OREGON STATE UNIVERSITY

2019 NASA SL TEAM

104 KERR ADMIN BLDG. # 1011

CORVALLIS, OR 97331

Flight Readiness Review

March 4th, 2019

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Acronym Dictionary

9DOF Nine Degrees of Freedom. 16

AGL Above Ground Level. 16, 47–49, 61, 63, 65, 67, 207, 212, 243, 248

AIAA American Institute of Aeronautics and Astronautics. 285, 291

APCP Ammonium Perchlorate Composite Propellant. 245

ARRD Advanced Retention and Release Device. 6, 118, 149, 152–154, 162, 183, 186, 221, 223, 228

ASL Above Sea Level. 61

ATI Allegheny Technologies Incorporated. 285

ATU Avionics Telemetry Unit. 5, 6, 9, 33–35, 37, 49, 50, 56, 66, 79, 86, 117, 126, 133, 134, 144, 163, 189, 217–220, 263, 269

AWG American Wire Gauge. 282

BEAVS Blade Extending Apogee Variance System. 6, 8, 19, 21, 23, 30, 36–38, 57, 102, 117, 136, 137, 139, 199, 203, 204, 276

CAD Computer-Aided Design. 8–10, 19, 28, 33–37, 39, 182, 183, 187, 189

CAR Canadian Association of Rocketry. 245

CDR Critical Design Review. 18–20, 35, 37, 51, 165, 220, 240, 241, 246, 286

CV Computer Vision. 237, 269

DC Direct Current. 279, 283

DPDT Double Pole Double Throw. 186, 192

DPST Double Pole Single Throw. 47, 185, 237, 265, 268, 283

FAA Federal Aviation Administration. 109, 244, 258

FEA Finite Element Analysis. 10, 88, 89, 174

FHP Fore Hard Point. 8, 10, 17, 19, 20, 30, 32, 33, 38, 141, 142, 162, 165, 182, 183, 186, 187, 221

FMEA Failure Mode Effects Analysis. 70, 87, 93, 257, 258, 272

FN Foreign National. 240

FRR Flight Readiness Review. 18, 35, 37, 38, 69, 190, 223, 236–238, 240, 241, 247, 253, 254, 269, 270, 272, 273, 286

GLONASS Global Navigation Satellite System. 50

GPS Global Positioning System. 16, 22, 25, 33, 49, 50, 66, 79, 86, 94, 95, 126, 163, 176, 178–181, 189, 219, 220, 236, 237, 262, 266, 269, 270, 273, 279, 284

GUI Graphical User Interface. 49

HD High Definition. 284

HPCB High-Power Carbon Brush. 283

I/O Inputs and Outputs. 176, 186

IC Integrated Circuit. 220

ICE Innovative Composite Engineering. 21, 285

ID Internal Diameter. 21

IMU Inertial Measurement Unit. 16, 235, 269, 279

JHA Job Hazard Analysis. 96, 98, 255, 271, 273

LED Light Emitting Diode. 162, 183, 185, 186, 235, 237, 270, 274

LiPo Lithium Polymer. 50, 119–121, 126, 133, 150, 159, 163, 186, 218, 273, 279, 283

LRR Launch Readiness Review. 254

LS Low Strength. 283

MPRL Machine Product and Realization Laboratory. 21, 29, 98, 116, 167, 170, 176, 255, 271

MSDS Material Safety Data Sheet. 98, 257

NAR National Association of Rocketry. 99, 102, 159, 201, 245, 258, 272

NASA National Aeronautics and Space Administration. 20, 58, 176, 178, 181, 188, 190, 226, 238, 241, 244, 246–248, 255, 258, 285, 290, 291

NTS Not To Scale. 9, 52, 53

OD Outer Diameter. 278, 283

OROC Oregon Rocketry. 114, 258

OSGC Oregon Space Grant Consortium. 11, 285, 286

OSHA Occupational Safety and Health Administration. 110

OSPL Oregon State Propulsion Lab. 221

OSRT Oregon State Rocketry Team. 9, 11, 16–22, 27, 29–32, 37, 38, 45, 46, 49–51, 54, 55, 58–60, 67, 69, 70, 87, 93, 96, 111, 115, 116, 133, 167, 177, 178, 181, 184, 185, 189, 191, 193, 201–204, 208, 209, 211, 221, 222, 238, 240–242, 244, 250, 256–259, 269, 271, 276, 279, 285–291

OSU Oregon State University. 20, 21, 27, 39, 98, 113, 116, 166, 170, 176, 242, 247, 255, 271, 272, 277, 285

PCB Printed Circuit Board. 9, 10, 37, 50, 86, 93, 94, 133, 134, 179–181, 269, 279

PDR Preliminary Design Review. 36, 240, 243, 286

PEARS Payload Ejection and Retention System. 3, 6, 10, 17, 19, 32, 33, 57, 92, 107, 108, 118, 142, 152–154, 165, 168, 170, 182, 183, 185–188, 221–223, 228, 229, 281

PID Proportional-Integral-Derivative. 37

PLA Polylactic Acid. 17, 33–35, 37–39, 89, 90, 165, 169, 170, 173–176, 268, 279

PLAR Post Launch Assessment Review. 240, 286

PLEC Payload Ejection Controller. 6, 10, 11, 17, 19, 22, 50, 92, 108, 116, 118, 121, 141–143, 152, 157, 158, 160–162, 164, 165, 182–186, 216, 217, 221, 233, 237, 238, 268, 270, 274, 282, 283

PPE Personal Protective Equipment. 26, 98, 104, 135, 145, 196, 199, 207, 224, 225, 228, 256, 273

PWM Pulse Width Modulation. 179

RBF Remove Before Flight. 139, 140, 145, 146

RF Radio-Frequency. 11, 21, 25, 27, 33–35, 49, 50, 56, 78, 79, 94, 95, 103, 108, 163, 176, 178, 180, 183, 216, 217, 219, 220, 236, 237, 251, 260, 269, 284

RIF Rotary Indexing Fixture. 8, 21, 25, 29, 36

RPM Revolutions per Minute. 281, 283

RPSMA Reverse Polarity Sub-Miniature Version A Connector. 279

RRC3 Rocket Recovery Controller 3. 5, 9, 17, 46–49, 61, 63, 65, 134, 135, 155, 192, 210, 212, 215

RSO Range Safety Officer. 101, 108, 111, 114, 127, 128, 185, 245, 248, 256, 258

SCAR Soil Collection and Retention. 88–90, 112, 159, 166, 170, 173, 176, 224, 227, 235

SL Student Launch. 17, 20, 40, 45, 50, 58, 59, 114, 188, 190, 203, 220, 238, 242, 246, 248, 269, 286, 290, 291

SO Safety Officer. 98, 101–104, 108, 109, 116, 254–258, 271, 272

SPDT Single Pole Double Throw. 274, 282

SS Stainless Steel. 281

STEM Science, Technology, Engineering and Mathematics. 240, 241, 290, 291

TRA Tripoli Rocketry Association, Inc.. 245, 258, 272

UART Universal Asynchronous Receiver-Transmitter. 177

UNC Unified National Coarse. 283

UNF Unified National Fine. 283

USB Universal Serial Bus. 49, 163

USLI University Student Launch Initiative. 226, 255

UTS Ultimate Tensile Strength. 42, 43

VMC Vertical Milling Center. 29, 30, 36, 170

1 Summary of FRR Report

1.1 Team Summary

Table 1: Team Summary Chart

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

1.2 Launch Vehicle Summary

The launch vehicle is 129.375 in. long and weighs 56.9 lbf. The selected motor is a Cesaroni L2375-WT. The launch vehicle will target an apogee altitude of 4,500 ft and launch from a 1515, 12 ft rail with a rail exit velocity of 83.4 $^{ft}/_{s}$. The airframe is a 6.25 in. inner diameter fiberglass and carbon fiber tube. The launch vehicle is recovered in two independent sections: the aft section with the motor, and the fore section with the payload and nosecone. At apogee, the launch vehicle has two simultaneous separation events: the aft section separates from the fore section and releases the first drogue parachute, and the fore section separates from the nosecone and releases the second drogue parachute. The main parachutes are retained with two Tender Descenders in series and released at 800 ft Above Ground Level (AGL). 1.0 and 1.5 seconds after the Tender Descenders ignite, primary and secondary ejection charges are ignited, ensuring the main parachute leaves the airframe. The drogue parachutes are cruciform in shape, and have a diameter of 1.5 ft. The main parachutes are toroidal in shape. The fore and aft sections have an 8 ft diameter main parachute.

1.3 Payload Summary

The Oregon State Rocketry Team (OSRT) has built a deployable rover that collects a soil sample. The rover is contained within the fore section of the airframe. Upon landing, the rover is ejected from the airframe using black powder charges. It has two coaxial, independently driven wheels with a chassis suspended between them. A spring-loaded stabilizer arm acts as a third point of contact with the ground. An Arduino Teensy 3.6 microcontroller autonomously controls the motors to move the rover, receiving input from a sensor array including sonar, Global Positioning System (GPS), and a Nine Degrees of Freedom (9DOF) Inertial Measurement Unit (IMU). An auger is mounted at the midpoint of the chassis. When the rover is deployed the auger periodically gathers soil samples and seals them in an internal containment unit. After collection, the rover autonomously drives to a scientific base station where it performs an additional scientific experiment.

2 Changes Made Since CDR

2.1 Changes to Vehicle Criteria

The Fore Hard Point (FHP) was changed from a permanent epoxied bulkhead and plastic funnel to a removable radially bolted assembly. This change request was sent to the Student Launch (SL) Team for review and it was determined the new system would not impact the function or performance of the launch vehicle. The radial bolted system added a safety feature in the event of a failed payload ejection, as the FHP can be removed from the airframe, and the ejection battery can be completely disconnected from the Payload Ejection Controller (PLEC). The pass through bulkhead portion of the FHP has remained a permanent epoxied bulkhead within the fore airframe.

Two black powder charges were placed behind the main deployment bag instead of one. The primary charge is ignited one second after the Tender Descenders are released and the backup charge is ignited 0.25 seconds after the first charge. This ejects the main parachute out of the airframe. Because of this additional charge there is a need for an additional auxiliary port in the altimeters. To fill this need the OSRT will use two Rocket Recovery Controller 3 (RRC3)'s instead of one RRC3 and one PerfectFlite StratoLoggerCF.

The Tender Descenders that retain the main parachute deployment bag were reconfigured. Instead of attaching them to the parachute bag in a series, they are attached in parallel. A small nylon harness covered in a Kevlar sleeve is connected to the two Tender Descenders. The main deployment bag is attached to this harness where it is retained. This setup performs identical to the design with two Tender Descenders in series, however it mitigates a small risk of an e-match being caught in the top Tender Descender, preventing it from releasing the main parachute properly.

The camera system no longer uses only GoPro Hero cameras. Because of budget constraints, the OSRT is using cameras rented from the school library instead of purchasing them. The cameras that this system uses are two GoPro Hero3 cameras, one GoPro Hero 5 Camera, and two YI 4K Action cameras. Because the cameras are all different and not the property of the OSRT, a camera trigger system will not be used.

2.2 Changes to Payload Criteria

The rover now has a pair of diametrically opposite notches on each wheel to ease integration with Payload Ejection and Retention System (PEARS)'s Kevlar harness. The drive motor mounts are positioned as before, but have been machined from aluminum rather than manufactured from Polylactic Acid (PLA) for better structural integrity.

2.3 Changes to Project Plan

The project plan had significant modifications since Critical Design Review (CDR). The most notable modification was only one launch being completed before Flight Readiness Review (FRR). The first launch, scheduled for February 9th, 2019 was postponed due to manufacturing delays on several launch critical components. Launches scheduled for February 16th, and 17th, 2019 were cancelled due to inclement weather in the Oregon mountain ranges. The team was only able to complete one launch on February 22nd, 2019. Only completing one launch necessitates the team to complete an FRR Addendum before competition.

From a financial perspective, the OSRT has not made any major changes since CDR. The biggest difference is the addition of new sponsors such as Woodstock's Pizza and Actobotics. As all components have been purchased and the only major remaining costs to the OSRT are travel and logging, the budget has been finalized. The OSRT held tightly to the budget and spent only $496.45 over the expected expenditures. This falls well within the 10% contingency plan meant to keep the OSRT from overspending with nearly $2,000 left in the budget.

3 Vehicle Criteria

3.1 Design and Construction of Vehicle

The final design of the launch vehicle is presented in Figure 1 and Figure 2. The exterior of the launch vehicle is shown in Figure 1. From fore to aft, the airframe consists of the 5:1 ogive nosecone, the coupler to attach the nosecone to the fore body tube, the fore body tube, the canister to attach the fore section to the aft section, the aft body tube, the motor tube, four trapezoidal fins, a motor retainer, and 2 rail buttons. The internal components of the launch vehicle are shown in Figure 2. From fore to aft, the internal launch vehicle systems are as follows: fore avionics bay, fore recovery system, fore ejection bay, fore ballast bay, FHP, PEARS, aft recovery system, aft electronics bay, Camera System, aft ballast bay, Blade Extending Apogee Variance System (BEAVS), motor, and fins. There is no recovery systems depicted in Figure 2.

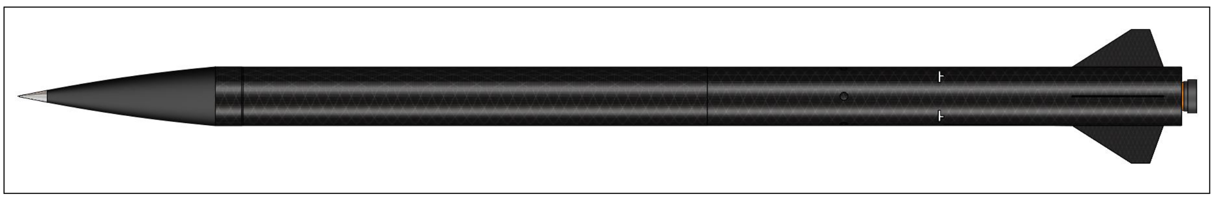

Figure 1: Final Launch Vehicle Computer-Aided Design (CAD)

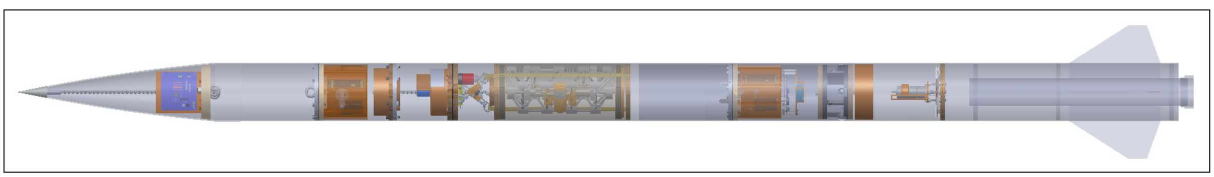

Figure 2: Final Launch Vehicle Components CAD

3.1.1 *Changes to Launch Vehicle from CDR*

The primary change to the launch vehicle from CDR is the FHP design. At CDR, OSRT designed the FHP to be a bulkhead permanently retained in the airframe with epoxy. During development of the checklist to handle an unexploded payload ejection charge within the PEARS, shown in Table 66, OSRT recognized that there was no access to disconnect the battery from the PLEC if the FHP was permanently epoxied in. After recognition of the hazard, a new design for the FHP was developed which consisted of an aluminum ring attached to the airframe via radial bolts. This system allowed the FHP to be removed in the event that unexploded payload ejection charges must be removed. The design change was considered a major change to the retention system of the payload, therefore the design change was sent to the National Aeronautics and Space Administration (NASA) SL Team who gave final approval of the change.

Other minor changes to launch vehicle design have occurred, but primarily represent dimension changes due to manufacturing challenges or purchased component availability. The fore body tube increased in length from 49 in. to 54 in. to accommodate for parachute packing and full integration space. The aft body tube increased in length from 50 in. to 52.5 in. A couple inches were added for possible error while integrating and for manufacturing error of all other components. OSRT decided to error on the side of over-sizing by a few inches rather than under-sizing and losing functionality of the body tubes. The intention was to oversize, integration test, and reduce the size of the tubes as needed. However, the final dimensions proved to be beneficial for packing space, and not worth creating a manufacturing error for a few lost inches of length. Total length increased from 123.5 in. to 129 3/8 in.

Weight increased since CDR from 48.9 lbf to 56.9 lbf. The increase was due to increased structural component lengths, final nosecone weight which increased by 2 lbf due to miscalculating the manufactured thickness, heavier couplers after manufacturing, the addition of an aluminum ring in the FHP, and the reinforcement of the ejection bays' attachment tabs. The aft avionics bay changed in orientation from being vertical to horizontally flat on the ejection bay. This change was made to accommodate for the increase in size of the custom avionics board which initially fit inside the canister after integration testing. The ejection bays were adjusted in design to reinforce the tabs that attached the altimeter housing to the pressure seal. The Camera System changed from using five GoPro cameras to using five action cameras of a few different variations. This change occurred because Oregon State University (OSU) has these cameras available to rent, free of charge.

3.1.2 Unique Mission Success Criteria

Several vehicle specific criteria have been developed. 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 launches off of a 12 foot 1515 T slot aluminum extrusion launch rail.
- The launch vehicle travels in a stable configuration toward apogee.
- The airframe successfully separates into two recovery sections.
- The drogue parachutes deploy successfully.
- The main parachutes deploy successfully.
- Both airframe sections land on the ground, without causing structural damage.
- The launch vehicle ejects the payload successfully.

3.1.3 Airframe

The launch vehicle is recovered in two sections. The fore section contains the payload and its ejection system, and the nosecone. The aft section contains the motor, motor retention system, the BEAVS, the Camera System, and the fins. Both sections house their individual electronics for tracking and their recovery system. The entire airframe consists of two tubes with an Internal Diameter (ID) of 6.25 in. These tubes, which were donated to OSRT, were manufactured by Innovative Composite Engineering (ICE) using a mandrel rolling process. The OSRT got the opportunity to visit ICE and assist with the airframe rolling process. The material for the fore tube was chosen to be fiberglass, since it is Radio-Frequency (RF) transparent. Material options for the aft tube were carbon fiber and fiberglass, with a seamless transition from one material to the next within the same body tube. The carbon fiber and the fiberglass sections are slightly different thicknesses, but maintain the same strength ratings throughout. Each of these materials brings unique characteristics that allow for a better airframe design.

Both body tubes were cut to size at OSU using a custom fixture to facilitate cutting of varying diameters of airframes. The fixture is shown in 3. In combination with the fixture depicted in Figure 3, the Rotary Indexing Fixture (RIF), shown in Figure 4, was used to stabilize the body tube on the fixture and rotate it evenly as the die grinder stayed in place and cut through the composite. This procedure gave the team a clean straight cut across the tube.

Figure 3: Cutting Fixture

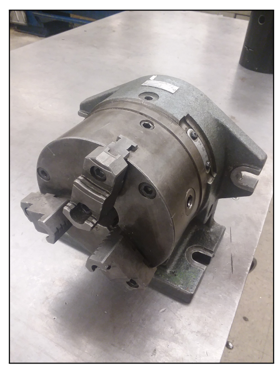

Figure 4: RIF

In addition to cutting the body tubes to length, the RIF was also used for all holes and slots cut in the airframe. These more precise cuts were made on a manual mill with high speed tool steel end mills in the Machine Product and Realization Laboratory (MPRL). To maintain a level cut and alignment along the length of the body tube during manufacturing, a separate fixture was manufactured to support the end opposite to the RIF, as seen in Figure 5.

Figure 5: Drilling Holes

Along with confirmation from OSRTs full scale launch where the airframe did not experience any structural damage, the airframe had multiple tests performed on it to ensure safety with its systems and modifications. These tests were conducted on the airframe with forces beyond the maximum expected forces experienced during the flight. These tests are outlined in Section 6.1.1.9 and Section 6.1.1.10.

3.1.3.1 Fore Body Tube

The fore airframe is 54 in. long, and the notable features include a thickness of 0.06 in. fiberglass, anti-zippering properties on the fore edge, and several drilled holes. The anti-zippering properties include added layers of fiberglass material, which increased the thickness to 0.10 at the edge of the fore side, running 3 in. into the body tube, and 0.08 in. thickness from 3 in. to 6 in. along the body tube. The following holes were drilled into the fore section of the airframe:

- Shear pin holes: 3.5 in. from fore edge; 120° apart; 0.0860 in. clearance hole.
- Radial bolt holes: 11.25 in. from fore edge; 60° apart; 3/16 in. clearance hole.
- Static port holes: 14.125 in. from fore edge; 90° apart; 3/16 in. clearance hole.
- Radial bolt holes: 19.75 in. from fore edge; 60° apart; 3/16 in. clearance hole.
- PLEC port hole: 24.3125 in. from fore edge; 1 hole; 3/16 in. clearance hole.

On board the fore section is the payload retention system, which receives transmissions from the ground station. The payload is also equipped with a GPS device for tracking. Both systems require fiberglass to communicate with other electronics. The dimensional drawing can be seen in Figure 140. A picture of the final manufactured fore body tube can be seen in Figure 6.

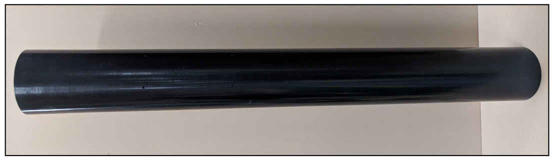

Figure 6: Fore Body Tube

3.1.3.2 Aft Body Tube

The aft airframe is 52 1/16 in. long with notable features that include a thickness of 0.06 in. for the fiberglass section, 0.04 in. thickness for the carbon fiber section, fin slots at the aft-most end, and several drilled holes. The fiberglass section is 24 in. long and the carbon fiber section is 28 in. with an overlap of 1 in. on either side of the seem. The following holes were drilled and slots were cut into the airframe:

- Radial bolt holes: 3 1/8 in. from fore edge; 60° apart; 3/16 in. clearance hole.
- Static port holes: 5 15/16 in. from fore edge; 90° apart; 3/16 in. clearance hole.
- Camera holes: 15 in. from fore edge; 72° apart; 7/8 in. diameter.
- BEAVS slots: 25 7/16 in. from fore edge; 90° apart; 3/16 in. wide; 34° long.
- Radial bolt holes: 26 1/16 in. from fore edge; 60° apart; 3/16 in. clearance hole.
- Fin slots: 2 in. from aft edge; 90° apart; 1/8 in. wide; 10 in. long.
- Rail button holes: 24 1/4 from fore edge and 5/8 in. from aft edge; in-line with one another; 1/4 clearance holes.
- Static port holes; one hole in between each centering ring; 1/16 in. diameter.

On board the aft section is the motor, BEAVS, and the canister. Within the canister is the Camera System, the aft ejection electronics bay, and the aft recovery system. The aft end also houses the fins, outlined in Section 3.1.4. Two Rail buttons are mounted to the airframe to accommodate for a 1515 launch rail, one being placed at the aft most edge of the airframe and the other placed at the closest distance to the center of pressure without interfering with any internal components. The rail buttons were epoxied into the airframe and reinforced with a nylon locknut on the inside of the body tube. The dimensional drawing can be seen in Figure 141. A picture of the final manufactured body tube can be seen in Figure 7.

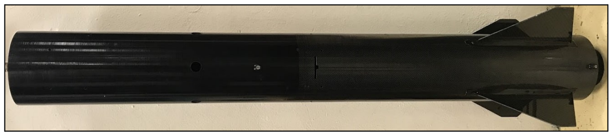

Figure 7: Aft Airframe

3.1.4 Fins

The fin configuration is comprised of four trapezoidal fins with a square leading edge and no airfoil taper. This configuration allows for a stability margin of 2.14 calibers verified in Section 6.1.1.5. The stability margin satisfies competition requirement 2.17 in Table 74. The general shape and placement on the airframe was decided by the analysis shown in Section 6.1.1.8, which demonstrates the analysis for mitigating damage to the fins upon landing. The fins are made of 1/8 in. carbon fiber with a clear coat enamel over the exposed layers, as seen in Figure 8.

The fins were manufactured out of a 36 in. by 36 in. sheet of carbon fiber. Initial rough cuts were made on a table saw using a diamond friction blade. After the rough cuts were made, more precise cuts were made on a chop saw using the same blade. All angled cuts were done for all four fins simultaneously to ensure the fins were nearly identical. Any slight differences in the fins were fixed by clamping the four fins together and sanding down until they were perfectly consistent with one another.

Each fin was epoxied in six different locations along the entire root cord length, in a through-body mounting configuration. There is a fillet on either side of the fin along: the motor tube, the inside of the body tube, and the exterior of the body tube. Each epoxy fillet has leg lengths of 3/8 in., as seen in Figure 9. To ensure perfect alignment, a fixture which held the fins 90° apart from one another was made by process of additive manufacturing. The specific dimensions can be seen in Figure 143.

Figure 8: Final Manufactured Fins

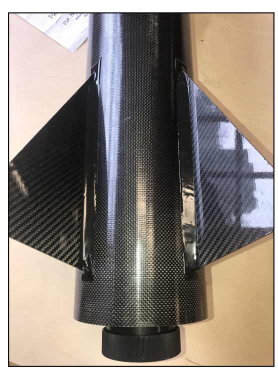

Figure 9: Fins Epoxied Into Airframe

3.1.5 Nosecone

The nosecone of the launch vehicle is made of G12 filament wound fiberglass with an aluminum tip and a 5:1 ogive profile. The nosecone houses the fore avionics which transmit radio frequencies to the ground station for tracking using GPS. The high strength properties of fiberglass, and RF transparency make it ideal for construction of the launch vehicle. The aluminum tip provides an attachment point for the threaded rod that holds the avionics in place. No commercial vendor provides a stock nosecone that matched the size of the airframe, therefore a 7.5 in. diameter nosecone was purchased and cut down to fit the body of the launch vehicle. The nosecone came with a thickness of 0.140 in. The setup for cutting the nosecone can be seen in Figure 10.

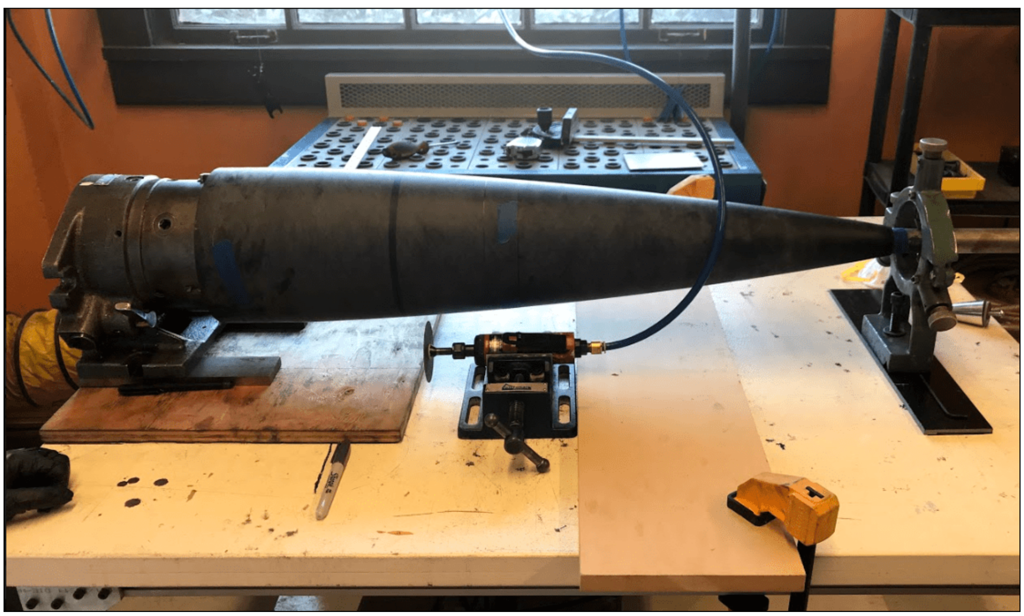

Figure 10: Cutting the Nosecone

The process for cutting the nosecone began by removing the aluminum tip. The RIF was then aligned concentrically with a three point centering fixture in terms of height by running a 1 in. diameter rod through both the fixtures, to ensure perfect z-axis alignment. The fixtures were then aligned in the x-axis and y-axis by measuring to their centers and marking the table for exact positioning. The rod fit tightly inside the hole at the top of the nosecone and acted as a support for alignment. The wide end was mounted inside the RIF. The rod going through the tip of the nosecone was mounted inside a three point centering fixture. Before any cuts were made, all center measurements were double and triple checked to make sure the nosecone remained aligned throughout the entire cutting process.

