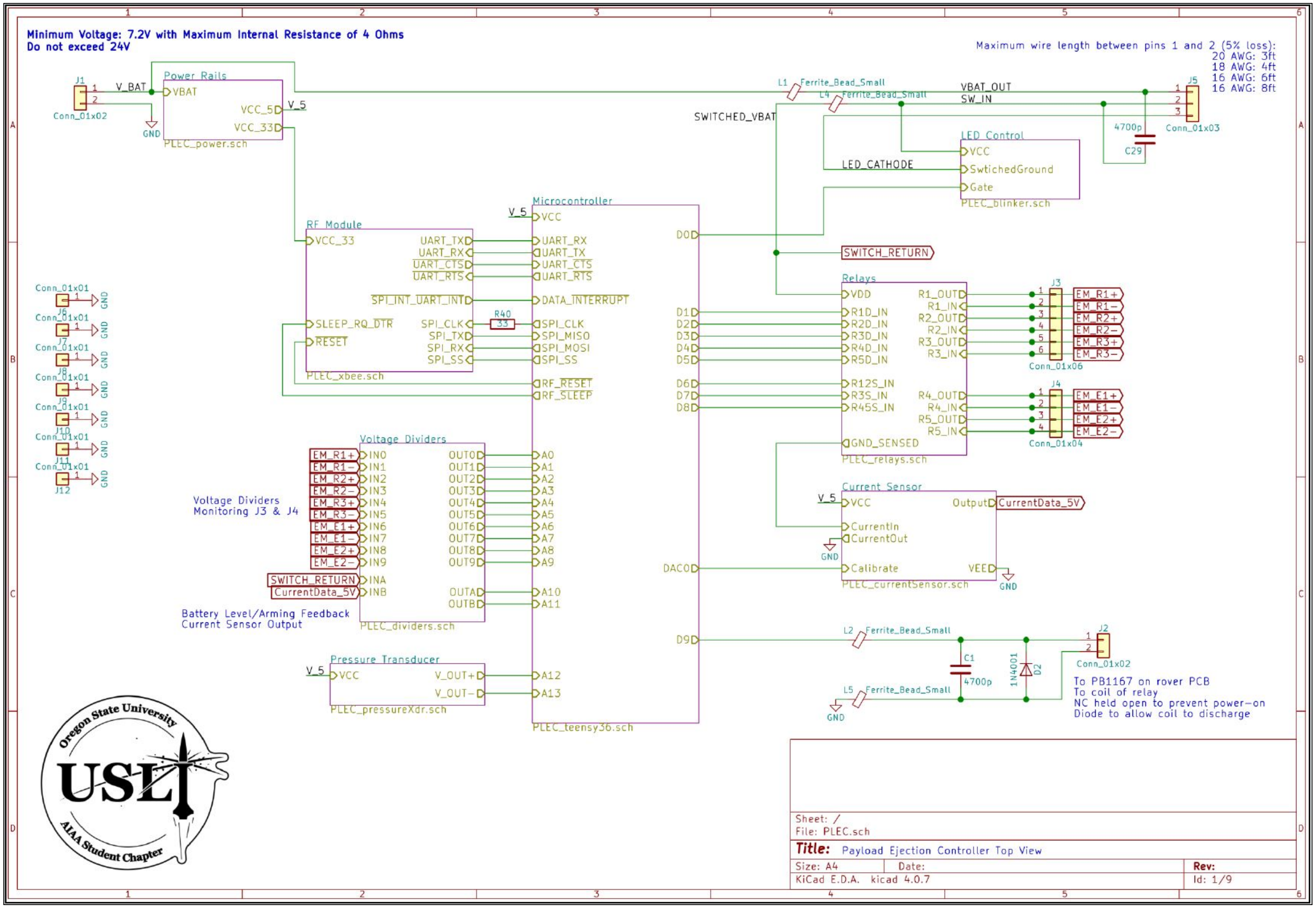

Figure 51: Top Level View of PLEC

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 52 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.

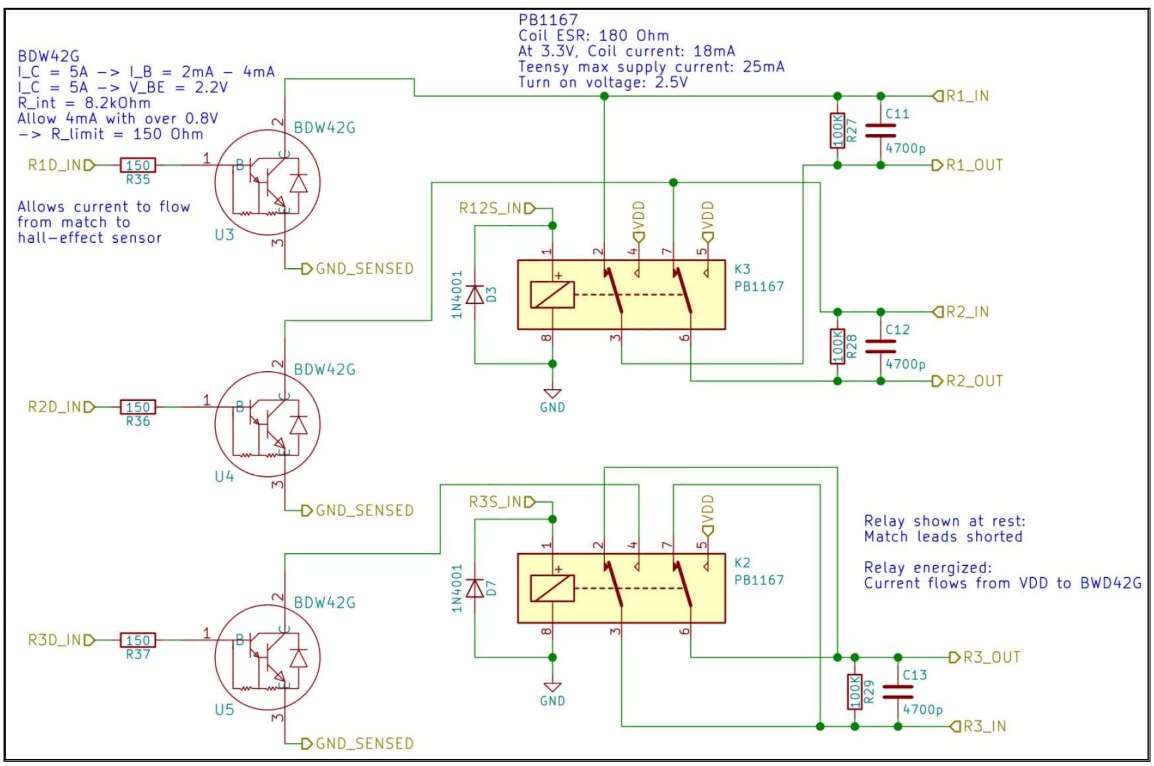

Figure 52: Three of the Five Relay Circuits (4 and 5 are Identical to 1 and 2)

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 Through
- 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. These software safeguards are primarily for repetitive testing, but for safety at competition, all black powder will be burned by the controller after a timeout period. This will ensure no accidental ignition of ejection charges while approaching the forward section of the launch vehicle.

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 Ohm 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 53 shows a the printed circuit board (with pour planes hidden). The PCB will be fitted to the forward 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.

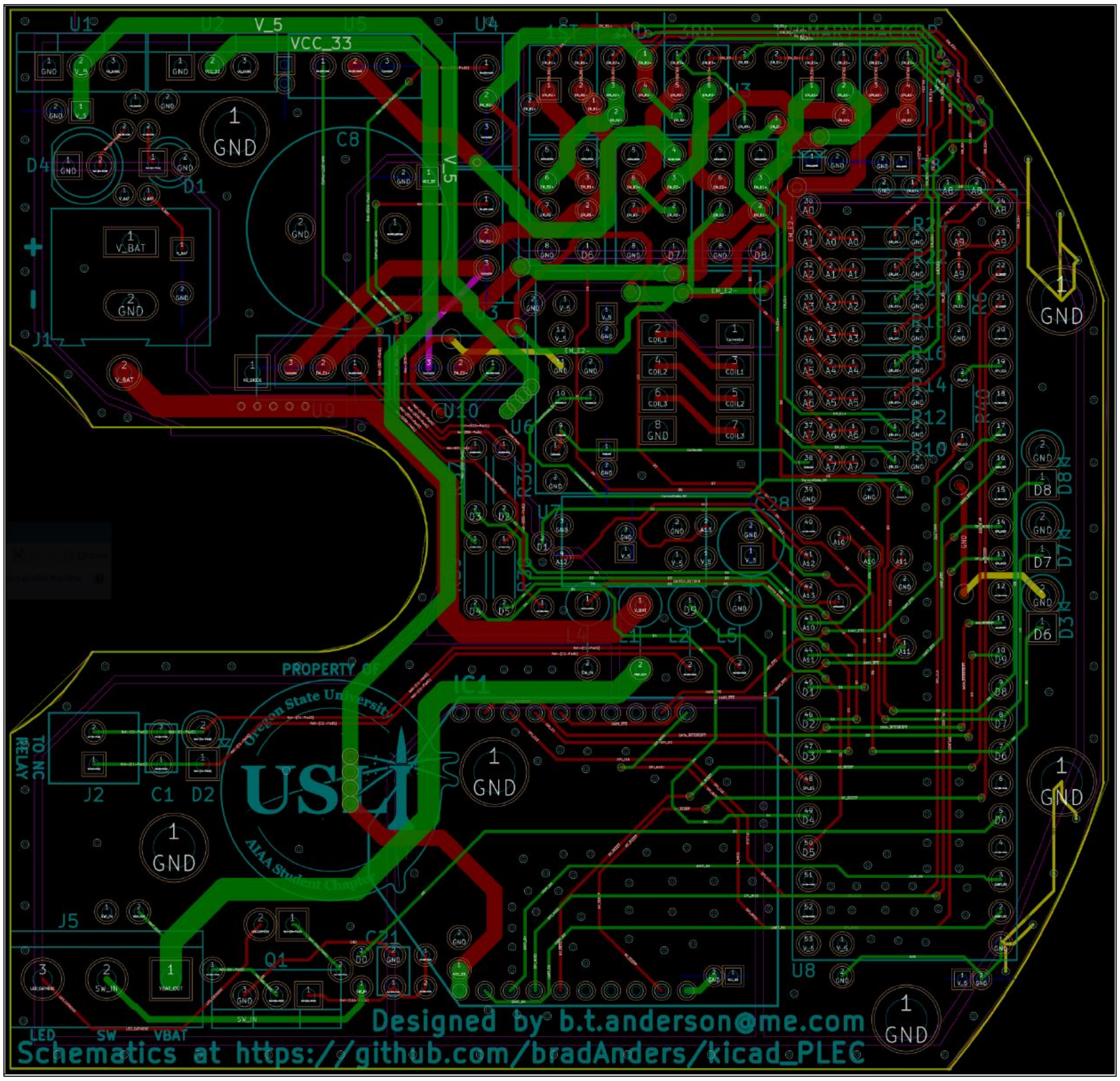

Figure 53: Ordered PLEC PCB

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 54. The three components are:

1) Pass-through Bulkhead
2) Guiding Funnel
3) Main Bulkhead

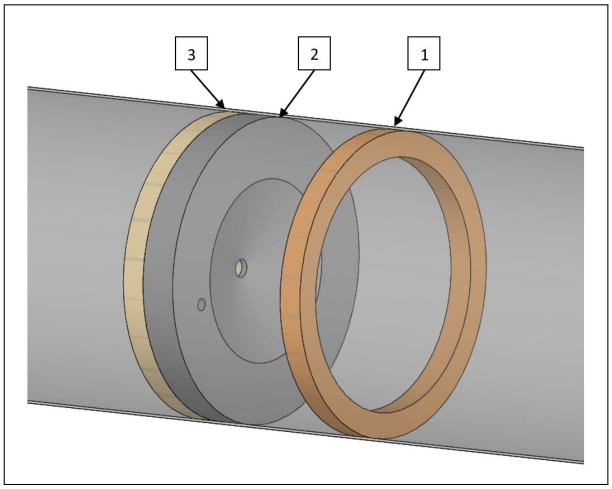

Figure 54: FHP permanently fixed in fore airframe section

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 6.2.4.1. Table 39 shows the results of calculating the accelerations each component is able to experience without failure.

Table 39: 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. The final component weight breakdown can be seen in Table 40, with a total weight of the system at 3.54 lbf excluding the rover itself.

Table 40: 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 Dog Barf 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.

5.6.6 Scientific Experiment

The OSRT is attempting to perform an additional scientific experiment. At the PDR milestone, the OSRT experiment design was planned to be an X-Ray Fluorescence experiment, which would determine the chemical composition of the soil sample. The experiment design has changed due to safety concerns about the experiment.

The X-Ray Fluorescence experiment 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, OSRT designed the experiment as follows:

1) A U shaped channel is lined with 1/2 in. thick acrylic, which is capable of attenuating beta particle and X-Ray emissions. Above and below the channel is also lined with 1/2 in. thick acrylic.
2) A Strontium-90 radioactive isotope which emits beta particles in a random direction is placed in one end of the U shaped channel.
3) An XXXX source is placed in the corner of the U which is adjacent to the Strontium-90 sample.
4) A detector, composed of Silicon doped with Lithium is placed in the opposite end of the U shaped channel from the Strontium-90 sample.
5) The beta particles which impinge on a XXXX source are absorbed and low energy X-Rays are emitted in a random direction.
6) The soil sample is deposited by the rover in a 90° orientation from the beta particle emitter and XXX source, in the corner which is adjacent to the XXXX source.
7) When X-Rays emitted from the XXXX source collide with the soil sample, X-Rays of quantized wavelengths are emitted in a random direction. The quantized wavelengths are unique to each element contained within the soil sample, based on an X-Ray emission phenomenon known as Brehmsstrahlung. Only the quantized X-Rays emitted from the soil sample are capable of reaching the Silicon doped with Lithium.
8) The Silicon doped with Lithium detects the wavelength of the X-Rays which collide with it.
9) The wavelength of the X-Rays and the frequencies which they collide with the Si(Li) detector are used to determine the chemical composition of the soil.

The experiment design which OSRT developed above requires potential exposure to both a radioactive isotope and X-Rays. No one on the team has significant experience in the protections necessary to work in these environments. Additionally, the cost of the Si(Li) detectors can be very expensive, requiring a significant portion of the OSRT budget to purchase. Therefore, the team has decided to perform this experiment as a mock experiment. The mechanical systems of the experiment will be manufactured, however the Strontium-90 sample and the X-Ray detector will not be put into place. With additional resources and training, a Strontium-90 sample and X-Ray detector could easily be added to the scientific base station, allowing for the X-Ray Fluorescence experiment to proceed.

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. For the secondary experiment, the team chose to perform a pH experiment. The pH sensors necessary to perform this experiment are cost effective and

6 Project Plan

6.1 Testing Procedures

6.1.1 General Requirements Tests

6.1.2 Launch Vehicle Tests

6.1.2.1 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 National Aeronautics and Space Administration (NASA) Student Launch (SL) 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 55 lbf, and no less than 47.16 lbf.

Testing Variable: Weight of fully integrated launch vehicle.

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.

6.1.2.2 Motor Thrust Curve

A motor thrust curve will be obtained through motor testing at OSU.

Test Objective: To create a motor thrust curve of a Cesaroni L2375-WTand compare with the motor characteristics used in the OpenRocket model.

Success Criteria: A motor thrust curve with similar average thrust and maximum thrust outputs.

Testing Variable: Thrust output by the motor.

Testing Procedure:

- Test procedure will go here

6.1.2.3 Camera System

Test Objective: Determine the force that the camera system can withstand.

Success Criteria: The camera system will withstand 50 Gs of force

Testing Variable: Force exerted on camera system

Test Procedure:

- Safety Consideration: Ensure proper PPE is worn by all participants

1) Assemble camera system
   - textbfNote: Use additive manufactured fake camera in assembly instead of real camera.
2) weigh camera system.
3) Use weight to calculate 50 Gs of force.
4) Prepare Instron machine.
5) Mount camera system into Instron machine.
   - Safety Consideration: Ensure all body parts and loose clothing or jewelry are secure and away from Instron machine.
6) Begin Instron machine test.
7) Record data.

8) If camera system does not withstand force, the system may need to be redesigned and tested again.

6.1.2.4 Bulkheads

Test Objective: Determine the number of machine screws needed to assemble a bulkhead into the airframe.

Success Criteria: The bulkhead withstands the forces expected during launch and recovery with a safety factor of no less than five.

Testing Variable: Number of machine screws.

Test Procedure:

- Safety Consideration: Ensure proper PPE is worn by all participants

1) Assemble bulkhead into airframe with four machine screws, equally spaced radially along the bulkhead.
2) Prepare Instron machine.
3) Mount assembly into Instron machine.
   - Safety Consideration: Ensure all body parts and loose clothing or jewelry are secure and away from Instron machine.
4) Begin Instron machine test.
5) Record data.
6) If safety factor is less than five, repeat steps one through five with six machine screws.
   - **Note:** Due to fixture limitations, the number machine screws is limited to four or six.

6.1.3 Recovery Tests

6.1.3.1 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.

Testing Procedure:

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 Prep' 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.

Additional Safety Considerations:

- LiPo batteries can be damaged through overcharging. Use of smart charger should prevent this.
- 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.
- ATU Data logs should be cleared or moved before this test to remove any junk data that may accrue prior to operation.

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.

6.1.3.2 433 MHz Continuous Transmission Test

The 900 MHz technology currently in use on the avionics system has been demonstrated to be feasible for regular, long-range, consistent continuous transmission on multiple occasions - both in test environments and in launches. The addition of the 433 MHz renders further continuous transmission testing necessary to ensure that the 433 MHz band and hardware that OSRT is using will function as intended. Continuous tracking can be defined as providing accurate tracking data in intervals no greater than 5 seconds. This test will employ the same methodology that was used to test continuous transmission on the 900 MHz band.

Test Objective: To ensure that the 433 MHz hardware being implemented on the avionics system can operate with performance similar to that of the 900 MHz system currently in use.

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

Testing Variable: Packet arrival frequency.

Testing Procedure:

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.

Additional Safety Considerations:

- Weather conditions must be good to ensure circuit safety. Do not perform test in poor weather such as rain, snow, or even fog.
- Walking tester must be alert and aware of potential hazards or obstructions such as traffic.
- Battery leads must not be touched to ensure circuits don't short.
- Ground station operator should be careful not to touch any exposed circuitry or ICs during operation in case of damaging equipment (personal harm unlikely, but also avoidable through not touching the circuits).

Results and Necessary Modifications: Test not yet conducted.

6.1.3.3 Transmission Range Test

As with continuous transmission, the operable range of the 900 MHz hardware has been determined in practice, but the 433 MHz system has yet to be tested under real operating conditions. 900 MHz demonstrated sufficient power, range, and accuracy to pass a line of sight test. The 433 MHz system will be subjected to a similar though simpler methodology to verify its functionality.

Test Objective: To determine the effective reliable distances for 433 MHz transmission.

Success Criteria: 433 MHz system is determined to have 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.

Testing Procedure:

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.

Additional Safety Considerations:

- Weather conditions must be good to ensure circuit safety. Do not perform test in poor weather such as rain, snow, or even fog.
- Walking tester must be alert and aware of potential hazards or obstructions such as traffic.
- Battery leads must not be touched to ensure circuits don't short.
- Ground station operator should be careful not to touch any exposed circuitry or ICs during operation in case of damaging equipment (personal harm unlikely, but also avoidable through not touching the circuits).

Results and Necessary Modifications: Test not yet conducted.

6.1.4 Payload Tests

6.1.4.1 Chassis

The rover as a whole will experience large axial compression forces during the launch and during ejection, so it is important that it will be able to withstand those forces. One way to ensure the rover will not break before completes its mission is to simulate the launch and ejection forces on each of the rover components to test their strength, especially the chassis that all the components are attached to.

Test Objective: This test will measure the strength of the chassis assembly under axial compression.

Success Criteria: The chassis has no broken or damaged components after compression forces are added that are greater then those expected during launch and ejection.

Testing Variable: Yield Strength of the chassis assembly

Testing Procedure:

1) Fully assemble the chassis.
2) Use fixture to stand the chassis upright, as if it were resting with the flat side of the wheel on the ground.
3) Attach fixture to apply force evenly to top entire chassis cross section.
4) Incrementally add weight until the compression force created exceeds a calculated 50Gs.

6.1.4.2 Soil Collection Test

Passing Conditions: At least 10 mL of soil is measured within the soil retention container.

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.

6.1.4.3 Rover Batteries

6.1.5 Safety Tests

6.2 Analysis Procedures

6.2.1 General Requirements Analyses

6.2.2 Launch Vehicle Analyses

6.2.3 Recovery Analyses

6.2.3.1 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 theOSRT, the change in air density due to altitude was taken into consideration.

Analysis inputs needed:

- 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

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.

6.2.3.2 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 13

$$Volume = \pi R^2 L \tag{13}$$

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 14 if $Volume \leq 100\ in^3$ or Equation 15 if $Volume \geq 100\ in^3$.

$$D = \frac{Volume}{400} \tag{14}$$

$$D = 2\sqrt{\frac{Volume}{6397.71}} \tag{15}$$

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 16.

$$Area = \pi(\frac{D}{2})^2 \tag{16}$$

4) Lastly, calculate the diameter of each port with Equation 17

$$D_{multi-port} = 2\sqrt{\frac{Area/N}{\pi}} \tag{17}$$

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 41.

Table 41: 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 18

$$D = \frac{D_{AvBay}^2 L}{.0016} \tag{18}$$

The four port diameters can be calculated with Equation 19

$$D = \frac{D_{AvBay}^2 L}{.0008} \tag{19}$$

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

6.2.4 Payload Analyses

6.2.4.1 PEARS Component Strength

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.

Analysis Outcome

The results can be seen in Table 42. 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 42: 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

6.2.5 Safety Analyses

6.3 Demonstration Procedures

6.3.1 General Requirements Demonstrations

6.3.2 Launch Vehicle Demonstrations

6.3.3 Recovery Demonstrations

6.3.3.1 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 between 0 and 2 seconds. The main parachute will be retained in the airframe by a Tender Descender and ARRD until a lower altitude. At a minimum of 500 ft, the altimeters will fire e-matches, releasing the Tender Descender and the ARRD, which, in turn, releases the main parachute.

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

6.3.3.2 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: Update 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 *** REFERENCE THE SECTION OF THE SUBSCALE CHECKLIST

Success Criteria: The subscale launch data matches that of the analysis to a reasonable degree.

6.3.3.3 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.

6.3.3.4 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 repressurizes, 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.

6.3.3.5 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 Ohms rating.

6.3.3.6 Ejection Testing Demonstration

Demonstration Objective:

This test 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) Attach extension leads to the e-match leads.
5) Follow recovery integration procedure to ensure the assembly is integrated correctly.
6) Slide the coupler into the airframe and put nylon shear pins in place.
7) Strap down the airframe with ratchet straps to cinder blocks.
   - **Note:** it is important for the fin section to be immobile during this demonstration.
8) Move appropriate distance away from airframe.
9) Ensure the ignition system is in the off position.
10) Plug extension into the ignition system.
11) Attach a 9 Volt 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

12) 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. Improper battery - e-match combination used, leading to a current over 6 amps, charges are likely not wired correctly, the e-matches have a broken lead, or the e-matches are faulty. Check in this order until the problem is solved.
        ii) **One:** If one ignited, charge was sized incorrectly, or a pressure seal was not formed.
13) 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 was not attached correctly.
14) Repeat this process until five consecutive, successful tests have been performed.

Success Criteria: This demonstration is considered successful if 5 consecutive separation events are successful.

6.3.3.7 Altimeter Arming Demonstration

Demonstration Objective: This demonstration will verify that the altimeters can be armed from the exterior of the airframe with the launch vehicle on the launch rail.

Demonstration Procedure: Ensure no ejection charges are wired to the altimeters. Place a 9V battery in the altimeter circuit, with the switch in the off position. Follow assembly procedures until the ejection bays are placed in the correct position. Place the launch vehicle with launch lugs facing towards the table. Follow launch vehicle arming checklist to turn on altimeters, accessing switches through static port holes. Once beep sequence begins, ensure altimeters can be disarmed through static port holes.

Success Criteria: The demonstration is successful when the altimeters can be armed and disarmed through static port holes.

6.3.3.8 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 side 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.

6.3.3.9 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 is to be completed prior to launch vehicle assembly. Ground station checklist is then completed; 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.

6.3.4 Payload Demonstrations

6.3.4.1 Rover Deployment

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.

6.3.4.2 Rover Mobility Demonstration

Demonstration Objective: This procedure is used to 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.

6.3.4.3 Soil Retention Demonstration

Demonstration Objective: This procedure is used to 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.

6.3.4.4 Rover Weight

Demonstration Objective: The objective of this demonstration is to show that the rover is an appropriate weight for all aspects of the mission.

Demonstration Description: The assembled rover will be retained in the payload bay during flight, and its weight verification will be demonstrated during the team's first full scale launch. It must also be able to carry out its soil collection mission, and that portion will be verified with ground tests of the auger system.

Success Criteria: Rover is successfully retained in flight and can collect enough soil to satisfy the handbook criteria.

6.3.4.5 Rover Deployment

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.

6.3.4.6 Collision Avoidance

6.3.4.7 Rover Low Power State

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.

6.4 Inspection Procedures

6.4.1 General Requirements Inspections

6.4.2 Launch Vehicle Inspections

6.4.2.1 Launch Vehicle Sections

6.4.3 Recovery Inspections

6.4.3.1 Recovery Electrical Circuits

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 altimeter, one SPDT switch, and one 9V battery.

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

6.4.3.2 Ejection Charge Inspection

Inspection Objective: The objective of this inspection is to validate the viability of the ejection charge construction method being incorporated.

Inspection Materials:

- Safety Glasses

Inspection Procedure:

- Safety consideration: Ensure all proper PPE is being worn.

1) Wait for smoke and hot gases left over from the charge to have left the airframe.
2) Shine a light into the airframe and inspect the ejection charges. If you cannot tell if the charges have ruptured successfully, take the launch vehicle to a safe area and begin disassembly procedure.
3) Once the charges can be properly inspected, ensure the surgical tubing ruptured on the side. If the santoprene plug was blown out the end instead, this is considered a failed charge.
4) If a significant amount of charges are failing at the santoprene plug instead of rupturing the side of the surgical tubing, the ejection charge packing method should be reconsidered.

Success Criteria: If the charge has ruptured on the side of the surgical tubing, the charge is considered to be successful.

6.4.3.3 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 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 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.

6.4.4 Payload Inspections

6.4.4.1 Rover Battery Impact Protection

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.

6.4.4.2 Rover Battery Visibility

Inspection Objective: The objective of this inspection is to ensure that the rover's batteries are appropriately colored and marked as a fire hazard.

Inspection Materials:

- Rover batteries

Inspection Procedure:

1) Inspect the rover's batteries.

Success Criteria: Batteries are wrapped in brightly colored electrical tape and marked as a fire hazard.

6.4.4.3 Ejection Charge Protection

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.

6.4.4.4 Expandable Wheels

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.

6.4.5 Safety Inspections

6.5 Requirement Compliance

6.5.1 Competition Requirements

6.5.1.1 General Requirements

Table 43: 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.	In progress - 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.	Section **??**
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.	In progress - OSRT has provided and maintained a project plan so far. A project plan will be maintained throughout the remainder of the project life cycle.	Section **??**
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 foreign exchange students by PDR.	Complete - no foreign exchange students are a part of the current OSRT roster.	Section **??**
1.3	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 be identified by CDR.	Section **??**
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 be identified by CDR.	Section **??**

Continued on next page

Table 43 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
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 be identified by CDR.	Section **??**
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 CDR.	Section **??**
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 Flight Readiness Review (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 980 participants in STEM lessons.	Section **??**
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.	Section **??**
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.	In progress - all documentation has been and will continue to be submitted appropriately.	Section **??**
1.8	All deliverables must be in PDF format.	I	The team will submit all deliverables appropriately.	In progress - all documentation has been and will continue to be submitted appropriately.	Section **??**

Continued on next page

Table 43 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
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.	In progress - a table of contents has been included on all documentation, and will be included for all future documentation.	Section **??**
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.	In progress - page numbers have been on all documentation, and will continue to be included for all future documentation.	Section **??**
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.	Section **??**
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.	Section **??**
1.13	Each team must identify a mentor.	I	Team will identify a mentor.	Complete - Joe Bevier has been identified as the OSRT mentor.	Section **??**

6.5.1.2 Launch Vehicle Requirements

Table 44: 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.	T	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.	In progress - launch vehicle has been designed to meet requirements.	Section
2.2	Teams shall identify their target altitude goal at the PDR milestone.	A	The target AGL goal has been set during PDR.	Completed - launch vehicle has been designed to reach 4,500 ft.	Section
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 in current design. Commercially available barometric altimeters will be used with any future design changes.	Section
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
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
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

Continued on next page

Table 44 – 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.	T	The launch vehicle will be designed to survive launch and recovery without needing repairs or modifications prior to an additional same day launch.	Completed - launch vehicle designs have been made to withstand all expected forces of launch and recovery. Any design changes will be capable of withstanding all expected forces of launch and recovery.	Section
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.	Section
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.	Section
2.10	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration (FAA) flight waiver opens.	D	The team will perform preparation drills to practice assembling and readying the launch vehicle within two hours.	In progress - design for assembly is being emphasized. Testing and practice will be implemented to ensure assembly process is less than two hours.	Section
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	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 launch.	Section
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.	T	The launch vehicle will have a separate launch system that is powered by an external 12-volt system.	Completed - current motor choice and all alternative motor choices are capable of being launched by standard 12-volt direct current firing system.	Section

Continued on next page

Table 44 – 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.	Section
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).	A	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 - current motor choice and all motor alternative choices meet these requirements.	Section
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.	Section
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 - current motor choice and all motor alternative choices meet these requirements.	Section
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 and will be adjusted as design progresses. A minimum stability of 2.0 will be maintained.	Section
2.18	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	A	The selected motor will be simulated to achieve over 52 fps off of a 12 ft rail provided by USLI.	Completed - rail exit velocity is 83.8 fps with motor choice.	Section

Continued on next page

Table 44 – 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.	In Progress - manufacturing of a subscale launch vehicle has begun. The launch will be completed prior to CDR.	Section
2.20	All teams will complete demonstration flights.	T	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.	In Progress - will be completed by each of the specified deadlines.	Section
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
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

Continued on next page

Table 44 – 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.	Section

6.5.1.3 Recovery Requirements

Table 45: 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	At apogee, an ejection charge will separate the fore from the aft, and another will separate the fore from the nosecone. The ejection charge in the middle of the launch vehicle will separate the aft from the fore section, as well as push the drogue out of the aft section. An ejection charge located in the upper fore section will separate the nosecone from the fore section as well as push the drogue out of the fore section. At 700 feet AGL, the main parachutes will be pulled out by the drogue parachutes after a Tender Descender and ARRD connected in series release.	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 6.3.3.1

Continued on next page

Table 45 – 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	Barometric altimeters will sense the altitude AGL, and they will ignite the black powder in the Tender Descenders and ARRDs, deploying the parachutes 700 ft AGL.	Complete - In a subscale launch, the barometric altimeters successfully ignited the black powder in the Tender Descender and ARRD at 700 ft AGL, releasing the main parachute.	Section 6.3.3.1
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	D	The primary altimeter apogee delay will be set to zero seconds, and the backup altimeter apogee delay will be set to one second, which meets the requirement.	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 6.3.3.1
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 will be performed prior to all launches, subscale and full scale, to ensure all parachutes are ejected properly during the launch.	In Progress - Ejection testing has been Complete for all subscale launches and will be Complete prior to all full scale launches.	Section 6.3.3.6
3.3	At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	A, D	Appropriate main parachute sizes have been chosen through simulations to keep each independent section under 75 ft-lbf of kinetic energy upon landing. These simulations will be verified through demonstration by using the same analysis for the subscale launch.	Complete - Parachute sizes have been selected based off analyses which have been verified through the results of a subscale launch.	Section **??** & 6.3.3.2
3.4	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	I	All recovery and payload circuits will be independent of each other.	Complete - The final full scale launch vehicle design has accounted for completely independent circuits for payload and recovery.	Section 6.4.3.1

Continued on next page

Table 45 – 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	All batteries will be purchased from a vendor determined to have batteries which meet all required needs.	Complete - All batteries have been purchased through reputable vendors.	
3.6	The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	I	The launch vehicle will contain four altimeters, two primary and two secondary. The primary will be PerfectFlite StratologgerCF, and the secondary will be Missile Works RRC3.	Complete - Redundant, commercially available altimeters have been selected.	
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	I	The motor will not be ejected from the launch vehicle during primary or secondary deployment.	Complete - The motor will be retained during all subscale and full scale flights.	
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	I	Nylon shear pins will be used for all parachute compartments to ensure the launch vehicle's sections are fixed together until ejection charges are fired.	Complete - all couplers include nylon shear pins in design.	
3.9	Recovery area will be limited to a 2,500 ft radius from the launch pads.	A, D	Each independent section will fall quickly and controlled under drogue parachutes. The main parachutes will deploy, and the launch vehicle sections will fall as quickly as possible while staying under the kinetic energy requirement to limit drift.	Complete - Multiple simulations have been performed which demonstrate recovery of all sections will fall within 2,500 ft radius. The subscale launch verified these simulations.	Section **??** & 6.3.3.2
3.10	Descent time will be limited to 90 seconds (apogee to touch down).	A, D	To limit descent time spent under the main parachutes, the launch vehicle has been split into two independent sections. This allows for safer descent rates under the drogue parachutes while still staying under the required 90 seconds and meeting the kinetic energy requirement.	Complete - Multiple simulations have been performed which demonstrate recovery of all sections within 90 seconds. The subscale launch verified these simulations.	Section **??** & 6.3.3.2

Continued on next page

Table 45 – 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	The launch vehicle will contain two avionics units: one in the fore section and one in the aft section.	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
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	The fore and aft sections will land independently of each other. Both will contain avionics systems in their respective avionics bays.	Complete - Design includes one avionics systems on each independently recovered section of the launch vehicle.	Section 6.4.3.3
3.11.2	The electronic tracking device(s) will be fully functional during the official flight on launch day.	D	All tracking systems will be tested on launch day to ensure they are working correctly by locking on to the coordinates of the launch vehicle prior to launch.	In Progress - This was completed for the subscale launch and will be completed prior to the full scale launch pending further launch testing.	Section 6.3.3.9
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	All recovery system electronics will be properly shielded, eliminating any adverse reactions.	Complete - design has accounted for appropriate shielding and protection of electronics.	
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	All electronics producing radio frequency or magnetic waves will be located in separate compartments from all altimeters and recovery electronics.	Complete - design has accounted for appropriate shielding and protection of electronics.	
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	All recovery system electronics will have proper protection, shielding from transmitting devices using conductive spray paint, ensuring charges are not ignited early.	Complete - design has accounted for appropriate shielding and protection of electronics.	

Continued on next page

Table 45 – 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	The recovery system electronics will be shielded from all magnetic waves produced by any device onboard the launch vehicle using conductive spray paint to avoid inadvertent excitation of the recovery system.	Complete - design has accounted for appropriate shielding and protection of electronics.	
3.12.4	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	I	The recovery system will be appropriately shielded from all devices which may have any adverse effect on the recovery system electronics using conductive spray paint.	Complete - design has accounted for appropriate shielding and protection of electronics.	

6.5.1.4 Payload Requirements

Table 46: 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 is 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 6.3.4.1
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 6.2.4.1

Continued on next page

Table 46 – continued from previous page

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 6.3.4.1
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 6.3.4.2
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.	In Progress - Testbed and test assembly have been designed are in the manufacturing phase.	Section 6.1.4.2
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 6.3.4.3
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 6.4.4.1
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 module(s) will be marked with colored electrical tape.	Incomplete - Batteries will be marked once purchased.	Section 6.4.4.2

6.5.1.5 Safety Requirements

Table 47: 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.	

Continued on next page

Table 47 – 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.	

Continued on next page

Table 47 – continued from previous page

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.	

Continued on next page

Table 47 – continued from previous page

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.	

Continued on next page

Table 47 – 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 General Team Derived Requirements

Table 48: General Verification Matrix

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
General - 1	All documentation will be created by OSRT and submitted by the OSRT competition deadlines.		I	The team will be made aware of all deadlines well in advance. All team members will contribute to have all documents ready for submission in advance of the deadlines.	In progress - to date, all OSRT documentation has been submitted on time.	Section **??**
General - 2	The team will develop a unique mission patch which is representative of the 2019 OSRT competition that is specific to OSRT.		I	Team members will develop ideas and select the best of these ideas.	In progress - several rough draft mission patches have been submitted.OSRT will continue to refine and update these ideas.	Section **??**
General - 3	The team will engage over 500 people from the community in STEM lessons and activities.		I	Conduct a variety of lesson plans targeted at all age groups, with the team's primary focus on students K-12.	Complete - more than 500 students have been taught already. Additional opportunities will still be pursued by the team to benefit the community and maintain a strong OSRT presence.	Section **??**

Continued on next page

Table 48 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
General - 4	The STEM lesson plan ideas and outreach contact information will be saved in an appropriate location to provide the 2020 OSRT members with.		I	All of the pertinent information will be stored on the OSRT Google Drive.	In progress - all current information is being managed and stored on the OSRT Google Drive.	Section **??**
General - 5	Documentation of available OSRT resources and materials will be saved in an appropriate location to provide the 2020 OSRT members with.		I	All of the pertinent information will be stored on the OSRT Google Drive.	In progress - all current information is being managed and stored on the OSRT Google Drive.	Section **??**
General - 6	The team will appropriately display logos of all sponsor logos and information.		I	The finance team will request high resolution logos from all sponsors when they decide to sponsor OSRT.	In progress - all sponsors who have committed to sponsoring the team have high resolution logos which have been obtained.	Section **??**

Continued on next page

Table 48 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
General - 7	At least 25% of the team members will receive a Level 1 HPR Certification from NAR or TRA.		I	Build certification rockets and provide the team with opportunities at all OSRT launch opportunities.	In progress - 16 team members have purchased or built a Level 1 HPR Certification rocket. Kits will be flown when opportunities are available.	Section **??**
General - 8	The team will get volunteer members involved with the project.		I	Develop a list of projects which are capable of being completed by engineers of varying levels of expertise, providing support for these projects throughout their life cycle.	Complete - to date, 39 volunteers have attended OSRT meetings. These students are working on a wide array of volunteer lead team projects, which are each supported by a mentor who is completing the OSRT competition for course credit as a part of their Capstone class for OSRT. The OSRT will continue to involve volunteers and engage students in the project for the duration of the school year.	Section **??**

Continued on next page

Table 48 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
General - 9	All senior Mechanical Engineers will obtain certifications to work in the MPRL at OSRT.		I	Complete the ME 250 course offered by OSRT to receive safety training and learn about manufacturing processes on a variety of equipment present at OSRT.	Complete - All senior Mechanical Engineers are certified to work in the MPRL.	Section **??**

6.5.2.2 Launch Vehicle Team Derived Requirements

Table 49: 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.		I	All components will be inspected after ground tests are completed for damage or burning. Designs will be changed if they do not pass.	Incomplete - testing will be conducted on subscale and full scale launch vehicles.	Section
LV-2	Launch vehicle will not be over stable or susceptible to weather cocking.		A	Stability will be limited to maximum of 3.5 at rail exit.	Complete - OpenRocket simulations have shown stability to be 2.1. The simulations will be updated to account for future design changes.	Section
LV-3	Launch vehicle will be able to be stowed in a 5 ft x 4 ft x 2 ft container for shipping.		I	Launch vehicle will be able to disassemble into sections no longer than 5 ft and no wider than 2 ft to fit into container.	Complete- sections will fit within the container.	Section

Table 49 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
LV-4	The launch vehicle will be recoverable and reusable.		I	The launch vehicle will be using the recovery system in place to minimize any kinetic energy upon landing. Once the launch vehicle is recovered, an inspection will be done to determine its structural integrity. The inspector will be looking for any signs of tearing, deformation, and any other visual indicators of wear. If there are any visual indicators of damage, then appropriate actions will be taken to repair the body. If there are no indicators of damage to the body, then the launch vehicle will be deemed capable of launching again.	Incomplete - will be completed after successful recovery of full scale launch vehicle.	Section
LV-5	Motor will provide required thrust to launch vehicle.		A	Using OpenRocket simulations, OSRT will be able to test the thrust output of the motor acting on the launch vehicle.	Completed - L2375-WThas been selected based on OpenRocket simulations.	Section
LV-6	The launch vehicle will accommodate the payload and avionics systems.		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 assembly of full scale launch vehicle.	Complete - payload and avionics will fit in the airframe.	Section

Table 49 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
LV-7	The launch vehicle will be able to be rapidly integrated for launch.		D	Launch vehicle assembly integration will be practiced to minimize assembly time.	In progress - design for assembly is being emphasized throughout the design process.	Section
LV-8	MATLAB scripts will be used in conjunction with all OpenRocket simulations.		A	Descent velocities, descent trajectory, landing energy, and an estimated apogee 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 6.2.3.1
LV-9	Bulkheads will have a factor of safety of 2.0 with respect to the maximum pressure forces experienced during separation.		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
LV-10	Threaded rods will have a minimum tensile safety factor of 5.0 during recovery.		A	Simulations will determine maximum forces on the recovery harness, which will be compared to the tensile strength of selected threaded rod.	Complete - threaded rods have been sized appropriately to provide a safety factor above 5.0.	Section
LV-11	All threaded attachments have a length greater than 1.5 times the minimum shear length of the selected threads.		D	All purchased threaded components will be compliant, all manufactured components will be compliant.	Incomplete - will be accounted for and completed in final design.	Section

6.5.2.3 Recovery Team Derived Requirements

Table 50: 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	Separation ejection charges will be sized based on initial calculations and ground tested for reliable parachute ejection. If a ground test fails, charge size will be increased or charge construction reevaluated. Testing will take place prior to subscale and full scale flights.	In Progress - Ejection testing was completed prior to subscale launch and will be completed prior to all full scale launches.	Section 6.3.3.6
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	Designs will allow for an open end of the launch vehicle for the payload to deploy from.	Complete - Recovery system design allows for the payload to be deployed from the aft end of the fore airframe.	Section 6.3.3.4
Recovery - 3	Avionics will be able to track the 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	An avionics board has been developed by OSRT which is capable of tracking the launch vehicle throughout flight. This will be tested on all flights, including subscale.	In Progress - The avionics system was partially successfully tested on the first subscale flight and will be tested on the full scale launches.	Sections 6.1.3.2 & 6.3.3.9

Table 50 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
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 6.1.3.3
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 6.1.3.1
Recovery - 6	Recovery system will have appropriately sized static port holes.	This verification ensures the altimeters will correctly sense the pressure outside of the the launch vehicle. Under or oversized static port holes will cause early or late separation events respectively.	A	Calculations will be performed to determine the correct sizing and number of static port holes.	Complete - The port hole calculations have been performed.	Section 6.2.3.2

Table 50 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Recovery - 7	Altimeters will not be armed until the launch vehicle is vertical on the rail.	The team determined that arming the launch vehicle while it is vertical on the rail will mitigate safety and battery life concerns.	D	The team will arm and disarm all altimeters (without charges) from outside the airframe prior to each launch.	Complete - Design has allowed for altimeter arming from the exterior of the launch vehicle.	Section 6.3.3.7
Recovery - 8	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	Prior to ejection charge assembly, the resistance of each e-match will be verified to be within the nominal operating range.	Complete - Ejection charge manufacturing process includes verification of e-match resistance.	Section 6.3.3.5
Recovery - 9	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	Prior to each launch a vacuum will be used to lower the pressure the altimeter is at, which the altimeters should record.	Complete - This process is included in the altimeter demonstration procedures.	Section 6.3.3.4
Recovery - 10	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 6.3.3.4

Table 50 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Recovery - 11	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 - This process is included in the recovery integration procedures.	Section 6.3.3.3
Recovery - 12	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 6.3.3.8

6.5.2.4 Payload Team Derived Requirements

Table 51: 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.	D	Design weight will be based upon ideal flight simulations. A demonstration will occur during test launches and payload test missions.	In Progress - Designs have been modeled with expected weights. Manufacturing is beginning, and the demonstration will be held during payload testing and the first full scale launch.	Section 6.3.4.4
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 6.3.4.5
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 6.4.4.3

Continued on next page

Table 51 – 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.	In Progress - 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 6.3.4.6
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 6.4.4.4
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.	In Progress - Component specifications have been determined and testing will occur once components are purchased.	Section 6.1.4.3
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 6.3.4.7

6.5.2.5 Safety Team Derived Requirements

Table 52: 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.	-	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.	Section **??**
Safety - 2	Additional team members will assist the Safety Officer (SO) in explicitly promoting team safety and the preparation of safety documents.	-	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.	Incomplete - 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.	-	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 **??**

Continued on next page

Table 52 – 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.	-	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.	-	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 **??**
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.	-	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 **??**

Continued on next page

Table 52 – 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.	-	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.	-	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.	-	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.	-	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.	-	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 **??**
Safety - 12	The payload ejection controller will have an arming switch.	-	I	Turn the switch to verify the LED is blinking to indicate armed status.	Incomplete - Will be implemented when team reaches that point.	Section **??**

Continued on next page

Table 52 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Safety - 13	The Mentor and Educational Advisor will have a final say in safety decisions on all activities and designs.	-	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.	-	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

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 53 shows the funding plan.