A rail was created by clamping down a straight edge across the table, perpendicular to the direction of the nosecone. This rail acted as a guide for sliding the die grinder into and away from the surface of the nosecone. The die grinder was clamped into a vice for added stability. To check the alignment of the entire process, before mounting the die grinder, a pen was mounted on the vice and marked the surface of the nosecone as the nosecone was manually rotated. After the pen marker was seen to return to the starting position, measurements were taken from the base of the nosecone to the line to ensure the line drawn was marking perpendicular to the nosecone. Fixtures were checked again for alignment and finally marked the nosecone to the position which would give a diameter slightly larger than the outer diameter of the airframe. The die grinder, mounted on the vice was turned on and slid into position to cut into the nosecone as the nosecone was manually rotated. After the cut, the nosecone was mounted on the airframe and sanded down to match the 6.45 in. outer diameter. Safety precautions were taken with everyone involved wearing appropriate Personal Protective Equipment (PPE), which included safety glasses, latex gloves, clothing or shop coat to reduce exposed skin, and respirators or dust masks.

The dimensional drawing of the nosecone can be seen in Figure 142. The aerodynamic impact of cutting the nosecone should not be significant due to the low speed of the launch vehicle, and the nosecone being close to tangent to the body. This component was demonstrated to withstand all sections of the demonstration flight as seen in Section 6.1.1.1. The fully constructed nosecone can be seen in Figure 11.

Figure 11: Nosecone With Coupler

3.1.6 Couplers

The OSRT uses two couplers in the airframe of the launch vehicle. The first attaches the nosecone to the fore airframe and the second attaches the fore airframe to the aft airframe during flight. The couplers are lightweight, RF transparent, and strong enough to withstand the forces of flight. Fiberglass satisfied these conditions and is used for both couplers.

To integrate the nosecone with the rest of the launch vehicle, a custom coupler had to be manufactured at OSU. Upon arrival, the nosecone was measured to be thicker than initially calculated, mismatching the inner diameter of the body tube. This was negated by several layers of fiberglass weave that were laid-up inside the nosecone and into an extra section of the body tube and was permanently affixed to the nosecone by co-bonding the uncured coupler to the cured nosecone. This created a bonded coupler to the nosecone with the correct outer diameter to interface with the airframe with the desired properties of the nosecone maintained. The coupler protrudes 5 in. into the nosecone and 6 7/8 in. into the fore airframe. The two sections are held together with three 2-56 nylon shear pins. The fiberglass layup directly into the nosecone can be seen in Figure 12. The dimensional drawing can be seen in Figure 145.

Figure 12: Coupler Layup within Nosecone

For the aft coupler, the OSRT has implemented a system called the canister. This component is 23.5 in. long. 7 in. of the canister is used as the coupler in the fore airframe, with 16.5 in. in the aft airframe. Three components are assembled into the canister which is then assembled as a whole into the aft airframe simplifying the assembly process. From aft to fore, the components inside the canister are the Camera

System, the aft electronics bay, and the aft recovery system. The canister has a bulkhead permanently attached with epoxy on the aft end. This can be seen in the fully assembled canister CAD in Figure 13. The canister is shown in Figure 14. The canister is connected to the aft airframe with radial bolt rings and connected to the fore airframe with three 2-56 nylon shear pins.

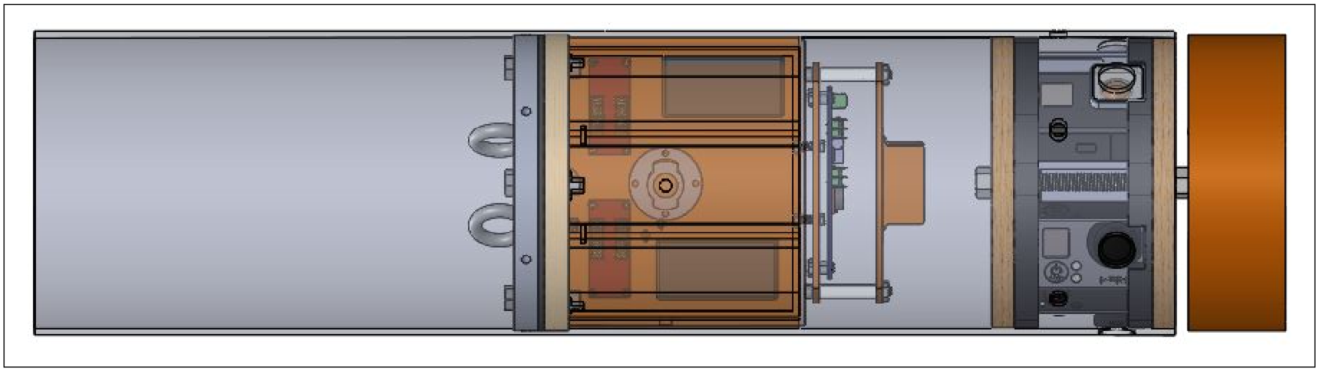

Figure 13: Assembled Canister CAD Model

Figure 14: Assembled Canister

The couplers were laid up using Cytec 7701 Structural Prepreg Fiberglass. Two excess sections of airframe were heavily mold released to prevent bonding, while the nosecone was roughed up with sand paper and cleaned with acetone to allow bonding. The layup schedule was 18 plies, alternating 0° and 45° fiber direction. The layups were performed inside the airframe sections, then covered with a layer of peel ply, followed by a layer of breather material. The different sections were vacuum bagged and a vacuum was drawn on the parts. Finally, the parts were placed in an autoclave for curing according to the manufacturer specifications. The resulting parts were then separated from the molds, leaving the nosecone coupler permanently attached to the nosecone.

3.1.7 Bulkheads and Centering Rings

The launch vehicle uses several bulkheads and centering rings that are integrated into the airframe. Bulkheads are made from 0.47 in. 9 ply Baltic Birch plywood and can withstand axial, bending, and torsion forces experienced during launch and recovery. The plywood withstood the expected forces during testing, as well as subscale and full scale launches. The plywood is also readily available to the OSRT and easy to manufacture. All bulkhead and centering ring manufacturing was done in the MPRL.

The manufacturing process for both centering rings and bulkheads are fairly similar. The first step is to cut the plywood into 6.5 in. squares. Then, the plywood is put into into a custom made square fixture that holds down the plywood. This fixture is then placed into a rotary table fixture which is mounted to the Vertical Milling Center (VMC). The custom made fixture and rotary table are pictured in Figure 15. From here, the plywood can be cut into bulkheads. Each bulkhead is measured and test-fit into the airframe after machining is finished.

Figure 15: Bulkhead Manufacturing Fixtures

Centering ring manufacturing follows the same initial steps as bulkhead manufacturing. However, the centering rings go through an extra process after the completion of the first circular cut on the VMC. From here, the square fixture and centering ring are removed from the Rotary Table. The RIF is then mounted on top of the Rotary Table, allowing the bulkheads to be clamped down on the outer edge, leaving the middle section free to be milled using the VMC. This setup closely matches the setup depicted in Figure 17 in Section 3.1.8.

There are three centering rings in the airframe. These support the motor tube and are secured into into the airframe with G5000 RocketPoxy. For more detail about the epoxying process, see Section 3.1.10.

Bulkheads are secured into the airframe in various ways depending on the function and force exerted on the bulkhead. Bulkheads that experience more load are secured into the airframe with aluminum radial bolt rings or G5000 RocketPoxy. Radial bolt test results are displayed in Section 6.1.1.9. Bulkheads that experience much less load, such as the bulkhead that supports the BEAVS, are secured into the airframe with radial bolts directly into a plywood bulkhead.

3.1.8 Radial Bolt Rings

After the subscale launches, the OSRT decided that radial bolts would be a better option for integration. They are easier to integrate and resulted in a weight reduction due to elimination of the threaded rod. The first design consisted of using a 1/2 in. 9 ply bulkhead with six 8-32 bolts spaced 60° apart directly into the center of the plywood. This model was tested to failure using an Instron machine. This design proved to be too weak - the adhesive between the plies failed and the bulkhead failed at about 500 lbs. A detailed analysis on testing and justification for switching from plywood bulkheads to aluminum rings can be seen in Section 6.1.1.9.

The next design consisted of an aluminum ring. The ring has six 10-24 radial bolt holes spaced at 60° apart and six quarter in. diameter holes placed exactly between the radial bolt holes. These holes are for the bolts used in the pressure seal and compress the rubber sheet. To test the validity of this design, the Instron machine was used again and exceeded the minimum success criteria as detailed in Section 6.1.1.9. The airframe was not damaged until a force was reached which was significantly higher than forces expected during launch.

This design worked well and was implemented in the full scale launch vehicle. Three rings were needed: one at the top of the fore ejection bay, another at the top of the aft electronics bay, and one in the FHP. The manufacturing process was similar to the manufacturing process of centering rings, but with lower feed and speed rates on the VMC. Similarities in manufacturing are shown in Figure 16. During the first full scale launch, the radial bolt design performed well, improving the assembly process of the launch vehicle and withstanding the forces of flight and recovery. After inspection, no damage was done to any ring or the radial bolt holes in the airframe. Figure 19 depicts the aluminum ring integrated into the pressure seal.

Figure 16: Manufacturing Rings

Figure 17: Manufacturing Ring's Center

3.1.9 Pressure Seals

To minimize the needed ejection charge sizes, pressure seals are installed on either side of the parachutes. To create these seals, a piece of 1/8 in. Santoprene rubber is compressed so that it presses against the inner wall of the airframe. The pressure seals which cap off the fore ejection bay and the aft electronics bay are made by bolting an aluminum ring and a wooden bulkhead together with a 1/8 in. thick piece of Santoprene rubber compressed in the middle. The nosecone pressure seal is made with a wooden ring rather than aluminum because it is not radially bolted. This also minimizes weight. Once the seals are installed, a socket wrench is used to tighten six 1/4-20 bolts, compressing the ring and bulkhead together. This method has been proved to create a strong pressure seal in all subscale and full scale flights, and it is also easily removable. Figure 18 shows the nosecone pressure seal and Figure 19 shows the pressure seal for the aft and fore sections.

Figure 18: Nosecone Pressure Seal

Figure 19: Fore and Aft Pressure Seal

3.1.10 Epoxy

The OSRT uses G5000 RocketPoxy to permanently connect certain components to the airframe. RocketPoxy is used to create fillets between the face of a component and the surface of the airframe to produce very strong joints. The components that are epoxied to the airframe are the fins, the centering rings, the pass through bulkhead of the PEARS, and the launch lugs. The aft bulkhead in the canister is also joined with epoxy. Before any epoxy is applied, the section of airframe that is being epoxied is cleaned with acetone so that the bond strength is maximized.

The G5000 RocketPoxy is a two part epoxy that must be combined in a one to one ratio by weight to be activated. To do this, the OSRT put each part of epoxy in a separate mixing cup and weighed both to ensure a proper ratio. For the centering rings and fins, an epoxy plan was developed to maximize the number of epoxy fillets which retain components, optimizing the overall strength of the centering rings and fins. Epoxy was then spread liberally to create internal fillets to join components. For external components, such as the fins and launch lugs, black dye provided by the manufacturer was added to the mixture. This helps ensure that each exterior fillet is aesthetically pleasing.

3.1.11 Fore Hard Point

The FHP consists of two systems in the final launch vehicle: a pass through bulkhead and a radially bolted assembly. The pass through bulkhead, manufactured the same as the centering rings described in Section 3.1.7, is epoxied into the airframe as described in Section 3.1.10. This bulkhead gives a hard point for the PEARS to press against and create a pressure seal. This seal will be described further in Section 5.6.5.

The radially bolted assembly can be see in Figure 20. The assembly consists of a plywood bulkhead fixed to an aluminum ring as described in Section 3.1.8, and an additively manufactured guiding funnel. The aluminum ring is retained to the airframe with six 10-24 radial bolts, while the bulkhead is retained to the ring with six 1/4-20 bolts. The funnel is retained to the bulkhead with epoxy as well as wood screws. Finally, there are two permanent 3/8-16 bolts through the bulkhead that allow for eye hooks to be placed when inserting or removing the FHP assembly.

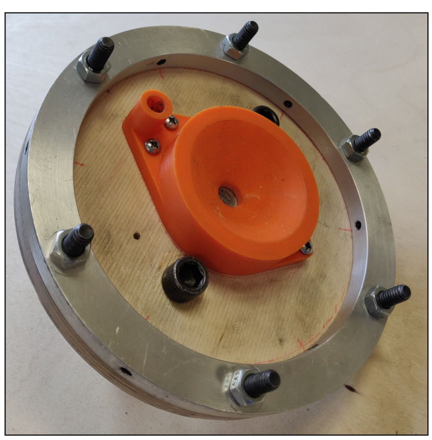

Figure 20: FHP Removable Assembly

The plastic funnel serves to guide the threaded rod of the PEARS through the wood bulkhead. The weight of the rover and PEARS is transferred through the wooden bulkhead, which in turn puts force on the aluminum ring and radial bolts. When the launch vehicle experiences the maximum acceleration, even under the atypical flight conditions of 50 G with an added safety factor, the FHP is easily able to retain the payload as can be seen in the analysis conducted in Section 6.1.3.2.

3.1.12 Motor Retention

The motor is contained within a filament wound G10 fiberglass tube, with a length of 24.5 in. and an inner diameter of 3.00 in. A 2.95 in. (75 mm) 6061 aluminum motor retainer is epoxied on to the end of the motor tube with G5000 RocketPoxy. These components are aligned down the body tube with three centering rings made out of 18 ply/in. 0.46 in. Baltic Birch plywood. These centering rings are epoxied onto the motor tube, as well as to the body tube, creating four epoxy fillets per centering ring.

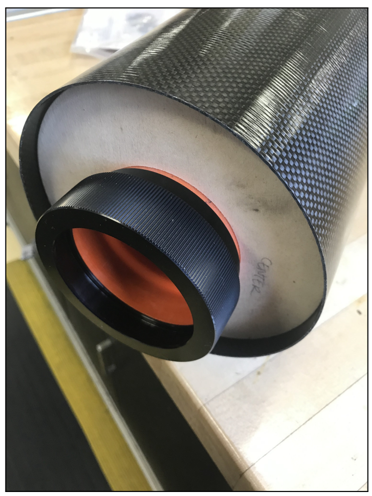

Figure 21: Motor Retention Assembly

3.1.13 Fore Avionics Bay

The fore avionics are located in the nosecone and are responsible for transmitting the GPS coordinates of the fore section of the launch vehicle to the ground station. The nosecone is made of fiberglass which is RF transparent, allowing avionics signals to transmit through the surrounding material. The Avionics Telemetry Unit (ATU) and battery attaches to an additively manufactured mount, made from PLA, which attaches to the nosecone pressure seal using four 4-40 bolts. A 1/4 in. threaded rod slides through the bay, providing extra support, while holding the nosecone pressure seal in place with a nylon locknut. The CAD for the fore avionics can be seen in Figure 22 and the manufactured bay can be seen in Figure 23.

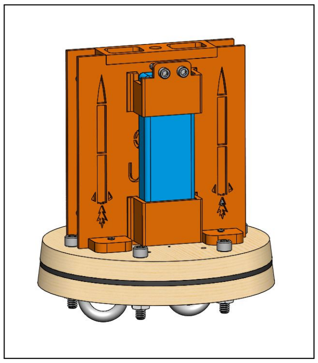

Figure 22: Fore Avionics Bay CAD

Figure 23: Manufactured Fore Ejection Bay

In the full scale launch, the fore ATU bay protected the ATU well. No damage was done to the hardware and the mount was able to hold all components in place. The ground station also received signals from the ATU throughout the flight, proving that the signal from the ATU is able to escape the housing without issues.

3.1.14 Fore Ejection Bay

The fore ejection bay is located just aft of the fore parachutes bay. This bay houses the fore altimeters in a housing that is RF shielded. The shield is created using conductive tape that lines the inner walls of the bay. Details about the RF shielding can be found in Section 6.1.2.11. The altimeters, switches, and batteries are all mounted onto two additively manufactured plates of PLA which slide into the housing. To mitigate the risk of static charges building up during integration, the circuit is shunted using a switch configured as described in Section 6.1.2.10. There are four $3/16$ in. static port holes set 90° apart. Two switches are located just within the housing for easy access. Tabs at the open end of the housing provide mounting points to the fore pressure seal. Figure 24 shows the CAD model of the fore ejection bay and Figure 25 shows the manufactured fore ejection bay.

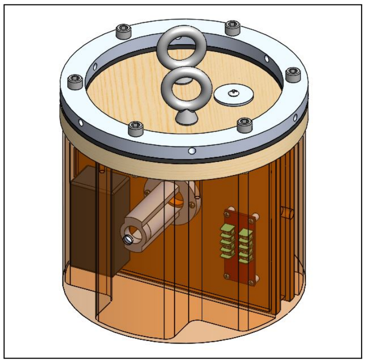

Figure 24: Fore Ejection Bay CAD

Figure 25: Manufactured Fore Ejection Bay

The final design for the fore ejection bay does not include a rail to help align the bay rotationally as designed at CDR. This is because integrating the bay into the full scale launch vehicle proved to be much easier than the subscale model. Rotating the bay within the airframe is not as difficult as expected. The rail not only complicated the system, but also added weight and more holes to the airframe, which lowers its integrity and aerodynamics. The permanent ring beneath the bay used to align the bay vertically was also eliminated for the same reason. Integrating the bay proved to be easy without the addition of the ring.

During the first full scale flight, the tabs broke off when the parachutes were deployed. No further damage was sustained and the broken tabs did not lead to other failures, however, it was more difficult to remove the bay from the airframe. To mitigate this risk, the housing is made so that the mounts extend from the bottom of the housing to the top, eliminating the need for any adhesive. This also eliminates the moment created with the tab design, which is what caused the initial failure. This slight design change will be validated on the FRR Addendum flight. Figure 26 shows the broken tabs, Figure 27 shows a closeup of the broken tabs, and Figure 28 shows the final design with columns for added strength.

Figure 26: Previous Design

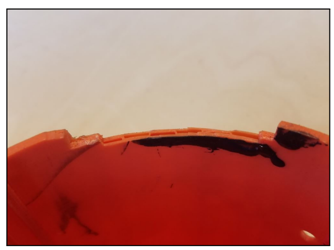

Figure 27: Broken Tab Close

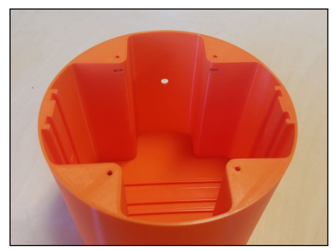

Figure 28: New Column Design

3.1.15 Aft Electronics Bay

The aft electronics bay combines the aft altimeters and the aft ATU. The housing and mounts for the aft altimeters is the exact same as in the fore, but with a slightly smaller diameter, due to it being located within the canister. The inner walls are wrapped in conductive tape to provide an RF shield. Details about the RF shielding can be found in Section 6.1.2.11. The altimeter circuitry is shunted when the main switch is in the off position. Details about the switch wiring can be found in Section 6.1.2.10. The aft ATU sits flat to conserve space and attaches to the aft of the altimeter housing with four 4-40 screws. Just as in the fore ejection bay, all mounts are additively manufactured with PLA. The tabs on the aft electronics bay broke during recovery so the same strategy was taken to add strength to the tabs. Figure 29 shows the final CAD model and Figure 30 depicts the finished bay. This slight design change will be validated on the FRR Addendum flight.

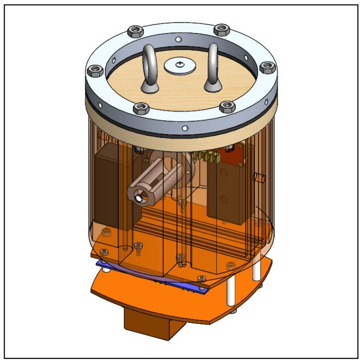

Figure 29: Aft Electronics Bay CAD

Figure 30: Manufactured Aft Electronics Bay

3.1.16 Blade Extending Apogee Variance System

The BEAVS is used to adjust apogee altitude to match the target altitude declared at Preliminary Design Review (PDR) of 4,500 ft. The BEAVS consists of two subsystems for increased mission assurance. The active subsystem is a set of blades which are extended through the exterior of the airframe as a central drive gear is rotated. The passive subsystem is a coupled pair of ballast bays in the fore and aft which can be filled with ballast to lower the apogee altitude of the launch vehicle based on launch day conditions. The active subsystem is discussed in Section 3.1.16.1, while the passive subsystem is discussed in Section 3.1.16.2.

3.1.16.1 Active Subsystem

Prior to cutting slots in the aft airframe for the active subsystem of the BEAVS, an excess portion of the airframe was tested using an Instron compression testing machine to ensure the airframe would not buckle upon takeoff. The test results are displayed in Section 6.1.1.10.

The mechanical systems of the BEAVS active subsystem were built and present for the Vehicle Demonstration Flight on Februaru 22nd, 2019. The mechanical systems are based around a central drive gear mounted on a motor. This ensures that the fins all deploy at once or not deploy it all, which prevents the launch vehicle from destabilizing or taking an unanticipated flight trajectory. Shown in Figure 31 and 32 are images of the as built BEAVS and the final CAD of the system. In addition, the blades extending through the aft airframe are shown in Figure 33.

The primary manufacturing for the BEAVS consisted of a bulkhead with precisely located holes to mount the linear guides and motor. This was done using the RIF mounted on a VMC. In addition to the bulkhead manufacturing, the blades were milled using 1/8 in. aluminum plate. Once the aluminum plate was trimmed to size and the holes were located in the correct position to mount on the linear guides, the rounded edges were performed using a rotary fixture with the same method as bulkhead manufacturing shown in Section 3.1.7. In addition, the rack features were additively manufactured using PLA.

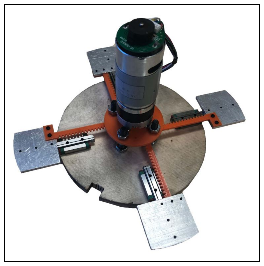

Figure 31: The as built active system of the BEAVS.

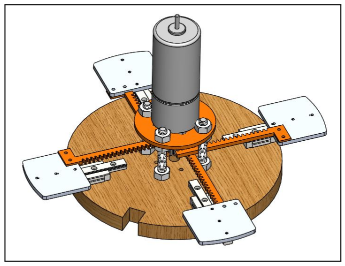

Figure 32: Final CAD models of the active system of BEAVS.

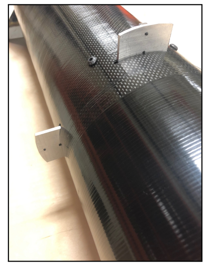

Figure 33: Blades extending through aft airframe.

The electronics system for BEAVS was planned to be an additional ATU. The ATU Printed Circuit Board (PCB) had unexpected delays in design, manufacturing, and assembly. The avionics systems for the launch vehicle had to be prioritized over the electronics for the active subsystem of the BEAVS. Not enough time was available to assemble and test the sensors required for the BEAVS, therefore the electronics were not present in the Vehicle Demonstration Flight on February 22nd, 2019.

Because the electronics were not completed, the control system of the BEAVS active subsystem was only tested in MATLAB and Simulink. The control system was greatly simplified between CDR and FRR to prepare it in time for flight on February 22nd, 2019. The control system was simplified to a one degree of freedom model that considered only vertical velocity. This approximation was determined to be valid based off of the OpenRocket simulations shown in Table 4 in which the launch vehicle stays within 100 ft regardless of wind conditions. The OSRT consequently decided to perform simulations for perfect conditions at 0 mph wind (vertical flight only) and accept a larger tolerance in apogee altitude.

A trajectory finding routine was developed which takes in the current altitude and outputs the velocity required to reach the desired apogee altitude. This trajectory finding routine can be used in conjunction with the current state of the launch vehicle to determine the error between the current velocity and the desired velocity. A Proportional-Integral-Derivative (PID) control scheme uses this feedback to minimize the error through blade deployments which are associated with a higher coefficient of drag. The output of this PID loop was used to control the DC Brushed motor with an encoder by using an additional motor control PID loop.

The active subsystem of the BEAVS was not successfully tested by FRR means the system will be present in the launch vehicle for the Payload Demonstration Flight and the Competition Flight, however it will not be turned on. The mechanical system which was flown on the Vehicle Demonstration Flight will still be present for all future launches.

3.1.16.2 Passive Subsystem

Two coupled ballast bays in the fore and aft section make up the passive subsystem of the BEAVS. These coupled ballast bays are compartments which were additively manufactured out of PLA to store small sand bags, which allow for modular ballast conditions. The weight of the sand bags can be adjusted to the exact desired weight of the ballast bay. For the Vehicle Demonstration Flight, the amount of ballast was set to 0 lbf, which serves as a control point to base future ballast decisions on. For the Payload Demonstration Flight, the ballast will be set to the maximum ballast condition. The Payload Demonstration Flight will occur after FRR and require an FRR addendum, in which the ballasted conditions will be documented. Shown in Figure 34 are the fore and aft ballast bays. Shown in Figure 35 and 36 are the fore and aft ballast bays as they will be mounted on the launch vehicle.

Figure 34: Fore and aft ballast bays and ballast material.

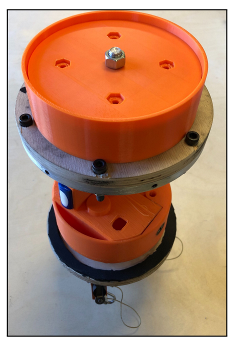

Figure 35: Fore ballast bay mounted to the FHP.

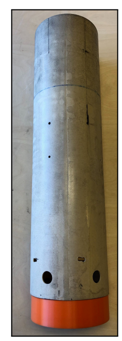

Figure 36: Aft ballast bay mounted to the canister.

After successful Payload Demonstration Flight, OSRT will be able to safely ballast anywhere between the tested minimum and maximum ballast configurations. This allows launch day conditions at competition to be accurately determined, and the passive subsystem can be used to fine tune the apogee altitude achieved. Shown in Table 2 are the ballast amounts required based on different launch day conditions to reach 4,500 ft.

Table 2: Simulated Payload Demonstration Flight with ballast.

Wind Speed (mph)	Aft Ballast (lbf)	Fore Ballast (lbf)	Stability (calibers)	Predicted Apogee (ft)
0	1.03	0.14	2.10	4500
5	0.98	0.10	2.10	4500
10	0.93	0.06	2.10	4500
15	0.88	0.02	2.10	4500
20	0.71	0	2.11	4500

3.1.17 Camera System

The Camera System uses five cameras within the airframe to film the flight of the launch vehicle. Each camera records the flight of the launch vehicle separately and then a 360° video is created afterwards using video editing software. This system uses two GoPro HERO3 cameras, one GoPro HERO5 cameras, and two YI 4K Action Cameras. These cameras were chosen because they were the lightest cameras that the OSU library could provide while still having all the functionality needed for this project.

The main constraint for this system is that it must be lightweight enough to not jeopardize the target apogee of the launch vehicle, while remaining strong enough to protect all five cameras. This was achieved with a simple design that puts any axial load exerted on this system through an aluminum threaded rod instead of the cameras. This system weighs 2 lbs, so the axial force exerted on the threaded rod from a 50 G acceleration is well under the tensile strength of the threaded rod. This is analyzed in Section 6.1.1.7. The cameras are held in place with a PLA fixture that is additively manufactured. These fixtures are supported by a bulkhead on either end. The bulkheads are connected with a threaded rod. Nuts on both side of the fore bulkhead ensure that the system cannot be compressed. This system sits within the canister. A side by side comparison of the finished system and the CAD model can be seen in Figure 37 and Figure 38. The aft bulkhead of this system is permanently attached to the canister with epoxy, which is why it is not shown in Figure 37. The threaded rod on the final system is longer because it also retains the aft ballast bay.

Figure 37: Final Camera System

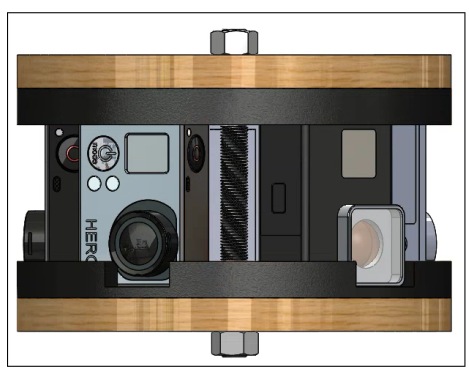

Figure 38: Camera System CAD Model

Because this system is located within the canister, five holes were cut through both the canister and the airframe for the cameras. Prior to cutting these holes, a portion of the airframe was tested using an Instron compression testing machine to ensure the airframe would not buckle upon takeoff. The test results are displayed in Section 6.1.1.10. The Camera System was successfully tested during a full scale launch on February 22nd, 2019. The view from the cameras can be seen in Figure 39.

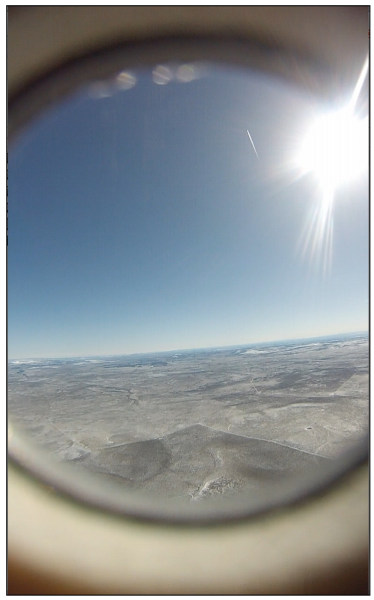

Figure 39: View from Camera System

3.2 Recovery Subsystem

3.2.1 Unique Mission Success Criteria

In order for the recovery system to successfully complete the mission, the launch vehicle must separate at apogee and release a drogue parachute from the fore and aft sections. At a lower altitude, a main parachute is released from both section. This process must meet requirements in the SL handbook. These requirements are as follows:

- A descent time of no longer than 90 s
- A kinetic landing energy of no more than 75 ft-lbf for all sections
- A drift radius of no more than 2,500 ft in winds up to 20 mph

3.2.2 Bulkhead Attachment Points

The aft recovery system is secured at one bulkhead located just above the aft altimeter bay. The fore recovery system is connected to two bulkheads: one located in the fore airframe and one located in the nosecone. Two

5/16 in. forged steel eye bolts are inserted through each bulkhead. Two eye bolts are used for redundancy in case one fails. A rubber washer attached is placed between the eye bolt shoulder and the bulkhead. On the bottom of the bulkhead, a large steel washer made of sheet metal is placed over both eye bolt threads to help distribute the force through the bulkhead. A nyloc nut is threaded onto both eye bolts. The reason two eye bolts were chosen over a u-bolt was to keep the attachment points as low as possible inside the airframe, and to allow for a wider base to attach recovery components to. A Quick Link is run between the two eye bolts to serve as an attachment point for the two Tender Descenders and the nylon riser. The Quick Link also keeps the eye bolts from turning and unthreading themselves during flight. The eye bolts are rated to a 1300 lbf working load, meaning they can withstand 4000 lbf in a shock loading scenario. The wide mouth Quick Link is rated for a 700 lbf working load, meaning it can withstand up to about 2500 lbf in a shock loading scenario.

Shown in Figures 40 and 41 are the attachments point for the eye bolts to the bulkheads. The fore and aft bulkhead attachment points are constructed in similar manner, and the bulkhead in the nosecone has a wooden ring instead of an aluminum ring.

Figure 40: Top of Bulkheads

Figure 41: Bottom of Bulkheads

3.2.3 Shock Cord Layout

The launch vehicle contains two 42 ft long, one in. wide, nylon webbing shock cords - one for the fore section and one for the aft section. The risers have a sewn loop on both ends, easing attachment to bulkheads and parachutes, and the layout of these nylon risers are nearly identical.

The fore riser has three butterfly knots tied in it, while the aft only contains two. Both have a first knot located 12 ft from a sewn loop, and both have a second knot located 10 ft from the first loop. The third knot in the fore riser is located 14 ft from the second loop, leaving six ft to the other sewn loop. The first knot serves an attachment point for the main parachute, the second serves as an attachment point for the top of the deployment bag, and the third serves as an attachment point for the drogue parachute. In the aft section, the drogue is attached to the sewn loop at the end of the riser. Each riser has two Kevlar sleeves and two Kevlar blast protectors. Both serve as protection from black powder charges. One is located between the deployment bag and the drogue parachute, and the other is located below the main parachute. Each harness contains an artificial zipper located between the deployment bag and the drogue parachute.

3.2.3.1 Shock Cord Material

Nylon was chosen due to its elastic nature. Having extra elasticity reduces the snatch load and the chance of the cord snapping under high loads. Nylon, however, cannot withstand long exposure to high heats, meaning it needs to be protected by a more heat resistant material. While nylon has its drawbacks, being the most reliable material under high loading scenarios was worth the downsides the material introduces. The 1 in. nylon webbing is rated to withstand 4,000 lb under a shock loading scenario. This results in a large factor of safety for the expected forces experienced by the launch vehicle. A 1 in. nylon webbing shock cord from Fruity Chutes is shown in Figure 42.

Figure 42: 1 in. Nylon Webbing Shock Cord

3.2.3.2 Knot Choice

Butterfly knots are versatile and have many benefits. Loops are needed in specific locations along the risers, meaning a knot is necessary along the riser. A butterfly knot was chosen due to its simplicity, Ultimate Tensile Strength (UTS), and space taken up on the riser. The knot reduces the riser UTS to 70% of the rated breaking load. While a few other knots offered a higher percentage of the rated breaking load, the knots were more complicated and took up larger sections of the riser than the butterfly knot. With a 30% reduction to the shock cord's UTS, the yield strength is 2,800 lbf in a shock loading scenario, which still provides a significant safety factor to the maximum 50 Gs of acceleration experienced during flight. Shown in Figure 43 is a butterfly knot tied in the fore recovery harness.

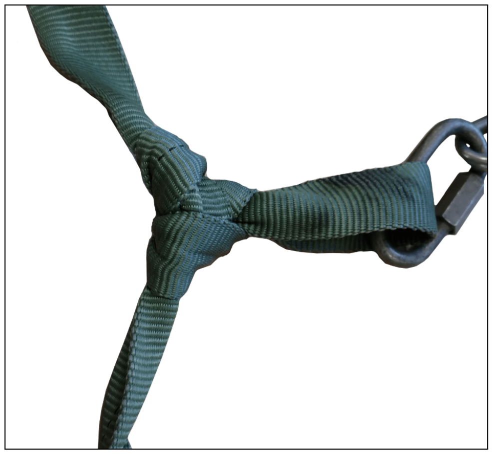

Figure 43: Butterfly Knot

3.2.3.3 Riser Protection

Nylon webbing has a relatively low melting temperature of approximately 500°F, while Kevlar starts breaking down around 800°F. With this information, Kevlar sleeves and parachute blast protectors were manufactured to protect the nylon risers and parachutes from the high temperatures produced at ignition of 4F black powder. These parachute blast protectors were sewn to the Kevlar sleeves, which were then sewn to the nylon risers to keep them from interfering with the parachutes. While the Kevlar protect the nylon risers and parachutes well, cellulose insulation is placed around all charges to further absorb any heat produced by the charges. At ignition, 4f black powder can produce temperatures up to 800°F. Even with the insulation, the Kevlar blast protectors were scorched from the ejection demonstrations and the full scale test flight. This can be seen in Figure 44. If it is decided after inspection that a Kevlar protection has been scorched too much to properly protect the recovery system, it will be replaced prior to the next ejection demonstration or full scale launch. The Kevlar blast protectors withstood five successful ejection tests and a full scale launch without burning through, which proves their durability when exposed to the high heat and pressure of ejection demonstrations.

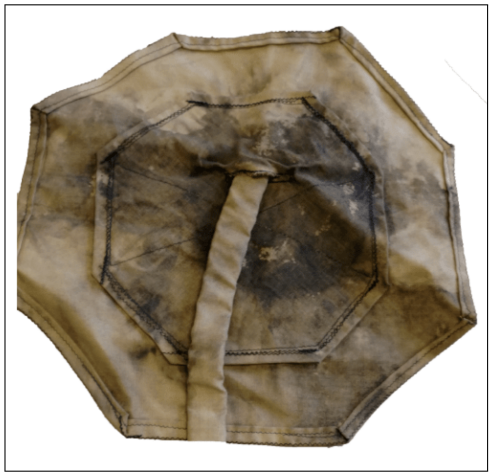

Figure 44: Parachute Blast Protector

3.2.3.4 Artificial Zipper

An artificial zipper, pictured in Figure 45, which is a variation of a frangible tie which uses tape instead of sewn sections of shock cord, has been incorporated into the drogue section of both the fore and aft recovery harnesses. This reduces 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 tears, 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 any force impacted on the edge of the airframe, decreasing the chance of zippering.

Figure 45: Artificial Zipper

3.2.4 Drogue Parachute

The OSRT will use a 1.5 ft diameter cruciform parachute as the drogue for both the fore and aft section. This canopy shape was chosen because of its low coefficient of drag and high stability characteristics. This allows the launch vehicle to fall quickly and controlled to a lower altitude where the main parachutes will be released. These parachutes are inexpensive and can easily be replaced after a flight if they are damaged in any way. A cruciform parachute is shown in Figure 46

Figure 46: Cruciform Parachute

3.2.5 Main Parachute

The OSRT will use an 8 ft toroidal parachute for the main parachute for both the fore and the aft sections. This canopy shape was chosen because of its high coefficient of drag and high performance rating. The size of the parachutes was calculated in Section 6.1.1.15. These parachutes will ensure the OSRT has a recovery that meets the requirements in the SL handbook. These parachutes are packed in the airframe using a deployment bag. Kevlar blast protectors described in Section 3.2.3.3 are used in the packing design to add additional heat protection to the parachutes from the black powder charges. A picture of a toroidal parachute is shown in Figure 47.

Figure 47: Toroidal Parachute

3.2.5.1 Main parachute packing

The main parachutes are packed in a deployment bag using a packing method recommended by OSRT advisers. The packing method can be seen in the Main Parachute Packing Checklist shown in Table 34. The use of a deployment bag provides heat protection to the parachute from ejection charges. Using a deployment bag will allow for a shroud line first recovery. This is when the riser and shroud lines extend and become taught prior to canopy inflation. This will reduce the snatch load experienced by the launch vehicle. The shock cord layout designed by OSRT allows for this type of recovery and will aid in pulling the parachute out of the deployment bag when the shroud lines become taught. The use of a deployment bag also increases the ease of storage and transportation of the parachutes.

3.2.6 Altimeters

The OSRT's launch vehicle contains four barometric altimeters which fire ejection charges. Two are contained in the fore altimeter bay and two are contained in the aft altimeter bay. The two altimeters OSRT has flown are the PerfectFlite StratoLoggerCF and the Missile Works RRC3 altimeters. All three output ports on the RRC3 are in use, and both ports on the StratoLoggerCF are in use. The StratoLoggerCF has been used as the primary altimeter, and the RRC3 has been used as the secondary altimeter. Shown in Figures 48 and 49 are the layouts of the two altimeters.

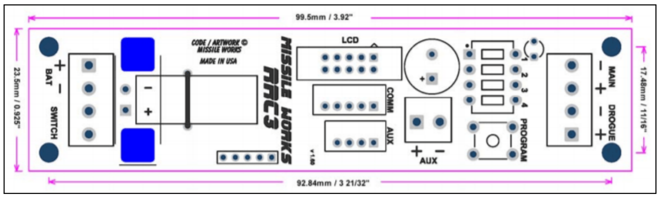

Figure 48: RRC3 Schematic

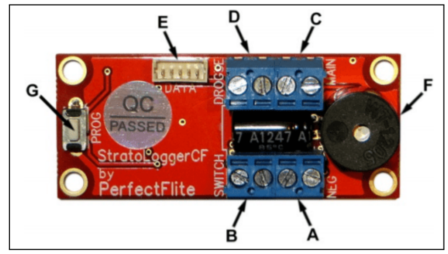

Figure 49: StratoLoggerCF Schematic

A Double Pole Single Throw (DPST) switch mechanism has been implemented into all the switches which turn the altimeters on/off. Shown in Figure 50 is the electrical diagram for the altimeter/switch/battery assembly.

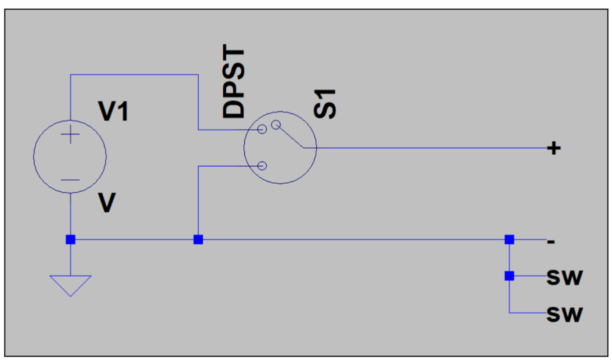

Figure 50: Altimeter Electrical Schematic

The "positive" and "negative" leads are connected to the battery ports on all four altimeters. The leads labeled "SW" are connected to the two switch ports on all four altimeters. This switch functions in shunting all altimeters while in the off position. All switch and battery ports are connected directly to ground while the switch is off, eliminating the possibility of static charge building up and igniting an ejection charge. The discharge time of the capacitors contained on the altimeters was analyzed in Section 6.1.2.10 and was determined to be negligible.

3.2.6.1 Primary Altimeter

The StratoLoggerCF altimeters were set to ignite their drogue charges when apogee is sensed, and the main port is set to fire at an altitude of 700 ft AGL. The StratoLoggerCF altimeters have consistently fired their main charges within five ft of sensing 700 ft. Shown in Figure 51 is the layout for both StratoLoggerCF altimeter sleds.

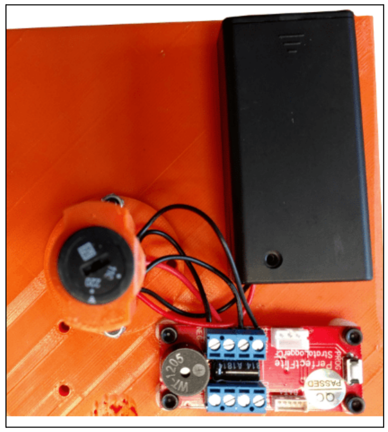

Figure 51: StratoLoggerCF Sled Layout

3.2.6.2 Backup Altimeter

Both RRC3 altimeters were set to ignite their drogue charges one second after apogee was sensed. The main ports were set to ignite at an altitude of 700 ft AGL. For the full scale launch, these ports fired 655 ft and 639 ft AGL, which is slightly lower than expected. The auxiliary ports were set to ignite after the main ports were fired. A loop comparator was set to ensure the launch vehicle sections were below an altitude of 1,000 ft AGL, and then the ports were set to fire one second after the main ports were fired. Shown in Figure 52 is the layout for both of the RRC3 altimeter sleds.

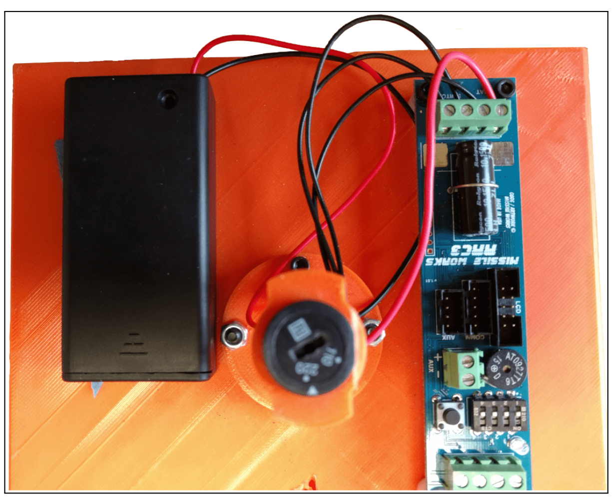

Figure 52: RRC3 Sled Layout

3.2.6.3 Necessary Changes to the Primary Altimeter

Based on post flight analysis of the Vehicle Demonstration Flight footage, it appears that the main parachute was not pulled from the airframe immediately after the Tender Descenders released as intended. The deployment bag charge of the RRC3 can easily be identified in the footage by the smoke, which also represents the first time any portion of the main parachute can be seen. This was consistent for both sections. The purpose of the charge was intended to be a triple redundancy, with two Tender Descenders and the charge to ensure the deployment bag left the airframe. Based off of the footage, there is concern that the system would not have functioned successfully without the deployment bag charge. Therefore, OSRT has decided to change the primary altimeter to a second RRC3, allowing a backup deployment bag charge to be in place. It is possible the deployment bag was in the process of exiting the airframe given more time; however, OSRT feels the best course of action is to mitigate the hazard regardless of if the recovery system would have functioned without the deployment bag charge. Therefore, the primary altimeter is being changed to an RRC3 in both the fore and aft sections of the launch vehicle.

All output ports on both the RRC3 altimeters will be in use after the change is made. One RRC3 in both the fore and aft will fire its drogue charge as soon as apogee is sensed, and the secondary altimeters will fire 1 second after apogee is sensed. For both RRC3 altimeters in the fore and aft sections, the main output port will be fired at 800 ft AGL, releasing all four Tender Descenders. This has been raised from 700 ft AGL due to the consistent latency of the main output ports being fired. For every launch, each RRC3 has fired the main port anywhere from 30 ft to 100 ft below the intended altitude. For the auxiliary charges, the primary will be set to a loop comparator to ensure the altitude is less than 1,000 ft AGL, and then the output port will fire 1.0 seconds after the main port has been fired. The secondary auxiliary charge will have the same loop comparator and the output will fire 1.50 seconds after the main output port has been fired.

3.2.7 Avionics

The ATU system is composed of two flight units and a ground station capable of RF communication over the 900 MHz and 433 MHz frequency bands. The flight units collect and log GPS data, filter out unnecessary packets, then transmit the data over the RF link to the ground station. The ground station outputs the most recent GPS coordinates over the Arduino serial monitor or the ground station Graphical User Interface (GUI) on a Universal Serial Bus (USB) connected computer.

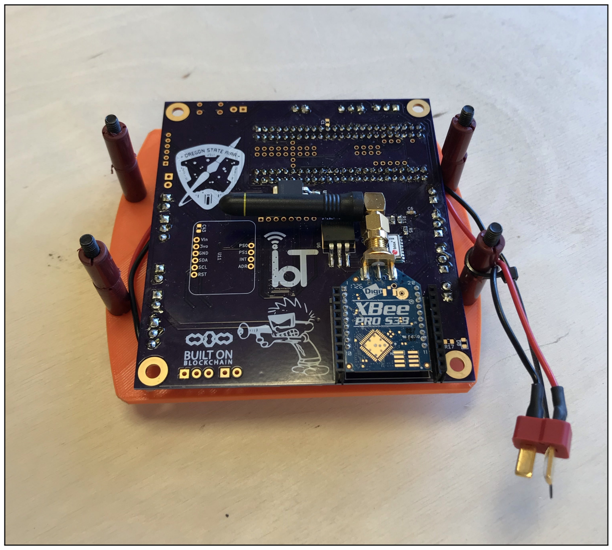

Figure 53: Mounted OSRT ATU with new custom PCB.

The 900 MHz RF band uses an XBee Pro S3 transceiver operating at 250 mW. The 433 MHz RF band uses a Texas Instruments CC 1200 transceiver operating at 40 mW. This does not violate competition power requirements as only one of the bands will be active at any given time. Both bands offer line-of-sight range and have been tested for functional operation at the maximum allowable drift distance of 2,500 ft specified in the SL handbook. The 900 MHz band has been previously tested with reliable ranges greater than 1 mi and thus satisfies competition and team-derived requirements. The OSRT is continuing testing and development of the 433 MHz system to characterize performance at extended ranges. The inclusion of both transmission bands serves as a redundant communication measure in the case of the failure or interference with either signal during flight.

The flight units use a u-blox GPS unit to gather GPS data from several satellite navigation systems including GPS, Global Navigation Satellite System (GLONASS), and BeiDou. Both systems use an Arduino-compatible Teensy 3.6 microcontroller running embedded C/C++ code for computational operations. The flight units use a new custom OSRT designed PCB shown in Figure 53. On-board data logging is accomplished with the Teensy's built in SD card functionality. The ATUs are powered by 7.4 V 2200 mAh Lithium Polymer (LiPo) batteries, providing significant total up-time thanks to the low power draw of the chosen RF transceivers. Battery life testing has exceeded 8 hours in testing discussed in Section 6.1.2.12.

The ground station is an additional ATU which is used to display received location coordinates from the flight ATUs. In addition, the ground station ATU is used to wirelessly trigger the PLEC after the launch vehicle has landed and the payload is ready for deployment.

3.2.8 Main Parachute Retention

Both the fore and aft sections of the launch vehicle are recovered with single compartment recovery, requiring the main parachute to be retained within the airframe. This has successfully been done with two Tender Descenders in both the fore and aft sections of the airframe. At CDR, the OSRT design featured two Tender Descenders in series. The design was changed to be in parallel due to a minor risk the team had identified with the design. If the lower Tender Descender released, but the top Tender Descender failed to release, an e-match would be contained within the body of the top Tender Descender. This e-match could cause the deployment bag to be retained within the airframe by an e-match, which would result in recovery failure and hazardous descent of the launch vehicle. To mitigate the hazard, the Tender Descenders were placed in parallel, with a small Kevlar cord between them. If either Tender Descender is released, one end of the Kevlar cord will be able to slip through the loop in the main parachute riser, allowing the main parachute to be deployed. The OSRT feels that this change is minor in that it maintains redundancy the same way as the Tender Descenders in series, but mitigates the concern of an e-match in the top Tender Descender preventing the main parachute from exiting the air frame. The two Tender Descenders are attached to a wide-mouthed Quick Link running between the two eye bolts at each bulkhead. This design was flown in the Vehicle Demonstration Flight and functioned properly. The system is depicted in Figure 54.

Figure 54: Main Parachute Retention Method

A nylon harness is run between the two Quick Links at the top end of the Tender Descenders. It is folded into thirds and looped through the Quick Links. The nylon harness has a Kevlar sleeve over it to protect it from excessive heat produced by ejection charges. The loop tied to the top of the deployment bag is slid over this nylon-Kevlar assembly, before the Quick Links are attached to the Tender Descenders. When either Tender Descender separates, the loop slides over the Kevlar sleeve, allowing the main parachute to be pulled or ejected from the airframe. The reason to have two Tender Descenders is to allow for redundancy in the recovery system. If either, or both, Tender Descenders fire, the main parachute is deployed.

3.2.9 Parachute Sizes and Descent Rates

A MATLAB script was written to simulate the descent of the airframe. This script was used to predict descent time, descent rate, landing kinetic energy, and drift radius. Using the script, it was determined an 8 ft diameter main parachute could be used for both the fore and aft sections of the airframe. The fore and aft sections were simulated to fall under the main parachute with a terminal velocity of 15.06 ft/s and 14.16 ft/s respectively. The fore and aft sections will complete its descent in 67.1 s and 70.8 s respectively. More information on this analysis can be found in Section 6.1.1.15. This simulation was verified through the subscale and full scale flights discussed in Section 6.1.1.13 and 6.1.1.1.

3.2.10 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 55 shows the expected flight phases of the launch vehicle.

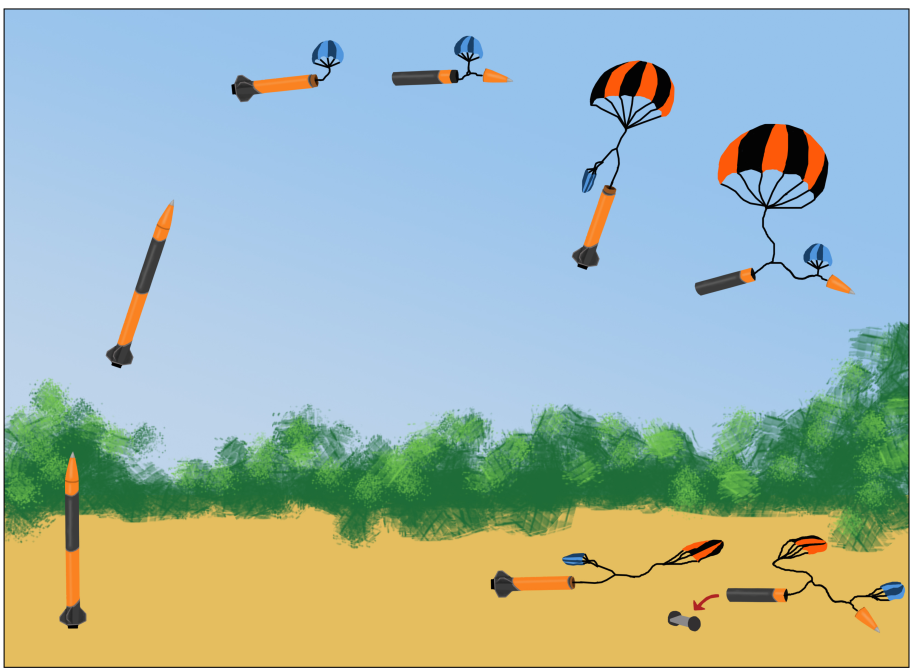

Figure 55: Recovery Separation Events (Not To Scale (NTS))

The two dual deployment systems are nearly identical. The fore system is shown in Figure 56, and the aft system is shown in Figure 57.

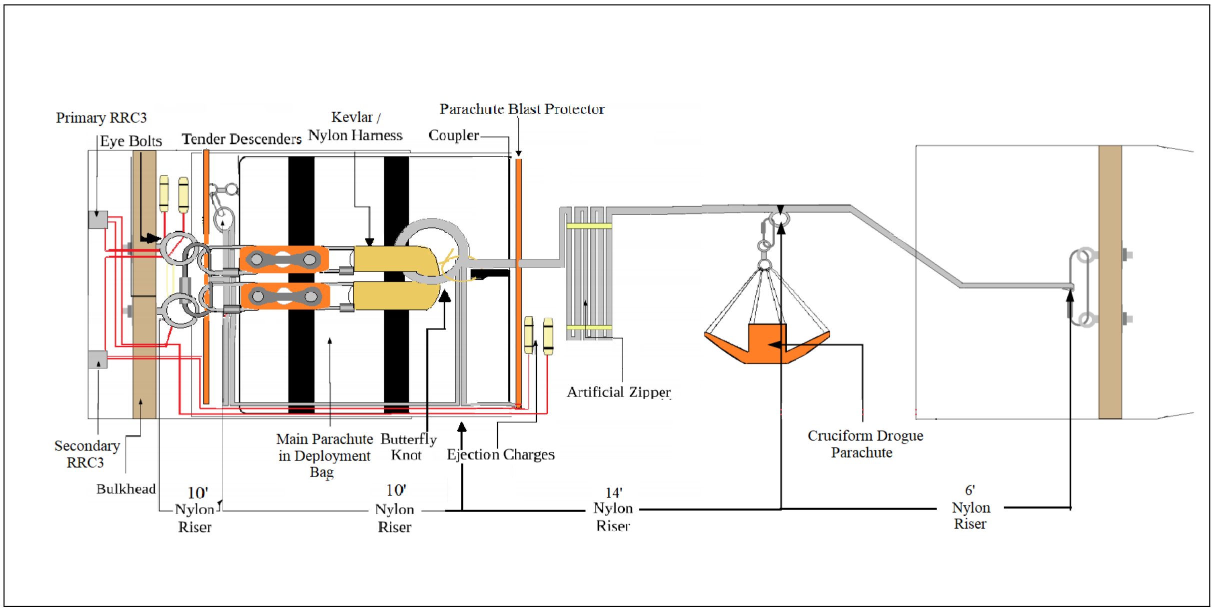

Figure 56: Fore Recovery Integration (NTS)

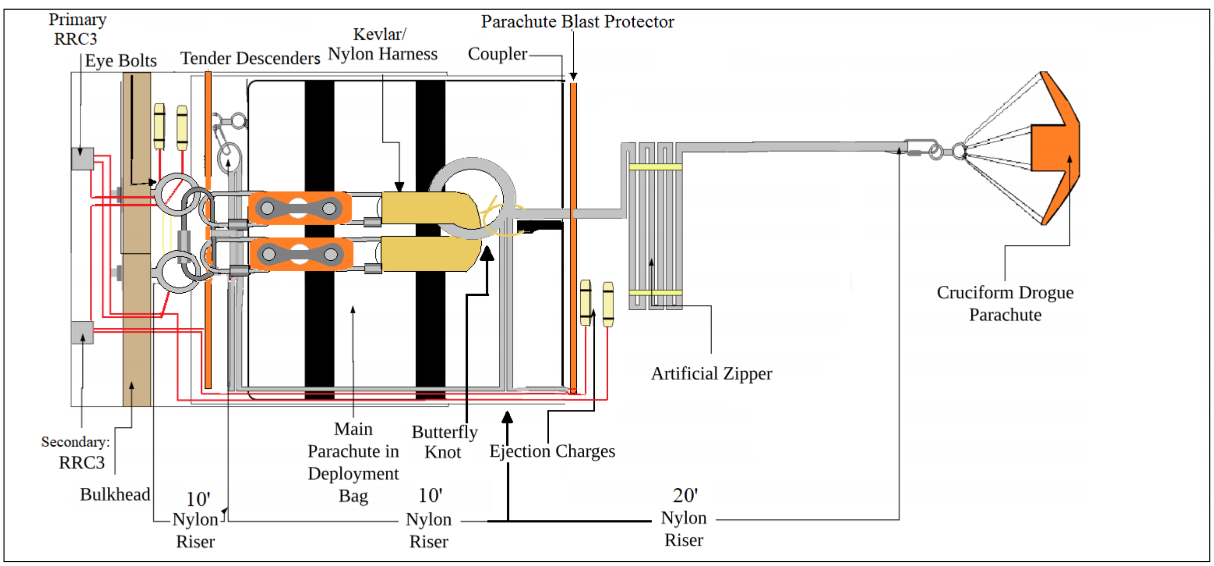

Figure 57: Aft Recovery Integration (NTS)

In the fore recovery system, the aft bulkhead has two eye bolts bolted to it with nyloc nuts. The eye bolts are aligned and located along the center of the bulkhead. A wide-mouthed Quick Link is spread between the two eye bolts. Two Tender Descenders in parallel are attached to this wide-mouthed Quick Link, and two e-matches are threaded through the bulkhead and attached to them. A nylon-Kevlar assembly is linked between the two top Quick Links of the Tender Descenders. Four more e-matches attached to ejection charges are threaded through the bulkhead. Two of these have 15 in. of slack, and the other two are located at the bottom of the recovery system. All e-matches are connected to altimeters in the Altimeter Bay. All of these components attached or passed through the bulkhead have rubber washers to aid with a pressure seal. The end of the riser closest to the main parachute is looped around this extra wide Quick Link, between the two Tender Descenders. A Kevlar sleeve blast protector assembly is sewn to the Nylon riser at this pre-sewn loop. The main parachute swivel will be attached to a butterfly knot 10 ft down the riser with a Quick Link. A second butterfly knot is 10 ft down the riser from the first butterfly knot. This is attached to the loop at the top of the deployment bag with a 1 ft long section of braided Kevlar. This Kevlar is tied to the deployment bag and the loop with a square knot followed by a bowline knot. This loop is slid over the nylon-Kevlar assembly linking between the two Tender Descenders. Just past the deployment bag knot is a Kevlar sleeve parachute blast protector assembly sewn to the nylon riser. The ejection charges and cellulose insulation are wrapped with this blast protector. Cellulose insulation is also placed on both sides of the blast protector. A third butterfly knot is tied 14 ft down the riser from the previous knot, and the drogue swivel is attached to this loop with a Quick Link. Between the deployment bag knot and the drogue parachute knot is an artificial zipper. The end of the riser is 6 ft further down the riser. This end is attached to the fore bulkhead, located in the nosecone, in the same manner as the aft bulkhead.