Table 53: OSGC Cost Sharing

	Expected	**10% Contingency**	**OSGC Contribution**	**Matching Contribution**	**Matching Sources**
Aerodynamics and Recovery	$3,211.28	$3,568.09	$3,568.09		
Structures	$4,590.27	$5,100.30	$2,100.30	$3,000.00	ICE
Payload	$658.76	$731.95	$731.95		
Outreach	$300.00	$330.00		$300.00	AIAA
Travel	$12,00.00	$13,200.00		$13,200.00	AIAA, Student Expenditure
Lodging	$6,300.00	$6,930.00	$3,499.66	$3,430.34	AIAA, Student Expenditure
Total	**$28,060.31**	**$30,964.34**	**$11,000.00**	**$19,930.34**	

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 donation. The airframe tube is being donated by ICE and is valued at $3,000. 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 55: Special Thank You to OSGC

6.6.3 Timeline

FIX YOUR CAPTION

If your reference links here, fix your caption dummy

Appendix A

Drawings and Schematics

Contained within this appendix are dimensional drawings for each of the parts OSRT will manufacture. The part numbers correlate to the part numbers listed on the Bill of Materials in Section 6.6.1

A.1 Structures

A.1.1 Body Tube

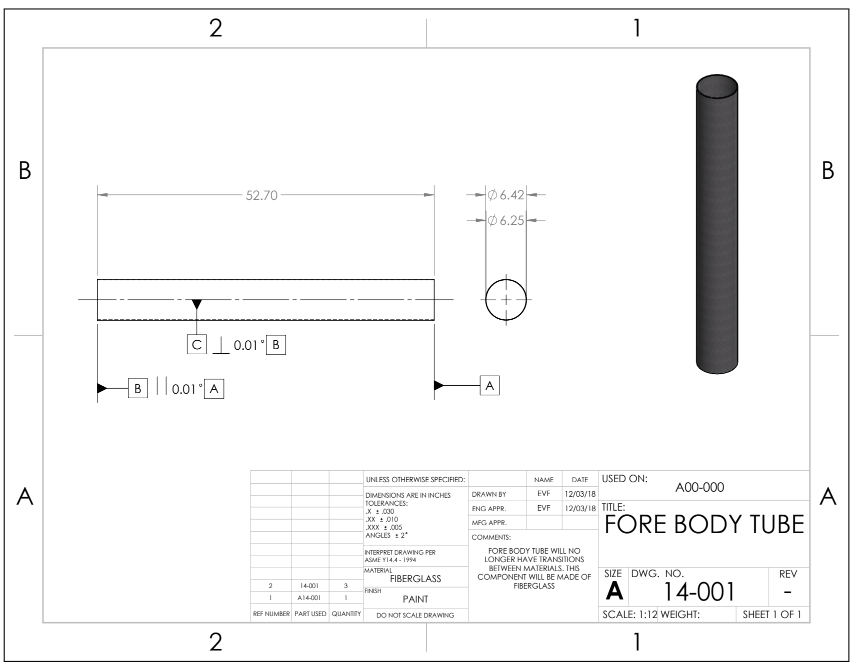

Figure 56: Fore Body Tube Drawing

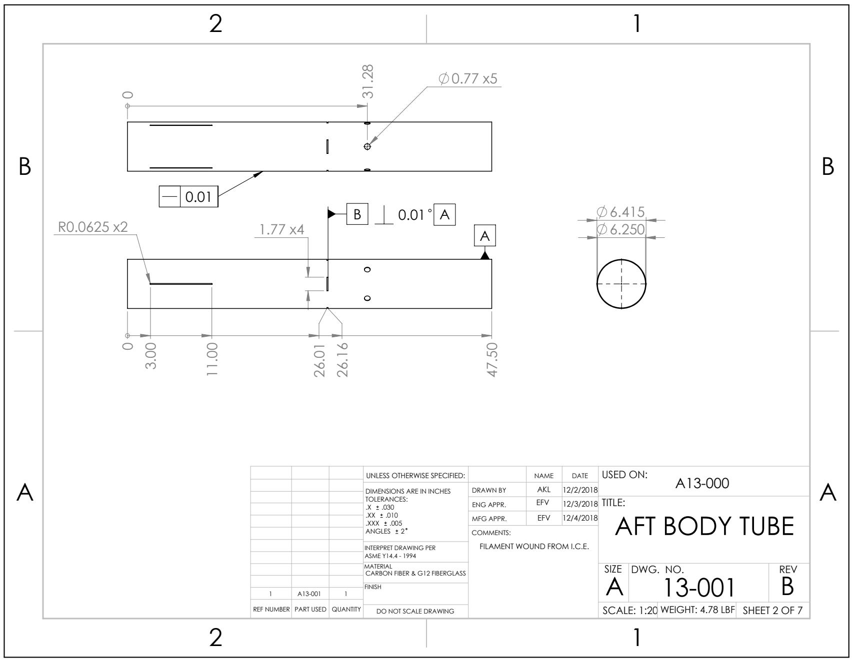