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

3.2.11 Ejection Charge Sizing

OSRT has used 4F black powder for all ejection testing and all launches. The reason 4F was chosen was due to its fast ignition time and proven reliability.

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 1/2 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 rubber 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.

This provides a reliable charge with an easy packing method. All charges are examined to ensure the explosion is through the wall of the surgical tubing without ejecting the Santoprene plug as described in Section 6.1.2.8. This ensures that the tightness of the zip-tie used does not affect the charge. Figure 58 displays an example of an ejection charge which exploded through the wall of the surgical tubing during full scale testing.

Figure 58: Ejection charges exploding through the wall of the surgical tubing.

Demonstration 6.1.2.4 describes the process for sizing the charges. Table 3 lists the charge sizes for the recovery sections.

Charge Name	Charge Size [g]
Fore Primary	4.0
Fore Secondary	6.0
Fore Deployment Bag Primary	4.0
Fore Deployment Bag Secondary	4.0
Aft Primary	5.5
Aft Secondary	8.0
Aft Deployment Bag Primary	4.0
Aft Deployment Bag Secondary	4.0

Table 3: Recovery Charges Sizing

All secondary, separation charges have been sized to be roughly 1.5x the primary ejection charge size. This was done per recommendations from OSRTs team mentors. The deployment bag charge size is not changed because a 4 gram charge was proven to expel the deployment bag from the airframe with a high velocity. If the bag does not come out because of ignition of the first charge, it is not because of the sizing of the charge. Instead, it is likely because neither Tender Descender separated. In the case the primary charge does not ignite, but one or both Tender Descenders fire, the backup will still be capable of expelling the bag with a 4 gram charge.

3.2.12 Recovery System Sensitivity to Onboard Devices

To mitigate the risk of the altimeters firing early due to interference with unwanted signals, the inner walls of both the fore and aft altimeter housings are wrapped in conductive tape. This creates an RF shield that does not allow undesired signals, such as the ATU signals, to interfere with altimeter functions. To test the validity of the shield, the resistance across the housing was tested in several locations. The maximum allowed resistance is one ohm. Both altimeter housings passed with the highest recorded resistance at 0.516 ohms. RF shielding inspection is discussed further in Section 6.1.2.11.

This method has been used in both subscale launches and the first full scale launch. To date, there have been no issues with unwanted signals firing the altimeters early. All ejection charges have been fired based on the pressure readings and preset settings on each altimeter as planned.

3.3 Mission Performance Predictions

3.3.1 Unique Mission Success Criteria

For the launch vehicle to successfully complete the mission, several mission performance specific criteria must be completed. The mission performance predictions must:

- Leave the launch rail at more than 52 ft/s
- Ascend to an apogee altitude between 4,000 and 5,500 ft
- Have a stability margin above 2.0 calibers

3.3.2 Flight Profile Simulations

The softwares OpenRocket and RockSim were used to calculate altitude and stability predictions. Both softwares used the same motor thrust curve, seen in Figure 59. The average and maximum thrust values of this motor thrust curve for the Cesaroni L2375-WT are 534 lbf and 586 lbf, respectively. With zero mph wind in Brothers, OR, OpenRocket predicted an apogee altitude of 4,746 ft. RockSim predicted an apogee altitude of 4,913 ft in Brothers, OR with zero mph wind. In Huntsville, AL with zero mph wind, OpenRocket and RockSim simulated an apogee altitude of 4,642 ft and 4,814 ft respectively. The mass and length of the launch vehicles in both simulations were 56.9 lbf and 129.375 in.Table 4 shows the projected altitude of the launch vehicle at 0, 5, 10, 15, and 20 mph winds from the OpenRocket simulation with no ballast.

Table 4: OpenRocket Projected Altitude at Different Cross-Winds

Wind Speed (mph)	Brothers, OR. Projected Altitude (ft)	Huntsville, AL. Projected Altitude (ft)
0	4,746	4,642
5	4,743	4,637
10	4,733	4,628
15	4,718	4,608
20	4,705	4,595

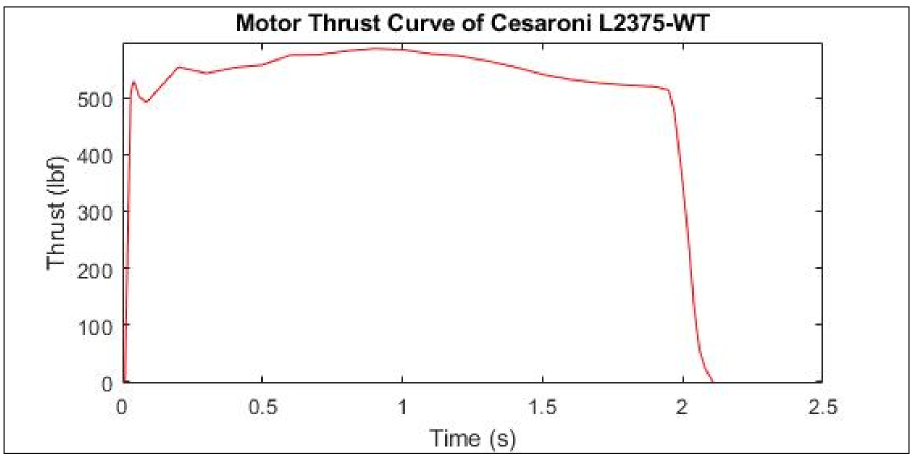

Figure 59: Motor Thrust Curve of Cesaroni L2375-WT

The mass statement of the launch vehicle can be seen in Table 5. The body mass contains the nosecone, fore airframe, aft airframe, couplers, fins, motor tube, centering rings, motor retainer, and epoxy. The bays include the fore and aft avionics bays, fore and aft ejection bays, PEARS, Camera System, and BEAVS. The recovery component includes the fore and aft parachutes, shock cords, deployment bags, Kevlar blankets, and retention mechanisms.

Table 5: Mass Statement

Component	Mass (lbf)
Body	19.92
Bays	13.24
Recovery	8.56
Rover	6.01
Motor	9.17
Total	**56.9**

During ascension, the maximum acceleration of the launch vehicle is predicted to be 322.9 $^{ft}/_{s^2}$. With a launch vehicle total weight of 56.9 lbf, the maximum expected force on the launch vehicle is calculated to be 570.6 lbf during ascension. The testing procedure in Section 6.1.1.9 verifies that the bulkheads will withstand expected forces during ascension. The testing procedure in Section 6.1.1.10 verifies the airframe will withstand expected forces during ascension.

During recovery, the OSRT designed for loads of 50 G's of acceleration. This value accounts for a sufficient safety factor. Testing of the airframe and other structural components of the launch vehicle was successfully completed and shown in Section 6.1.1.9 and Section 6.1.1.10.

3.3.3 Stability Margin

The center of gravity of the launch vehicle was measured with the fully integrated launch vehicle using procedure in Section 6.1.1.11. This test determined the center of gravity location to be 71.0 in. from tip of the nosecone. The as-built fin dimensions were input into OpenRocket along with the rest of the launch vehicle to determine the center of pressure location. The center of pressure was simulated to be 84.7 in. from the tip of the nosecone. The static stability margin of the launch vehicle on the rail is calculated to be 2.14 calibers. The fin dimensions and exterior of the airframe were also input into a RockSim simulation. The center of pressure in the RockSim simulation was calculated to be 84.2 in. from the nosecone tip, a difference of just $^1/_2$ in. between the two simulations. The static stability of the RockSim simulation is calculated to be 2.07 calibers. Both static stability margins are above the NASA SL minimum requirement of 2.0 calibers.

3.3.4 Kinetic Energy

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 and the full scale launches. On average, the subscale and full scale launch vehicle has descended slightly slower than what the simulations predict. This provides the OSRT with a small safety factor. The weight, landing velocity, and landing kinetic energy of each section are shown in Table 6. 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.

Table 6: Landing Kinetic Energy

Measurement	Fore Section	Aft Section	Nosecone
Weight [lbf]	18.2	20.1	5.1
Velocity with Main and Drogue Deployed [ft/s]	15.1	14.2	15.1
Kinetic Energy with Main and Drogue Deployed [ft-lbf]	64.1	62.7	17.9
Velocity with Only Drogue Deployed [ft/s]	111.0	112.0	111.0
Kinetic Energy with Only Drogue Deployed [ft-lbf]	3,485.0	3,922.4	970.8
Velocity with No Parachutes Deployed [ft/s]	115.0	116.0	115.0
Kinetic Energy with No Parachutes Deployed [ft-lbf]	3,740.7	4,207.5	1,042.0

Based on altimeter data from OSRT's first launch, all recovery requirements in the SL Handbook were met. All sections of the launch vehicle were recovered successfully. The kinetic energy at landing of these sections can be seen in Table 7. It can be seen that the fore section of the airframe descended slower than the predicted rate and the aft section descended at a rate very close to the predicted value.

Table 7: Landing Kinetic Energy of Full Scale Launch

Measurement	Fore Section	Aft Section	Nosecone
Weight (lbf)	18.201	20.121	5.070
Velocity with Main and Drogue Deployed [ft/s]	11.66	14.50	11.66
Kinetic Energy with Main and Drogue Deployed [ft-lbf]	38.455	65.92	10.71

3.3.5 Descent Time

A MATLAB script was written to calculate the descent time of each section of the airframe. This simulation was verified to be accurate by the results of the subscale launch. Under a 1.5 ft cruciform drogue parachute and a 8 ft toroidal main parachute for both the fore and the aft sections, the descent trajectories for both sections were calculated on MATLAB. This script accounts for the changing air densities at different altitudes and the acceleration of the launch vehicle at apogee and deployment. This is shown in Figure 60. It can be seen that both sections land in under 90 seconds. The exact descent time can be seen in Table 8.

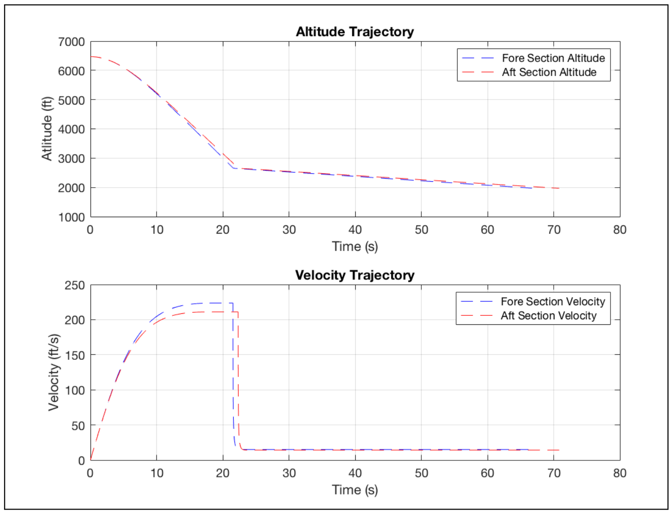

Figure 60: Descent Trajectory

3.3.6 Drift

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 and full scale launches. 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 8. These are compared with drift calculations from OpenRocket which does include weather cocking.

Table 8: Drift and Descent Time

Wind Speed (mph)	**0**	**5**	**10**	**15**	**20**	**Descent Time (s)**
Drift of the Fore Section (ft)	0	492	984	1,476	1,967	67.07
Drift of the Aft Section (ft)	0	519	1,039	1,558	2,077	70.830
OpenRocket Simulation (ft)	2	369	711	1,071	1,394	67.8

3.4 Vehicle Demonstration Flight

On February 22nd, 2019, OSRT completed the Vehicle Demonstration Flight with a launch in Brothers, OR.

3.4.1 Launch Day Conditions and Simulation

The weather conditions on February 22nd, 2019, were recorded from the Pine Mountain Observatory in Bend, OR. At the time of launch, the temperature was 25.4°F with 0 mph winds. The air pressure was 30.28 inHg. The altitude of the launch site in Brothers, OR is 4,639 ft Above Sea Level (ASL). An OpenRocket simulation with these conditions outputs an apogee altitude of 4,746 ft.

3.4.2 Analysis of Vehicle Demonstration Flight

3.4.2.1 Predicted Data

In Brothers, OR, launch day conditions simulated an apogee altitude of 4,746 ft. Time to apogee was predicted to be 17.6 s with a rail exit velocity of 63.8 ft/s. The launch vehicle fore and aft sections were expected to fall at 115 and 116 ft/s under drogue and 15.1 and 14.2 ft/s under main, respectively. These velocities would result in landing kinetic energies of 64.1 and 62.7 ft-lbf under the main parachute for fore and aft, respectively. The predicted descent times were 67 and 70.8 seconds for the fore and aft sections. The maximum predicted drift (with 20 mph winds) of the fore and aft sections were 1,967 and 2,077 ft.

3.4.2.2 Altimeter Results

Four altimeters were recording data during the launch: one Missile Works RRC3 and one PerfectFlite StratoLoggerCF in both the fore and aft sections. Three of the four altimeters functioned as expected. The fourth altimeter, the StratoLoggerCF in the fore section, stopped functioning just after motor burnout, roughly 2.5 seconds into the flight and 900 ft AGL. Figure 61 shows all three flight plots recorded by the altimeters. Figure 62 shows ascent altitude, velocity, and acceleration plots. The vertical lines in the altitude plot represent when the fore and aft charges ignited, separating the launch vehicle at apogee.

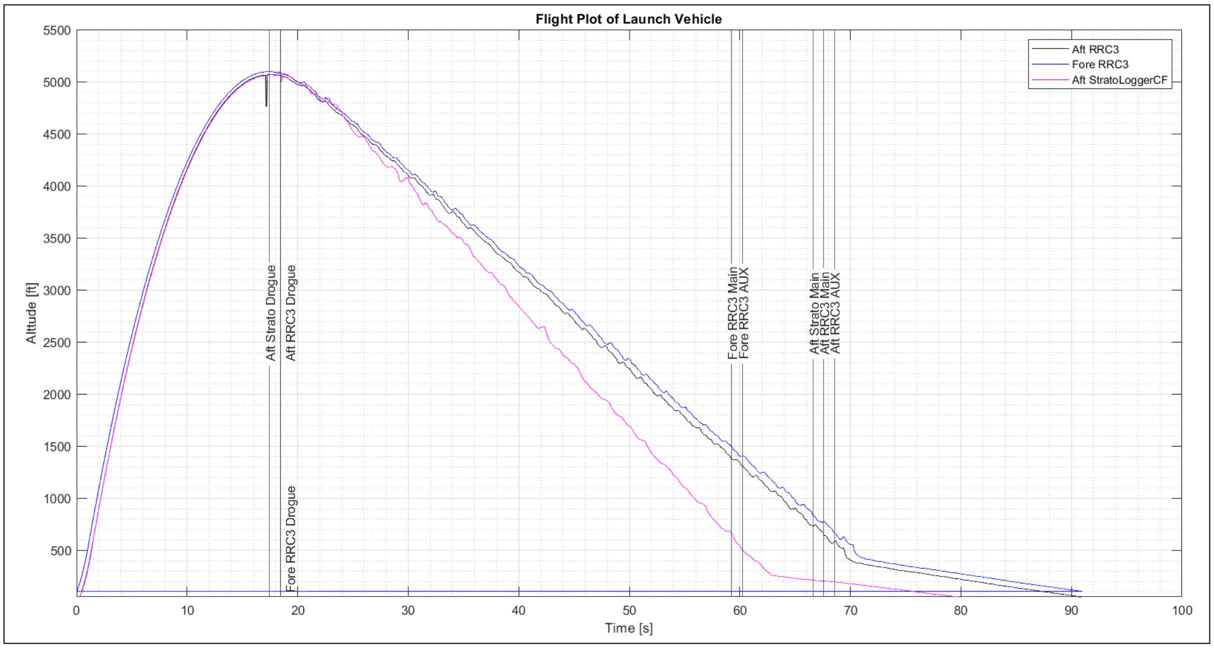

Figure 61: Launch Vehicle Flight

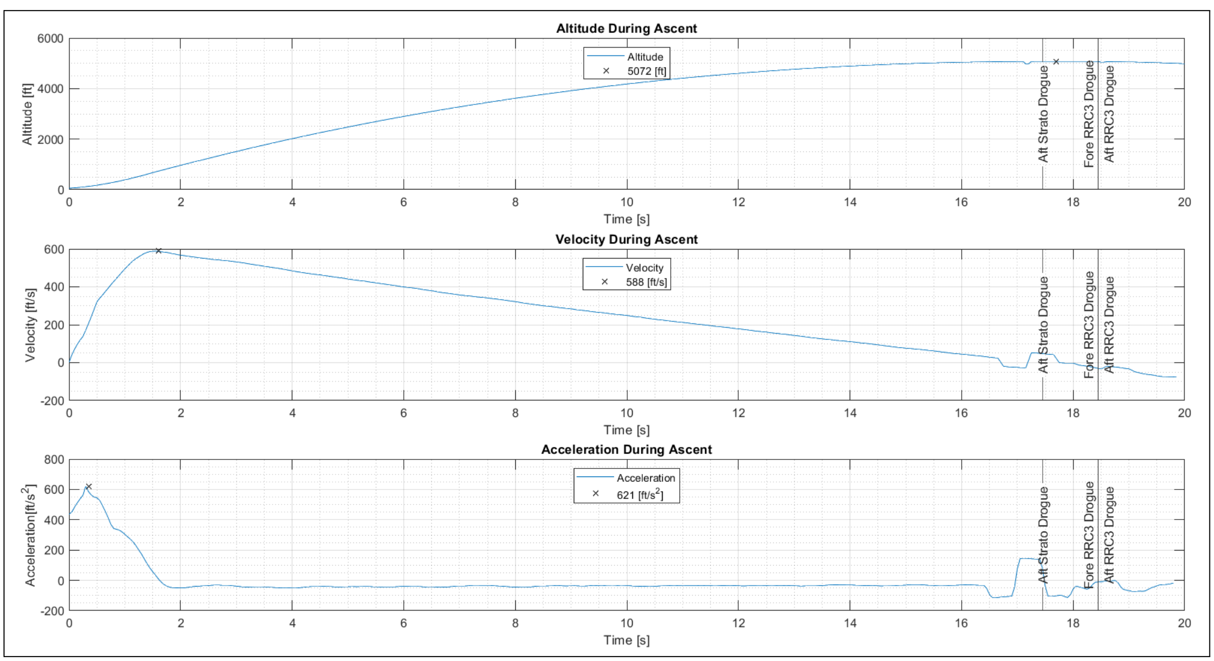

Figure 62: Launch Vehicle Ascent

Figure 63 shows the altitude and velocity plots for the descent of the fore section of the launch vehicle. The red, horizontal lines are the average descent rates under main and drogue.

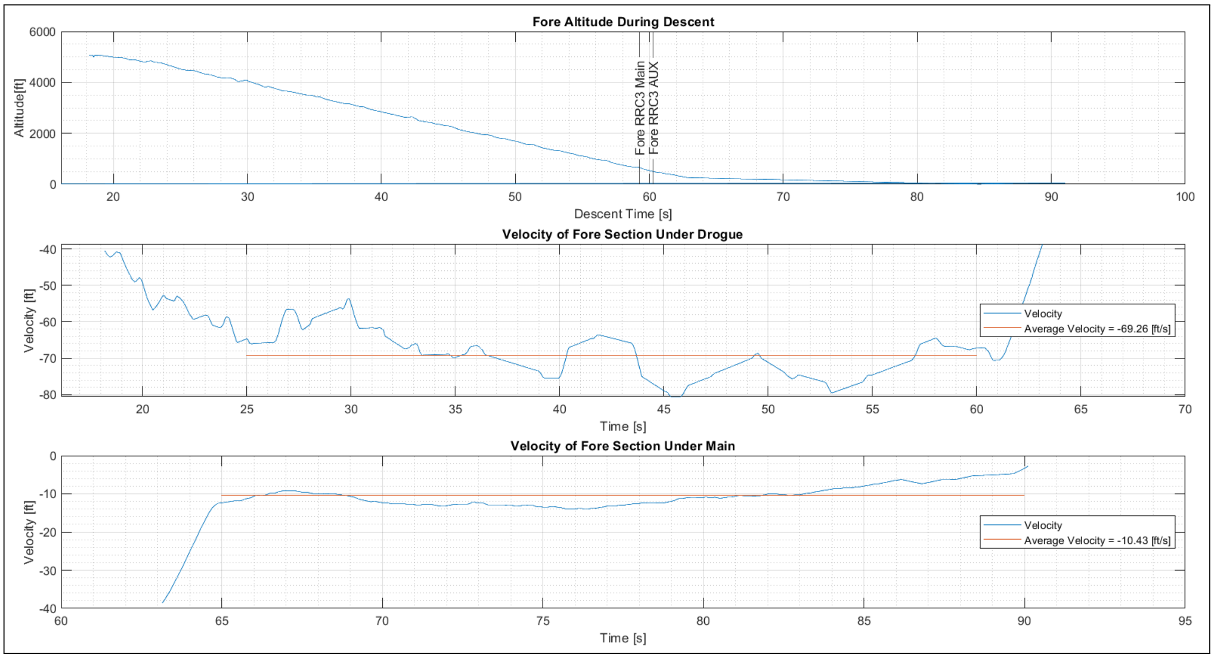

Figure 63: Fore Section Descent

The fore RRC3 fired the drogue charge 18.45 seconds into the flight, meaning apogee was sensed to be 17.45 seconds into the flight. The main charge was fired 59.25 seconds into the flight at 655 ft AGL, releasing one of the Tender Descenders, and the auxiliary charge was fired 60.25 seconds into the flight at 523 ft AGL. The main parachute came out of the airframe at this point and took 2.1 seconds for the riser to become taut and the deployment bag to be completely removed from the parachute. The parachute fluttered for one more second before fully inflating. The launch vehicle slowed from 100 ft/s to 15 ft/s as the main fully inflated. The fore section of the launch vehicle started descending under main about 63.9 seconds into the flight at 262 ft AGL. The fore section impacted the ground 27 seconds later, averaging 9.65 ft/s while descending under main.

Shown in Table 9 are the maximum altitude, impact velocity, landing kinetic energies of the nosecone and fore section, and the total descent time.

Table 9: Fore RRC3 Relevant Data

Maximum Altitude [ft]	Impact Velocity [ft/s]	Fore Impact KE [ft-lbf]	Nosecone Impact KE [ft-lbf]	Total Descent Time [s]
5076	11.66	38.45	10.71	72.6

After the launch vehicle was disassembled, it was determined that the reason the fore StratoLoggerCF stopped recording flight data was a wire becoming disconnected from the altimeter. One of the wires connected to the battery port on the altimeter was not connected after the flight. This can be seen in Figure 64. It has been assumed that the high accelerations off the launch pad dislodged the wire. All connections to each altimeter were inspected closely prior to installation into the launch vehicle and were determined to be secure. To mitigate this in all launches to come, loops in the wire will be located near all ports for each altimeter. These loops will help relieve high stress areas, keeping the wire from breaking or dislodging at the ports.

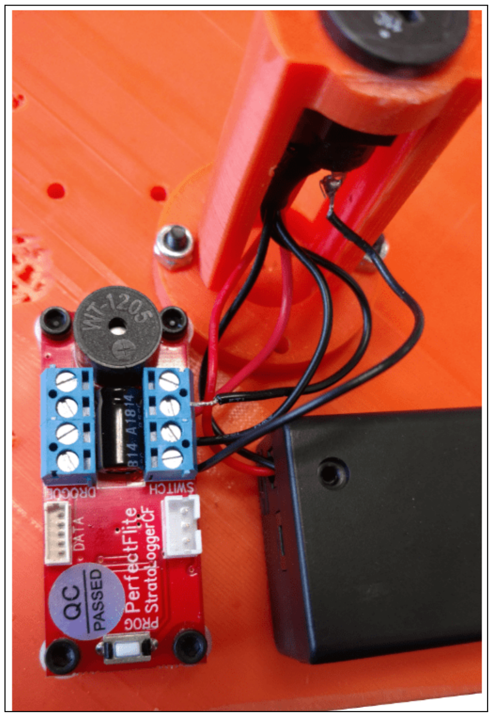

Figure 64: Fore StratoLoggerCF After Launch

Shown in Figure 65 are the altitude and velocity plots for the descent of the aft section of the launch vehicle. The red, horizontal lines are average descent rates under main and drogue.

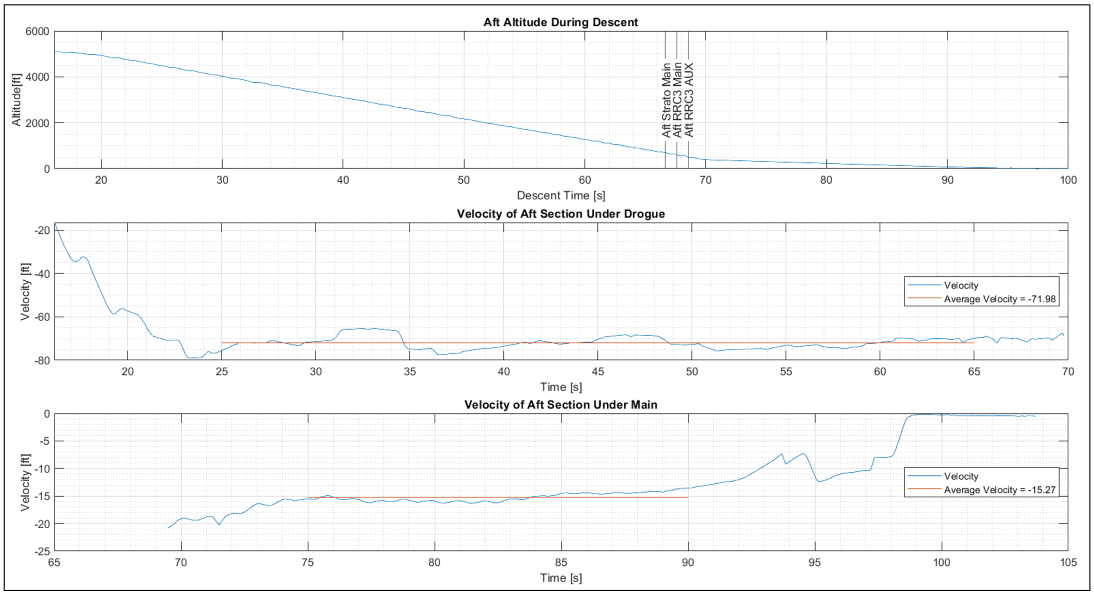

Figure 65: Aft Section Descent

The aft StratoLoggerCF fired the drogue charge 18.25 seconds into the flight, at an altitude of 5094 ft AGL. The aft RRC3 fired the backup drogue charge at 18.45 seconds, at an altitude of 5056 ft AGL. The main charge fired by the StratoLoggerCF was fired at 697 ft and the RRC3 fired its main charge at 639 ft AGL, releasing both Tender Descenders. The auxiliary charge fired one second later at an altitude of 585 ft. About 72 seconds into the flight, the main parachute for the aft section deployed 380 ft AGL. The aft section landed roughly 96.5 seconds from the ignition of the motor, meaning the aft section descended 380 ft in 24.5 seconds, giving an average descent rate of 15.5 ft/s.

Shown in Tables 10 and 11 are the maximum altitude, impact velocity, impact kinetic energy of the aft section, and the total descent time for the aft RRC3 and the aft StratoLoggerCF respectively.

Table 10: Aft RRC3 Relevant Data

Maximum Altitude [ft]	Impact Velocity [ft/s]	Aft Impact KE [ft-lbf]	Total Descent Time [s]
5071	14.52	65.87	79.55

Table 11: Aft StratoLoggerCF Relevant Data

Maximum Altitude [ft]	Impact Velocity [ft/s]	Aft Impact KE [ft-lbf]	Total Descent Time [s]
5094	14.41	64.96	81.1

For all altimeters, the impact velocity was calculated by taking the average of the recorded velocities over the last 3 seconds before impact, and this velocity was used to calculate the landing kinetic energy. In order to plot the data, the noise was filtered out of the altimeter altitudes. Velocities were calculated using a central difference scheme of the altitude, and the accelerations were calculated using a central difference scheme on the velocities. During ascent, all measured velocities and accelerations were filtered for noise then averaged together using a root mean square. During descent, the same thing was done for the individual launch vehicle sections.

3.4.2.3 Avionics Results

Recovery and analysis of the full scale launch data from the fore ATU indicates a logged flight duration of 92 seconds, maximum recorded drift distance of about 907 ft at 9 seconds and a final drift distance of 313 ft. As indicated by the two flat sections in Figure 66, the ATU lost GPS lock briefly during the flight - it was still transmitting to the ground station though not receiving accurate positional data - but quickly regained satellite signal and continued transmitting reliable data for recovery. Due to user error, data was not recovered from the aft ATU.

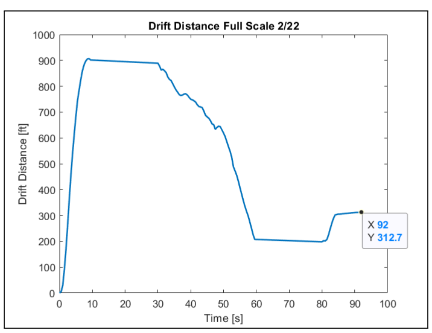

Figure 66: Full Scale ATU Drift Plot

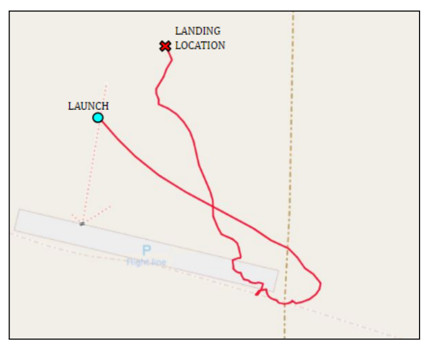

Figure 67: Full Scale ATU Drift Map

3.4.2.4 Errors Between Predicted and Actual Data

The altitude achieved during full scale launch was 325 to 348 ft higher than predicted in the OpenRocket simulations. The increased altitude achieved at launch is attributed to a higher average and maximum thrust of the Cesaroni L2375-WT on launch day. The Cesaroni L2375-WT has a factory specified maximum thrust of 629 lbf and an average thrust of 551 lbf. The motor thrust curve used in OpenRocket simulations had maximum and average thrust values of 586 lbf and 534 lbf respectively.

Table 12 shows the predicted and actual descent rates under the drogue and main parachutes, drogue parachute, total descent time, and kinetic energies of the fore, aft, and nosecone sections of the launch vehicle.

Table 12: Errors Between Predicted and Actual Data

Measurement	Fore Section	Aft Section	Nosecone
Weight (lbf)	18.201	20.121	5.070
Predicted Descent Rate Under Main and Drogue [ft/s]	15.063	14.155	15.063
Actual Descent Rate Under Main and Drogue [ft/s]	11.66	14.52	11.66
Predicted Descent Rate Under Drogue [ft/s]	111.0	112.0	111.0
Actual Descent Rate Under Drogue [ft/s]	108	90	108
Predicted Descent Time [s]	67.08	70.83	67.08
Actual Descent Time [s]	72.60	79.55	72.60
Predicted KE under Main and Drogue [ft-lbf]	64.07	62.65	17.877
Actual KE Under Main and Drogue [ft-lbf]	38.45	65.87	16.60

Due to unaccounted drag and spin characteristics of the launch vehicle while descending under drogue and main, each section was expected to fall slower than the predicted values. This can explain the descent rates under drogue. For the descent rates under main and drogue, it can be assumed that unpredictable gusts of wind acted on both the fore and aft sections. The overall descent times are harder to explain. The launch vehicle flew higher than expected, which increased the descent time. The main parachute on the fore section opened at a lower altitude than expected, which was due to the parachute not catching air and inflating immediately. The aft parachute opened as expected, and the altitude it opened at was within the estimated range of 350-450 ft AGL. It was expected for the overall descent times to be slightly slower than the predicted values, which happened to be the case, even with the abnormal thrust characteristics of the motor.

Both of the OSRT's MATLAB scripts and OpenRocket simulations detailed in Table 8 predicted significantly higher drift values under almost all nonzero wind speeds. The final full scale drift of the fore section was almost 200 ft lower than the drift predicted by the MATLAB scripts. All of the scripts and models also predicted a slightly shorter descent time, with the longest descent time being 72.7 seconds and the real descent time being between 70 and 80 seconds as correlated by the data from the altimeters. Discrepancies in the models and actual drift data can be accounted for through environmental considerations; the models assumed an ideal constant crosswind and no weather cocking to keep estimates conservative. Discrepancies between the avionics and altimeter data can be accounted for in data filtering methods and data collection timing in the actual computational and sensing hardware.

3.4.2.5 Estimate Drag Coefficient

The drag coefficient was estimated based on the altimeter data from 3 of 4 altimeters to be 0.471. The fore StratoLogger data was not recorded due to power loss, so it could not be processed. The three remaining altimeters produced data which matched well with each other. Moving average filtering was used to reduce the noise in the altimeter data, then the data from all three altimeters was averaged to determine a drag coefficient. The reference area was chosen to match the reference area in OpenRocket simulations so the values could be directly compared. The reference area is the cross sectional area of the 6.25 in. diameter airframe, or 30.7 in.^{2}. A subset of the data was analyzed to determine the drag coefficient. Only data after 2.75 s was considered due to the motor burn. Additionally, data after 10 s was not considered due to the flight angle of the launch vehicle becoming significant. With a large flight angle, the horizontal velocity of the launch vehicle is increased, which pressure sensor data does not account for in the drag coefficient estimations. In the coefficient of drag data, increasing flight angle appears as increasing drag coefficient, which should be constant for subsonic flight. Therefore, only the constant region from motor burnout to 10 seconds was considered. Shown in Figure 68 is the coefficient of drag from motor burnout to apogee.

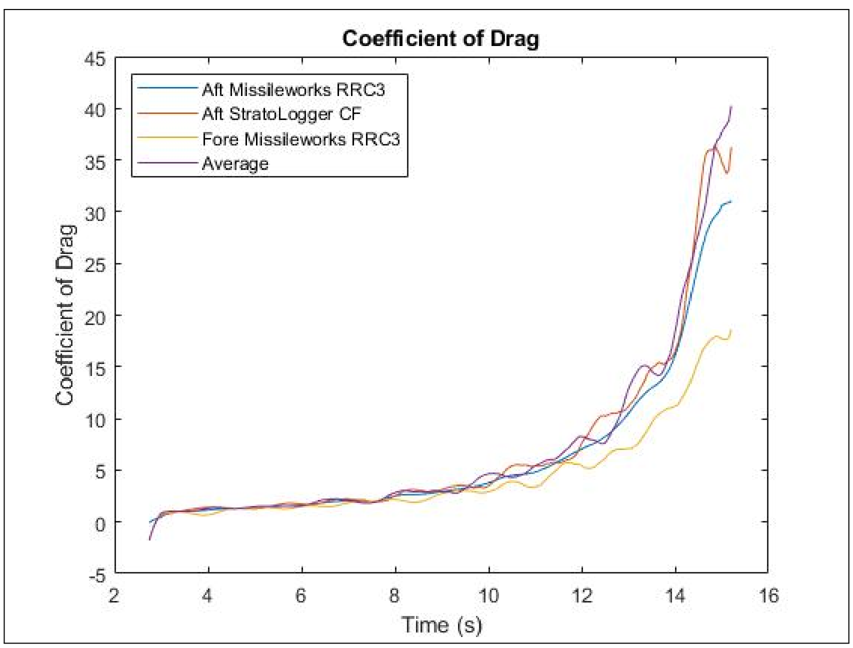

Figure 68: Estimation of the coefficient of drag during flight.

3.4.2.6 Compare Full Scale and Subscale Flights

The subscale flights both under achieved the predicted altitude. The subscale rocket had a very high static stability margin which caused increased weather cocking, reducing the apogee altitude. The full scale flight had a much lower static stability margin of 2.14 calibers, which helped the launch vehicle take a more vertical flight path. The optimal static stability value along with the higher than simulated thrust values are expected to have caused the overshoot from predicted apogee altitude.

The first subscale launch had a flight duration of 345 seconds and a final and maximum drift distance of 5,036 ft due to main parachute deployment at apogee. The second subscale flight (in which the main parachute failed to deploy) had a flight duration of 53 seconds, maximum drift distance of 1,423 ft, and a final drift distance of 428 ft. The full scale launch was a success with a flight duration of 92 seconds, maximum drift distance of 907 ft, and final drift distance of 313 ft.

The full scale launch managed to have a flight time almost 4 times less than the original subscale without any critical recovery system problems. Full scale launch vehicle drift was well within competition specified range requirements, as was descent time.

The changes implemented to the full scale launch vehicle based on the two different recovery failures of the subscale launch vehicle allowed OSRT to successfully recover. Hazards in the design and additional redundancy was added to the full scale launch vehicle based off of the subscale flights.

3.4.2.7 Achieving Mission Success Criteria

The launch vehicle demonstration flight successfully completed the recovery mission success criteria in Section 3.2.1 and launch vehicle mission success criteria in Section 3.3.1. Both launch vehicle sections had a descent time less than 90 s at 72.60 s for the fore section and 79.55 s for the aft section. The landing kinetic energy was 16.60 ft-lbf for the nosecone, 38.45 ft-lbf for the fore airframe, and 65.87 ft-lbf for the aft airframe, all below the maximum 75 ft-lbf requirement. The drift of the launch vehicle was 313 ft, well below the maximum drift radius of 2,500 ft.

The launch vehicle flew a simulated payload to an apogee altitude of 5,079 ft, completing the altitude requirement. The launch vehicle left the 87 in. launch rail above the required 52 ft/s at velocity of 71.85 ft/s. The launch vehicle had a static stability of 2.14 calibers, increasing during motor burn as the center of gravity moved towards the nosecone.

In addition to recovery success criteria and mission performance predictions success criteria, the full scale launch completed most of launch vehicle success criteria. Tabs were broken from the additively manufactured ejection bays, which resulted in a slight design change. The final ejection bay design will be verified on the Payload Demonstration Flight prior to FRR addendum. The payload did not meet all of its success criteria, as the electronics were not armed for flight. However, the payload was retained within the airframe for launch and recovery.

4 SAFETY AND PROCEDURES

4.1 Safety and Environment

4.1.1 Failure Modes and Effects Analysis

The OSRT has developed the following Failure Mode Effects Analysis (FMEA) to help develop mitigations for potential failures. These FMEA were broken into Launch Vehicle, Recovery, and Payload.

4.1.1.1 Launch Vehicle FMEA

Table 13: Launch Vehicle FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Motor ignition	The igniter fails to ignite the motor.	The armed launch vehicle remains on the launch rail.	4	There is a discontinuity in the igniter wire.	7	3	84	Igniter insertion was performed by team mentor and they followed the checklist in Table 59. In the event of ignition failure, the team has created a procedure to be followed in Table 64.
Motor ignition	The ignition system fails to send a current to the igniter.	The armed launch vehicle remains on the launch rail.	4	There is a discontinuity in the ignition system or an insufficient current is sent from the ignition system.	5	3	60	In the event of ignition failure, the team has created a procedure to be followed in Table 64 will be followed.
Drag reduction of the launch vehicle.	The nosecone becomes damaged or deformed.	A non-uniform flight path, which increases drag.	5	The nosecone's kinetic energy is too high upon landing.	5	4	100	The team has used an aluminum nosecone tip to absorb direct forces and has performed a careful inspection before and after use in Step 9 of the checklists in Tables 29 and 62.
Drag reduction of the launch vehicle.	The nosecone detaches during flight.	The flight fails, and the nosecone and avionics are lost.	8	The nosecone is not correctly attached to recovery system or the tip is not properly secured to the threaded rod.	3	3	72	The team has followed the installation checklists found in Table 49, verifying that the nosecone tip is centered on the nosecone, as in Step 11.

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Table 13: Launch Vehicle FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Drag reduction of the launch vehicle.	The nosecone detaches during flight.	The flight fails, and the nosecone and avionics are lost.	8	A change in altitude causes a buildup of pressure inside the recovery compartments, which pops the nosecone off during the ascent.	3	4	96	Analysis 6.1.2.9 has proven that the nosecone will not detach due to a buildup in pressure caused by altitude change.
Drag reduction of the launch vehicle.	The nosecone detaches during flight.	The flight fails, and the nosecone and avionics are lost.	8	The nosecone threads strip when recovery system forces are transferred to them.	2	4	64	Analysis has been performed to verify the threaded rods will withstand recovery forces in Section 6.1.1.6.
Provide protection for all onboard components.	The airframe buckles from the high loads at landing.	The launch vehicle is not recoverable or reusable.	8	The recovery system fails to deploy.	1	5	40	The team has ensured that checklists in Tables 51, 45, 31, and 39 are followed correctly for a successful recovery deployment. Section 6.1.1.10 demonstrates that the airframe will withstand all recovery forces.
Housing of internal components.	High temperatures cause the delamination of airframe materials.	The integrity of the launch vehicle airframe is severely jeopardized and the airframe may be destroyed during flight or recovery.	10	The airframe is stored long-term in an non-climate-controlled area or is used in high temperature conditions.	1	5	50	The launch vehicle has been stored in safe locations and has passed heat and pressure effects inspection, as detailed in Section 6.1.2.1.

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Table 13: Launch Vehicle FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Housing of internal components.	The airframe zippers along its edges.	The zippering destroys large sections of the airframe, leading to a recovery failure.	7	The recovery harness pulls across the edge of the airframe at high speeds.	4	7	196	Antizippering (thickening of the airframe) has been included on all sections that are at risk. An artificial zipper has been included on sections of the recovery harness to reduce the difference in velocity between the airframe and drogue, and is discussed in Section 3.2.3.4. Steps 8 and 9 of the checklist in Table 62 verify that the airframe is inspected for damage, including zippering, post flight.
Connect the nosecone to the fore airframe.	The coupler bends.	The launch vehicle components are damaged, the launch vehicle is not recoverable, and the unrecoverable launch vehicle can injure spectators.	7	The launch vehicle experiences excess bending forces which causes the coupler material to deform or fail.	4	3	84	Composites were laid up to maximize strength as detailed in Section 3.1.6.
Connect the nosecone to the fore airframe.	The coupler fractures.	The launch vehicle components are damaged, the launch vehicle is not recoverable, and the unrecoverable launch vehicle can injure spectators.	9	The launch vehicle experiences excess bending forces that cause the coupler material to fail and fracture.	4	3	108	The composites were laid up to maximize strength as detailed in Section 3.1.6.

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Table 13: Launch Vehicle FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Connect the fore airframe to the aft airframe and component retention.	The canister bends.	The launch vehicle components are damaged, the launch vehicle is not recoverable, and the unrecoverable launch vehicle can injure spectators.	8	The launch vehicle experiences excess bending forces that cause the canister material to fail.	4	3	96	The composites were laid up to maximize strength as detailed in Section 3.1.6.
Connect the fore airframe to the aft airframe and components retention.	The canister fractures.	The launch vehicle components are damaged, the launch vehicle is not recoverable, and the unrecoverable launch vehicle can injure spectators.	9	The launch vehicle experiences excess bending forces that cause the coupler material to fail and fracture.	4	3	108	The composites were laid up to maximize strength as detailed in Section 3.1.6.
Stabilize the launch vehicle.	The fins are not aligned properly.	The launch vehicle has an erratic flight profile, is lost, or causes damage to the surroundings.	7	The fins are significantly damaged.	3	4	84	The team has practiced careful handling of the aft section of the airframe, has not put weight on the fins, and has inspected the fins pre and post launch per Steps 1 and 2 of the checklists in Tables 29 and 62. The manufacturing procedure and epoxy procedure are detailed in Section 3.1.4.

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Table 13: Launch Vehicle FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Stabilize the launch vehicle.	The fins are not aligned properly.	The launch vehicle has an erratic flight profile, is lost, or causes damage to the surroundings.	7	The fins are not inserted and epoxied at the correct angles to the body tube, or the epoxy fails to cure correctly.	5	3	105	The team built a fin jig for aligning the fins during the build, and allowed epoxy to cure for the recommended duration before moving the launch vehicle, as detailed in Section 3.1.4.
Stabilize the launch vehicle.	The fins detach from airframe.	The launch vehicle has an erratic flight profile, is lost, or causes damage to surroundings.	9	The forces at the base of the fins are large enough to cause failure in the epoxy.	3	4	108	The team has inspected the fins pre and post launch per Steps 1 and 2 of the checklists in Tables 29 and 62 and has not launched if the fins are not secured to the airframe.
Stabilize the launch vehicle.	The fins detach from airframe.	The launch vehicle has an erratic flight profile, is lost, or causes damage to the surroundings.	9	The epoxy is not allowed to cure properly or the amount of epoxy applied is insufficient to maintain strength.	1	6	54	The team carefully applied epoxy and inspected it after drying. All edges were filleted properly. Epoxy procedure is detailed in Section 3.1.4.
Retain the components inside of the airframe.	The epoxy fails between the bulkhead and the airframe or canister.	The internal components are damaged, the launch vehicle is unrecoverable, and the debris injures spectators, or the debris litters property.	8	An incorrect epoxy mixture is used.	2	3	32	The team used a scale to measure the correct epoxy ratio and used new mixing sticks and bowls for each batch. The epoxy procedure is detailed in Section 3.1.10.

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Table 13: Launch Vehicle FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Retain the components inside of the airframe.	The epoxy fails between the bulkhead and airframe or canister.	The internal components are damaged, the launch vehicle is unrecoverable, and the debris injures spectators, or the debris litters property.	8	There is poor contact between the surfaces due to dirt or residue.	2	5	128	The team has sanded the area where the epoxy was applied and cleaned the surfaces with acetone as detailed in Section 3.1.10.
Retain the components inside of the airframe.	The epoxy fails between the bulkhead and airframe or canister.	The internal components are damaged, the launch is vehicle is unrecoverable, and the debris injures spectators, or the debris litters property.	8	An insufficient amount of epoxy is applied.	1	6	48	The epoxy has been generously applied to the bulkheads, as detailed in Section 3.1.10.
Retain the components inside of the airframe.	Cross-grain failure of the plywood bulkhead.	The internal components are damaged, the launch vehicle is unrecoverable, and the debris injures spectators, or the debris litters property.	8	Plywood is stored improperly.	3	6	144	Plywood has been stored in a cool, dry areas, and handled with care. Bulkhead strength was verified to exceed expected forces, which is detailed in Section 6.1.1.9.

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Table 13: Launch Vehicle FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Retain the components inside of the airframe.	Cross-grain failure of the plywood bulkhead.	The internal components are damaged, the launch vehicle is unrecoverable, and the debris injures spectators, or the debris litters property.	8	Low quality plywood is used.	3	6	144	The team selected the plywood from reputable sources and selected the best looking plywood. Plywood is tested in Section 6.1.1.9.
Retain the components inside of the airframe.	The bulkhead fractures or shatters.	The internal components are damaged, the launch vehicle is unrecoverable, and the debris injures spectators, or the debris litters property.	8	Excessive force from the threaded rod or the radial bolt system is exerted on bulkhead.	2	2	32	Use thick plywood and large washers to be able to withstand the force. This is tested in Section 6.1.1.9.
Secure radially-bolted bulkheads to the airframe.	Bolts or the aluminum ring fail.	The launch vehicle descends without the aid of parachutes. The payload fails to be retained through the flight.	9	The forces during flight exceed expectant forces, causing a failure in the radially-bolted bulkheads.	2	4	72	Radially-bolted bulkheads were verified to exceed all expectant forces with the radial bolt testing in Section 6.1.1.9.

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Table 13: Launch Vehicle FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Retain the motor.	The motor is not retained within the airframe.	The motor becomes an unpredictable projectile.	10	The motor retainer is not properly tightened. The epoxy does not hold up to the motor's forces.	5	1	50	Ensure the motor retainer is firmly hand tightened, as per the checklist in Table 33, Step 7. The centering ring epoxy has a strength rated higher than expectant forces. The application of the epoxy follows the procedure in Section 3.1.10, and is generously applied to maximize strength.
Retain the motor.	The motor is not retained within the airframe.	The motor destroys the internal components of the launch vehicle.	7	The epoxy does not hold up the to motor forces. The plywood centering rings fail.	1	6	42	The centering ring epoxy has a strength rated higher than the expectant forces. The application of the epoxy followed the procedure in Section 3.1.10, and was generously applied to maximize strength. During radial bolt testing, Section 6.1.1.9, the strength of the plywood bulkheads was determined to exceed expectant forces.
Shield the altimeters from unwanted signals.	The RF shield allows signals to pass through.	The altimeters receive a false signal to ignite the ejection charges and the ejection charges fire prematurely.	8	Unwanted signals interfere with altimeter readings.	4	5	160	An RF shield has been created within the altimeter bays. RF shielding has been verified per inspection in Section 6.1.2.11.

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Table 13: Launch Vehicle FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Arming the altimeters.	The static port holes are not accessible from the exterior of the airframe.	The altimeters cannot be armed while on the launch rail, and therefore, the launch vehicle must be reintegrated.	4	The altimeter housing is not aligned properly.	5	3	60	All steps in Table 40 and 50 for ejection bay assembly have been followed. Steps 10-12 in the checklist Table 43 and Steps 8-11 in checklist Table 50 verify the altimeters are accessible from the exterior of the airframe.
Pressurizing the altimeter bays.	The bays cannot pressurize through the static port holes.	The altimeters cannot accurately gauge the altitude of the launch vehicle and the ejection charges do not fire.	9	The altimeter housing is not aligned properly.	5	3	135	All steps in Table 40 and Table 50 have been followed.
Reporting GPS coordinates to the ground station.	The ATU signal cannot exit the airframe due to the conductive housing.	The ground station cannot track the launch vehicle.	5	The ATU housing is conductive, which creates an RF shield.	2	9	90	All sections of airframe that contain an ATU are made from fiberglass, which is not conductive. Integration of any ATU have followed the steps listed in Table 40 and Table 49. Ground station preparation has followed the checklist in Table 32.

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Table 13: Launch Vehicle FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Creating a pressure seal within the airframe.	The pressure seal fails to create a seal with the inner wall of the airframe.	Ejection charges are not large enough to break the shear pins and parachutes cannot deploy.	9	The bulkhead and ring are poorly manufactured or the pressure sealing bolts are not tightened.	5	4	180	The pressure seal has been tested with the ejection charges detailed in Section 6.1.2.4. Larger, redundant charges are used to break the shear pins if the pressure seal is not fully engaged. The fore pressure seal is verified in Step 9 in Table 49, and Step 12 of Table 50. The aft pressure seal is verified in Step 13 of Table 43.
Record the flight of the launch vehicle.	The camera fixture fails.	The cameras will be damaged and the flight will not be recorded.	8	The cameras cannot withstand the forces experienced during flight.	1	3	24	The cameras were selected based on their durability and the camera mounting system has been designed to handle the forces experienced during flight. This is analyzed in Section 6.1.1.7. The camera system design is detailed in Section 3.1.17

4.1.1.2 Recovery Integration FMEA

Table 14: Recovery Integration FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Launch vehicle separates at apogee.	Primary ejection charges do not properly ignite.	Secondary charges will be relied upon to separate the airframe sections.	3	The black powder charges are constructed improperly. The primary ejection charge is disconnected from the altimeter.	4	10	120	All of the black powder charges constructed have followed the procedure checklist in Table 31.
Launch vehicle separates at apogee.	All ejection charges fail to ignite	The launch vehicle fails to separate and goes ballistic, resulting in the destruction of the vehicle.	10	The black powder charges are constructed improperly.	2	10	200	All of the black powder charges constructed have followed the procedure checklist in Table 31. All of the altimeter bays have been set up correctly, following checklists in Table 39.
Launch vehicle separates at apogee.	The ejection charges ignite, but do not separate the launch vehicle.	The launch vehicle goes ballistic, resulting in the destruction of the vehicle.	10	The black powder charges are constructed improperly.	2	10	200	All of the black powder charges will follow the procedure checklist in Table 31. The ejection sizes have been verified as correct from ground ejection demonstrations in Section 6.1.2.4.

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Table 14: Recovery Integration FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
The altimeters sense apogee of the launch vehicle.	The altimeters sense apogee at different times.	The recovery bay could become over pressurized if both the primary and secondary charges go off at the same time, and blow out the side of the airframe.	8	The altimeters malfunctioned.	3	8	192	The altimeter sensitivity was tested in Section 6.1.2.7. The ejection bay assembly has followed the checklist in Table 40 and Table 50.
The altimeters sense apogee of the launch vehicle.	The altimeters sense apogee prematurely.	Unpredictable snatch loads will be experienced, possibly resulting in the failure of any recovery component.	7	The static port holes were sized improperly, or the primary or secondary altimeters malfunctioned.	2	5	70	The altimeter sensitivity was tested in Section 6.1.2.7. The ejection bay assembly will follow the checklist in Table 40 and Table 50.
The altimeters sense apogee of the launch vehicle.	The altimeters sense apogee late.	Unpredictable snatch loads will be experienced if the sections separate late. If the charges go off too late, the airframe sections will not separate.	7	The static port holes were sized improperly, or the primary or secondary altimeters malfunctioned.	2	5	70	The altimeter sensitivity was tested in Section 6.1.2.7. The ejection bay assembly has followed the checklist in Table 40 and Table 50.
The altimeters sense apogee of the launch vehicle.	The altimeters fail to sense apogee.	The launch vehicle fails to separate, resulting in ballistic descent.	10	All altimeter's barometric sensors malfunction.	1	10	100	The altimeter sensitivity was tested in Section 6.1.2.7. The ejection bay assembly will follow the checklist in Table 40 and Table 50.

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Table 14: Recovery Integration FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
The altimeters sense the altitude during descent of the launch vehicle sections.	The altimeters sense descent altitude prematurely.	The main parachutes are released too early, which will increase the drift radius and descent time.	3	The altimeter's barometric sensor malfunctions.	2	5	30	The altimeter sensitivity was tested in Section 6.1.2.7. The ejection bay assembly has followed the checklist in Table 40 and Table 50.
The altimeters sense the altitude during descent of the launch vehicle sections.	The altimeters sense the descent altitude late.	The launch vehicle impacts the ground before the main parachute opens fully.	7	The altimeter's barometric sensor malfunctions.	2	5	108	The altimeter sensitivity was tested in Section 6.1.2.7. The ejection bay assembly has followed the checklist in Table 40 and Table 50.
The altimeters sense the altitude during descent of the launch vehicle sections.	The altimeters fire the Tender Descenders at apogee.	The main parachutes are released at apogee, which will drastically increase the drift radius.	5	The altimeter's barometric sensor malfunctions. The release mechanism malfunctions.	7	5	108	The altimeter sensitivity was tested in Section 6.1.2.7. The ejection bay assembly have followed the checklist in Table 40 and Table 50. The fore and aft recovery integration have followed the checklists in Tables 51 and 45.

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Table 14: Recovery Integration FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Parachutes are deployed from the launch vehicle.	The shock cord snaps during descent.	The launch vehicle section tumbles to the ground.	7	High snatch loads and/or a weak point in the shock cord cause a failure.	1	5	35	The fore and aft recovery integration have followed the checklists in Tables 51 and 45
Parachutes are deployed from the launch vehicle.	The shock cord is tangled after parachute deployment.	Unpredictable snatch forces will be experienced by the shock cord. The parachutes may not fully unfurl or not exit the launch vehicle	7	The shock cords are folded and packed improperly.	2	5	70	The fore and aft main parachutes have followed the checklist in Table 34. The fore and aft recovery integration have followed the checklists in Tables 51 and 45.
Parachutes are deployed from the launch vehicle.	The Quick Link fails during parachute deployment.	The launch vehicle section tumbles to the ground.	7	High snatch loads cause a failure of the Quick Link.	1	5	35	The fore and aft recovery integration have followed the checklists in Tables 51 and 45.
Parachutes are deployed from the launch vehicle.	The eye bolt fails during the parachute deployment.	The launch vehicle section tumbles to the ground.	7	High snatch loads cause a failure of the eye bolt.	1	5	64	The fore and aft recovery integration have followed the checklists in Tables 51 and 45.
Parachutes are deployed from the launch vehicle.	The bulkhead fails during parachute deployment.	The bulkhead slips out of airframe, causing the launch vehicle to tumble to the ground or fail to withstand flight forces.	7	The fasteners fail to hold bulkhead in place.	1	5	35	Fore and aft recovery integration will follow the checklists in Tables 51 and 45.