Figure 57: Aft Body Tube Drawing

A.1.2 Nosecone

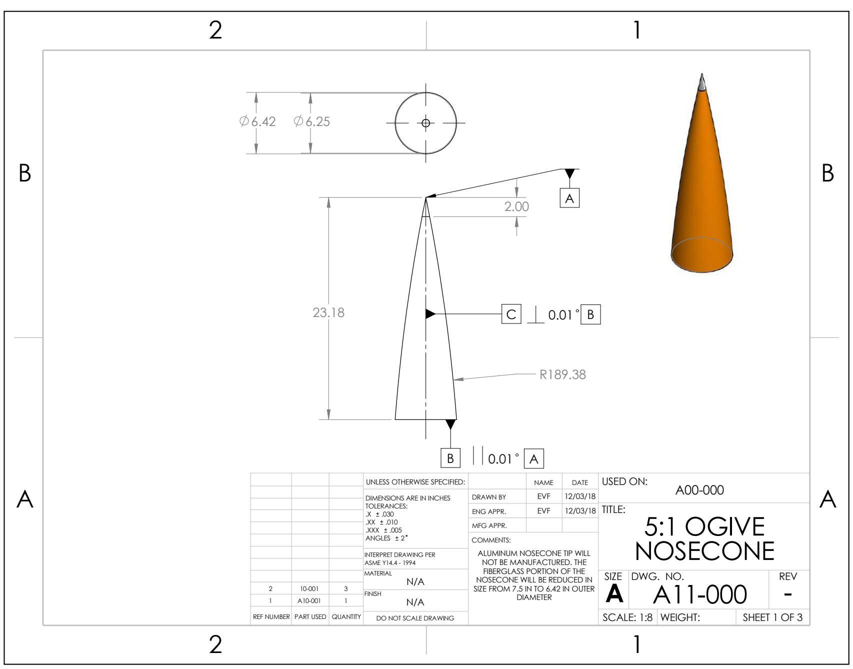

Figure 58: Nosecone Drawing

A.1.3 Fins

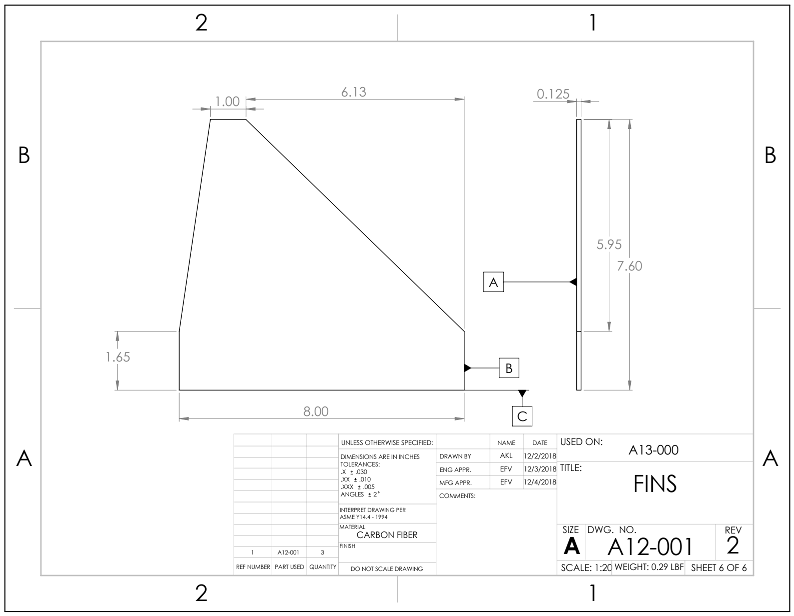

Figure 59: Fin Drawing

A.1.4 Fore Avionics

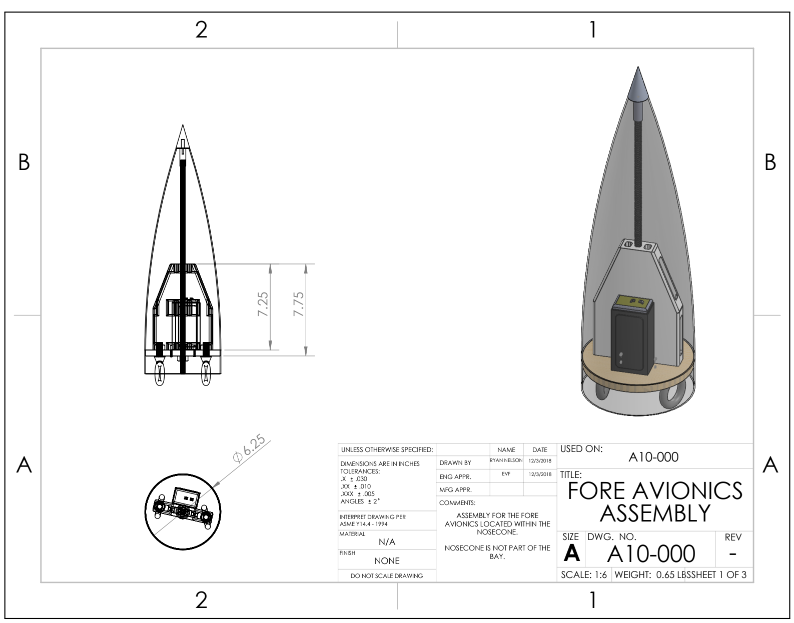

Figure 60: Fore Avionics Assembly

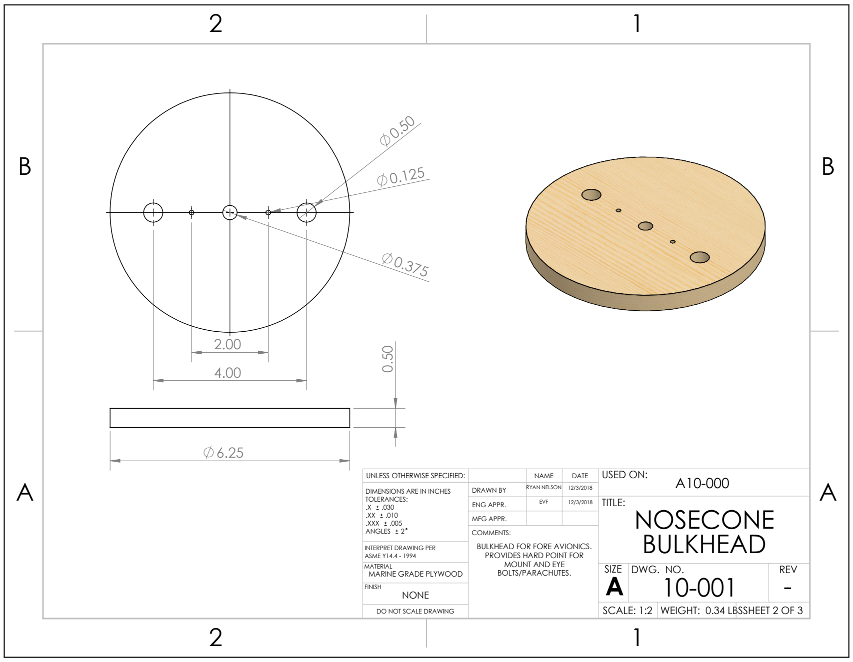

Figure 61: Nosecone Bulkhead

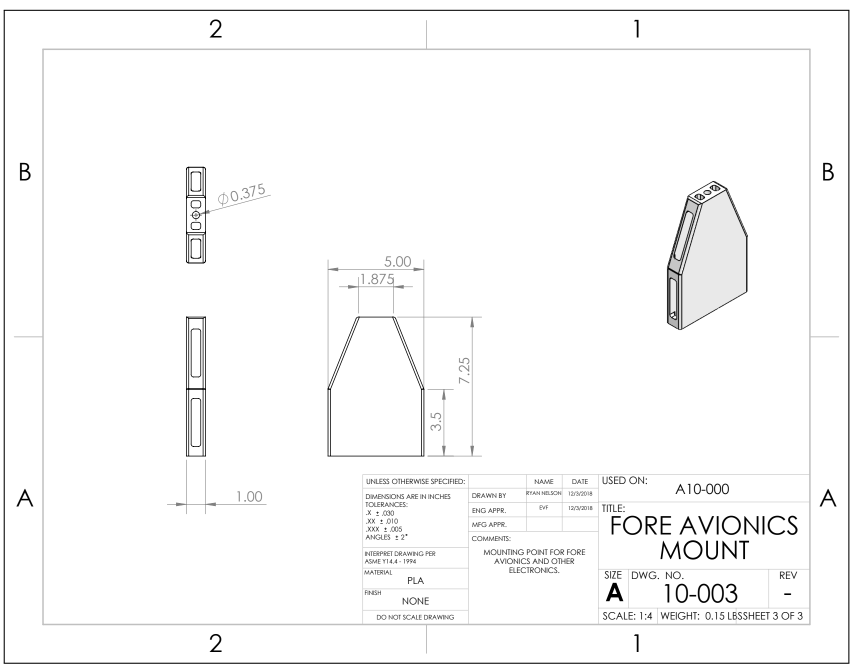

Figure 62: Fore Avionics Mount

A.1.5 Fore Ejection Bay

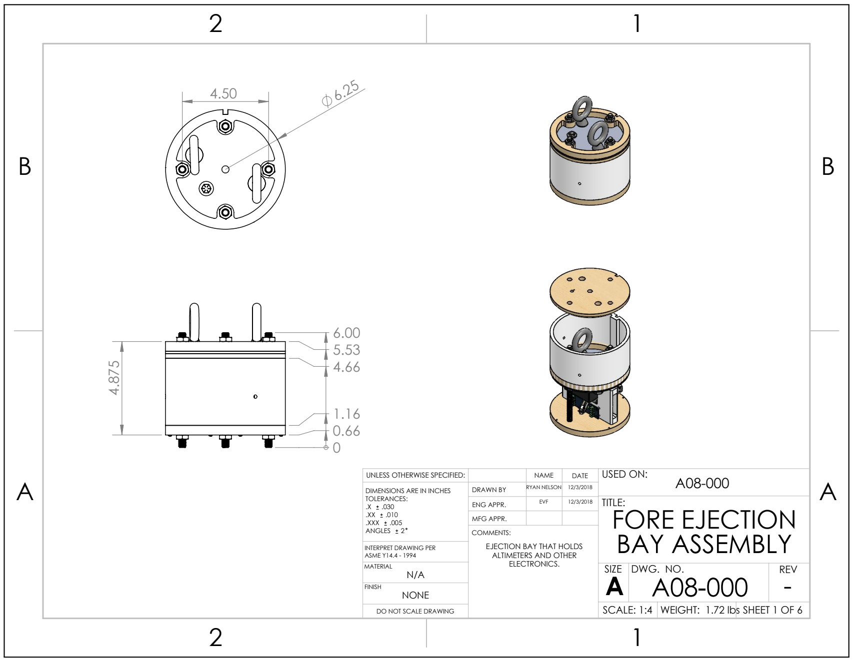

Figure 63: Fore Ejection Assembly

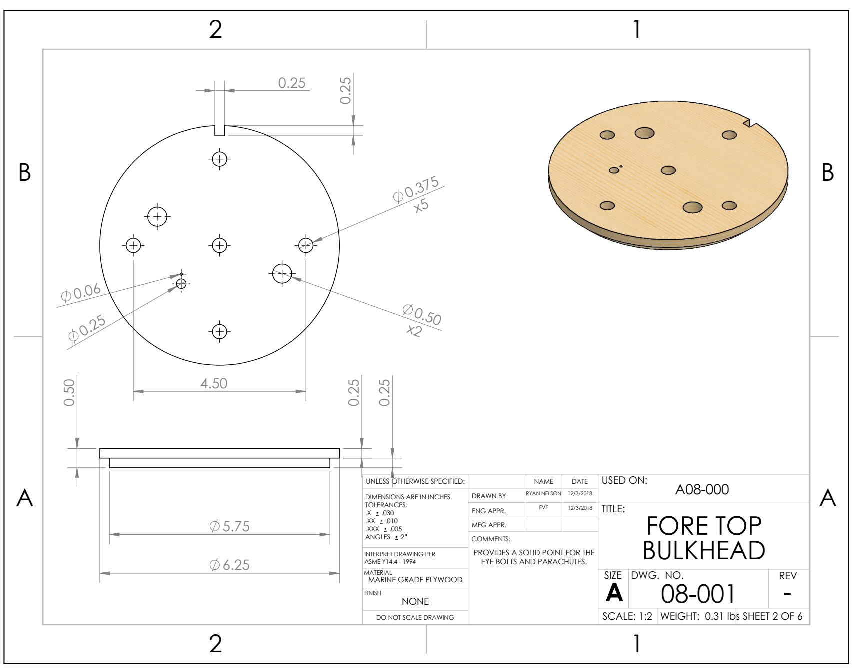

Figure 64: Fore Top Bulkhead

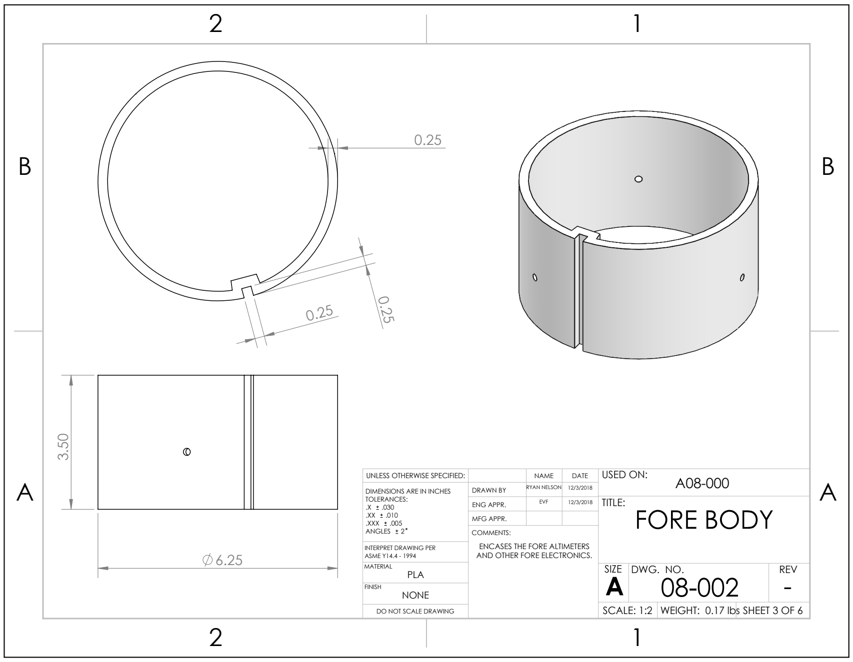

Figure 65: Fore Body

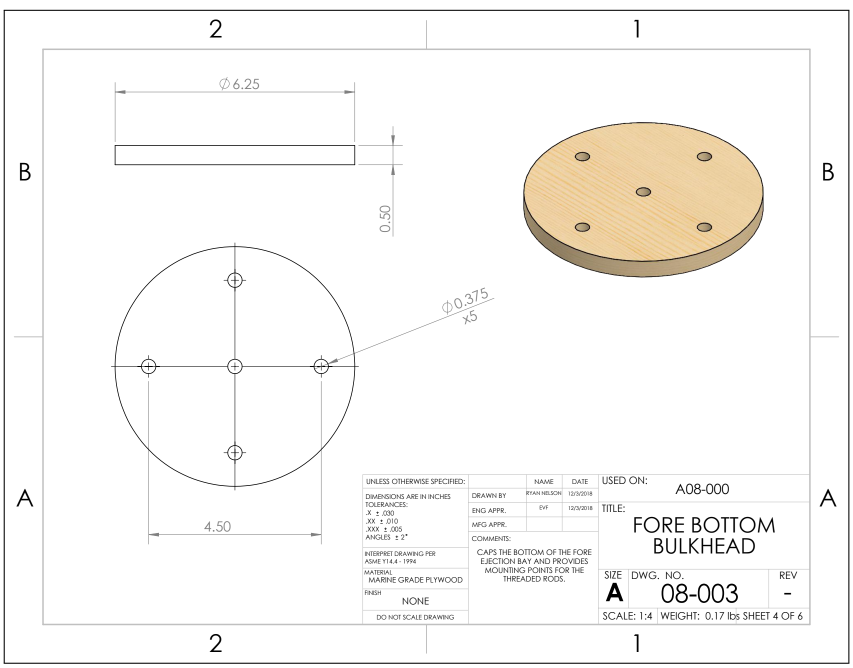

Figure 66: Fore Bottom Bulkhead

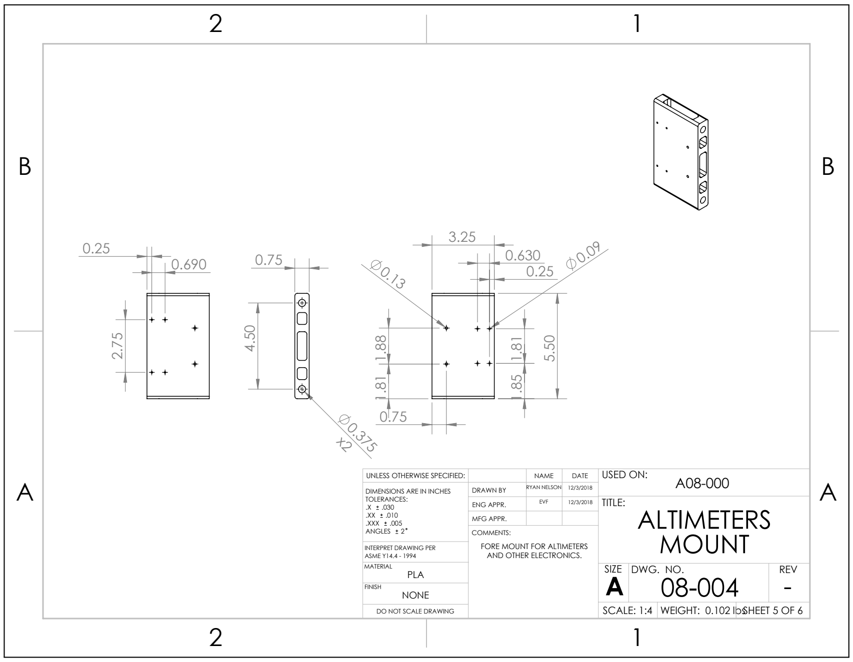

Figure 67: Altimeters Mount

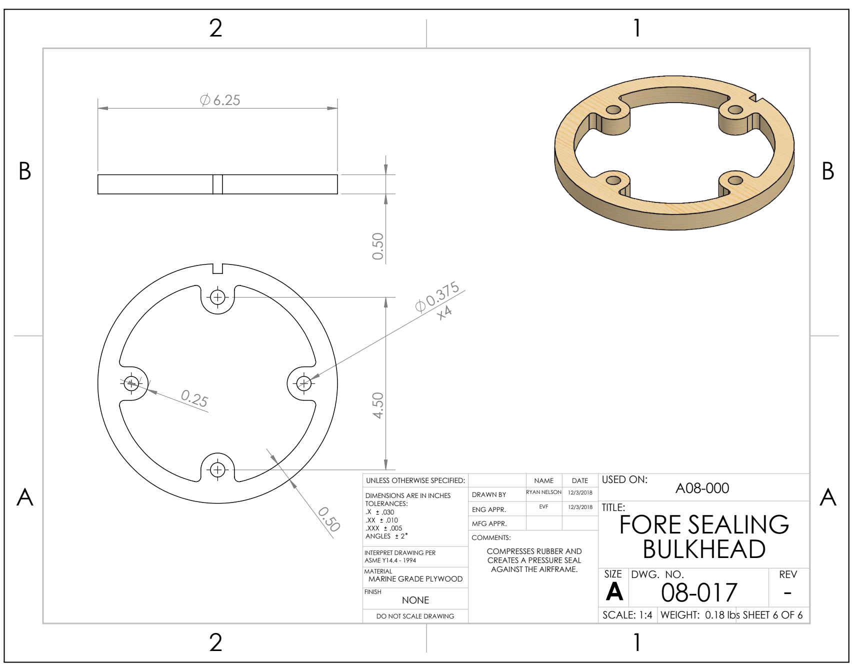

Figure 68: Fore Sealing Bulkhead

A.1.6 Aft Electronic Bay

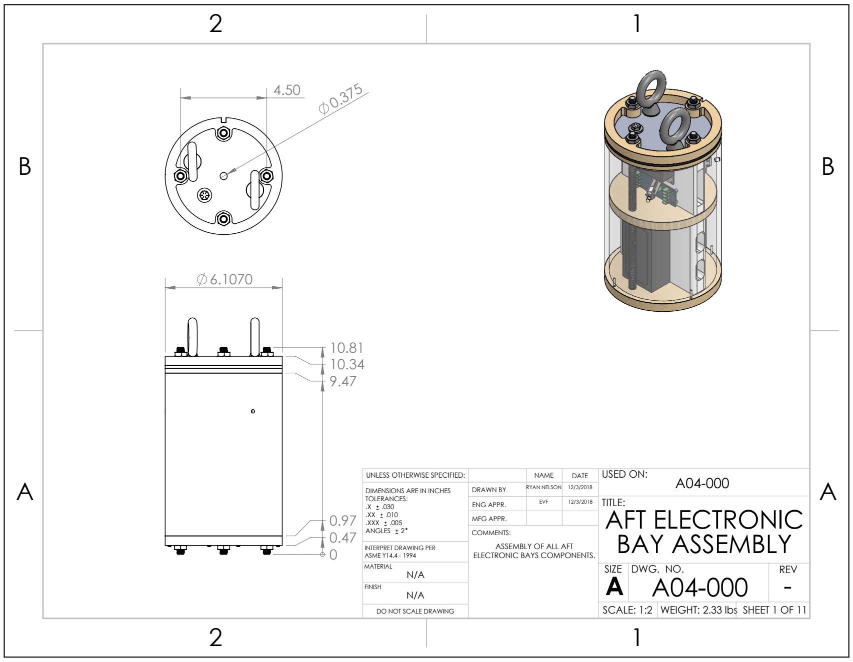

Figure 69: Aft Electronic Bay Assembly

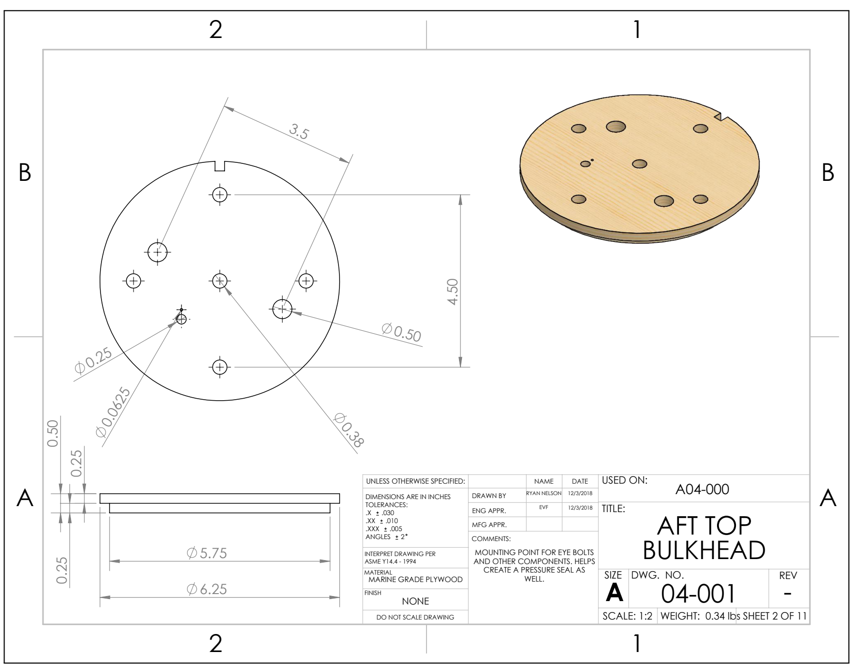

Figure 70: Aft Top Bulkhead

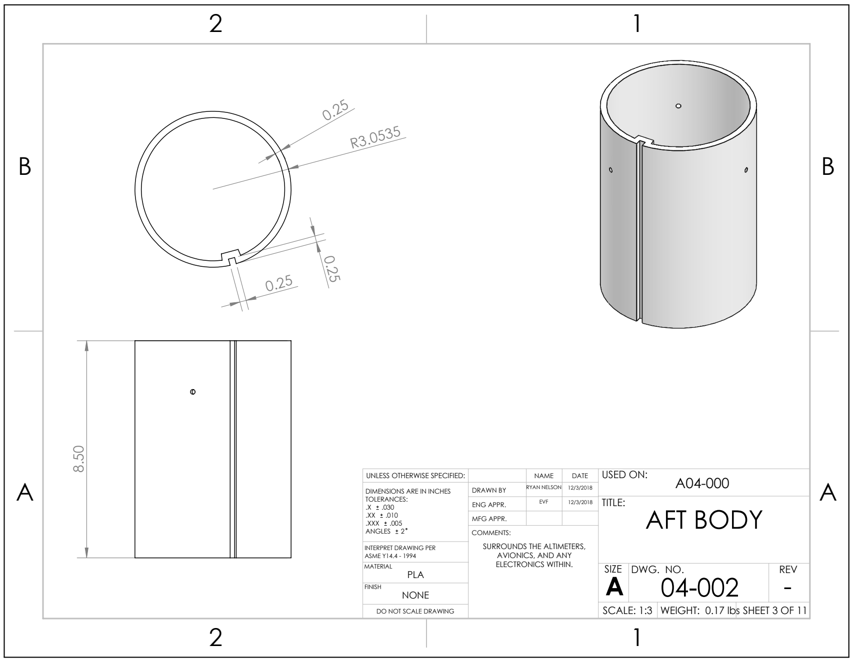

Figure 71: Aft Body

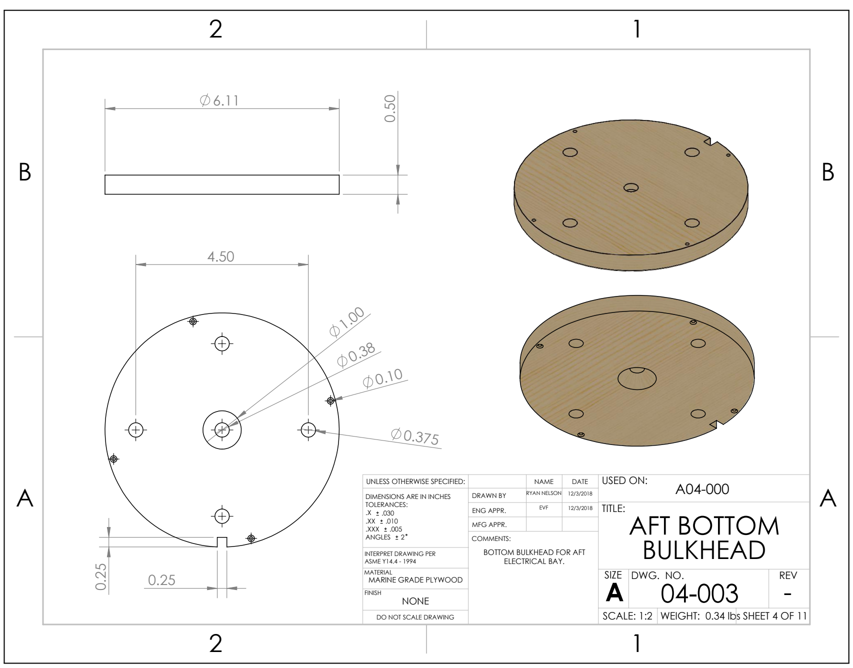