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Table 14: Recovery Integration FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Parachutes are deployed from the launch vehicle.	The shroud lines snap after parachute deployment.	The launch vehicle section tumbles to the ground.	7	Unaccounted snatch loads exceed the shroud lines maximum strength because separation occurs at an unpredictable time.	1	5	35	The altimeter sensitivity was verified in Section 6.1.2.7. The ejection bay assembly have followed the checklist in Table 40 and Table 50. Fore and aft recovery integration have followed the checklists in Tables 51 and 45.
Parachutes are deployed from the launch vehicle.	The swivel breaks during parachute deployment.	The launch vehicle section tumbles to the ground.	7	Unaccounted snatch loads exceed the swivel's maximum strength because separation occurs at an unpredictable time.	1	5	35	The altimeter sensitivity was tested in Section 6.1.2.7. The ejection bay assembly has followed the checklist in Table 40 and Table 50. The fore and aft recovery integration has followed the checklists in Tables 51 and 45.
Parachutes are deployed from the launch vehicle.	The shroud lines tangle after parachute deployment	The main parachute does not unfurl completely, which will cause increased kinetic energy upon landing.	7	The shroud lines and main parachute are packed improperly.	3	3	63	The fore and aft main parachutes have followed the checklist in Table 34. The fore and aft recovery integration have followed the checklists in Tables 51 and 45.

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Table 14: Recovery Integration FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Parachutes are deployed from the launch vehicle.	The parachute rips during descent.	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, or there is a pre-existing tear in the parachute that occurred during parachute packing.	3	3	63	The fore and aft main parachutes have followed the checklist in Table 34. The fore and aft recovery integration will follow the checklists in Tables 51 and 45.
Active tracking of launch vehicle.	The GPS systems lose satellite lock during flight.	The ground system is unable to receive coordinate data from the ATUs.	3	The satellite triangulation is lost.	3	8	72	The connection with the avionics units have followed the checklist in Table 38.
Active tracking of launch vehicle.	The flight ATU loses transmission lock with the ground station ATU.	The ground station ATU ceases receiving packets and is unable to output coordinate data for recovery.	3	The antenna is not pointed at the launch vehicle correctly or interference from electrical devices occurs.	6	8	144	The inclusion of multiple flight ATUs provides multiple signal locks and the ground station retains historical GPS data. The checklists in Tables 38 and 32 have been followed. The checklist in Table 67 has been used for troubleshooting.
Active tracking of launch vehicle.	The electrical components on the ATUs become loose or unseated.	The flight ATU will stop transmitting packets and the ground station ATU will stop receiving data.	7	The mechanical shock of the launch and flight knock electrical components out of the headers.	1	7	49	Electrical tape has been used to secure all electrical components to the ATU PCB as per checklist in Table 38.

4.1.1.3 Payload Mechanical FMEA

In Table 15 is the Payload FMEA that OSRT has been developed for the mission.

Table 15: Payload FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Tail to stabilize the rover.	The tail snaps, which causes the tail to not touch the ground.	The chassis will rotate in place instead of the wheels rotating, which will prevent movement.	8	The tail breaks due to unanticipated forces.	1	1	8	The tail has been verified to withstand flight forces in Section 5.3.3.
Tail to stabilize the rover.	The tail does not unwrap from the rover.	The chassis will rotate in place instead of the wheels rotating, which will prevent movement.	8	The torsion springs break or plastically deform.	2	1	16	The rover was verified to be stable with the rover tail via a demonstration in Section 6.1.3.3.
Chassis provides structure to the rover.	The rods disconnect from the chassis blocks.	The chassis disassembles or becomes structurally compromised and is unable to perform the mission.	5	Insufficient or weak epoxy is used on the rods and blocks.	5	3	75	The chassis was designed to withstand all flight and ejection forces, as detailed in Section 5.3.2.
Chassis provides structure to the rover.	The rods disconnect from the chassis blocks.	The chassis disassembles, or becomes structurally compromised, and is unable to perform the mission.	5	The rods break on the chassis.	4	2	40	The rod thickness for the chassis was designed to withstand all forces of flight and rover ejection as detailed in Section 5.3.2.

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Table 15: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Chassis provides structure to the rover.	The rods disconnect from the chassis blocks.	The chassis disassembles, or becomes structurally compromised, and is unable to perform the mission.	6	The chassis blocks fracture during mission operations.	2	6	72	The chassis material was designed to withstand all forces of flight and rover ejection as detailed in Section 5.3.2.
Soil Collection and Retention (SCAR) system collects soil.	The auger cannot collect soil and transport it to the container.	The auger fails to collect at least 10 mL of soil.	8	The auger motor has insufficient torque.	2	1	16	Force calculations were performed and a motor with the correct specifications was chosen. A soil collection test was performed in Section 6.1.3.4.
SCAR system collects soil.	The auger does not collect soil. The auger does not transport soil to the container.	The auger fails to collect at least 10 mL of soil.	8	The auger fractures.	5	2	80	Testing was performed as detailed in Section 6.1.3.4. Finite Element Analysis (FEA) was used to verify the structural integrity of the SCAR during the mission as detailed in Section 5.3.5.
SCAR system collects soil.	The auger cannot collect soil.	The auger fails to collect at least 10 mL of soil.	4	The cutting edge on the auger becomes dull.	5	7	140	Testing was performed as detailed in Section 6.1.3.4. FEA was used to verify the structural integrity of the SCAR during the mission as detailed in Section 5.3.5.

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Table 15: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
SCAR system collects soil.	The auger fails to collect at least 10 mL of soil.	The auger does not rotate. The auger does not deploy into soil. The auger device detaches from the chassis.	6	The threads become stripped on any component.	2	5	60	Testing was performed as detailed in Section 6.1.3.4. FEA was used to verify the structural integrity of the SCAR during the mission as detailed in Section 5.3.5. Fasteners were used with the adequate specifications for mission operations.
SCAR system collects soil.	SCAR fails to collect at least 10 mL of soil.	Soil cannot be collected.	8	Soil does not fall into the container opening.	3	4	96	The soil container is located tangent to the soil collection assembly, only allowing soil to fall into the container. Sections 6.1.3.4 and 6.1.3.5.
SCAR system collects soil.	SCAR fails to collect at least 10 mL of soil.	The auger cannot be fed into the soil. The auger does not collect soil.	4	SCAR components are corroded.	2	5	40	The SCAR is constructed of PLA, a non-corroding material.
Soil retention.	SCAR fails to seal the soil.	Soil is not sealed and the mission is incomplete.	8	Soil prohibits the retention doors from closing.	2	2	32	Testing was performed in Section 6.1.3.5. The container has an internal volume greater than 15 mL.
Soil retention.	SCAR fails to seal the soil.	The container detaches from the chassis. The auger does not drop soil onto the container doors. Doors do not open or close.	6	The threads are stripped on any component.	2	5	60	FEA was used to verify the structural integrity of the SCAR during the mission, as detailed in Section 5.3.5. Testing was performed, as detailed in Section 6.1.3.5. Fasteners with adequate specifications were used for the mission operations.

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Table 15: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Soil retention.	SCAR fails to seal the soil.	Gaps are present between the door and container. The doors do not reach the completely closed position.	7	Soil is not contained by the lower door.	2	2	28	The motors have adequate torque for mission operations. The team employs encoders with the motors, allowing for precise motion. Testing was performed in Section 6.1.3.5. The distance between the doors and container walls prevent soil from falling between them.
Soil retention.	SCAR fails to seal the soil.	Doors do not open or close. Soil is not sealed.	4	SCAR components are corroded.	2	5	40	Aluminum for the container doors and PLA for the container were chosen as the final materials; both are not corrosive.
Torque generation 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 rover mobility demonstration in Section 6.1.3.3 verifies that the DC motors have sufficient torque to drive the rover.
Generate torque via DC motors	Motors fail to produce adequate torque.	The rover is unable to move or unable to climb slopes.	8	Flight forces break an electrical connection.	4	3	96	Electronics are protected within the rover's chassis per the design in Section 5.3.2 and verified with the inspection in Section 6.1.3.6.
Torque generation 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	Battery life for the rover exceeds mission time and is verified with the demonstration in Section 6.1.3.8.

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Table 15: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Torque transmission.	Motors fail to transmit adequate torque to wheels.	The rover is unable to handle gentle slopes and may become stuck.	6	The drive shaft slips.	2	3	36	The shaft coupler set screws and drive shafts with filed-down ends ensure 1:1 rotation. Steps 7 and 11 of the Preflight Rover Inspection shown in Table 28 verify that the drive shafts are secure in the couplers and clamping hubs, respectively.
Torque transmission.	Motors fail to transmit adequate torque to wheels.	The rover is unable to handle gentle slopes and may become stuck.	6	The drive shaft assembly becomes misaligned.	4	2	48	The drive shaft assembly has multiple attachment points to the truss to limit displacement. Attachment points are verified to be secure in Step 14 of the Preflight Rover Inspection checklist in Table 28.
Torque transmission.	Motors fail to transmit adequate torque to wheels.	The rover is unable to handle gentle slopes and may become stuck.	6	The drive shaft fails via torsion or bending.	1	1	6	The rover deployment demonstration in Section 6.1.3.1 verifies the drive shafts will withstand the maximum forces of the mission.
Payload is retained.	Failure to retain the payload.	The payload falls from the airframe during flight.	9	Retention devices fail either mechanically or the electrical system is released early.	3	1	27	Redundant retention devices are rated for any abnormal flight forces above 50 G, as shown in Section 6.1.3.2. The electrical system is designed to keep the retention devices closed should an electrical failure occur.

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Table 15: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Payload is retained.	The payload fails to be retained.	The payload moves around within the airframe.	4	The payload is improperly integrated into the airframe.	4	6	96	The payload integration checklist in Table 47 ensures the payload will not be fully retained during the flight.
Payload is retained.	Failure to retain the payload	The payload is damaged and unable to complete the mission.	7	The rover is improperly integrated with PEARS or the with the airframe.	3	3	63	The payload assembly checklist in Table 47, the payload wrap assembly checklist in Table 57, and the PEARS removable assembly checklist in Table 56 ensure proper assembly and integration of the rover in the launch vehicle.
Payload is retained.	Failure to release the payload.	The payload is stuck inside airframe and unable to complete the mission.	3	The retention devices fail in a closed position due to electrical failure.	2	1	6	The demonstration in Section 6.1.3.20 verifies that the PLEC electrical system is consistently successful.
Payload is retained.	Failure to release the payload.	The payload is damaged and unable to complete the mission. The airframe sustains damage.	9	The payload is retained when ejection is attempted.	1	1	9	Set sequencing of charges as demonstrated in Section 6.1.3.20.
Payload ejection.	The payload fails to eject.	The payload is stuck inside the airframe and unable to complete the mission.	3	PLEC experiences an electrical failure or non-released retention devices.	2	1	6	Rigorous ground testing of PLEC for consistent ejection success. 6.1.3.1

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Table 15: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Payload ejection.	The payload is damaged upon ejection.	The payload is not able to complete the mission.	5	High velocity impact with the ground upon ejection.	2	1	10	Reduced the speed at which rover hits objects by sizing ejection charges through rigorous ground testing, which is described in Section 6.1.3.1.

4.1.1.4 Payload Electrical FMEA

In Table 16 is the Payload Electrical FMEA that OSRT has developed for the mission.

Table 16: Payload Electrical FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Connection of payload electronics.	Wires disconnect during flight.	Portions of the rover system will be unresponsive and unusable during the mission.	7	Improperly retained wires.	2	7	98	Screw terminals secure wires at all endpoints aboard the rover. Checklists have been used to verify that each terminal has been properly tightened. The wires have been verified as secure by tugging on each wire during integration as defined in Table 55.
Connection of payload electronics.	The black powder residue causes electrical shorting.	Traces of black powder aboard the PCB overloaded by current, destroying traces.	6	The wires and terminals are not properly insulated.	1	4	24	Exposed metal on all boards have been coated in an insulating material to avoid shorting between components. 55

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Table 16: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Connection of payload electronics.	The voltage regulators deliver the incorrect voltage to the components.	The components will cease to function.	7	The passive components or voltage regulators must be physically altered or shorts occur.	2	7	98	The voltage regulation circuits have been designed to handle more current than will ever be pulled through the voltage regulator. 55
Connection of payload electronics.	The breakout board becomes detached from the PCB during flight.	The detached breakout board will not perform its function.	7	Mission critical portions of the routine will remain incomplete.	3	7	147	The breakout boards have been properly seated and secured using electrical tape prior to each launch. 55
Rover control.	The incorrect code is flashed to microcontroller before flight.	The rover systems will not function as intended, if at all.	9	The test code, or other incomplete code, is flashed to the microcontroller upon launch.	1	3	27	Teensy microcontroller has been flashed with correct code prior to each launch.
RF communication.	GPS coordinates of soil samples are transmitted incorrectly.	The GPS coordinates of soil samples are inaccurate or unusable for plotting and data analysis.	2	The interference from other RF signals in the area.	4	3	24	The data has been logged locally to storage aboard the rover, which can be compared with the transmitted values.
RF communication.	Incorrect GPS coordinates of the scientific base station are received.	The rover will navigate to an incorrect location.	4	The interference from other radio signals in the area.	2	3	24	The GPS has been transmitted to the rover multiple times, and an average of the coordinates has been taken to ensure outliers will have less effect on the outcome.

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Table 16: Payload FMEA – continued from previous page

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Receive external data.	The GPS module will not have a lock immediately upon ejection.	The rover will wait an undetermined amount of time before attempting the mission.	2	The slow lock times are due to rapid movement or non-ideal weather conditions.	5	3	30	The GPS has been powered on when the rover is in its wrapped state inside the airframe.

4.1.1.5 Payload Software FMEA

Table 17: Payload Software FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
The rover functions autonomously.	The rover object avoidance does not detect obstacles.	The rover becomes stuck on environmental obstacles.	6	The sonar receives a low quality or incorrect data reading.	2	8	96	The sonars used software methods as described in Section 6.1.3.10.
The rover functions autonomously.	The RF transceiver does not receive launch vehicle transmission.	The payload is unable to verify distance from launch vehicle and change to correct control sequences.	2	The interference from environmental conditions or other technologies to the signal transmitted to the payload.	2	3	12	The signal has been transmitted to payload multiple times.

4.1.2 Personnel Hazard Analysis

Tables 18 through 22 represent the personnel hazard analysis that OSRT, including a risk assessment code to determine the level of risk associated with each hazard. Different levels of risk correspond to different levels of management approval necessary, as shown in Table 19. The level of risk is determined based on the severity and probability of each hazard occurring, as summarized by Tables 20 and 21.

Table 18: Risk Assessment Code Template

Risk Assessment Codes (RAC)				
	Severity			
Probability	1 - Catastrophic	2 - Critical	3 - Marginal	4 - Negligible
A - Frequent	1A	2A	3A	4A
B - Probable	1B	2B	3B	4B
C - Occasional	1C	2C	3C	4C
D - Remote	1D	2D	3D	4D
E - Improbable	1E	2E	3E	4E

Table 19: Level of Risk and Level of Management Approval

Level of Risk	**Level of Management Approval**
High Risk	Highly Undesirable. Documented approval from the team advisor, team lead, and safety officer. A Job Hazard Analysis (JHA) is required.
Moderate Risk	Undesirable. Documented approval from the team lead or safety officer. A JHA is required.
Low Risk	Acceptable. Documented approval from the sub-team lead, team lead, or safety officer. A JHA is required.
Minimal Risk	Acceptable. Documented approval not required, but an informal review by the supervisor directly responsible for operating the facility or performing the operation is highly recommended. A JHA is required.

Table 20: Severity Definitions

Description	Personnel Safety and Health	Facility/Equipment	Environmental
1 - Catastrophic	Loss of life or a permanent disabling injury.	Loss of facility, systems or associated hardware.	Irreversible severe environmental damage that violates law and regulation.
2 - Critical	Severe injury or occupational related illness.	Major damage to facilities, systems, or equipment.	Reversible environmental damage causing a violation of law or regulation.
3 - Marginal	Minor injury or occupational related illness.	Minor damage to facilities, systems, or equipment.	Mitigable environmental damage without violation of law or regulation where restoration activities can be accomplished.
4 - Negligible	First aid injury or occupational related illness.	Minimal damage to facility, systems, or equipment.	Minimal environmental damage not violating law or regulation.

Table 21: Probability Definitions

Description	Qualitative Definition	Quantitative Definition
A - Frequent	High likelihood to occur immediately or expected to be continuously experienced.	Probability > 0.1
B - Probable	Likely to occur to expected to occur frequently within time.	0.1 > Probability > 0.01
C - Occasional	Expected to occur several times or occasionally within time.	0.01 > Probability > 0.001
D - Remote	Unlikely to occur, but can be reasonably expected to occur at some point within time.	0.001 > Probability > 0.000001
E - Improbable	Very unlikely to occur and an occurrence is not expected to be experienced within time.	$0.000001 \geq$ Probability

Table 22: Personnel Hazard Analysis

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Using the OSU shop machinery.	Improper use of machinery, insufficient knowledge about machinery, negligence, improper PPE.	Injury to personnel, damage to machinery, poor component manufacturing.	2B	All personnel must have obtained the appropriate certification by the OSU MPRL and all personnel must wear the appropriate PPE. All hazards related to the task are identified prior to work commencing, and a JHA is completed.	All capstone members have completed a machine shop introduction course at OSU. The machine shop introduction course is intended to teach students to safely operate the machinery and equipment available in the MPRL All team members have been trained by the Safety Officer (SO) on how to fill out JHAs.	2E
Exposure to hazardous chemicals.	Use of chemicals throughout manufacturing and cleaning of the launch vehicle.	Rash, burns, and other injuries due to chemical exposure.	3B	All members using chemicals wear the appropriate PPE and are required to review the Material Safety Data Sheet (MSDS) for all hazardous chemicals. All hazards related to the task are identified prior to working by filling out a JHA. All hazardous chemicals are kept in locked storage cabinets with only certified personnel having access.	All members have worn the appropriate PPE while working with chemicals. Hazardous chemicals are stored appropriately. The SO verifies MSDS has been reviewed before allowing access to chemicals.	3D
Fiberglass and carbon fiber particle exposure to personnel.	Machining of fiberglass or carbon fiber without proper use of PPE or ventilation.	Skin, eye, and respiratory tract damage.	2C	All machining procedures require a vacuum near the end-mill or saw blade and all personnel involved wear appropriate PPE. A JHA is to be filled out when the team manufactures with composites.	Proper PPE was worn during the manufacturing of the launch vehicle. A signature from the SO was obtained on all JHAs.	3D

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Motor ignites during igniter insertion.	Ignition system is armed during igniter insertion.	Unanticipated motor ignition with potential to critically injure any personnel in the area. Possibility of damaging equipment near the launch pad.	2D	Only the team mentor inserts the igniter into the motor verifying the ignition system is disarmed prior to insertion.	The ignition system is verified to be disarmed in Step 9 of the Igniter Insertion Checklist in Table 59 and is completed by the team mentor.	2E
Motor ignites unexpectedly.	Spark or other ignition source unintentionally ignites the motor.	Potential to catastrophically injure any personnel in the area. Complete mission failure.	1C	All National Association of Rocketry (NAR) safety codes are to be followed during motor assembly, motor insertion, and launch rail set-up. Upon motor assembly, the motor is to be stored in a secured box until it is ready to be installed in the launch vehicle. All potential ignition sources are to be kept a safe distance from the motor.	Motor assembly is only performed and handled by team mentor as stated in the safety precautions of the Motor Assembly Checklist in Table 30. All motors are stored in a secure box after assembly per step 14 of the Motor Assembly Checklist in Table 30.	1E
Motor fails catastrophically after ignition.	The motor is assembled improperly or the motor casing is damaged.	Motor casing explodes, causing damage to the airframe and components in the launch vehicle. Possible injury to personnel in area due to flying debris.	2D	Motor assembly will be completed by the team mentor. Before insertion of the motor into the launch vehicle, the motor will be checked for damage.	The Motor Assembly Checklist in Table 30 is completed by the team mentor. The motor case is inspected per Step 6 of the Motor Assembly Checklist in Table 30 before inserting the motor into the launch vehicle.	2E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Motor tube fails to retain the motor.	Excessive force from motor burn causes an epoxy failure on the centering rings and motor retainer.	The motor is not retained inside the aft airframe leading to catastrophic launch failure. Catastrophic damage to launch vehicle and possible injury to personnel in area due to flying debris.	1C	Epoxy fillets that retain the motor tube and centering rings are capable of withstanding force and heat from the burning motor. G5000 RocketPoxy is chosen for its ability to withstand force and high temperatures.	Manufacturer specifications for RocketPoxy G5000 were followed during application of epoxy to permanently attach centering rings and motor tube to the aft airframe as seen in Section 3.1.10.	1E
Motor burns out prematurely.	The motor is improperly assembled.	Launch vehicle fails to reach desired altitude. Potentially a recovery failure if the launch vehicle fails to reach the main parachute deployment altitude.	3C	Motor assembly is completed by team mentor.	The Motor Assembly Checklist in Table 30 is followed.	3D
Launch lugs fail before rail exit.	Improper manufacturing techniques on launch lug mounting. Damage to launch lugs from a previous launch.	Unanticipated trajectory of the launch vehicle off of the launch rail leading to a possible ballistic flight and catastrophic injury to personnel in the area.	1C	Use of epoxy on both sides of the launch lugs and nuts to secure launch lugs on to airframe. Manufacturer requirements for a full strength cure are to be followed. Co-linearity of launch lugs and launch rail will be verified before every launch.	Launch lugs are epoxied in accordance with Section 3.1.10. Launch lugs are inspected per Step 11 of the Preflight Launch Vehicle Checklist in Table 29. Co-linearity of launch lugs and launch rail are verified per Step 4 of the Setup on Launcher Checklist in Table 58.	1E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Launch rail collapses before launch vehicle exits the rail.	Improper assembly of the launch rail.	Unanticipated trajectory of the launch vehicle off of the launch vehicle leading to a possible ballistic flight and catastrophic injury to personnel in area.	1C	Launch rail will be setup following a checklist and the angle will be specified by the Range Safety Officer (RSO).	Launch rail is locked in place per RSO instructions in Step 5 of the Setup on Launcher checklist in Table 58. SO signature is obtained on the Setup on Launcher Checklist in Table 58 to ensure launch rail bolts are tight and the launch rail is locked at the correct angle.	1E.
Flight is unstable after launch rail exit.	The stability margin is lower than expected due to a different center of gravity or center of pressure locations than stability margin analysis. A fin breaks during ascension, changing the center of pressure location.	Ballistic flight path and possible injury to personnel in area. Possible damage to launch vehicle and equipment in area.	2C	Validate center of gravity and center of pressure. Ensure no pre-flight damage to the launch vehicle fins or epoxy fillets. People in the area of launch are made aware of the launch.	Center of gravity demonstration and center of pressure analysis in Sections 6.1.1.11 and 6.1.1.5 equates to a static stability value of 2.14 calibers. The fins are inspected prior to launch in Steps 1 and 2 in the Preflight Launch Vehicle Checklist in Table 29 and SO signature is obtained. People in area of launch are made aware of launch with the countdown in Step 5 of the Launch Checklist in Table 60.	2E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Launch vehicle fails to lift off launch rail.	Damage to the launch rail or launch lugs, faulty motor, or faulty ignition.	Mission failure if the motor ignites without liftoff. Possible damage to components. Armed launch vehicle remains on rail.	2D	The Setup on Launcher checklist will be followed and verified by the SO. Motor assembly will be completed by team mentor. NAR safety procedures will be followed in the event of ignition failure.	The Setup on Launcher Checklist in Table 58 is followed and signed by the SO. In Step 10 of the Preflight Launch Vehicle Checklist in Table 29 the launch lugs are inspected and verified by the SO. In the event of ignition failure, the Disarming Misfired Launch Vehicle Checklist in Table 69 will be followed.	2E
The launch vehicle exceeds launch waiver ceiling.	Failure in active system of BEAVS.	Danger to aircraft.	2C	Perform analysis to determine correct amount of ballast for the launch day conditions.	Analysis shows that launch vehicle will not exceed waiver ceiling under any wind and ballast conditions as shown in Table 4 and Table 2	3D
Blade deployment by BEAVS during flight.	Failure in mechanical, electrical, or control system of BEAVS.	Unpredictable and potentially dangerous flight path.	1B	Analyze the location which the blades deploy from the airframe to ensure a stable flight with or without BEAVS blade deployment.	Analysis completed in Section 6.1.1.14.	3E
Ejection charge fires before launch.	Static charges build during installation, circuit is energized, or a circuit is shorted.	Uncontained explosion or airframe sections being ejected near personnel or injury to nearby personnel.	2C	Keep all energy sources away from e-match leads and seal leads with electrical tape when not in use. Shunt all circuits that deal with ejection charges or black powder.	Circuits are wired with a switch to shunt circuits as verified in Section 6.1.2.10.	2E
Black Powder ejection charges ignite early.	Altimeters malfunction.	Launch vehicle separates early causing a high snatch load.	1C	Altimeters are tested to verify functionality.	Altimeters are checked for functionality via Section 6.1.2.7.	1E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Black powder charges ignite late.	Altimeters malfunction.	The launch vehicle separates late causing a high snatch load that could break inner components, electronics, or airframe.	3C	The altimeters are checked for functionality and are integrated correctly at every launch.	All altimeters have been checked for functionality via Section 6.1.2.7 and altimeter integration is followed based on Tables 40 and 50 so that altimeter bays are installed correctly. All checklists require a SO signature to be considered complete.	3E
Altimeter circuitry becomes disconnected at some point.	Altimeters are not connected properly to ejection charges.	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.	Altimeters are verified for functionality as described in Section 6.1.2.7. Ejection charge assembly follows the checklist in Table 31. Recovery integration will follow the Checklist in Tables 45 and 51. Circuitry disconnection is checked throughout integration process according to Tables 40 and 50. Wiring and beeps is verified in the Setup on Launcher checklist in Table 58.	1E
Unwanted signals to altimeters.	An altimeter housing has a poor or incomplete RF shield.	The ejection charges fire prematurely resulting in an unexpected or unconfined explosion.	2C	The inner walls of the fore and aft altimeter housings are lined in conductive tape according to the procedures in Section 3.1.15 and Section 3.1.14.	To test the RF shield, the housing will be tested according to Section 6.1.2.11.	2E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Static port holes do not properly pressurize an altimeter bay.	The static port holes are too small. There are not enough static port holes. An obstruction to static port holes does not allow for a pressure change.	The altimeters cannot accurately calculate the altitude and do not fire at the appropriate time or do not fire at all.	1C	The static port hole size and quantity have been calculated based on the volume of the housing detailed in Section 6.1.2.5. All static port holes are kept clear so that there is little to no pressure gradient across the holes.	Static port holes are checked for clarity in the checklist in Table 50 and in Table 40.	1E
The drogue and main parachutes are not deployed on time.	Altimeters are not set correctly so that ejection charges are fired late or not at all.	Possible injury to bystanders. Damage to launch vehicle and payload.	1C	All altimeters use a safe delay on firing primary and backup ejection charges.	Delay is less than 2 seconds as verified in Section 6.1.2.3.	1E
Inhalation of black powder combustion products.	Personnel are too close to airframe after ejection charge have ignited.	Damage to respiratory system.	3D	Personnel are a safe distance away from the airframe during all black powder ejection tests and wear proper PPE.	Black powder ejection demonstrations are detailed in Sections 6.1.2.4 and 6.1.3.1.	4E
Main parachute does not deploy.	Parachute bag gets stuck in the airframe.	Launch vehicle section falls only under the drogue parachute resulting in a high kinetic energy landing. Possible injury to personnel in area.	2B	Recovery deployment will be verified with ground testing. Two ejection charges are placed underneath the main parachutes as a back up.	The parachute ejection demonstration in Section 6.1.2.4 verified the main parachutes are deployed correctly. Recovery integration on launch day follows the Recovery Integration Checklist in Tables 45 and 51 and verified by SO signature. Step 5 in the Launch Checklist in Table 60 ensures all people in the area are aware of launch.	2E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Main parachute does not unfurl completely.	Improper packing methods or poor integration into launch vehicle.	Damage to launch vehicle and payload due to high kinetic energy landing. Possible injury to personnel in area.	2C	Use proper parachute folding technique as recommended by team mentor and practice parachute integration.	Packing the main parachute follows the Main Parachute Packing Checklist in Table 34. Step 5 in the Launch Checklist in Table 60 ensures all people in the area are aware of launch.	2E
Main parachute rips during deployment.	The main parachute was already damaged prior to launch.	Launch vehicle falls only under drogue parachute causing a high kinetic energy landing. Possible injury to personnel in area.	2C	The parachutes will be inspected for damage prior to packing.	Main parachute packing follows the Main Parachute Packing Checklist in Table 34, verifying the main parachute is not ripped in Step 3. Step 5 in the Launch Checklist in Table 60 ensures all people in the area are aware of launch.	2E
Fire damage to parachutes from ejection charges.	Improper heat protection from ejection charges.	Parachutes will perform sub-optimally. Possibility the launch vehicle tumbles to the ground. Possible injury to personnel in area	2C	Ensure ejection charges do not damage parachutes or recovery components by shielding with Kevlar blankets, cellulose insulation, and deployment bag.	Inspection after every ejection demonstration or launch according to Section 6.1.2.1. Recovery assembly follows the Fore and Aft Recovery Integration Checklist in Tables 45 and 51 to verify components are protected from the ejection charges. Step 5 in the Launch Checklist in Table 60 ensures all people in the area are aware of launch.	2D

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Launch vehicle falling on personnel under a parachute.	Wind causes launch vehicle to drift towards spectators.	Critical injury to personnel.	1D	Ensure launch vehicle is falling at a safe velocity so spectators have time to move out of the way. Ensure all spectators are aware of launch prior to ignition.	Launch vehicle descent rate was analyzed in Section 6.1.1.15. Step 5 in the Launch Checklist in Table 60 ensures all people in the area are aware of launch.	1E
Shroud lines becomes tangled upon ejection.	Main parachute is packed incorrectly.	Main parachute does not unfurl causing a high kinetic energy landing. Possible injury to personnel in area.	3C	Main parachute will be packed correctly following a checklist.	Main parachutes for both sections follow the Main Parachute Packing Checklist in Table 34. Step 5 in the Launch Checklist in Table 60 ensures all people in the area are aware of launch.	3E
Shock cord snaps upon main parachute deployment.	Unexpectedly high snatch load.	Launch vehicle section falls without parachutes causing a high kinetic energy landing. Possible injury to personnel in area.	2D	Descent rates have been calculated and the shock cords purchased are rated for expected loads.	Descent rates calculated in Section 6.1.1.15. Step 5 in the Launch Checklist in Table 60 ensures all people in the area are aware of launch.	2E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Fire damage to the riser.	Ejection charge heat and pressure causes a weak point in riser, causing it to break at damaged location.	Launch vehicle section falls without parachutes causing a high kinetic energy landing. Possible injury to personnel in area.	2D	Ensure appropriate amount of cellulose insulation is used, and ensure all nylon components are protected from heat with Kevlar or Nomex.	Inspection after every ejection demonstration or launch according to Section 6.1.2.1. Recovery assembly follows the Fore and Aft Recovery Integration Checklist in Tables 45 and 51 to verify components are protected from the ejection charges.	2E
Payload falling from apogee.	Retention devices release early or fail.	Payload falls at apogee.	2D	Redundant retention devices of differing manufacturers rated well above the forces experienced in a worst case scenario flight.	Analysis of mechanical components conducted in Section 6.1.3.2 shows mechanical failure will not occur. The vehicle demonstration flight conducted in Section 3.4 verifies the analysis.	2E
High impact landing of the fore section of the airframe.	High impact landing due to recovery failure or simulation error.	Damage to the rover or PEARS.	3C	Perform descent simulations in multiple softwares. Subscale launch vehicle will be used to verify simulations.	Redundant simulations have been performed as detailed in Section 3.3. The vehicle demonstration flight in Section 3.4 verified the rover was not damaged upon landing of the airframe.	3E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Payload ejection attempted with payload still retained.	Retention devices do not release prior to attempted ejection.	Black power ejection blows out side of airframe. Potential for airframe pieces to become shrapnel.	2C	The PLEC has redundancies to prevent ejection charges from being triggered unless all retention devices are successfully released first. Personnel will be at a safe distance during rover ejection.	Sequencing of e-matches in PLEC is demonstrated in Section 6.1.3.20. Payload ejection is not attempted until area is clear and approval granted from RSO as verified in step 1 of Table 61.	3E
Unexpected ejection of the payload.	RF signals build up charge in e-match leads.	Payload is ejected when personnel may be nearby. Potential injury to personnel in area.	2D	PLEC and e-match leads will be RF shielded in PEARS.	RF shielding is tested per Section 6.1.2.11.	2E
Rover is ejected from airframe on uneven terrain.	The fore airframe lands on uneven terrain.	Rover ejection travels a further distance than expected, possible causing damage to the rover or injury to personnel in area.	3C	Payload ejection demonstrations will be performed to adequately size ejection charges. Personnel will remain a safe distance from airframe post flight.	The rover deployment demonstration determined appropriate ejection charge size as detailed in Section 6.1.3.1. The checklist in Table 61 will be followed and the SO signature will be obtained.	4D
Unexploded ejection charges remain in PEARS.	Battery drain of the PLEC is above acceptable levels.	Unexploded charges present hazard to personnel.	3C	Current draw analysis of PLEC will be used to size battery. Unexploded ejection checklist will be created.	PLEC is verified to have substantial battery life for the mission per Section 6.1.3.8. SO signature on the Disarming PLEC and Payload Removal Checklist will be obtained in Table 66.	4D

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Batteries leak acid.	Batteries experiences unexpected force or damage during operation.	Battery acid burns personnel.	3C	Batteries will be properly protected in launch vehicle and payload to prevent damage.	Rover Battery Impact Protection and Marking Inspection was completed per Section 6.1.3.6.	3D
Launch vehicle is not assembled within Federal Aviation Administration (FAA) flight window.	Launch vehicle assembly takes longer than anticipated.	Launch will be postponed to future date.	3C	Full scale integration demonstrations will occur prior to launch day. Launch vehicle assembly will begin prior to FAA flight window to be ready to launch as soon launch vehicle is fully assembled.	The full scale launch vehicle integration demonstration verified that 1 hour and 47 minutes are required to fully assemble the launch vehicle as detailed in Section 6.1.1.3. Launch vehicle assembly started more than two hours prior to FAA flight to ensure launch that day. All future launches will have assembly begin with adequate time before FAA flight window.	3D
Launch vehicle is launched with improper assembly.	Checklists were not properly followed.	Possibility of ballistic flight, recovery failure, payload failure, injury to personnel, and damage to components.	1C	Checklists are to be created for every assembly and integration step. All checklists will be signed off by SO.	The Master Checklist in Table 25 verifies all checklists have been followed and signed by SO. Launch will not occur until every checklist is signed with completion.	1E

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Table 22 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Fully assembled launch vehicle transportation.	The fully assembled launch vehicle weighs more than 50 lbf and must be brought to the launch pad.	The launch vehicle weight can cause injury to personnel attempting to lift full weight alone.	3C	The fully assembled launch vehicle will be transported and held by more than two people at all times.	The team has been made aware of the Occupational Safety and Health Administration (OSHA) max lifting weight of 50 lbf. When bringing the fully assembled launch vehicle to the launch pad, a minimum of two people will carry the launch vehicle per Step 1 of the Setup on Launcher Checklist in Table 58.	3E
Components and necessary tools are not brought to launch site.	Components and necessary tools are neglected during packing.	Total mission failure if launch vehicle can not be fully assembled with all components.	2C	All components and necessary tools will be verified with a full scale launch vehicle demonstration prior to leaving on launch day.	A full scale integration demonstration as detailed in Section 6.1.1.3 was performed prior to leaving for launch of the Vehicle demonstration flight. Full scale integration demonstrations will continue to be performed prior to all future launches.	2E

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4.1.3 Environmental Hazard Analysis

In Table 23 and Table 24 are the Environmental Hazards that OSRT have developed for the mission. Environmental hazards were considered from two different perspectives: the hazards the mission present to the environment, and the hazards the environment present to the mission.

Table 23: Environmental Hazard on Mission Analysis

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
High speed winds during flight.	High speed winds at launch site.	Unpredictable flight path after rail exit. Vehicle becomes difficult to recover because of distance traveled, violate the competition drift radius.	2B	RSO instructions will be followed in the event of high winds. If wind speed is manageable launch rail will be adjusted during the Setup on Launcher Checklist per RSO instructions to counteract wind conditions. Parachute deployment will be designed to limit drift distance in all wind conditions.	Step 5 of the Setup on Launcher Checklist in Table 58 follows RSO instructions. Launch only proceeds with RSO launch clearance per Step 3 of the Launch Checklist in Table 60. The parachutes are designed to minimize drift as detailed in Section 3.2.9.	2D
Launch vehicle components are exposed to water.	Launch vehicle being left in the rain or snow. Assembly of launch vehicle is rain or snow.	On board electronics becoming damaged or destroyed leading to a mission failure.	2C	Launch may be postponed in the event of heavy rain. All components will be protected from water during assembly with the use of umbrellas or canopies. Launch vehicle will be retrieved immediately after the field is deemed safe by RSO.	Necessary electronics are verified to be working with Steps 8 and 9 of the Setup on Launcher Checklist in Table 58.	3D

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Table 23 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Sand or dirt filling sections of launch vehicle.	Landing in loose soil, mud or sand into the pressure relief holes or open ends; poor shipping conditions.	Reduced performance for the next launch; damage to electronics and motors.	3C	Inspect all openings on launch vehicle clean appropriately.	Inspection and cleaning are detailed in detailed in Section 27 and Section 62.	3D
Rover becomes stuck.	Rain creating muddy conditions; rough terrain; faulty computer vision sensing; insufficient motor torque.	Rover becomes stuck and is unable to continue; rover is damaged from the collision.	3B	Design drivetrain to be able to drive over and through rough terrain. Computer vision will be tested for collision detection.	Mobile rover using demonstration was completed in Section 6.1.3.3. Successful collision avoidance demonstration was completed in Section 6.1.3.10.	3D
Holes in airframe and electronics bays form pressure gradient.	High winds coming in through airframe holes.	Accuracy of altimeters is compromised; possibility of premature ejection charge firing.	1C	Design airframe and electronic bay holes such that the chance of a pressure gradient is minimal.	Design of the ejection bays in Sections 3.1.14 and 3.1.15 have been made to minimize the chance of a pressure gradient within the bay.	1E
Auger gets clogged with hard dirt or mud.	Muddy or dry conditions.	Auger will not be effective at collecting a soil sample for the rover. Rover becomes immobile.	2B	Design soil collection system to work with a wide range of soil conditions and will be verified with testing.	Auger design in Section 5.3.5 works with a wide range of soil. The auger and SCAR is able to collect a range of samples without failure following the procedure in 6.1.3.4.	2D

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Table 23 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Ice forms on airframe exterior.	Ice forms on airframe separation area or on static port holes.	Black powder charges fail to overcome added force from ice. Altimeters fail to sense change of pressure resulting in recovery failure.	1D	Sufficient port holes and Black powder charges to overcome ice buildup. Visual inspection of ice obstructing static port holes.	Visual inspection of static port holes are completed in Step 5 of Full Assembly checklist in Table 33. Successful recovery ejection demonstrations have completed per Section 6.1.2.4.	1E
Dangerous road conditions for personnel and components to travel from OSU to launch site.	Poor weather conditions along route from OSU to launch site.	Personnel and components may be unable to reach launch site. Possible injury to personnel and equipment if an accident occurs during transportation.	2C	Cars to be driven to Brothers, OR. will be suited for snow and ice conditions. The vanpool to Huntsville, AL. will avoid a route with dangerous road conditions.	All cars driven to Brothers, OR. from OSU have been suited for appropriate conditions with 4-wheel drive, traction tires, and chains if necessary. All drivers have experience driving in snow and ice conditions. The vanpool to Huntsville, AL. has been planned to drive a route avoiding mountain passes.	2E

Table 24: Mission Hazard on Environment Analysis

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Wadding ejected from launch vehicle.	Ejection charges expel wadding used to shield parachutes from heat and pressure from ejection charges.	Wadding degrades poorly causing chemical leakage into the ground.	3A	Choose a wadding that is biodegradable and collect all excess wadding during ground testing. Cellulose insulation is used to protect the parachutes.	Manufacturer's specification of cellulose insulation purchased is biodegradable and has minimal impact if left outside and will degrade over time.	4A
Batteries leak acid.	Batteries experiences unexpected force or damage during operation.	Battery acid leaks into ground.	3C	Batteries will be properly protected in launch vehicle and payload to prevent damage.	Rover battery impact protection and marking inspection was completed per Section 6.1.3.6.	3D
Fire from ignition.	Motor ignition sets surrounding brush on fire.	Creation of fire in brush or grass leading to possible wide spread damage to wildlife.	2C	Only launch at certified sites under the supervision of a licensed RSO and follow all instruction given by the RSO. The launch area will be inspected for flammable material and removed if necessary.	All launches take place at Oregon Rocketry (OROC) launch site in Brothers, OR. or at SL in Huntsville, AL. under direct supervision of qualified RSO. All instruction by the RSO are followed.	2E
Launch vehicle drifts outside recovery zone.	Launch vehicle descends slower than expected.	Launch vehicle could damage the environment or property.	3C	Descent analysis has been performed and verified through a full scale launch.	Descent trajectory was verified via Section 6.1.1.15 and verified via Section 6.1.1.1.	3E

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Table 24 – continued from previous page

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Launch vehicle lands in water.	Launch vehicle drifts outside recovery radius.	Possible water pollution.	3C	Descent analysis has been preformed and verified through a full scale launch.	Descent trajectory was verified via the descent trajectory analysis in Section 6.1.1.15 and the launch vehicle demonstration flight in Section 6.1.1.1.	3E
Garbage is left at launch site.	Failure to pick up personal waste or launch vehicle waste.	Pollution of environment at launch site.	3C	OSRT will collect all inspect launch site before leaving to ensure all waste is collected and properly disposed of.	After the vehicle demonstration flight no trash was left at the launch site upon departure. OSRT will continue to properly dispose of all waste at future launches.	3C

4.1.4 Remaining Concerns

All of the safety concerns which OSRT have identified have had a mitigation developed and a verification completed. The only outstanding concern which has not been completed relates to the Payload Demonstration Flight. The mechanical systems of the rover were tested during the Vehicle Demonstration Flight, however the PLEC and rover electronics were not present. This presents a concern of failure of the electronics due to forces of flight. Additionally, the payload ejection has only been tested with the airframe restrained to prevent cosmetic damage. No major concerns remain as all testing that can be performed on the ground has been completed.

4.2 Launch Operations Procedures

All checklists have an assembler and inspector assigned. Each pair has worked together in both roles to be interchangeable on launch day if necessary. If the assembler is unavailable for assembly for any reason, the inspector serves as a backup assembler. In the scenario where either an assembler or inspector is unavailable to complete a checklist, a SO will serve as the inspector. The checklists which are completed for a full scale launch are displayed in Tables 25 - 69.

The launch critical criteria for each checklist have been identified and are designated in the Safety Officer Checklist section of each checklist. Before signing a checklist as completed, a SO must verify all items in the Safety Officer Checklist section have been completed correctly. The assembler then signs to verify that all steps were inspected by a separate inspector during assembly and were completed in accordance with the checklist.

All assemblers and inspectors have been instructed to denote any deviation from the checklist, for any reason. The primary cause of deviation in full scale and subscale launches from checklists was components not fitting together as well as they have at the OSU MPRL, due to cold temperatures at the launch site. For any significant deviation from the checklist, the assemblers are instructed to consult the SO and team lead to determine if the change presents additional risk to the system. Additional risk to the system is not tolerated and is cause for the launch to be cancelled on site.

The Master Checklist shown in Table 25 is the only checklist which steps are not completed sequentially. The payload, fore, and aft sections of the launch vehicle can be assembled simultaneously. Prerequisite checklists are listed under each checklist to ensure that nothing is completed out of order, however they follow the general order shown below. Launch day responsibilities for a primary The Team Lead monitors assembly progress and shifts assembly resources if necessary to manage the integration time. Prior to launch, the safety officer must sign, indicating all checklists listed have been verified by safety officers.

Table 25: Master Checklist

Master Checklist

Team Lead Signature:_______________ **Safety Officer Signature:** _______________

#	Team Lead Initials	Assembler	Inspector	Step Instructions
S	______			**Safety Officer Checklist:** -Verify that a Safety Officer signature has been obtained on all assembly checklists prior to bringing launch vehicle to launch pad. **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff. **Safety Consideration:** Failure to ensure all checklists have been inspected, verified as completed by assembler, and important features verified by Safety Officer could result in injury to personnel and complete mission failure. Do not initial until all aspects of the following checklists are completed.
				Initial Inspections
1	______	Sam	Walker	Prefield Rover Inspection
2	______	Emmanuel	Al	Prefield Launch Vehicle Checklist
3	______	Sam	Walker	Preflight Rover Inspection
4	______	Emmanuel	Al	Preflight Launch Vehicle Checklist
				Launch Vehicle Assembly
5	______	Alex	Trevor	Motor Assembly
6	______	Caleb	Sebastian	Ejection Charge Assembly Checklist (x8)
S	______			**Safety Consideration: Ensure 8x ejection charges have been assembled and are properly labeled as 4g F1, 6g F2, 5.5g A1, 8g A2, 4g FDB1, 4g FDB2, 4g ADB1, 4g ADB2.**
7	______	Trey	Chris	ATU Ground Station Checklist
8	______	Emmanuel	Ryan	Full Assembly Checklist
				Aft Launch Vehicle Assembly
9	______	Luke	Caleb	Main Parachute Packing Checklist
10	______	Luke	Caleb	Drogue Parachute Checklist
11	______	Caleb	Luke	Recovery Harness Checklist
12	______	Caleb	Luke	Non-Adapted and Adapted Tender Descender Checklist
13	______	Trey	Chris	ATU Preparation Checklist
14	______	Caleb	Ryan	Aft Altimeter Setup
15	______	Ryan	Al	Aft Ejection Unit Assembly
16	______	Trevor	Al	BEAVS Assembly
17	______	Trevor	Al	Aft Ballast Bay Assembly
19	______	Al	Jon	Canister Assembly
20	______	Al	Ryan	Aft Section Assembly
21	______	Caleb	Luke	Aft Recovery Integration

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Table 25 – continued from previous page

#	Team Lead Initials	Assembler	Inspector	Step Instructions
				Fore Launch Vehicle Assembly
22	______	Sebastian	Emmanuel	Fore Hard Point Checklist
23	______	Sebastian	Sam	Payload Integration Checklist
24	______	Trevor	Sebastian	Fore Ballast Bay Assembly
25	______	Ryan	Emmanuel	Fore Avionics Integration
26	______	Ryan	Caleb	Fore Ejection Unit Assembly
27	______	Sebastian	Walker	Fore Recovery Integration
				Payload Assembly
28	______	Sebastian	Walker	Payload Ejection Charge Checklist (x2)
S	______			**Safety Consideration: Ensure 2x ejection charges have been assembled and are properly labeled as 1.2g Primary, 2.0g Backup.**
29	______	Sebastian	Walker	Payload Tender Descender Assembly (x2)
30	______	Sebastian	Walker	Payload Advanced Retention and Release Device (ARRD) Assembly
31	______	Brent	Robby	Protoboard Rover Electronics Checklist
32	______	Sebastian	Walker	PEARS Removable Assembly
33	______	Sebastian	Walker	Payload Wrap Assembly
				Launch Pad Procedures
34	______	Alex	Trevor	Setup on Launcher Checklist
35	______	Alex	Trevor	Igniter Insertion Checklist
36	______	Trevor	Jon	Launch Checklist
				Rover Deployment
37	______	Sebastian	Trevor	Rover Deployment Checklist
				Post Flight Inspections
38	______	Al	Emmanuel	Post Flight Launch Vehicle Checklist
39	______	Sam	Walker	Post Flight Rover Checklist
				Troubleshooting
40	______	Trevor	Jon	Disarming Misfired Launch Vehicle
41	______	Caleb	Trevor	Disarming Unexploded Recovery Charges
42	______	Sebastian	Robby	Disarming PLEC and Payload Removal
43	______	Trey	Chris	Malfunctioning Avionics Checklist
44	______	Brent	Robby	Malfunctioning Rover Electronics
45	______	Caleb	Sebastian	Disarming Full Launch Vehicle and Payload

4.2.1 Initial Inspection

Table 26: This checklist is used to inspect the rover prior to arriving at the launch site.

Prefield Rover Inspection		
Assembler Signature:__________________		**Safety Officer Signature: __________________**
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Inspect for loose electrical connections. - Verify that batteries are secure, in good condition, and protected from impact. - Verify that clamps on mounting blocks and motor mounts are secure. - Verify that clamping hubs, auger mounts, and soil retention motor mounts are secure. - Verify that slight resistance exists when turning wheels. - Inspect for damaged or missing foam tire. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** 1/16 in. hex key, 2 mm hex key, 3/32 in. hex key, 7/64 in. hex key, 5/32 in. hex key, smart LiPo battery charger
	______	**Components Needed:** assembled rover, PLEC assembly
1	______	Ensure that the two (2) nyloc nuts on each of the auger mounts are tight.
2	______	Using a 1/16 in. hex key, check that the four hex screws on the soil retention motor mount are tight.
3	______	Check that all electrical components are secured to the chassis.
4	______	Using a 2 mm hex key, check that the two (2) hex screws on the front of each drive motor mount are tight.
5	______	Using a 5/32 in. hex key, check that the two (2) hex screws on the top of each drive motor mount are tight.
6	______	Using a 3/32 in. hex key, check that the two (2) set screws on the couplers joining the drive shafts to the drive motors are tight.
7	______	Using a 7/64 in. hex key, check that the four (4) hex screws on the top of each mounting block are tight.
8	______	Using a 7/64 in. hex key, check that the four (4) hex screws on each the clamping hubs on the outside of each wheel are tight.
9	______	Using a 7/64 in. hex key, check that the horizontal hex screws in the clamping hubs on the outside of each wheel are tight.
10	______	Apply some tensile axial force to each wheel to ensure adequate clamping hub tightness. If the wheel moves along its drive shaft, reposition them to be flush and tighten the horizontal hex screw until the wheel no longer moves under axial force.
11	______	Turn each wheel a small amount and feel for resistance to indicate 1:1 rotation with motor shafts. If slippage occurs, recheck clamping hub and coupler.
12	______	Ensure that the foam tires on each wheel are not damaged or missing.
13	______	Ensure that the four (4) aluminum connecting rods are hooked to lower chassis crossbars and that the two (2) foam rubber linings are in place.
14	______	Remove one (1) 2200 mAh LiPo battery from PLEC assembly.
15	______	Remove one (1) 2200 mAh LiPo battery from rover.

Continued on next page

Table 26 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: Do not leave LiPo batteries unattended while charging; this is a fire hazard. Check batteries regularly for swelling or significant rise in temperature. If this occurs, immediately disconnect the battery and properly dispose.**
S	______	**Safety Consideration: Do not overcharge LiPo batteries; this is a fire hazard.**
S	______	**Safety Consideration: Keep LiPo batteries in a room temperature environment while charging and in storage. Hot LiPo batteries pose a fire hazard.**
16	______	Connect one battery to the smart charger.
17	______	Set the charger to 7.4 Volts on 'balanced charge' with a 2S in parentheses to the right of the voltage.
18	______	Set the charger to 2 Amps.
19	______	Hold the start button down until you hear beeps.
20	______	Press the start button once.
21	______	Let the battery charge for about 30 minutes until the charger plays a short tune.
22	______	Connect the other battery to the smart charger.
23	______	Set the charger to 7.4 Volts on 'balanced charge' with a 2S in parentheses to the right of the voltage.
24	______	Set the charger to 2 Amps.
25	______	Hold the start button down until you hear beeps.
26	______	Press the start button once.
27	______	Let the battery charge for about 30 minutes until the charger plays a short tune.
28	______	Replace batteries in PLEC and rover.
29	______	Ensure batteries are secure, in good condition, protected from impact, and covered in bright colored tape.

Table 27: This checklist is used to inspect the launch vehicle prior to arriving at the launch site.

Prefield Launch Vehicle Checklist

Assembler Signature:________________ **Safety Officer Signature:** ________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: -Any and all damage recorded, risk assessed for all damaged. -All Batteries are accounted for and charge is recorded for each LiPo. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** acetone, paper towels
	______	**Components Needed:** aft section, fore section, nosecone and attached coupler, canister, motor casing, motor retainer, 4x new 9 V batteries, and 5x 2200 mAh 7.4 V 2 cell LiPo Batteries
S	______	**Safety Consideration: Failure to notify team of damage to launch vehicle could result in unstable flight or full mission failure.**
1	______	Inspect fins for any chips or surface damage.

Continued on next page

Table 27 – continued from previous page

#	Inspector Initials	Step Instructions
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 then clean with acetone and paper towels.
7	______	Check couplers and airframe for shear pins and remove any found.
8	______	Inspect nosecone for chips or cracks.
9	______	Inspect nosecone tip for scratches or deformation.
10	______	Inspect motor casing for any marks, dents, or other visible damage.
11	______	Record any damage found and notify the team: ____
12	______	Check that all batteries are accounted for and charged:
13	______	4x New 9v batteries for Altimeters
14	______	1x 2200 mAh LiPo for PLEC
15	______	Record Charge: ____________
16	______	1x 2200 mAh LiPo for Ground Station
17	______	Record Charge: ____________
18	______	2x 2200 mAh LiPo for Avionics
19	______	Record Charge for each: ____________, ____________
S	______	**Safety Consideration: Failure to charge batteries could result in recovery system failure, rover deployment failure, and rover mission failure.**

Table 28: This checklist is used to inspect the rover prior to payload integration.

Preflight Rover Inspection		
Assembler Signature:________________		**Safety Officer Signature:** ________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Inspect for loose electrical connections. - Verify that batteries are secure, in good condition, and protected from impact. - Verify that clamps on mounting blocks and motor mounts are secure. - Verify that clamping hubs, auger mounts, and soil retention motor mounts are secure. - Verify that slight resistance exists when turning wheels. - Inspect for damaged or missing foam tire. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** 1/16 in. hex key, 2 mm hex key, 3/32 in. hex key, 7/64 in. hex key, 5/32 in. hex key
	______	**Components Needed:** assembled rover
1	______	Ensure that the two (2) nyloc nuts on each of the auger mounts are tight.

Continued on next page

Table 28 – continued from previous page

#	Inspector Initials	Step Instructions
2	______	Using a 1/16 in. hex key, check that the four hex screws on the soil retention motor mount are tight.
3	______	Check that all electrical components are secured to the chassis.
S	______	**Safety Consideration: Electrical components in poor condition pose a fire hazard.**
4	______	Ensure batteries are secure, in good condition, protected from impact, and covered in bright colored tape.
5	______	Using a 2 mm hex key, check that the two (2) hex screws on the front of each drive motor mount are tight.
6	______	Using a 5/32 in. hex key, check that the two (2) hex screws on the top of each drive motor mount are tight.
7	______	Using a 3/32 in. hex key, check that the two (2) set screws on the couplers joining the drive shafts to the drive motors are tight.
8	______	Using a 7/64 in. hex key, check that the four (4) hex screws on the top of each mounting block are tight.
9	______	Using a 7/64 in. hex key, check that the four (4) hex screws on each the clamping hubs on the outside of each wheel are tight.
10	______	Using a 7/64 in. hex key, check that the horizontal hex screws in the clamping hubs on the outside of each wheel are tight.
11	______	Apply some tensile axial force to each wheel to ensure adequate clamping hub tightness. If the wheel moves along its drive shaft, reposition them to be flush and tighten the horizontal hex screw until the wheel no longer moves under axial force.
12	______	Turn each wheel a small amount and feel for resistance to indicate 1:1 rotation with motor shafts. If slippage occurs, recheck clamping hub and coupler.
13	______	Ensure that the foam tires on each wheel are not damaged or missing.
14	______	Ensure that the four (4) aluminum connecting rods are hooked to lower chassis crossbars and that the two (2) foam rubber linings are in place.

Table 29: This checklist is used to inspect the launch vehicle prior to launch.

Preflight Launch Vehicle Checklist

Assembler Signature:__________________ **Safety Officer Signature:** __________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		-Any and all damage recorded and team members notified
		Prerequisite lists: N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** acetone, paper towels
	______	**Components Needed:** aft section, fore section, nosecone and attached coupler, canister, and motor retainer
S	______	**Safety Consideration: Failure to notify team of damage to launch vehicle could result in unstable flight or full mission failure.**

Continued on next page

Table 29 – continued from previous page

#	Inspector Initials	Step Instructions
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. Clean dirt with acetone and paper towels.
7	______	Check couplers and airframe for shear pins and remove any found.
8	______	Inspect nosecone for chips or cracks.
9	______	Inspect nosecone tip for scratches or deformation.
10	______	Inspect launch lugs, ensuring launch lugs are secure to airframe and in line with the center of the launch vehicle.
11	______	Record any damage below and notify the team. ____

4.2.2 Launch Vehicle Assembly

Table 30: This checklist is used to assembly the motor for the launch vehicle.