Figure 72: Aft Bottom Bulkhead

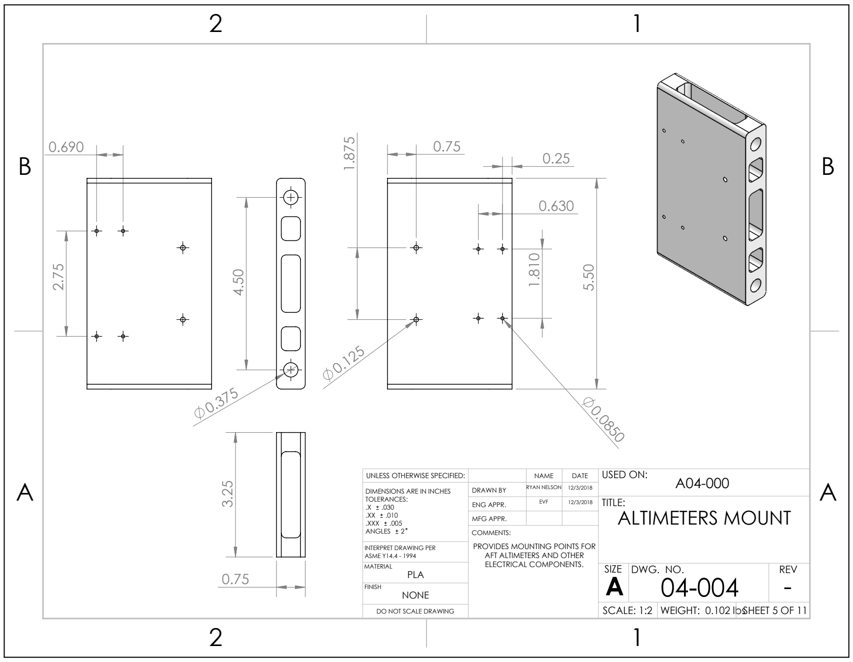

Figure 73: Altimeters Mount

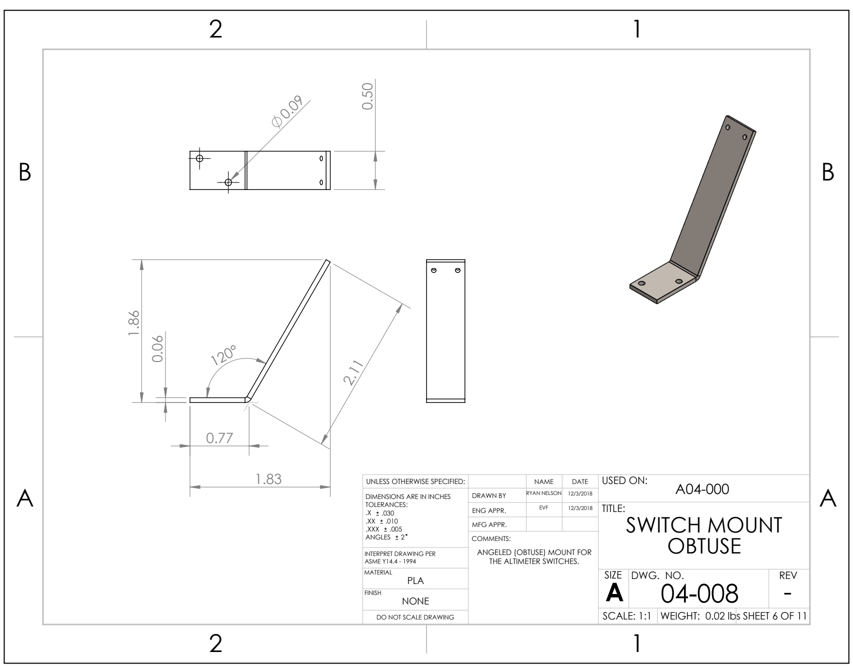

Figure 74: Switch Mount Obtuse

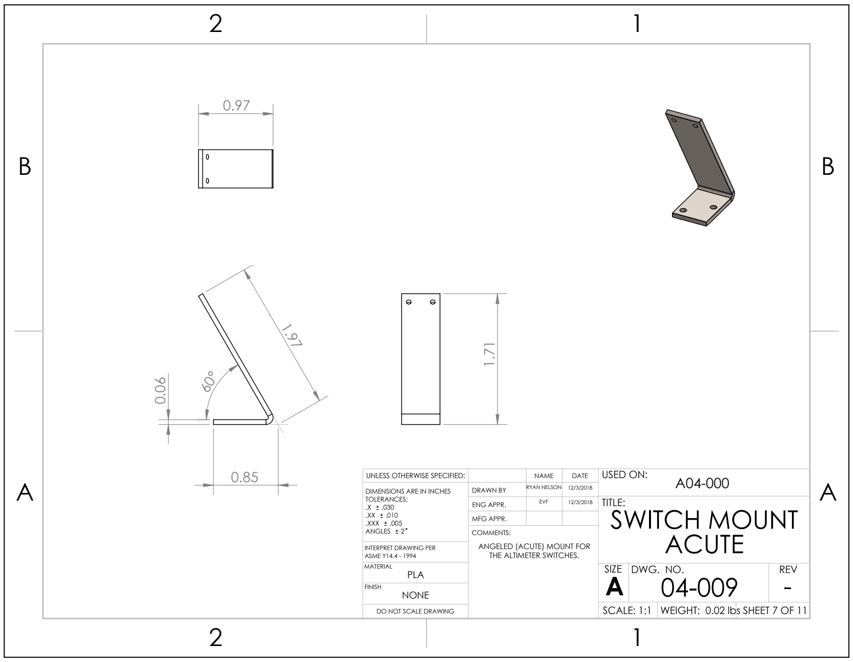

Figure 75: Switch Mount Acute

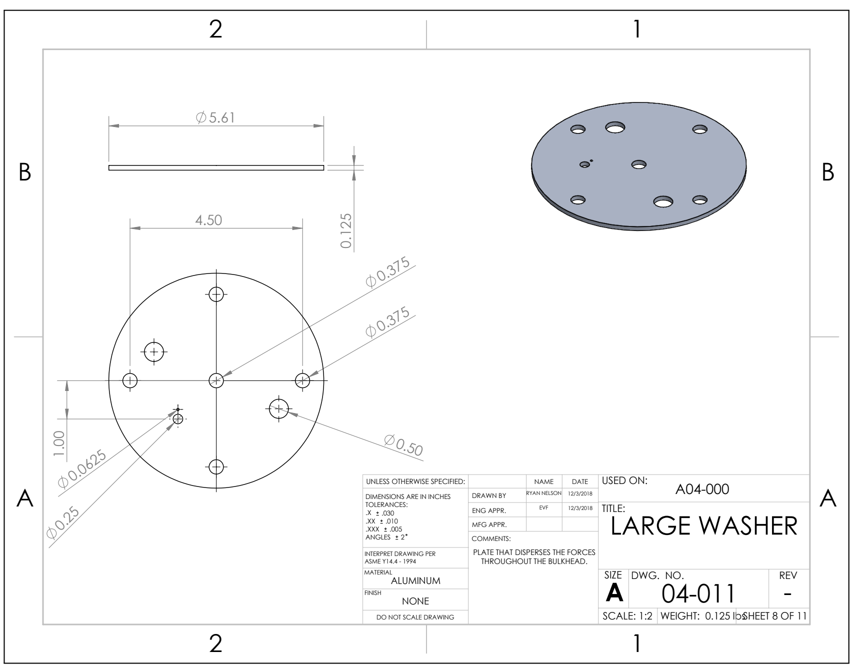

Figure 76: Large Washer

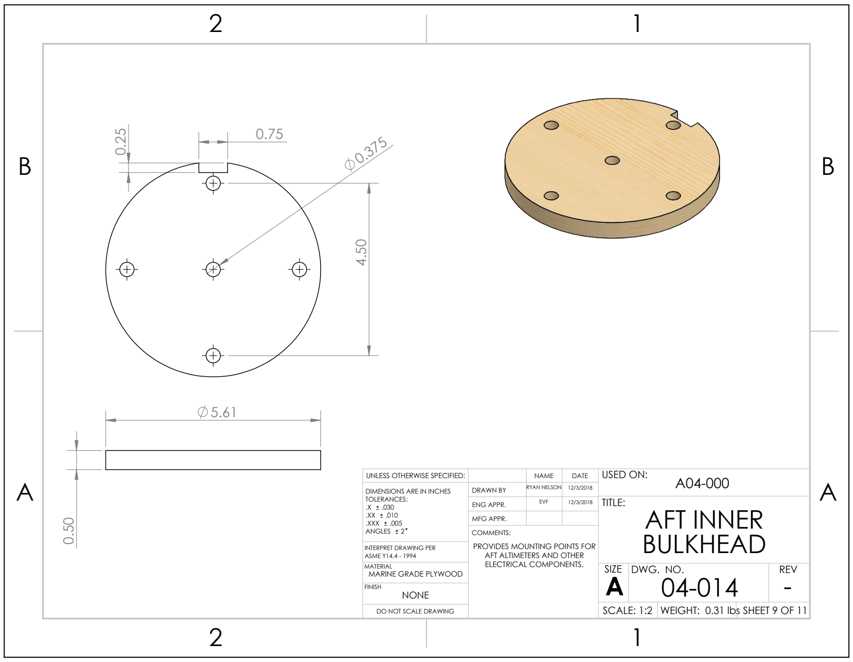

Figure 77: Aft Inner Bulkhead

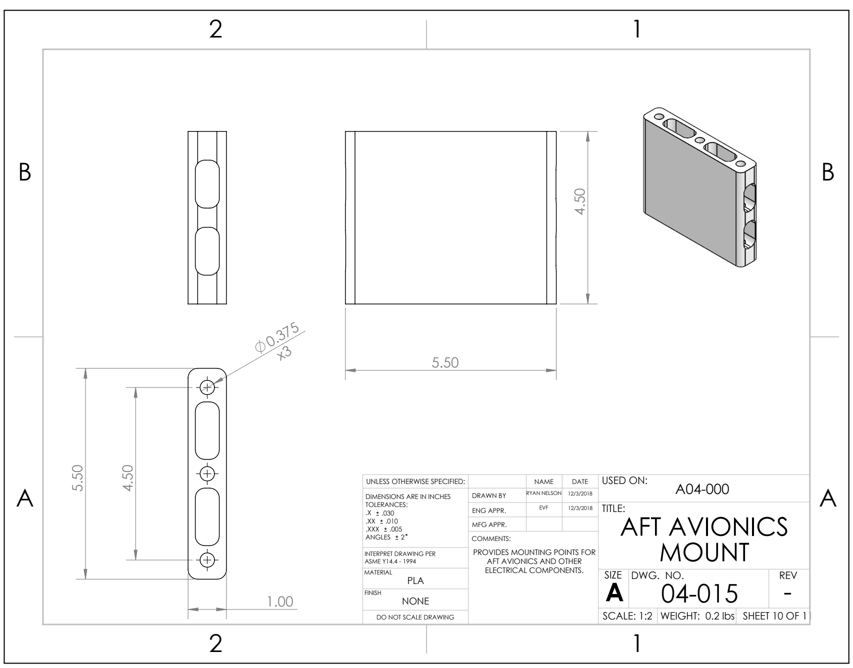

Figure 78: Aft Avionics Mount

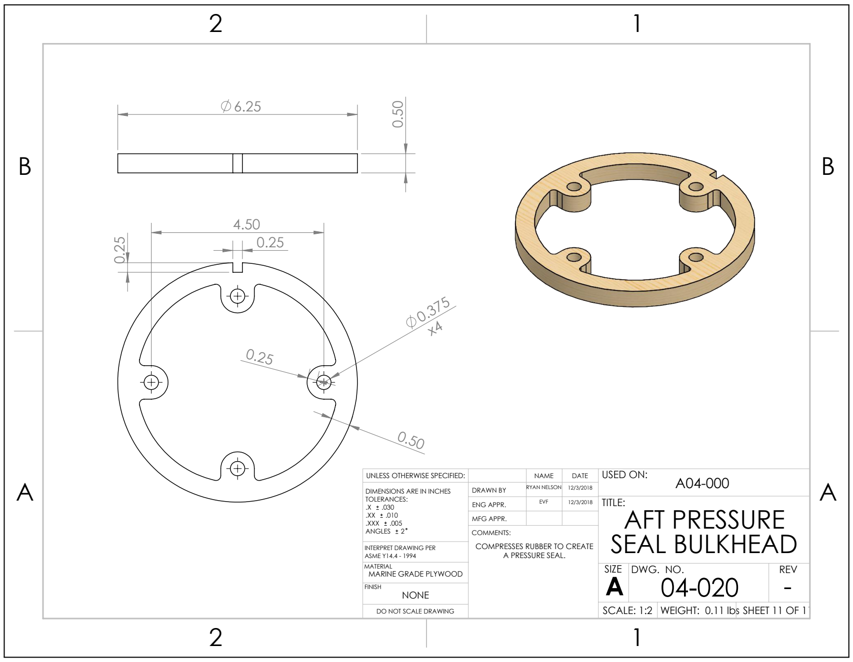

Figure 79: Aft Pressure Seal Bulkhead

A.1.7 Fore Coupler

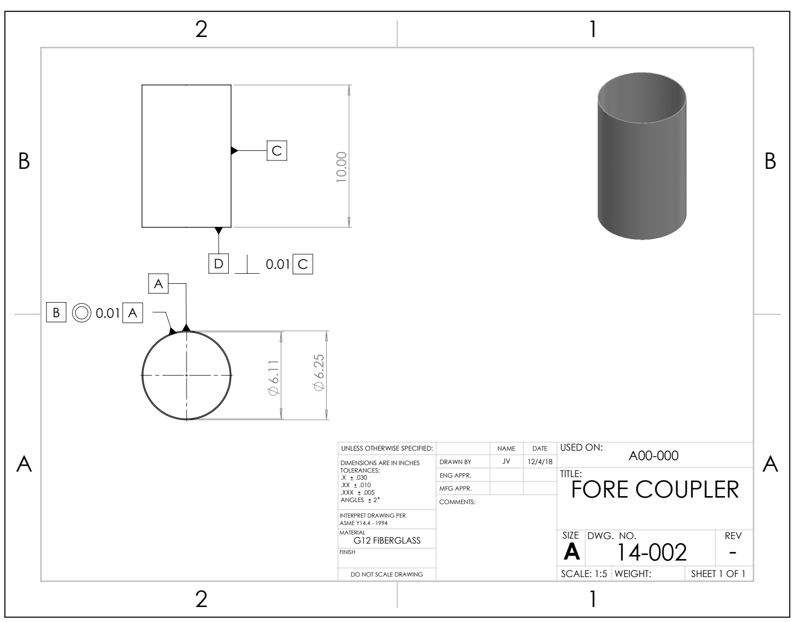

Figure 80: Fore Coupler

A.1.8 Aft Canister

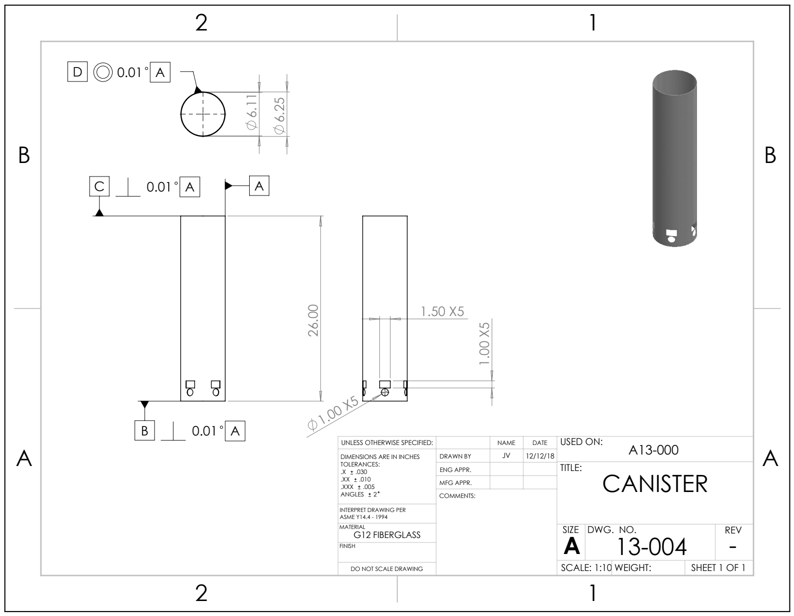

Figure 81: Canister

A.1.9 Camera System

A.1.10 Motor Retention

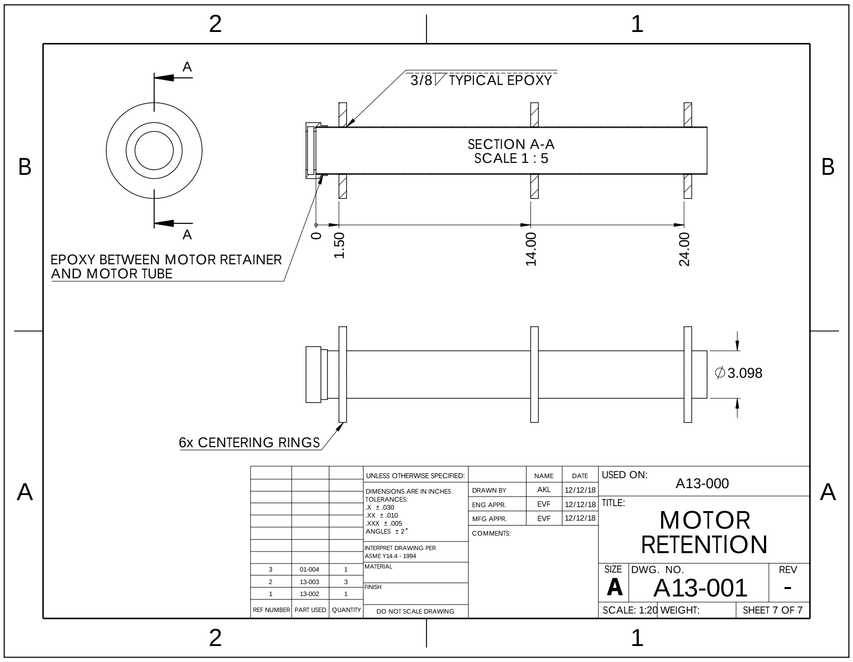

Figure 82: Motor Retention Drawing

A.1.11 Bulkheads

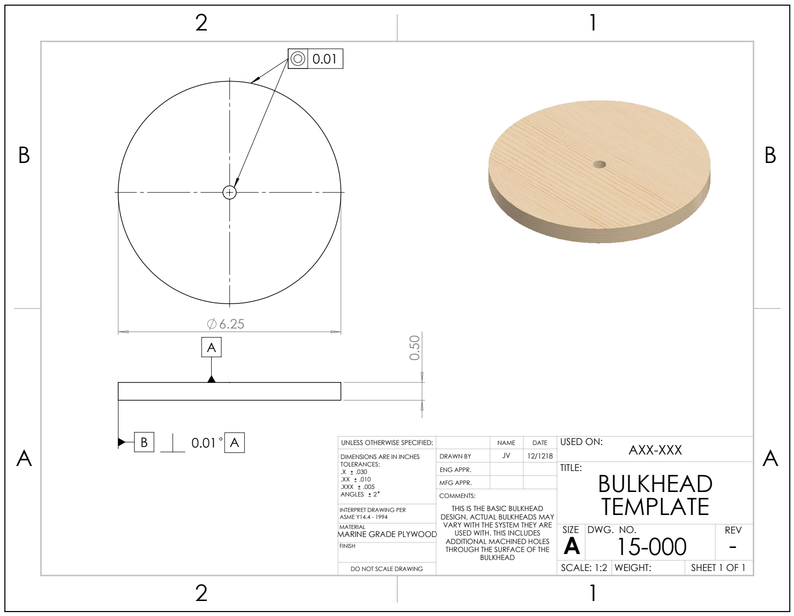

Figure 83: Standard Bulkhead

A.1.12 BEAVS

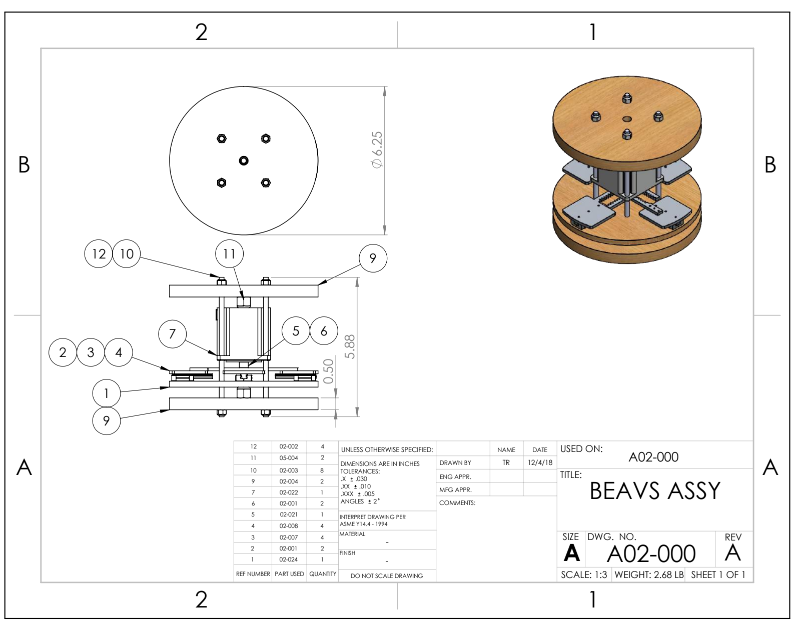

Figure 84: BEAVS Drawings

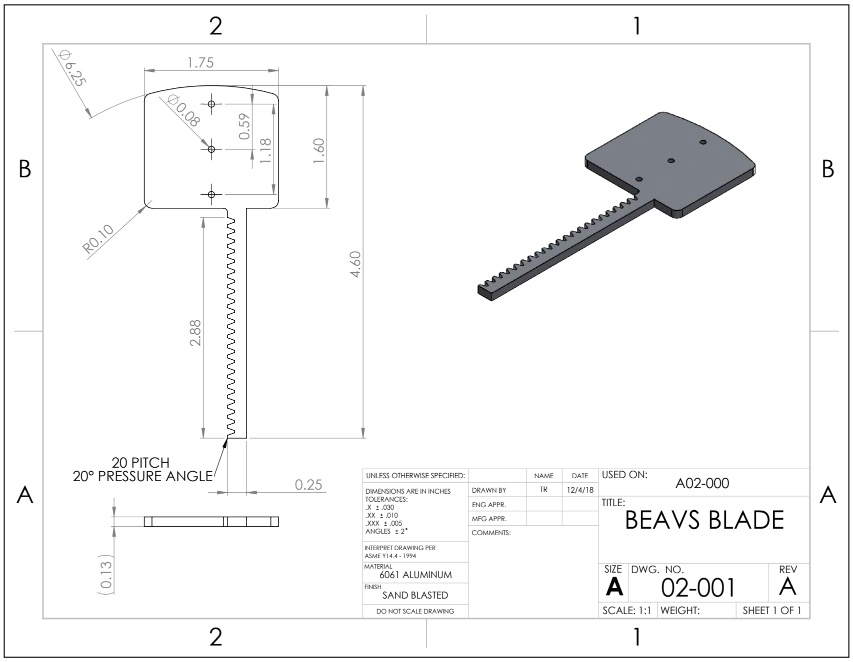

Figure 85: BEAVS Drawings

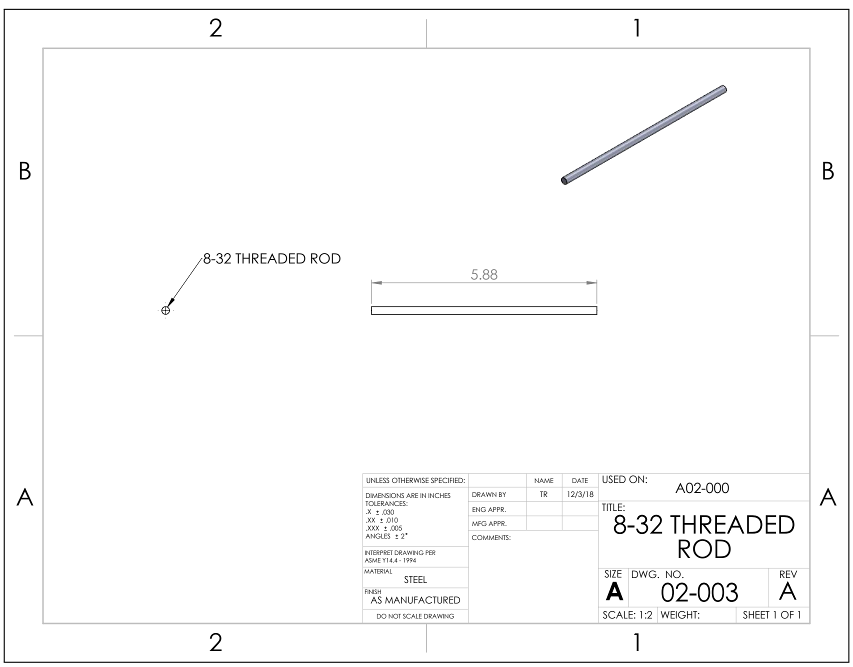

Figure 86: BEAVS Drawings

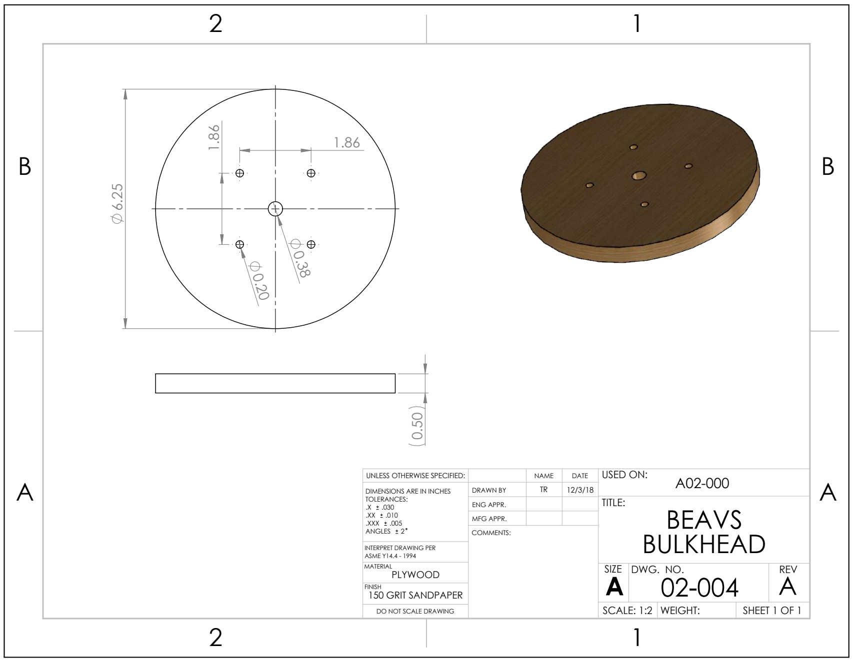

Figure 87: BEAVS Drawings

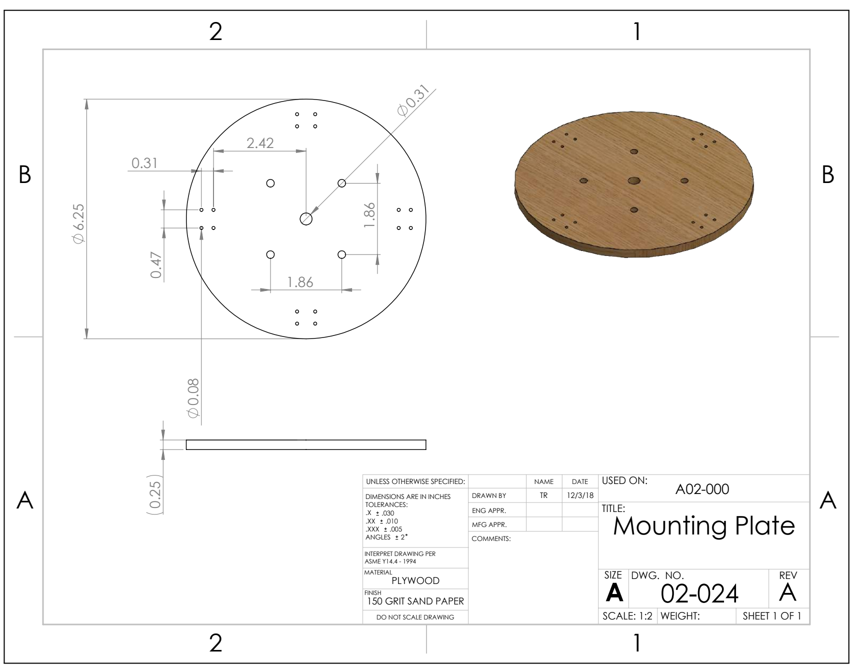

Figure 88: BEAVS Drawings

A.2 Payload

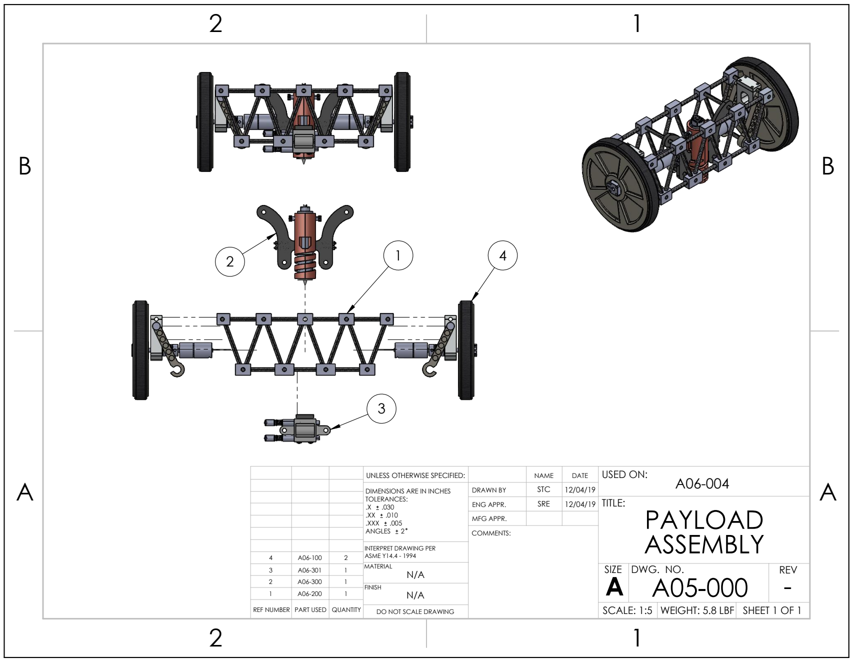

Figure 89: Rover Assembly

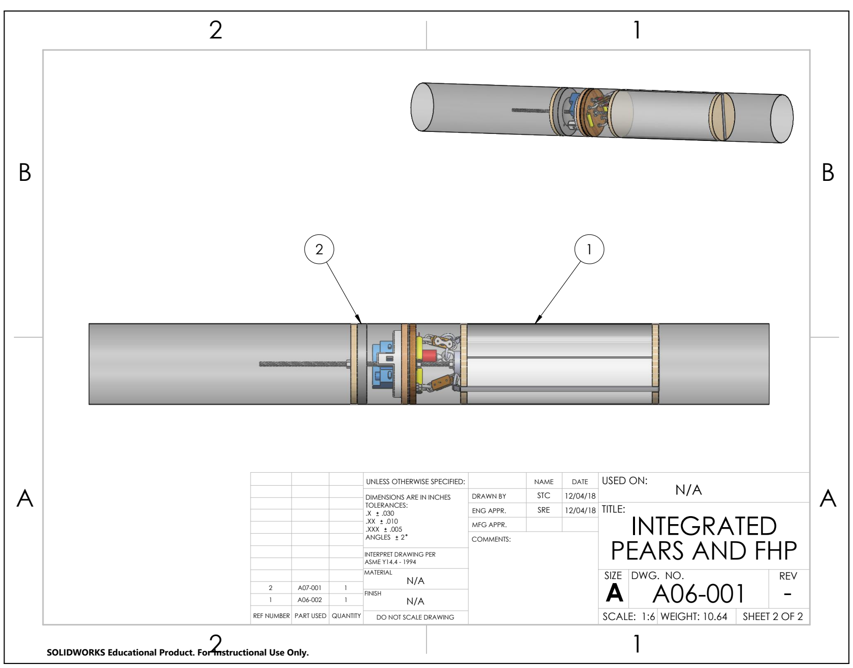

Figure 90: PEARS Integration Assembly

A.2.1 PEARS and FHP

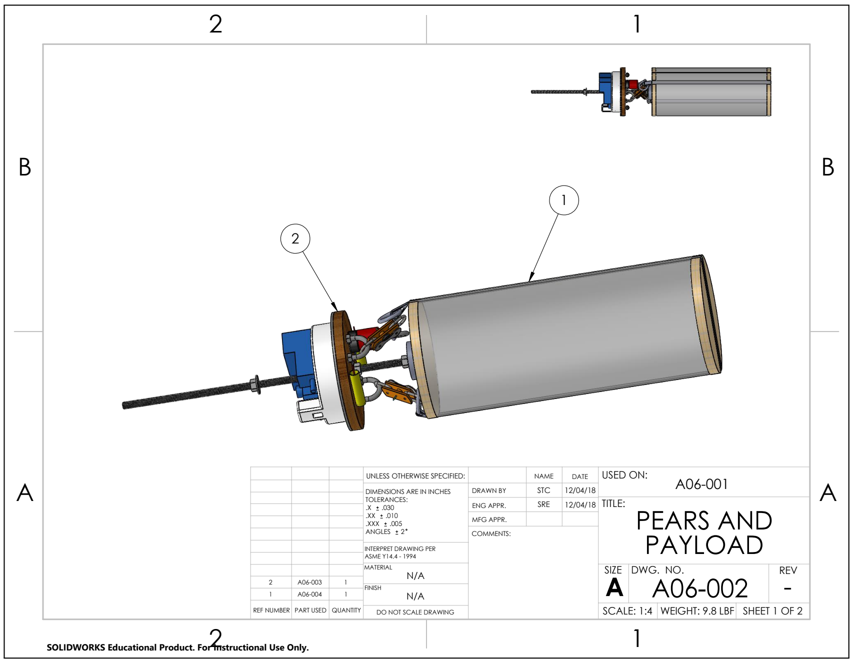

Figure 91: PEARS and Wrap Assembly

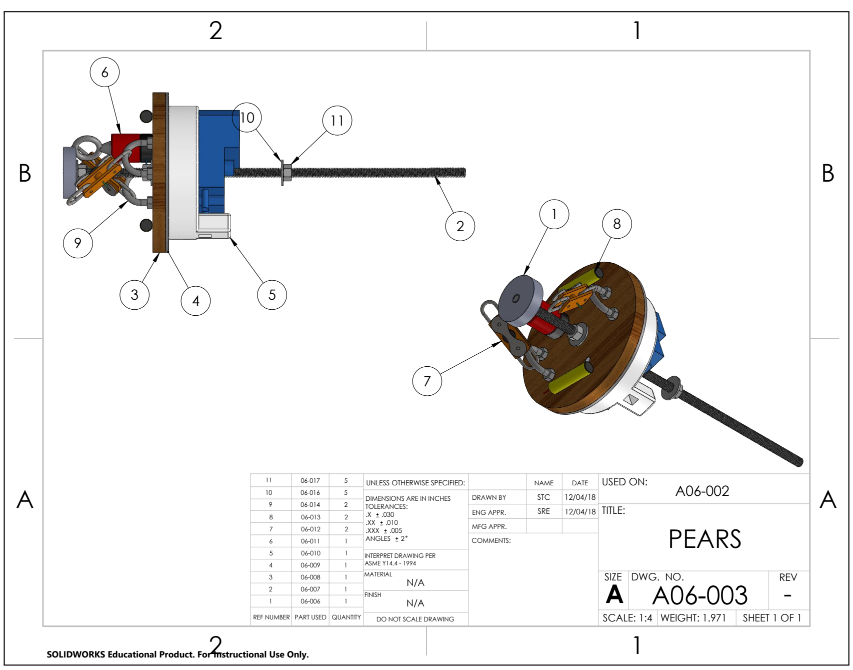

Figure 92: PEARS Assembly

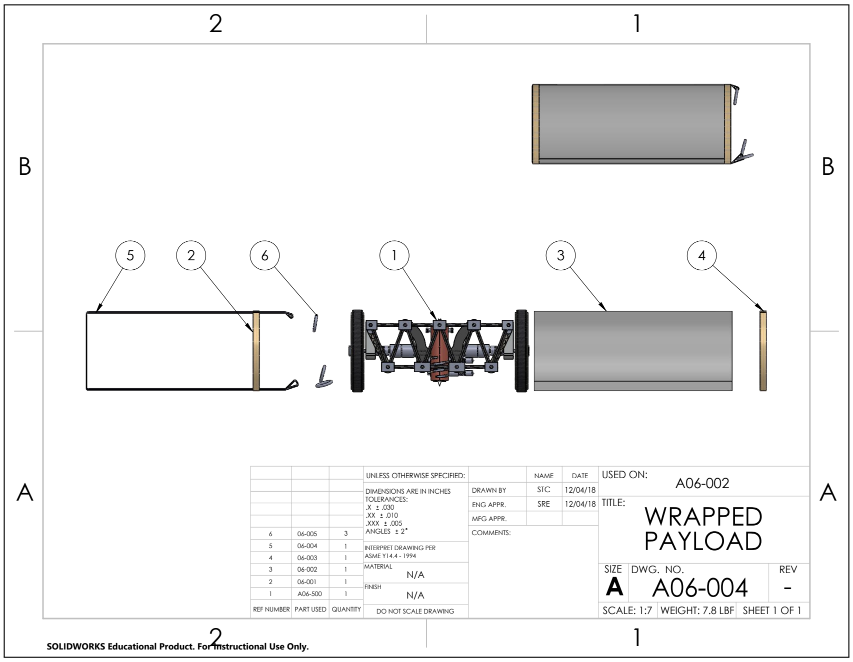

Figure 93: Wrapped Payload Assembly

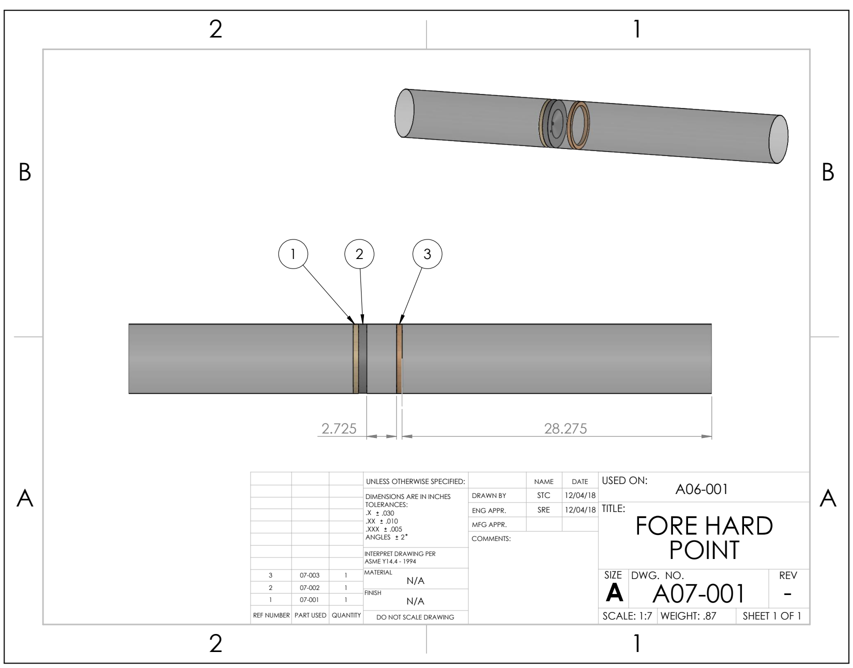

Figure 94: Fore Hard Point Assembly

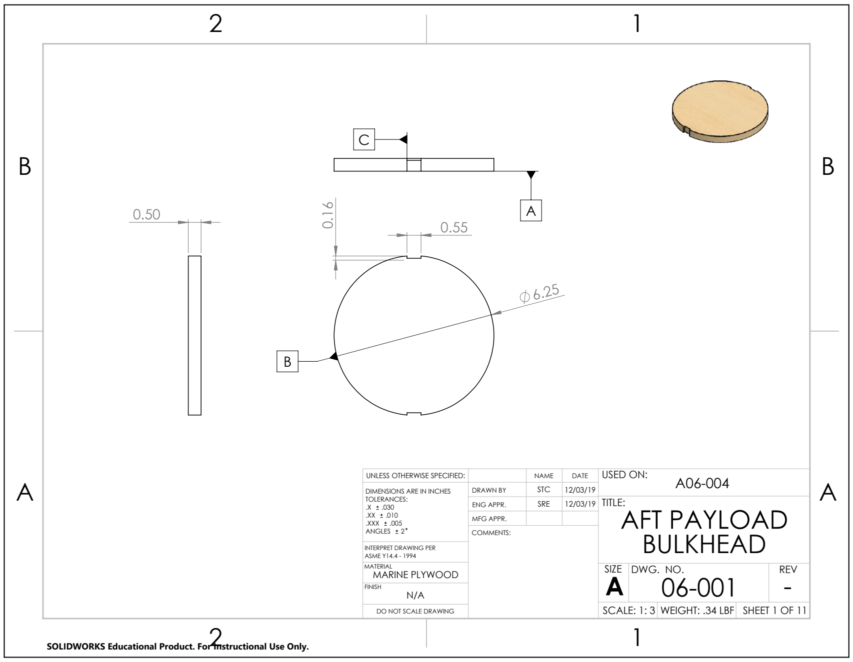

Figure 95: Aft Payload Bulkhead

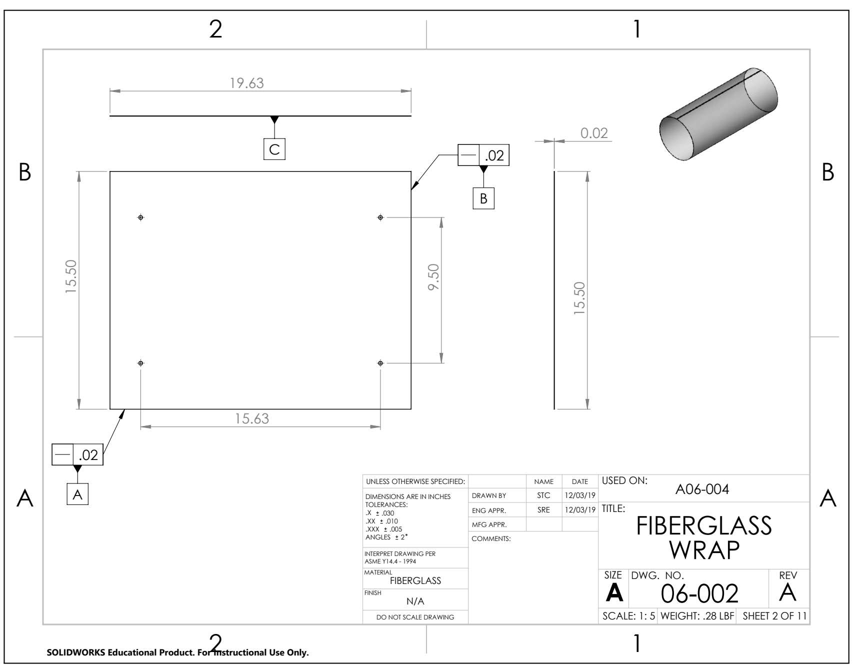

Figure 96: Fiberglass Wrap

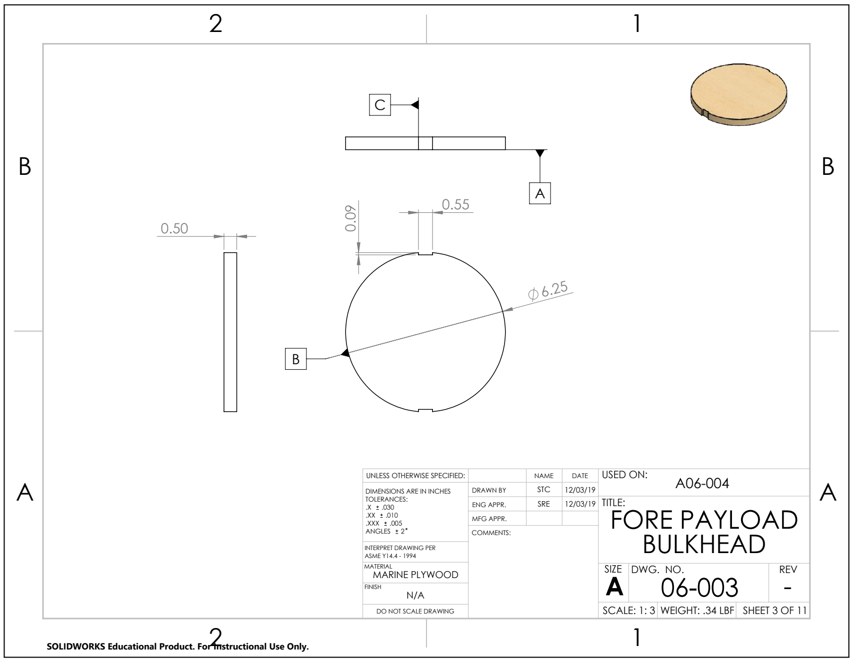

Figure 97: Fore Payload Bulkhead

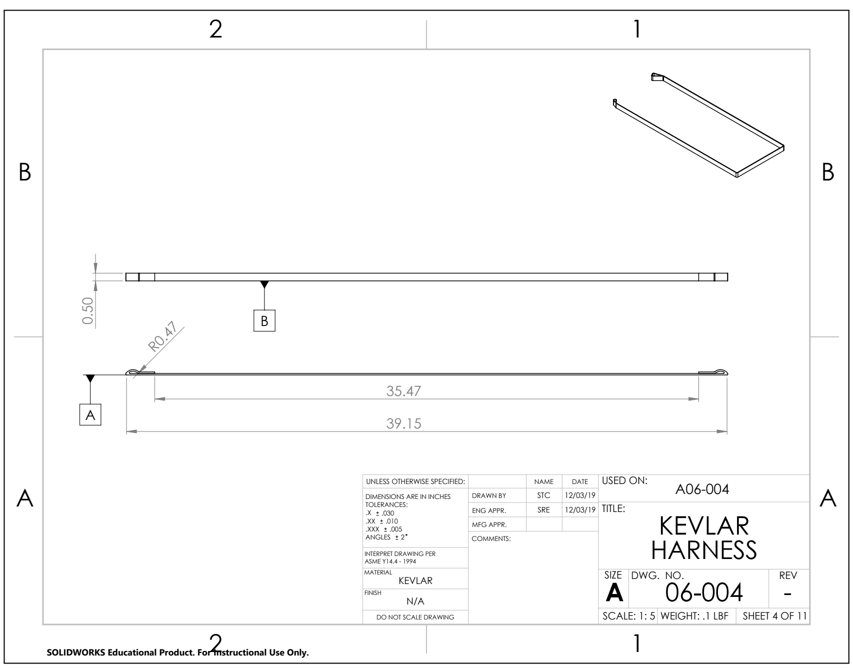

Figure 98: Kevlar Harness

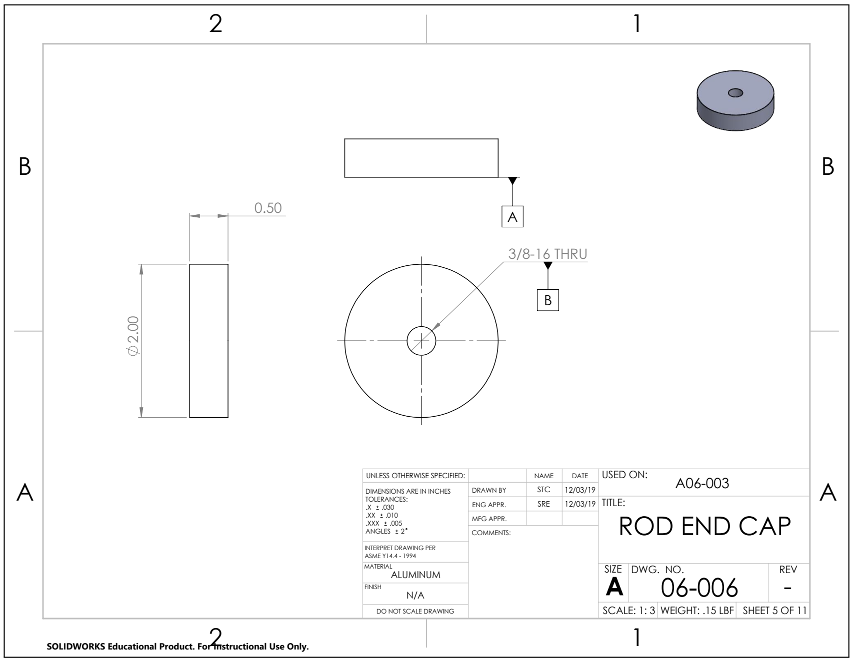

Figure 99: Rod End Cap

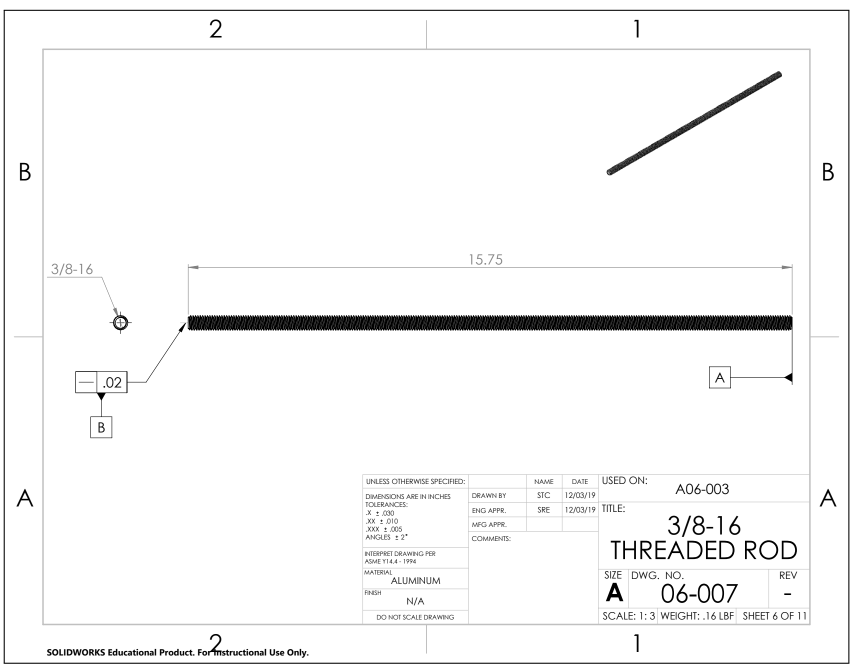

Figure 100: Threaded Rod

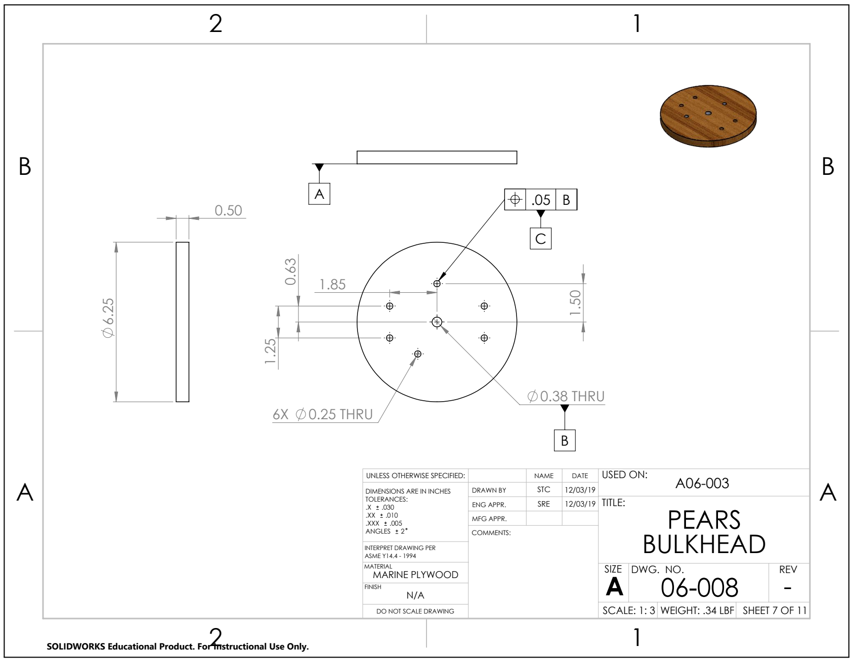

Figure 101: PEARS Bulkhead

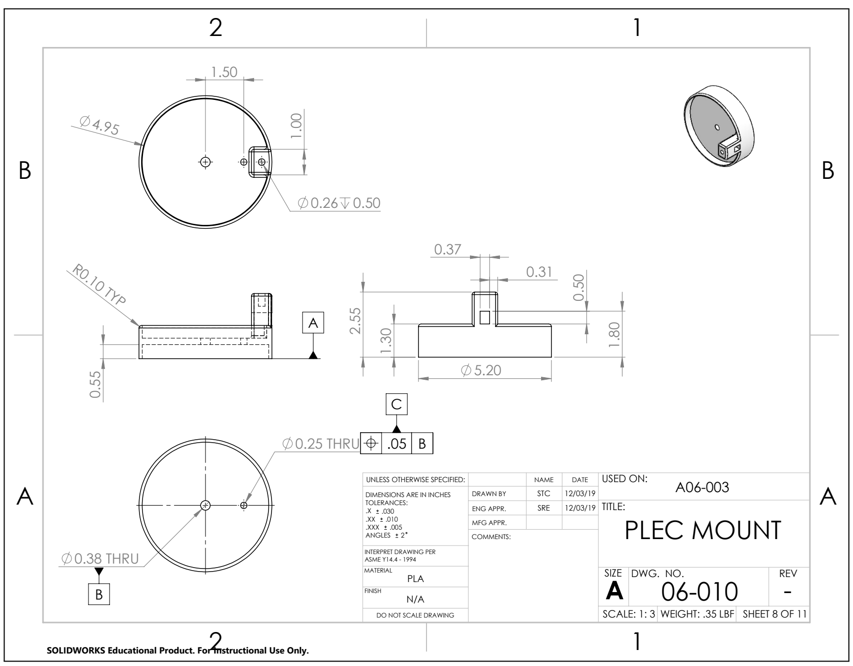

Figure 102: PLEC Mount

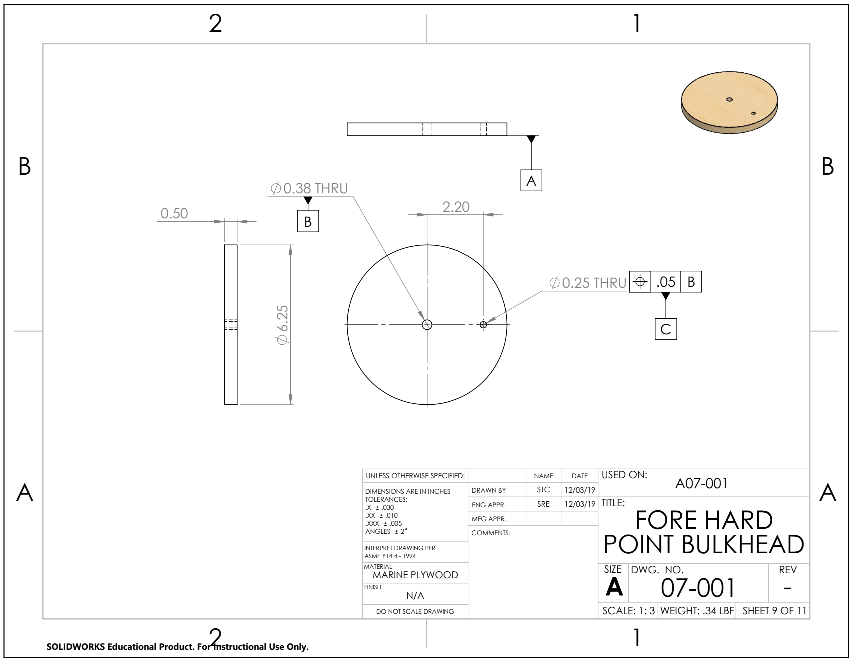

Figure 103: FHP Bulkhead

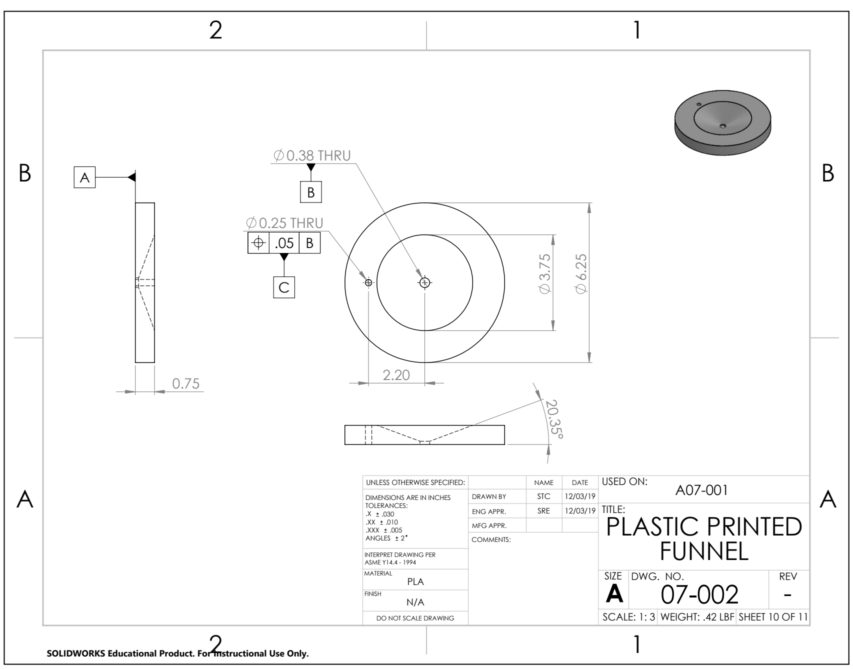

Figure 104: Plastic Printed Funnel

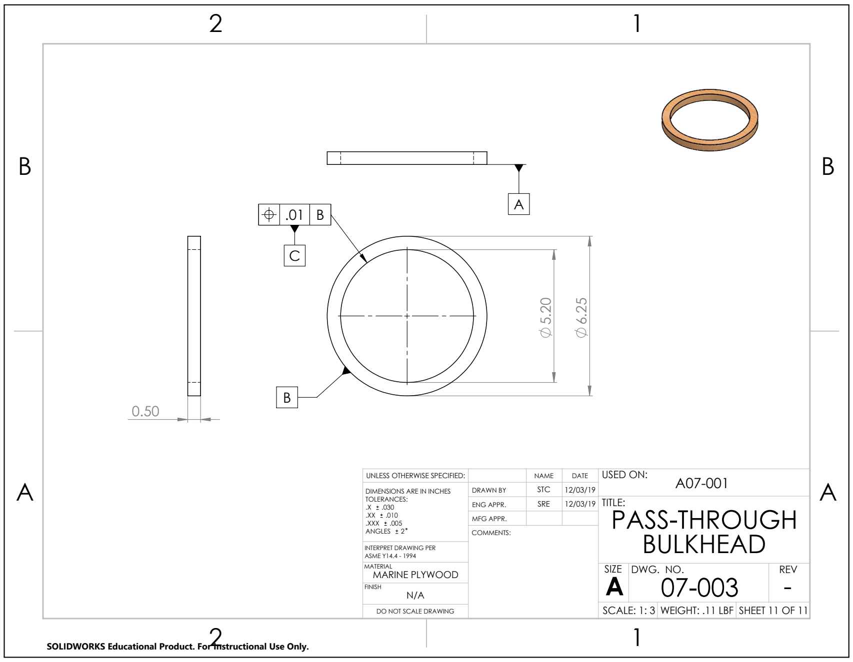

Figure 105: Pass-Though Bulkhead

A.2.2 SCAR

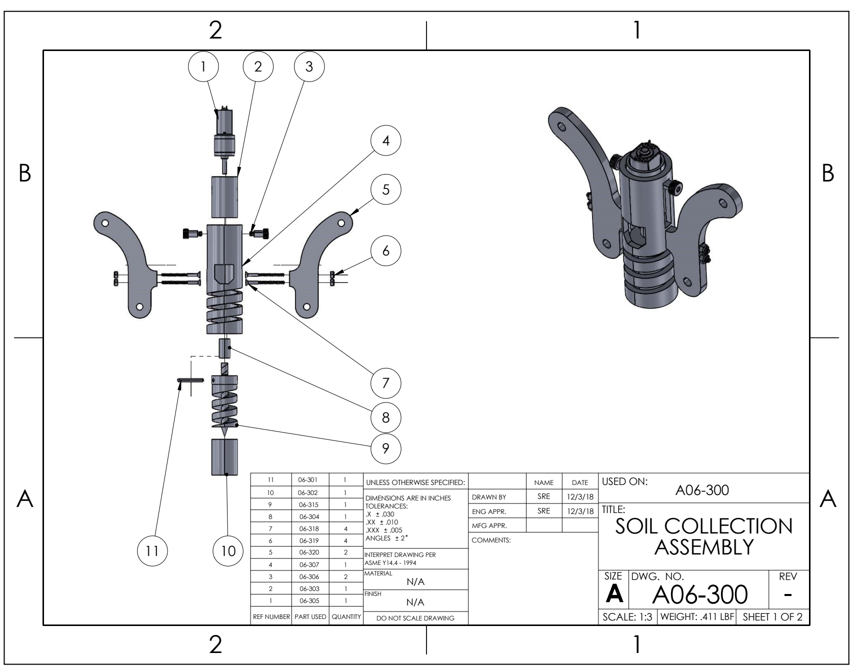

Figure 106: Soil Collection Assembly

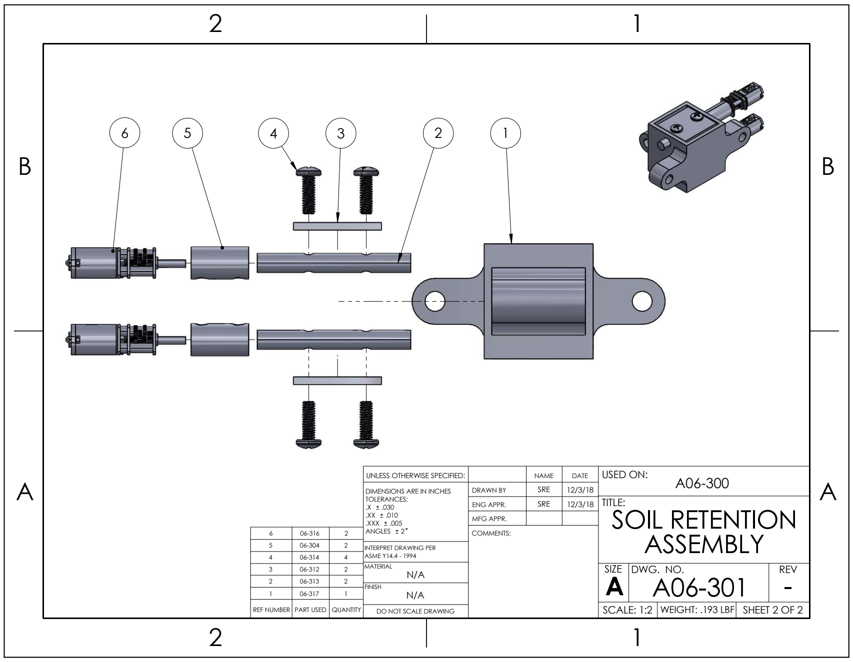

Figure 107: Soil Retention Assembly

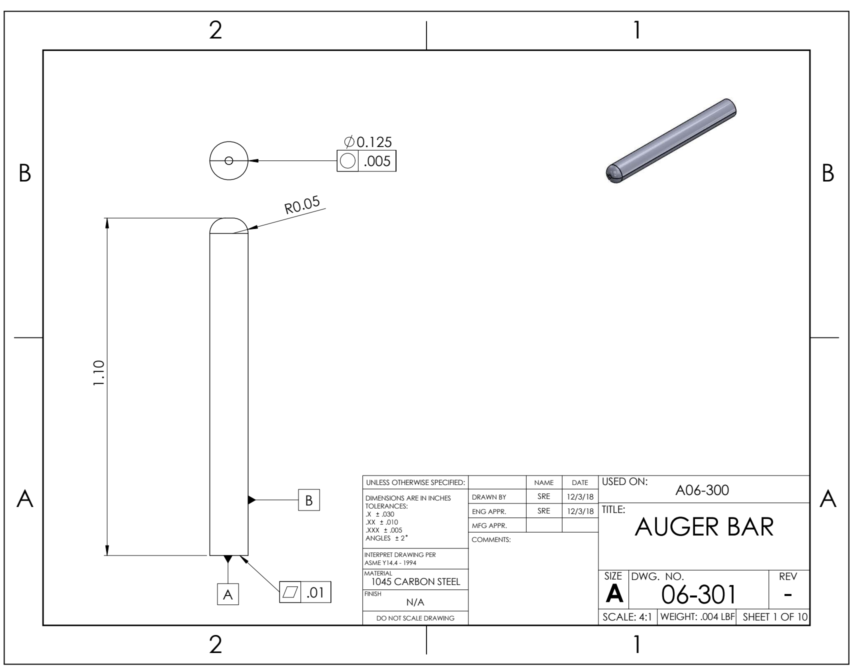

Figure 108: Auger Bar

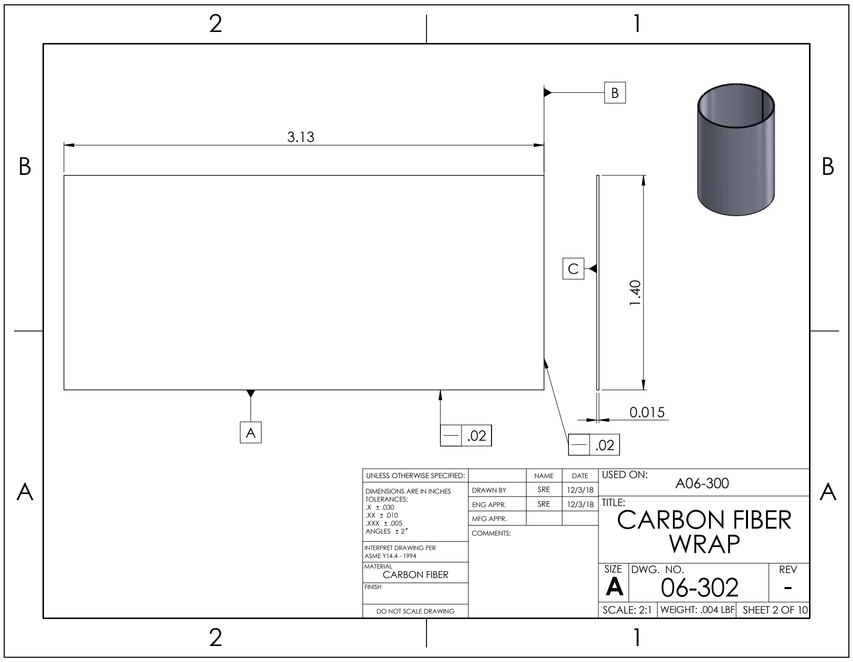

Figure 109: Carbon Fiber Wrap

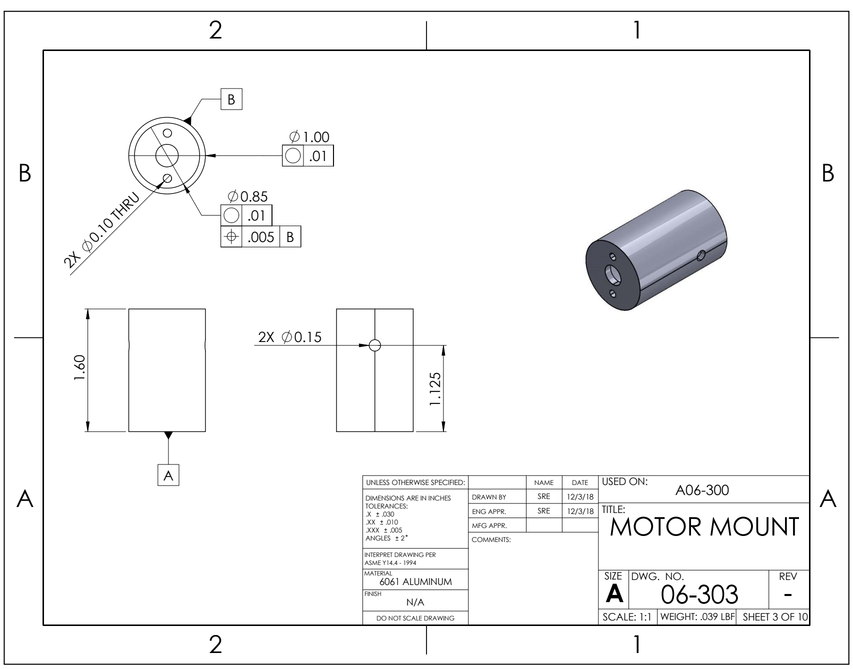

Figure 110: Motor Enclosure

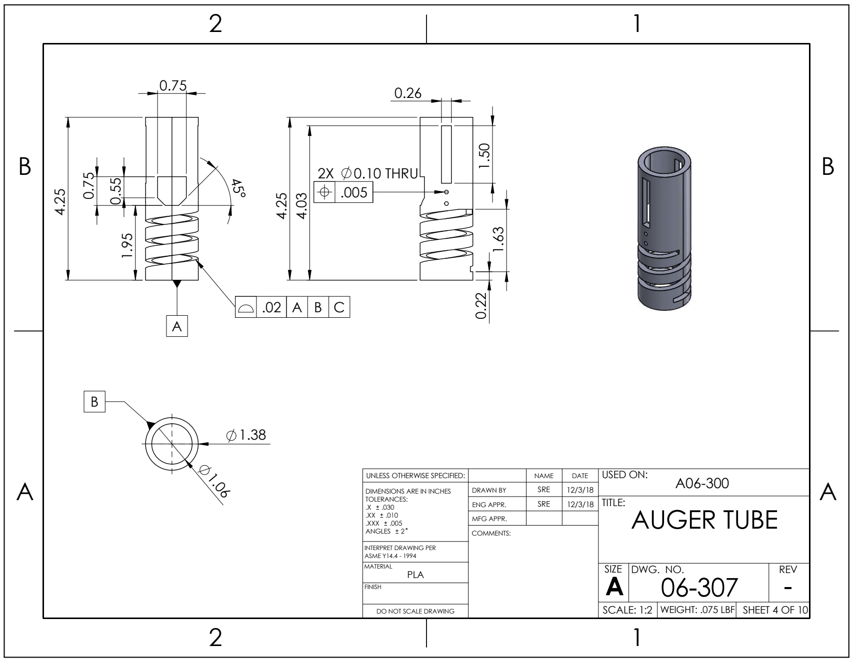

Figure 111: Auger Tube

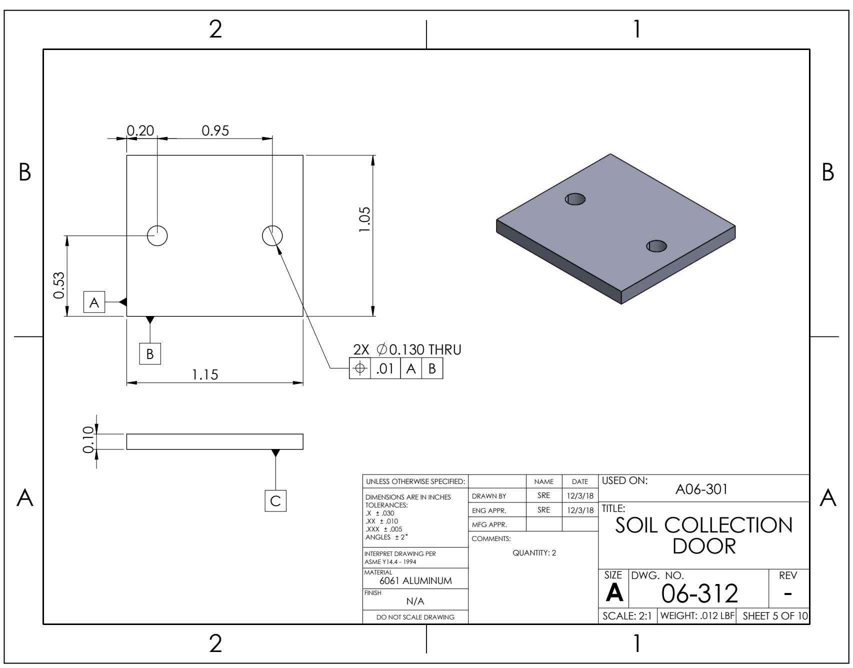

Figure 112: Soil Retention Door

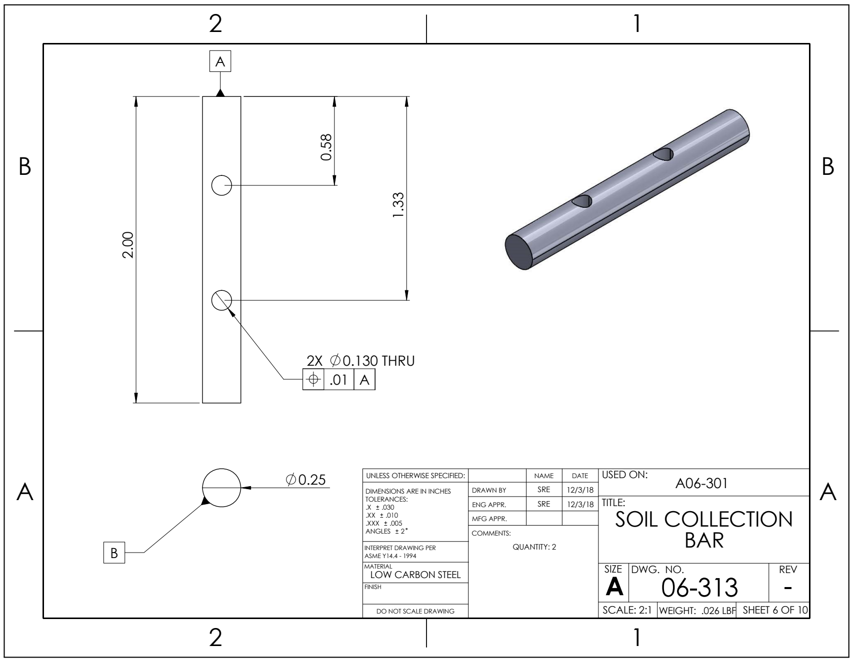

Figure 113: Soil Retention Shaft

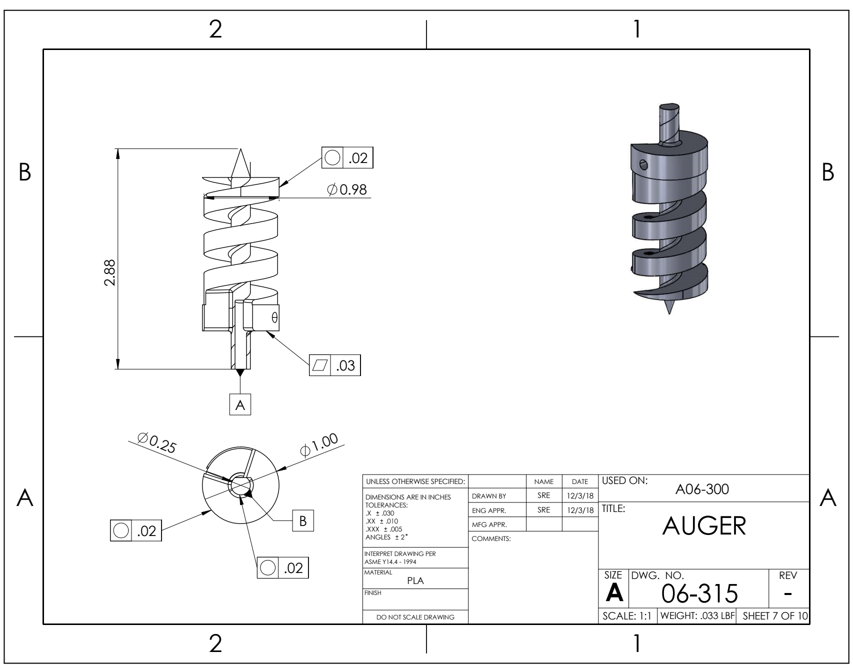

Figure 114: Auger

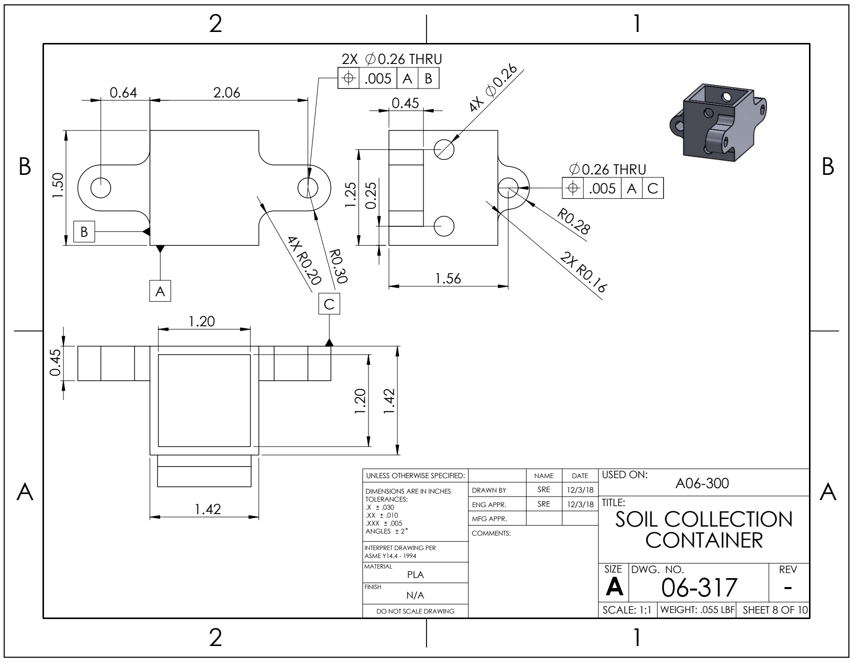

Figure 115: Soil Retention Container

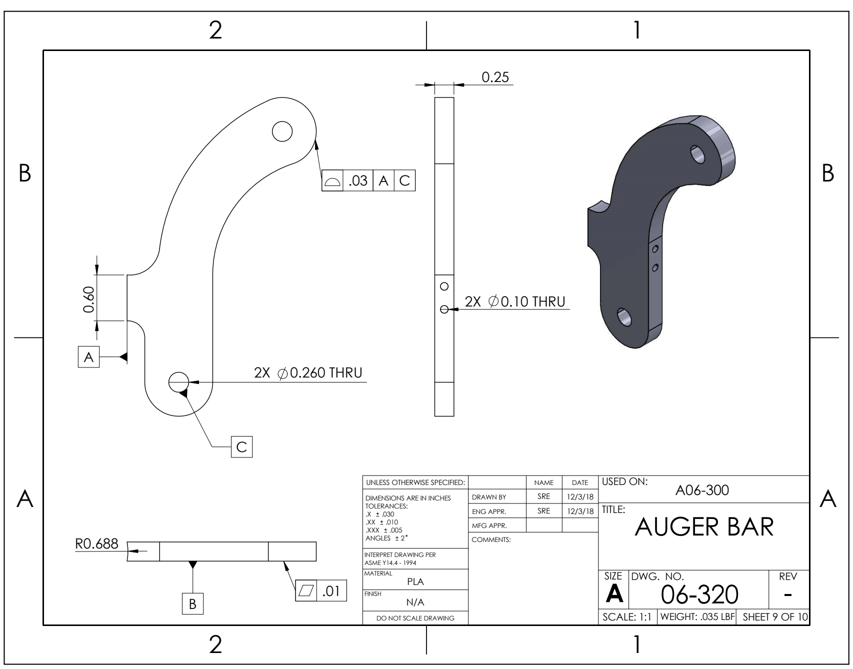

Figure 116: Auger Mount

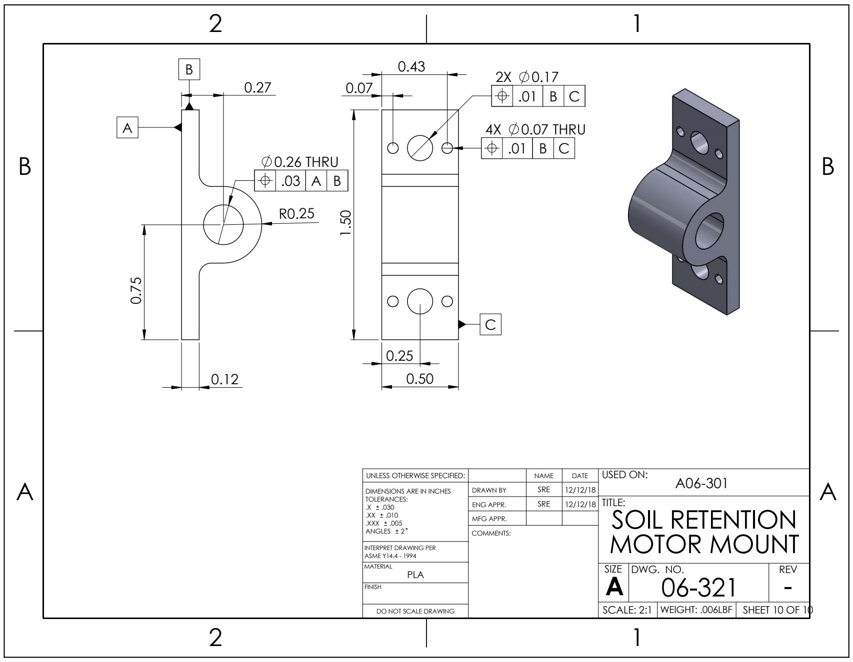

Figure 117: Soil Retention Motor Mount

A.2.3 Drivetrain

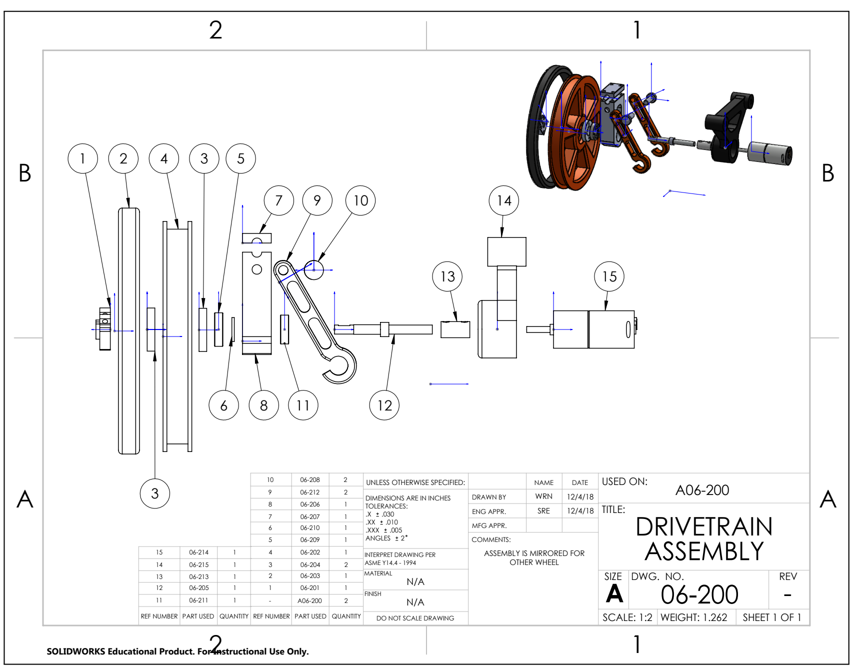

Figure 118: Drivetrain Assembly

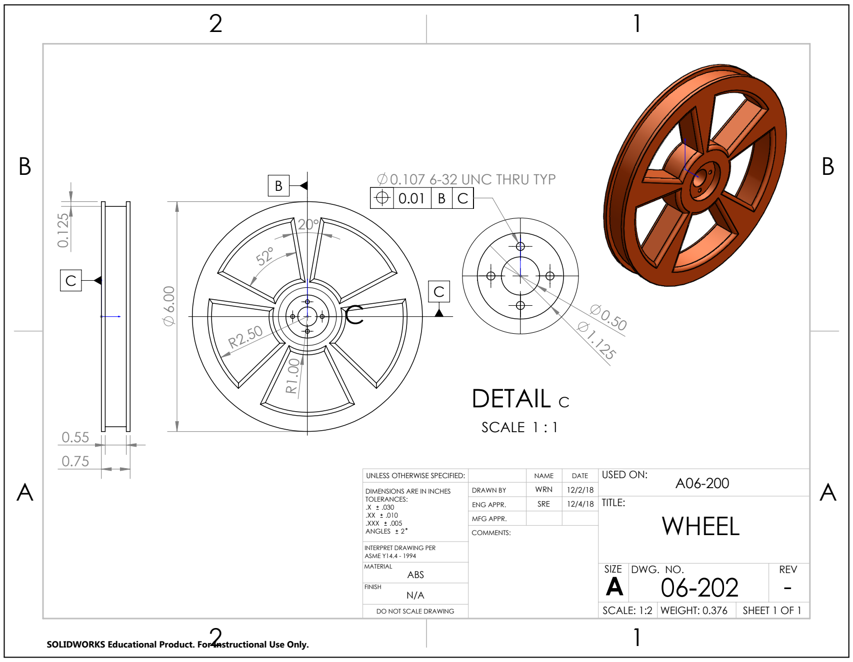

Figure 119: Wheel

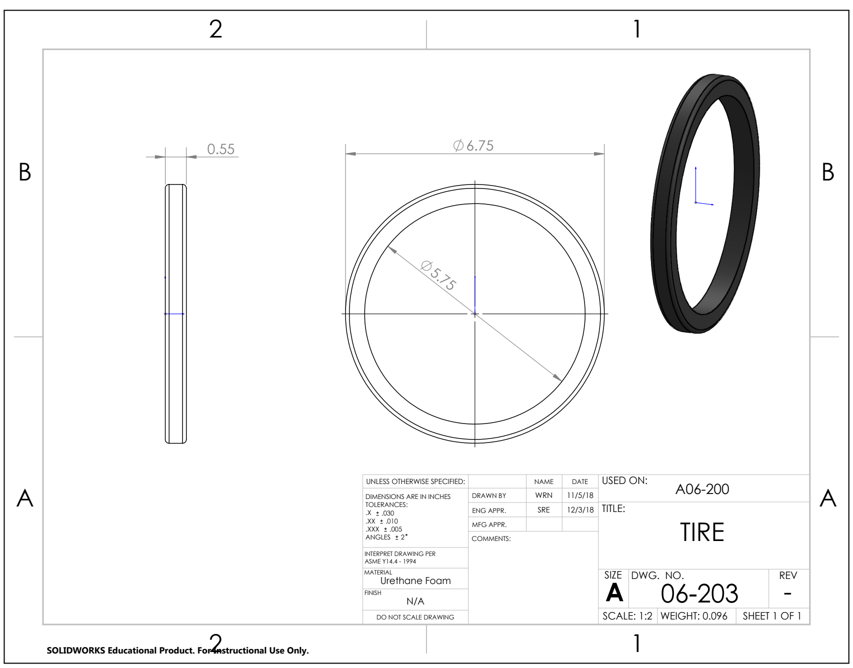

Figure 120: Tire

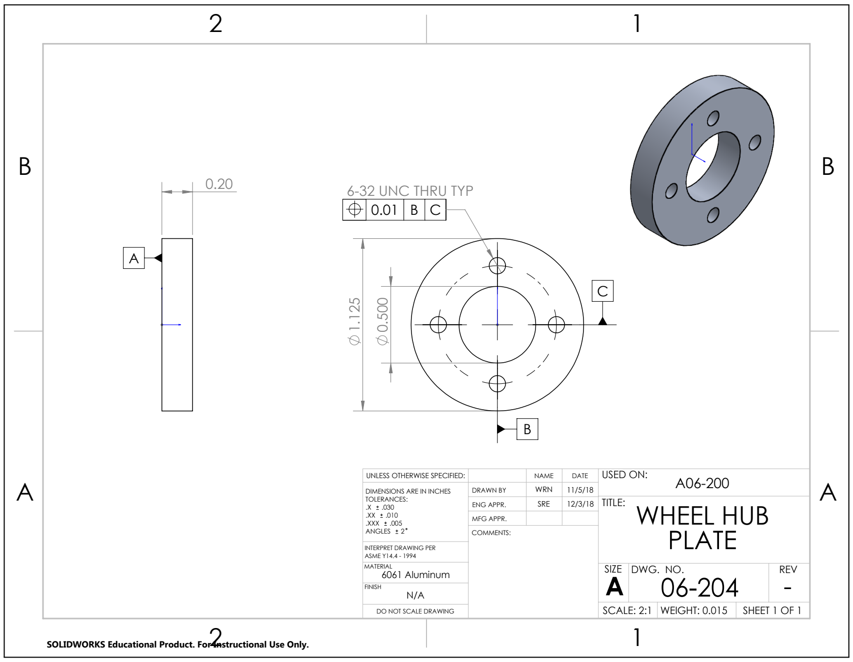

Figure 121: Wheel Hub Plate

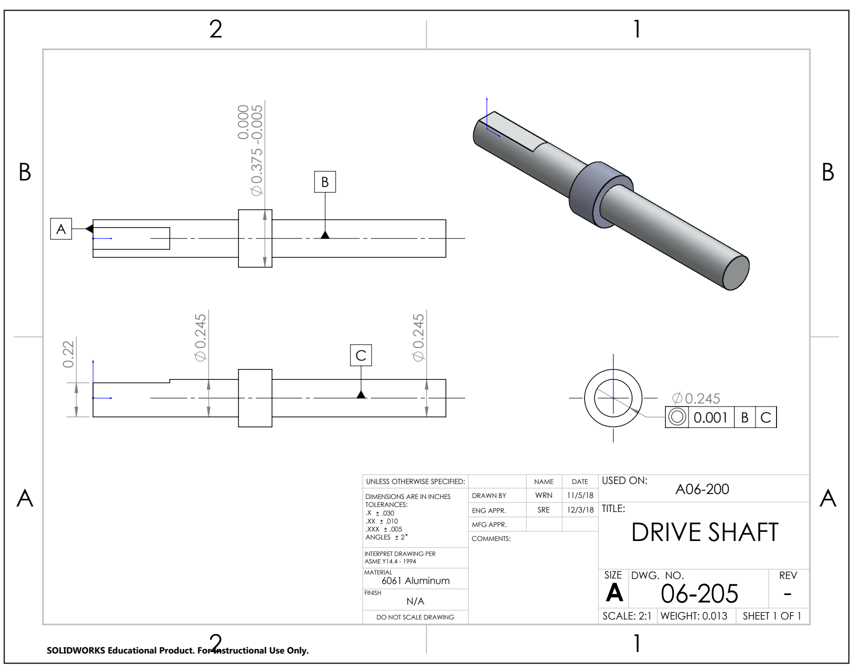

Figure 122: Drive Shaft

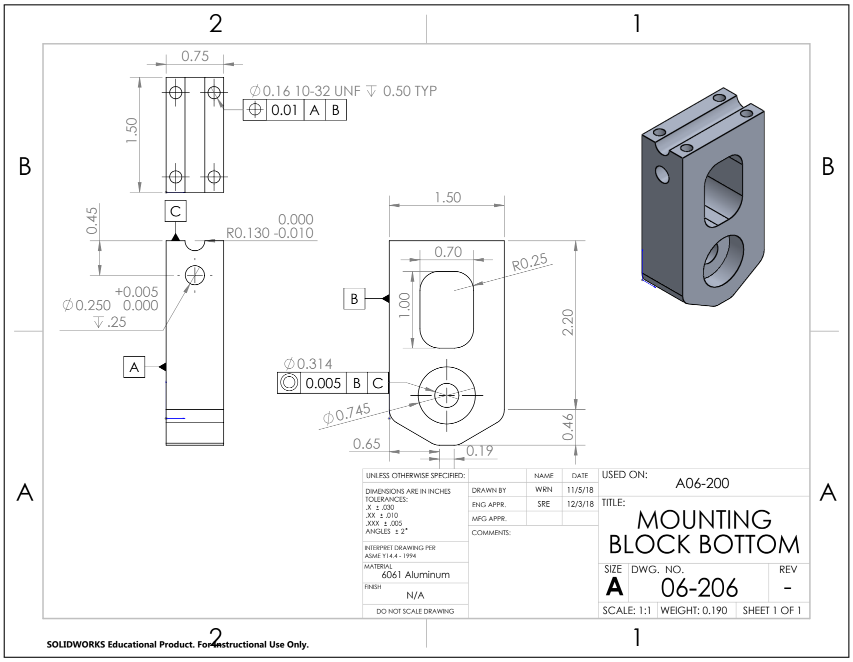

Figure 123: Mounting Block Bottom

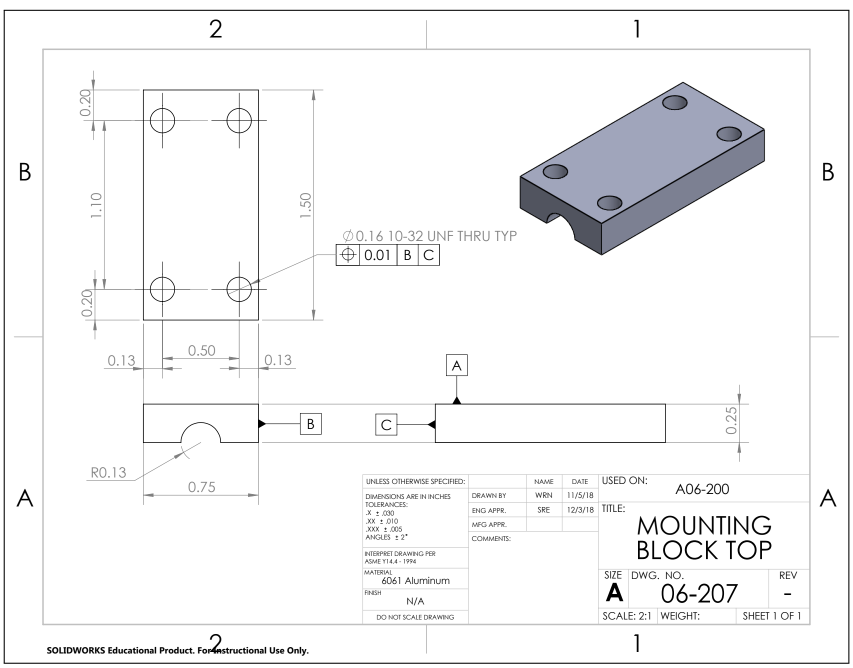

Figure 124: Mounting Block Top

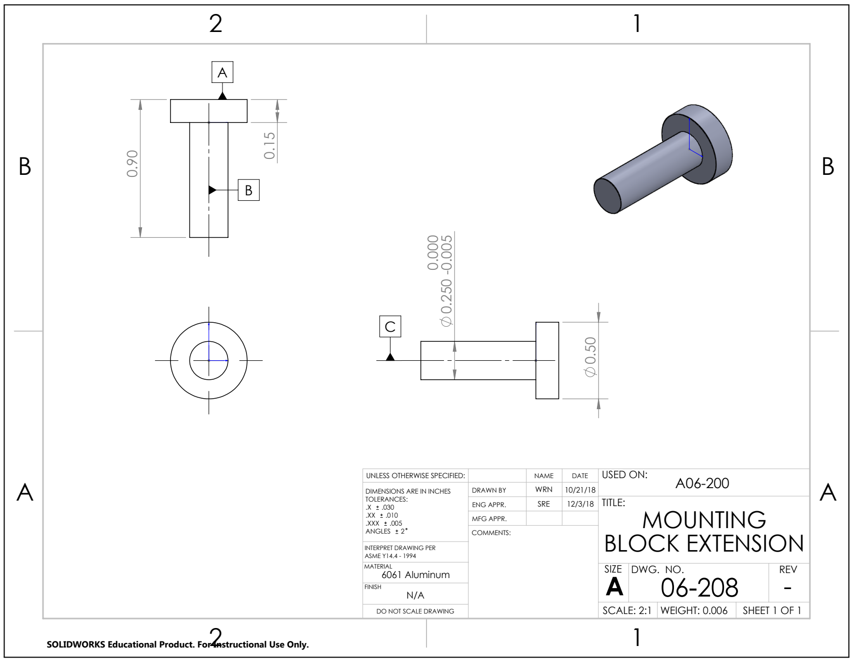

Figure 125: Mounting Block Extension

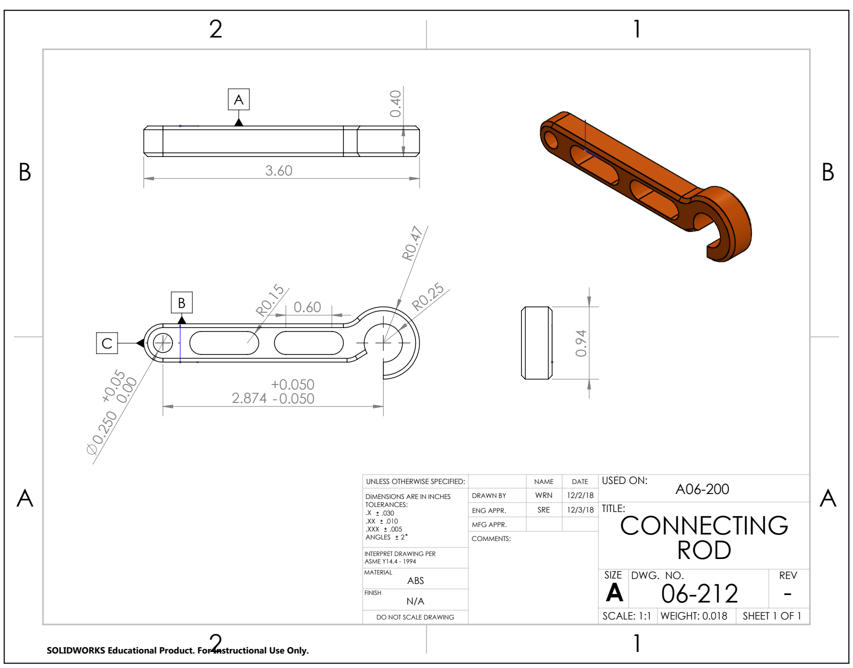

Figure 126: Connecting Rod

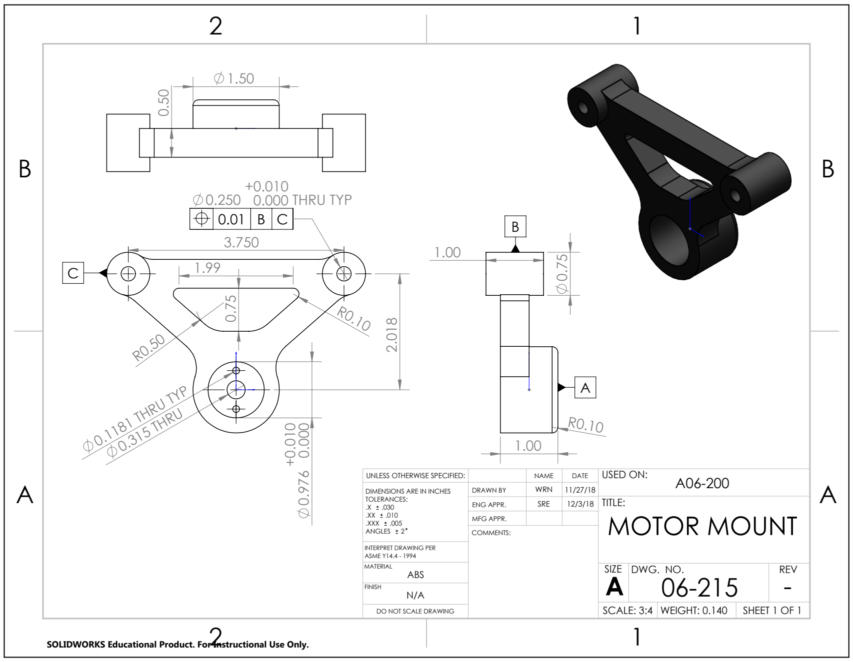

Figure 127: Motor Mount

A.2.4 Chassis

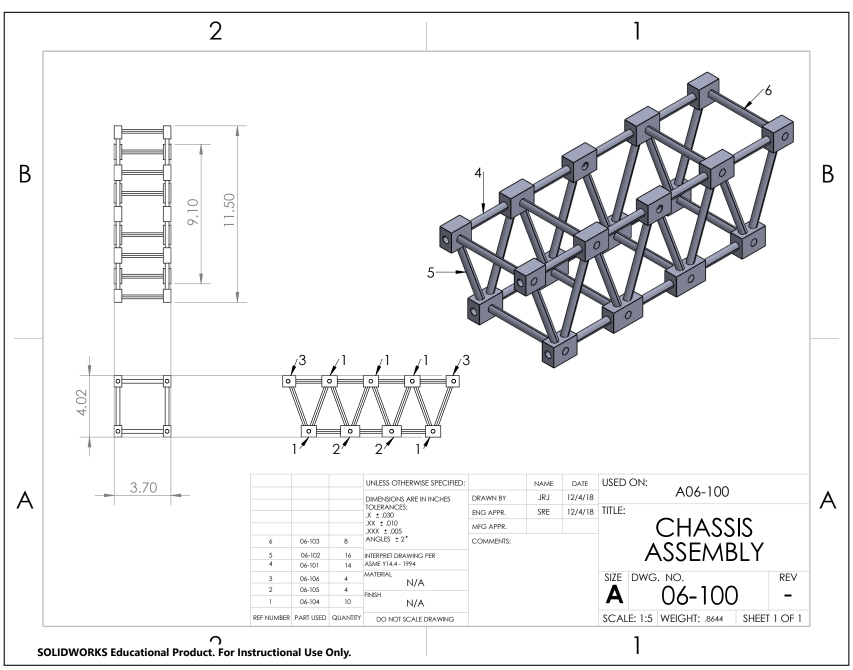

Figure 128: Chassis Full Assembly

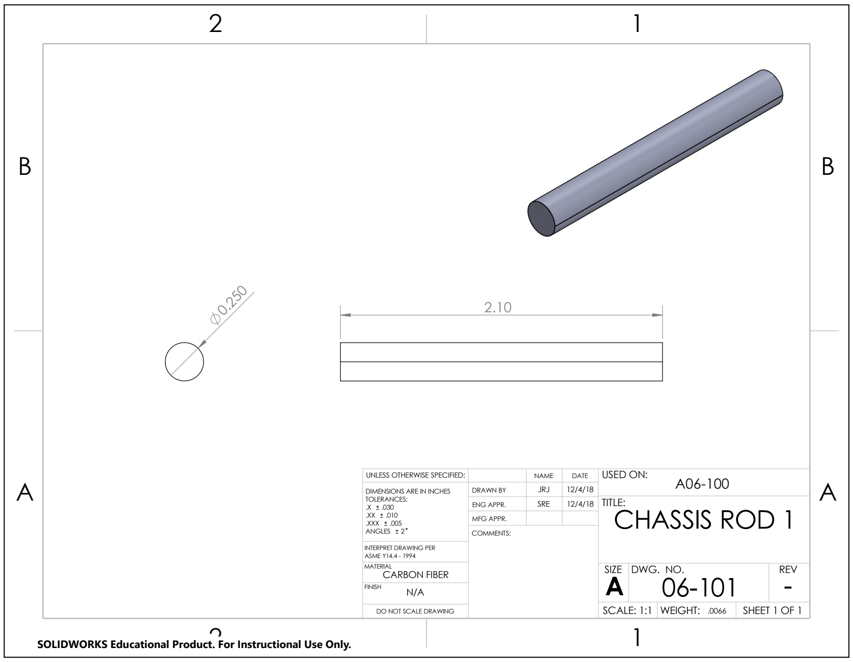

Figure 129: Short Truss Rod

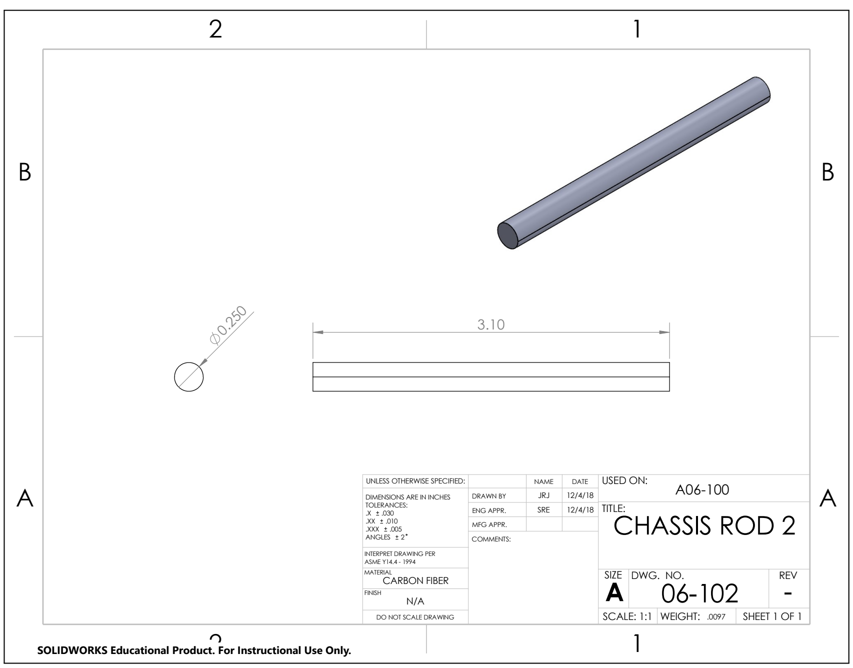

Figure 130: Long Truss Rod

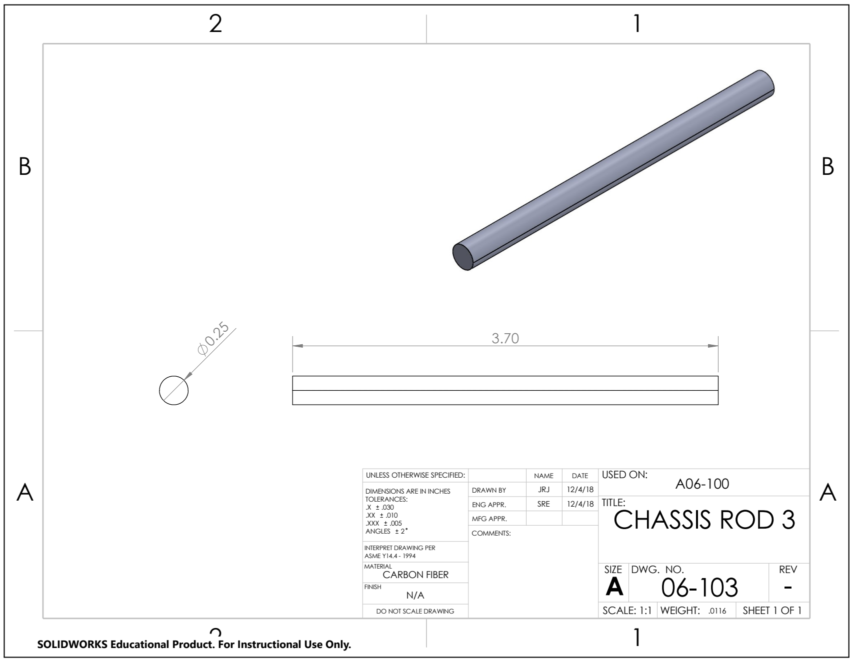

Figure 131: Chassis Cross Rod

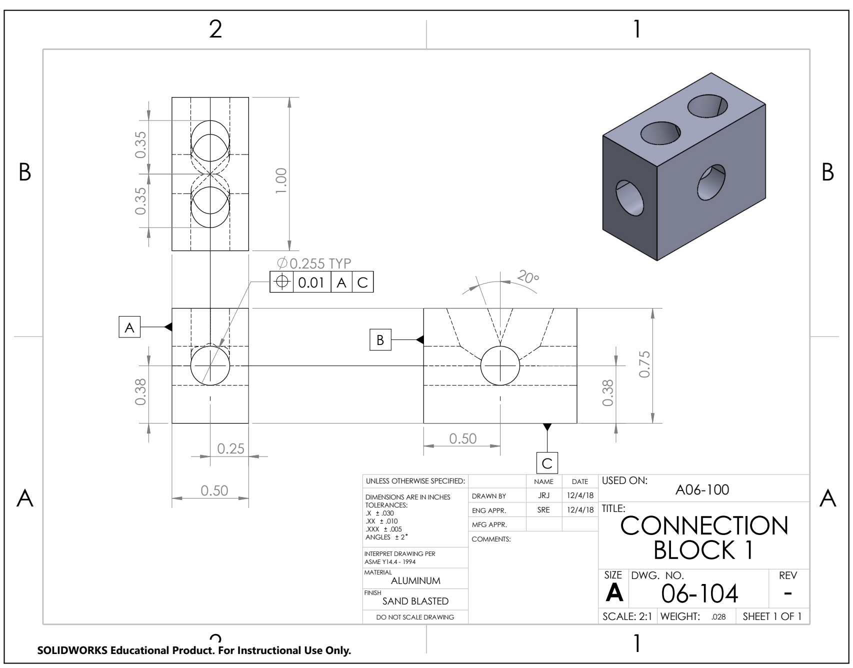

Figure 132: Connection Block 1

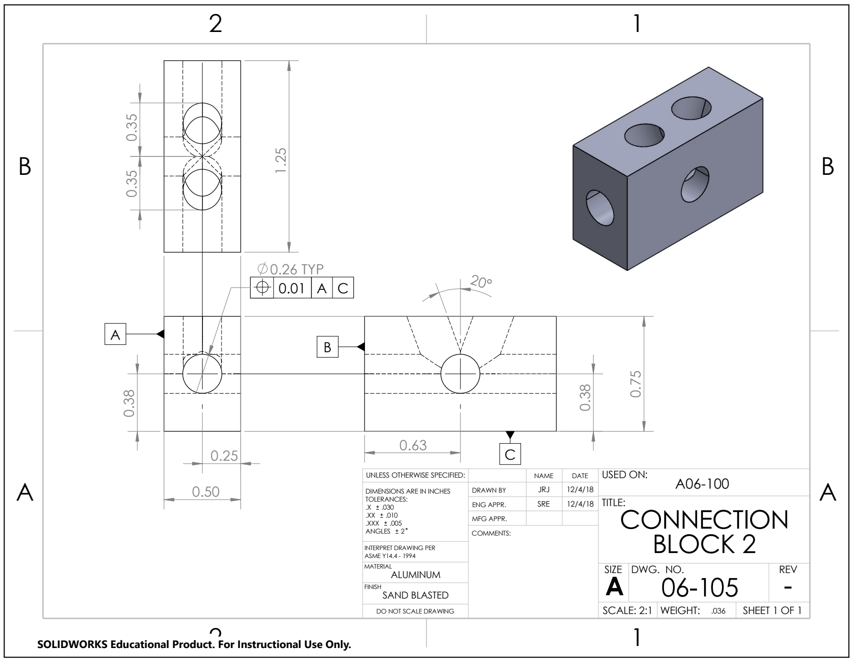

Figure 133: Connection Block 2

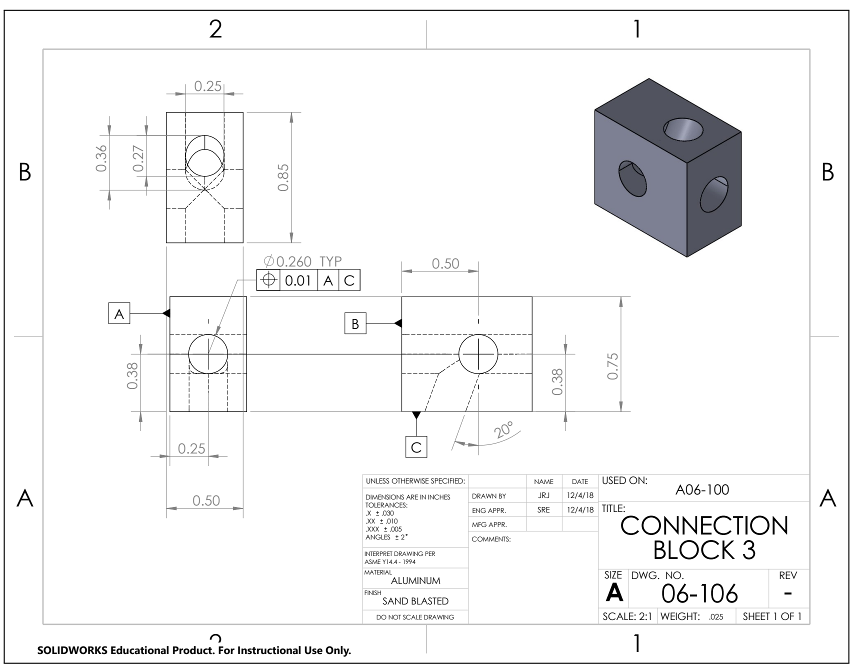

Figure 134: Connection Block 3

A.2.5 Payload Electrical

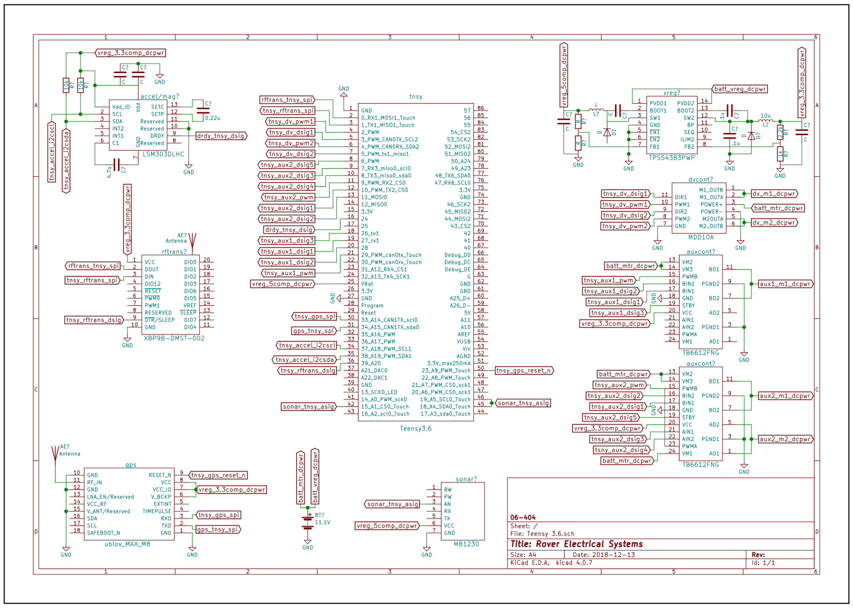

Figure 135: Schematic of Payload Electronics