Motor Assembly Checklist		
Assembler Signature:_______________		**Safety Officer Signature:** _______________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist:
		-Ensure both enclosures are tight.
		Prerequisite lists: N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** N/A
	______	**Components Needed:** Hardware bag, liner, 2x 2 grain box, industrial lubricant, motor casing, fore closure, aft closure
S	______	**Safety Consideration: All steps to be carried out by present mentor.**
S	______	**Safety Consideration: Process includes ammonium perchlorate composite propellant, therefore ensure moisture and combustion sources are not present.**
1	______	Apply a coating of lubricant around the entirety of the smoke tracking grain.
2	______	Insert the smoke tracking grain insulator into the cavity and ensure it is seated fully.
3	______	Apply a coating of lubricant on all o-rings.
4	______	Insert one propellant grain into the forward end of the case liner. Place a lubricated o-ring flush with the top of the propellant grain.
5	______	Insert another propellant grain in the liner ensuring an o-ring is separating the propellant grains.
6	______	Repeat steps 4 and 5 for all four propellant grains.
7	______	Apply a layer of lubricant on the exterior of the case liner.

Continued on next page

Table 30 – continued from previous page

#	Team Lead Initials	Step Instructions
8	______	Insert case liner with all four propellant grains into the motor casing so that the nozzle protrudes from the casing by about 1/8 in.
9	______	Insert the forward insulating disk to the top of the motor case.
10	______	Insert a lubricated o-ring into the top of the motor case so that it is flush against the forward insulating disk.
11	______	Thread the completed forward closure into the forward end of the motor casing. Do not tighten down the enclosure at this time.
12	______	Place a lubricated o-ring into the groove in the nozzle.
13	______	Thread the aft closure into the aft end of the motor casing. Do not tighten down the enclosure at this time.
S	______	**Safety Consideration: Ensure closures are not tightened.**
14	______	Place in secured container and store away from any potential ignition source until launch vehicle is ready for motor installation.

Table 31: This checklist is used to assemble the black powder ejection charges used for recovery.

Ejection Charge Assembly Checklist		
Assembler Signature:__________________ **Safety Officer Signature:** __________________		
Note: 8 copies of this check list are included - one for each black powder charge contained within the recovery systems. Charge Sizes 4g F1 (fore primary), 6g F2 (fore secondary), 5.5g A1 (aft primary), 8g A2 (aft secondary), 4g FDB1 (fore deployment bag primary), 4g FDB2 (fore deployment bag secondary), 4g ADB1 (aft deployment bag primary), 4g ADB2 (aft deployment bag secondary).		
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Ensure there are 8 charges marked properly. - Ensure all charges have been properly labeled - Backup charges e-matches should be marked with sharpie. - Ensure all zip ties are sufficiently tight. - Ensure all charges are packed tightly. Each charge should be squeezed and have minimal give. - Inspect all e-matches - they should be twisted in a tight spiral. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Digital multimeter, diagonal cutting pliers, pliers, scale, batteries for scale, funnel, red sharpie, measuring cup
	______	**Components Needed:** e-match, Santoprene, surgical tubing, 2 zip ties, 1/4 container of 4F black powder
S	______	**Safety Consideration: All steps to be carried out by HPR level 1 certified team member.**
S	______	**Safety Consideration: Process includes usage of black powder, follow Black Powder Handling for proper handling procedure.**
S	______	**Safety Consideration: Ensure all team members in close proximity wear safety glasses to avoid black powder contacting the eyes.**

Continued on next page

Table 31 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: Ensure all ignition sources have been removed from the area.**
S	______	**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.**
S	______	**Safety Consideration: Failure to load correct charge may result in a failed ejection at apogee.**
1	______	Test e-match resistance with a multimeter.
2	______	Verify e-match resistance is between 1.3-1.7 Ohms.
3	______	Record the e-match resistance: [Charge Name] ______
4	______	Cut 2x pieces of Santoprene rubber rod into approximately 0.75 inch lengths using diagonal cutting pliers.
5	______	Cut 1 piece of surgical tubing to a length of approximately 4.5 inch using diagonal cutting pliers.
6	______	Insert a piece of Santoprene into one end of the surgical tubing.
S	______	**Safety Consideration: Failure to measure in grams will result in wrong sizing of BP charges.**
7	______	Ensure the scale is measuring in grams.
8	______	Ensure the scale has been zeroed to include the measuring cup.
9	______	Measure [X.x] g of black powder for the Aft Primary charge.
10	______	Record Mass: [Charge Name]: ______g
11	______	Insert funnel into the open end of a surgical tubing set-up.
12	______	Pour approximately half of the black powder into the surgical tubing set-up. Remove the funnel.
13	______	Slide the red covering around the tip of the e-match down the blue and white wire about 12 inches.
14	______	Insert the tip of the e-match into the black powder in the surgical tubing set up.
15	______	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.
16	______	Pour the remaining black powder into the surgical tubing set-up. Remove the funnel.
17	______	Insert a piece of Santoprene into the open end of the surgical tubing set-up, ensuring that there is no open room between the black powder and the Santoprene.
S	______	**Safety Consideration: Allowing extra room in black powder charges will result in failed ejection.**
18	______	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. If there is extra room in the charge, push the piece of Santoprene that has not been ziptied down further into the surgical tubing until the black powder is packed down.
19	______	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.
S	______	**Safety Consideration: Failure to check zip tie tightness may result in failed ejection during recovery.**
20	______	Double check that the zip ties are secured as tightly as possible using pliers.
21	______	Remove zip tie tails using diagonal cutting pliers.
22	______	Double check that the zip ties are secured as tightly as possible using pliers.
23	______	Write [Charge Name] with the mass of the black powder on the outside of the surgical tubing in red sharpie.

Continued on next page

Table 31 – continued from previous page

#	Inspector Initials	Step Instructions
24	______	Twist the first 12" from the leads of the e-match wires loosely.
25	______	Mark all secondary charge e-matches with a sharpie, so differentiation is obvious.
26	______	Tape the ends of all e-matches separately.

Table 32: This checklist is used to prepare the ATU Ground Station for launch.

ATU Ground Station Preparation Checklist

Assembler Signature:_________________ **Safety Officer Signature:** _________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Inspect for loose electrical connections and components.
		- Verify LiPo battery voltage is above 8 V.
		Prerequisite lists:
		-ATU Preparation Checklist
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Digital multimeter, micro-USB cable
	______	**Components Needed:** ATU ground station, Windows laptop with Python 3.7/Arduino IDE 1.8.8/TeensyLoader, 7.4 V LiPo battery (typically already attached to ground station), Yagi antenna
1	______	Ensure that matplotlib, pyserial, and utm Python packages are installed on computer and that Python, Arduino IDE, and TeensyLoader are up to date.
S	______	**Safety Consideration: Use digital multimeter to ensure that battery is at maximum capacity before use; Acceptable operating range is > 8 V.**
2	______	Ground Station Battery Voltage: ______
3	______	Attach Yagi antenna to XBee or 433 MHz transceiver (based on desired functional band).
4	______	Plug micro-USB into Teensy.
S	______	**Safety Consideration: Avoid touching the leads on the Dean's connectors to skin or metal; doing so may cause damage to the electrical components or personal harm.**
5	______	Plug LiPo battery into ground station via Dean's connector, orange light on Teensy should turn on.
6	______	Plug micro-USB into Windows laptop.
7	______	Open Arduino IDE, configure for Teensy, and launch serial monitor to ensure link is established. Timestamps should display if link is established correctly.
8	______	Wait for GPS coordinates to display correctly in serial monitor. A link is present when most of the data is composed of commas, but when both flight ATUs have a GPS lock there should be coordinates instead.
9	______	Point antenna at launch vehicle.
10	______	If serial monitor shows no data, close and restart program or power cycle ground station by unplugging micro-USB from laptop, unplugging battery, then plugging battery back in and reconnecting micro-USB to laptop.

Table 33: This checklist is used for the full assembly of the launch vehicle.

Full Assembly Checklist

Assembler Signature:__________________ **Safety Officer Signature:** __________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: -Ensure shear pins are properly inserted -Ensure motor retainer is secured. **Prerequisite lists:** -Aft Section Assembly -Fore Section Assembly -Motor Assembly **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Micro screwdriver
	______	**Components Needed:** Fully assembled aft section, fully assembled fore section, fully assembled motor, six 2-56 nylon shear pins
S	______	**Safety Consideration: Remove all objects not related to final assembly from work area. Keep sharp objects away from the airframe; any damage to them may cause potential hazards. Safety Officer must sign off on final assembly.**
S	______	**Safety Consideration: Ensure no open flames, sparks, or other heat sources are in the area.**
S	______	**Safety Consideration: Ensure all altimeters are disarmed. Failure to perform assembly without altimeters disarmed could result in premature ignition of ejection charges.**
S	______	**Safety Consideration: Failure to follow all steps will result in complete mission failure due to recovery failure.**
S	______	**Safety Consideration: Recovery failure will cause hazards to nearby people and to the environment.**
1	______	Press nosecone onto fore section, aligning shear pin holes in coupler shoulder and fore airframe.
2	______	Secure nosecone with three 2-56 nylon shear pins.
S	______	**Safety Consideration: Fore and Aft section are heavy. Ensure enough people lift each section.**
3	______	Press the fore section onto the aft section, aligning shear pin holes in coupler and fore airframe.
S	______	**Safety Consideration: Do not use steel screws. Use of steel screws will cause the parachutes to not deploy and will cause significant hazards to nearby people and to the environment.**
4	______	Screw in the fore section using three 2-56 nylon screws.
5	______	Ensure static port holes are clear of obstructions and switches are accessible.
S	______	**Safety Consideration: All motor handling steps to be carried out with mentor present.**
6	______	Tighten both the fore and aft closures simultaneously until each is flush with the motor case and check the motor case for possible damage.
7	______	Insert fully integrated motor into motor tube.
8	______	Secure motor with motor retainer cap.
9	______	Ensure motor retainer cap is firmly hand tightened.
10	______	Inform RSO that the launch vehicle is ready to be installed on the launch rail.

Continued on next page

Table 33 – continued from previous page

#	Inspector Initials	Step Instructions
11	______	After the range is opened, follow RSO's protocols and proceed to launch rail.

4.2.3 Aft Assembly

Table 34: This checklist is used to pack both the fore and aft the main parachutes in deployment bags.

Main Parachute Packing Checklist		
Assembler Signature:__________________		**Safety Officer Signature:** __________________
Note: there are two of these checklists at launch, one for the fore parachute and one for the aft parachute.		
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: -Ensure REMOVE BEFORE FLIGHT tag is placed under the tape holding the bag closed and the shroud lines together. There should be two tags. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** N/A
	______	**Components Needed:** One 96 in. Standard Iris Parachutes, one 5.5 in. x 7 in. deployment bags, masking tape, and two red REMOVE BEFORE FLIGHT tags.
S	______	**Ensure all sharp objects, heat sources, and corrosive materials are removed from work space. Work space should be clear of any items not related to harness and parachute prep. Failure to follow all steps will result in complete mission failure due to recovery failure.**
1	______	Gather all the shroud lines in your hand with the parachute lifted off the ground. Grab the shrouds about 3 ft below the start of the parachute.
2	______	Take the parachute to an open area.
3	______	Run with the parachute until it inflates to ensure the shrouds are not tangled and the parachute is not ripped.
4	______	Let the parachute deflate and carefully take the parachute to the folding station.
5	______	Lay out parachute so that the shrouds are below it.
6	______	Locate the left and right shroud lines, these are bundled together by a rubber piece close to the swivel.
7	______	Gather 4 shrouds to the right, 4 shrouds to the left, and 4 shrouds to the middle, excluding the center shrouds.
8	______	Wrap tape around the right shroud lines at the farthest bottom point of the lines to keep them together.
9	______	Wrap tape around the left shroud lines at the farthest bottom point of the lines to keep them together.
10	______	There are 2 middle shrouds on top and 2 middle shrouds on bottom. Take 2 lines that are opposite and diagonal of each other and pull them together so that they are aligned with the center shrouds. This is now the center line. It does not matter which combination of shrouds as long as they are opposite and diagonal.

Continued on next page

Table 34 – continued from previous page

#	Inspector Initials	Step Instructions
11	______	Ensure that the gores laying on top of each other are opposite colors (yellow and black).
12	______	Pull on the center shroud lines until the spill hole is 3/4 to the bottom of the parachute.
13	______	Ensure the gores are still aligned by opposite colors on the top and bottom of the parachute.
14	______	Take the closest gore to the center and fold the stitched line onto the center line. Repeat this process for one side of the canopy until all the gores are folded. While doing this process, collect the shroud lines to each gore and ensure that they all lay on top of each other, aligned just to the side of the center line. With each fold, ensure the top and bottom of the parachute gores are still aligned.
15	______	Repeat the previous step for the opposite side.
16	______	Ensure the resulting gores left are opposite colors.
17	______	Flatten the folded canopy as much as possible by pushing out all the air.
18	______	Fold the canopy in thirds, similar to folding a letter. Take the right side of parachute and fold it 2 thirds of the way to the other side. Fold the left side over to the end of the right side.
19	______	Ensure the canopy is folded into a long rectangular shape.
20	______	Pack the folded canopy into the deployment bag with the shroud lines facing the open end by compressing the canopy until it fits.
21	______	Take all of the shroud lines and fold them over the deployment bag. Then, double back the shrouds to the bottom of the bag, and the guide the folded section through the bands on the bag.
22	______	Repeat the previous step for the second and third sections of bands.
23	______	Wrap tape around the deployment bag to ensure a safe storage and transportation of the parachute.
24	______	Grab the REMOVE BEFORE FLIGHT tag labeled #2 (for fore section) and #5 (for aft section). Attach the tag to the tape wrapped around the deployment bag.
25	______	Grab the REMOVE BEFORE FLIGHT tag labeled #3 (for fore section) and #6 (for aft section). Attach the tag to the bottom of the shrouds. This is too ensure tape is removed before flight.
26	______	Ensure all masking tape has a REMOVE BEFORE FLIGHT tag attached directly to it.

Table 35: This checklist is used to pack both the fore and aft the drogue parachutes.

Drogue Parachute Packing Checklist		
Assembler Signature:__________________ **Safety Officer Signature:** __________________		
Note: there are two of these checklists at launch, one for the fore parachute and one for the aft parachute.		
#	**Inspector Initials**	**Step Instructions**
	______	**Safety Officer Checklist:** -Ensure REMOVE BEFORE FLIGHT tag is placed under the tape holding the folded parachute closed. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff. **Tools Needed:** N/A

Continued on next page

Table 35 – continued from previous page

#	Inspector Initials	Step Instructions
	______	**Components Needed:** Two 18 in. X-form drogue parachutes, two swivels, masking tape, and two red REMOVE BEFORE FLIGHT tags.
S	______	**Ensure all sharp objects, heat sources, and corrosive materials are removed from work space. Work space should be clear of any items not related to harness and parachute prep. Failure to follow all steps will result in complete mission failure due to recovery failure.**
1	______	Get the 18 in. X-form drogue parachute (check the marking on center square to check size).
2	______	Ensure there are no tears in the parachute nylon.
3	______	Ensure shroud lines are untangled.
4	______	Inspect the shroud lines for burns or tears and ensure there is no fraying.
5	______	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. Tape the hitch to the swivel with masking tape.
6	______	Pull the drogue up and ensure the shrouds are not tangled.
7	______	Fold the parachute in half so 2 opposite squares are on one another.
8	______	Inverse fold the left and right squares so that they are tucked in between the top and bottom squares. The top should come to a point.
9	______	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 of the drogue parachute.
10	______	Fold the right 3rd of the chute over the shroud lines.
11	______	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.
12	______	Fold the left 3rd of the chute over the shroud lines, only 1-2" of the shrouds should be exposed out the bottom.
13	______	Tightly roll the drogue parachute from the top until it is bundled.
14	______	Wrap the bundle with masking tape to secure it closed and label the tape "18 in."; place a REMOVE BEFORE FLIGHT tag under the tape. This tag should be labeled #1 (for the fore) and #4 (for the aft).

Table 36: This checklist is used to set up both the fore and aft recovery harness.

Recovery Harness Checklist		
Assembler Signature:__________________		**Safety Officer Signature:** __________________
#	**Inspector Initials**	**Step Instructions**
	______	**Safety Officer Checklist:** - Check recovery harness for damage. - Shroud lines are protected in bag. - Parachute is packed well and there is no canopy showing. - Ensure three remove before before flight tags are on the assembly. **Prerequisite lists:** - Main Parachute Packing Checklist - Drogue Parachute Packing Checklist. **ALL** steps below must be completed and verified by an inspector for Safety Officer's signoff.

Continued on next page

Table 36 – continued from previous page

#	Inspector Initials	Step Instructions
	______	**Tools Needed:** N/A
	______	**Components Needed:** Two packed 18 in. X-form drogue assemblies, masking tape, two 96 in. Iris Ultra main parachutes packed in deployment bag assemblies, two Kevlar blast protectors, sharpie, two 42 ft nylon risers, seven standard Quick Links, five extra wide mouth Quick Links, four 3 ft Kevlar sleeves, Kevlar cord, four Tender Descenders Quick Links, two 2 ft Nylon harness, two 8 in. Kevlar sleeves, two 1 ft lengths of braided Kevlar
S	______	**Safety Consideration: Check the main packing looks correct, and that a REMOVE BEFORE FLIGHT tag is placed under the tape holding it closed.**
1	______	Get two 42 ft nylon risers.
2	______	Repeat the following steps for both risers. The first system to be made is the fore section.
3	______	Inspect the riser for any tearing or excessive scorching; inspect the butterfly loops (if still tied) for any stressed areas.
4	______	**Skip this step for the aft riser.** Tie/ensure a single butterfly loop is located 6 ft from the nosecone stitched loop. This loop is for the drogue and will be referred to as loop #3.
5	______	Tie/ensure a single butterfly loop is located 14 ft from loop #3. This is for the deployment bag and will be referred to as loop #2.
6	______	Ensure a Kevlar sleeve is located between loops #2 and #3. It should be secured just next to loop #2 with masking tape, and a Kevlar blast protector should be sewn to it.
7	______	Tie/ensure a single butterfly loop is located 10 ft from loop #2. This is for the main parachute and will be referred to as loop #1.
8	______	Check that there is about 10 ft left of riser between the stitched loop at the end of the riser and loop #1.
9	______	Tape an artificial zipper along the riser between loop #3 and loop #2. The artificial zipper should be 6 thicknesses of the riser.
10	______	Place the drogue swivel on a standard Quick Link, and attach this Quick Link to loop #1. Ensure Quick Link is tightened all the way down. For the aft section, attach it to the stitched loop at the drogue end of the riser.
11	______	Place the main swivel on a standard Quick Link, and attach this Quick Link to loop #3. Ensure the Quick Link is tightened all the way down.
12	______	Slide the second Kevlar sleeve over the main parachute end of the riser. Secure the sleeve to the riser just above the stitched loop with masking tape a Kevlar blast protector should be sewn to it.
13	______	Attach a wide-mouth Quick Link to each end of the riser. Leave the Quick Links fully open. For the aft section, only the main side of the riser has a wide mouth Quick Link.
14	______	Tie loop #2 to the sewn loop on the deployment bag with the 1 ft section of braided Kevlar.
15	______	Thread the nylon harness through the Kevlar sleeve in thirds. connect a Tender Descender Quick Link to both ends making sure to put the Quick Link through the stitched loop and the hole created by folding the nylon.
16	______	Thread the nylon and Kevlar assembly through loop #2

Table 37: This checklist is used to set up the fore and aft Tender Descenders used for recovery.

#	Inspector Initials	Step Instructions
		Non-adapted and Adapted Tender Descender Setup Checklist
		Assembler Signature:__________________ **Safety Officer Signature:** __________________
		Note: there are two of these checklists at launch, one for the fore section and one for the aft section.
		Note: Complete the assembly of the non-adapted and adapted Tender Descender simultaneously.
		Safety Officer Checklist:
		-Ensure there is an e-match in both Tender Descenders.
		Prerequisite lists:
		-Recovery Harness Checklist
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** 4f black Powder Funnel, Small Black Powder Vial, Scale, Measuring cup, tape, multimeter Safety Glasses, protective gloves
	______	**Components Needed:** Two Tender Descenders (one non-adapted and one adapted), Two e-matches, two aluminum plugs, nylon-Kevlar assembly
S	______	**Indicated material with finite life. Overuse of the material causes environmental impact. Wash Kevlar sheet rather than disposing.**
S	______	**All steps to be carried out by HPR level 1 certified team member.**
S	______	**Process includes usage of black powder, follow Black Powder Handling for proper handling procedure.**
S	______	**Ensure all team members in close proximity wear safety glasses to avoid black powder contacting the eyes.**
S	______	**Ensure all ignition sources have been removed from the area.**
S	______	**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.**
S	______	**Confirm that Quick Links have been threaded completely closed.**
1	______	Verify e-match resistance is between 1.3-1.7 Ohms.
2	______	Record Resistance: Tender Descender: ______Ohms ______Ohms ______Ohms ______Ohms.
3	______	Thread Kevlar keeper through one attachment Quick Link.
4	______	Apply tape right below the head of the e-match. This will serve as a seal for the Tender Descender once the e-match is pulled through the base hole.
5	______	Install e-match into steel housing. For the adapted Tender Descenders with the larger base hole, the aluminum adaptable piece will need to be placed below the base of the Tender Descender. The e-match will need to be threaded through this aluminum piece and the steel Tender Descender housing.
6	______	Apply tape to the outside of the e-match/Tender Descender connection. For the adaptable Tender Descenders wrap tape around the aluminum and the steel housing. Ensure the black top piece can still be attached.
7	______	Measure 0.4g of 4F Black Powder using the small black powder vial. Obtain this amount of black powder for both Tender Descenders.
8	______	Ensure the scale is measuring in grams.
9	______	If the small black powder vial is missing, follow the following steps:

Continued on next page

Table 37 – continued from previous page

#	Inspector Initials	Step Instructions
9.1	______	Ensure the scale has been zeroed to include the measuring cup.
9.2	______	Measure .4g of black powder for the charge.
9.3	______	Record mass: Tender Descender Charge: ______g
10	______	Pour 0.3g of 4F Black Powder into ejection canister.
S	______	**Confirm that Black Powder is sealed within the ejection canister.**
11	______	Take the Quick Link with the keeper attached to it and slide it over the wide-mouthed Quick Link at the main parachute end of the harness. Note: In order to correctly attach both Tender Descenders to the wide-mouthed Quick Link, the harness will need to be between the Tender Descenders.
12	______	Place the keeper tether Quick Link in one side of the Tender Descender. Only the longer end of the Quick Link will fit inside the Tender Descender.
13	______	Take a Quick Link from the nylon-Kevlar assembly and slide it into the other end of the Quick Link. Ensure loop #2 is still slid over the nylon-Kevlar assembly.
14	______	Place the black part of the Tender Descender in the housing, securing both Quick Links.

Table 38: This checklist is used to prepare the ATU for launch.

ATU Preparation Checklist		
Assembler Signature:__________________		**Safety Officer Signature:** __________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Inspect for loose electrical connections and components. - Verify that battery is secure and in good condition. - Verify LiPo battery voltage is above 8 V. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Digital multimeter, electrical tape
	______	**Components Needed:** Flight ATU, micro-SD card, Teensy 3.6 microcontroller, XBee Pro/433 MHz transceiver, OSRT custom PCB, 7.4 V LiPo battery
S	______	**Safety Consideration: Use digital multimeter to ensure that battery is at maximum capacity before use; acceptable operating range is > 8 V.**
1	______	ATU Battery Voltage: ______
S	______	**Safety Consideration: Avoid touching the leads on the Dean's connectors to skin or metal; doing so may cause damage to the electrical components or personal harm.**
2	______	Ensure that battery is secured in avionics bay fixture.
3	______	Insert micro-SD card into Teensy - clear old data via computer prior to launch.
4	______	Tape SD card to Teensy and custom PCB to make secure.
5	______	Check that all ATU electrical components are seated to pin headers correctly and secured to PCB with electrical tape:
5a	______	Teensy Microcontroller

Continued on next page

Table 38 – continued from previous page

#	Inspector Initials	Step Instructions
5b	______	XBee Pro or 433 MHz transceiver (based on desired functional band)
6	______	Connect XBee or 433 MHz transceiver antenna.
7	______	Secure transceiver antenna with electrical tape.
S	______	**Safety Consideration: Double check to ensure that all electronic components are seated correctly and secured to PCB; if any electronics are loose they will cause serious damage to internal components during launch and potentially render the ATU unusable.**
8	______	At least 1 hour prior to launch vehicle integration, plug in ATU to battery.
9	______	Check Teensy for solid orange light indicating system is active.

Table 39: This checklist is used to set up both the fore and aft altimeters.

Aft Altimeter Setup		
Assembler Signature:________________		**Safety Officer Signature:** ________________
Note: This process is identical for the fore and aft altimeter setup.		
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Ensure the e-match leads are attached to the correct leads. - Ensure no copper is exposed outside of the altimeter ports. - Tug on the wires to ensure the altimeter ports are sufficiently tight.
		Prerequisite lists: -Recovery Harness -Recovery Tender Descenders
		ALL steps below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Small flat-head screwdriver, standard Phillips screwdriver, standard flat-head screwdriver, wire cutters, wire strippers, multimeter
	______	**Components Needed:** [Aft/Fore] altimeter sleds, [aft/fore] primary ejection charge (labeled A1 - 5.5g/F1 - 4g), [aft/fore] secondary ejection charge (labeled A2 - 8g/F2 - 6g), primary [aft/fore] deployment bag ejection charge (labeled ADB1 - 4g/FDB1 - 4g), secondary [aft/fore] deployment bag ejection charge (labeled ADB2 - 4g/FDB2 - 4g), two fully assembled Tender Descenders, [aft/fore] altimeter bay bulkhead, one wood screw, one washer with a rubber seal, battery casing spacer
S	______	**Safety Consideration: Ensure table is clear of all sources of electricity (excluding batteries in the battery casings).**
1	______	Ensure all ejection charges and Tender Descenders are sealed in a box.
2	______	Open new pack of batteries and measure the voltage across it with a multimeter. It should be greater than 9.1 Volts. Battery 1: ______ Battery 2: _______
3	______	Place a battery inside each case.
4	______	Place a battery spacer inside each case.
5	______	Close the lid for the battery case. Screw it in.
6	______	Grab the primary and secondary ejection charges and the small flat-head screwdriver. Locate the drogue port on both RRC3 altimeters. The primary goes to the sled labeled primary, and the secondary goes to the sled labeled secondary.

Continued on next page

Table 39 – continued from previous page

#	Inspector Initials	Step Instructions
7	______	Thread both of the e-matches on the charges through the passthrough hole labeled ”D”. Open the ”Drogue” ports on both altimeters and attach the charges to the correct altimeter. Close the "Drogue" ports. If it is difficult to thread the second e-match through the hole, thread one wire at a time.
8	______	Grab the Tender Descenders. Ensure the e-matches attached to them are trimmed to about 12 in. Thread these e-matches through the passthrough hole labeled ”M”. Open the ”Main” ports on the altimeters and attach the adapted Tender Descender to the primary RRC3. Attach the non-adapted Tender Descender to the secondary RRC3. Close the ”Main” ports.
9	______	Grab the deployment bag charge labeled ”ADB1/FDB1” and thread the e-match through the passthrough hole labeled ”A.” Ensure this e-match is trimmed to about 8 in. Open the ”AUX” port on the primary RRC3 altimeter. Connect the e-match to this port. Close the port.
10	______	Grab the deployment bag charge labeled ”ADB2/FDB2” and thread the e-match through the passthrough hole labeled ”A.” Ensure this e-match is trimmed to about 8 in. Open the ”AUX” port on the secondary RRC3 altimeter. Connect the e-match to this port. Close the port.
11	______	Flatten all the e-match wires to the bulkhead where the wood screw and washer with seal go.
12	______	Grab the wood screw and washer with rubber seal and screw the assembly over the e-match holes.
13	______	Attach the stitched loop Quick Link at the main end to the two eye bolts in the aft end of the airframe. Ensure it is tight.

Table 40: This checklist is used to set up the aft ejection unit.

Aft Ejection Unit Assembly

Assembler Signature:__________________ **Safety Officer Signature:** __________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: -Verify that all ejection charges are appropriately tight and connected. -Verify that pressure is engaged and all six 1/4-20 nuts are tight. -Verify that both switches are accessible from static port holes. **Prerequisite lists:** -Aft Altimeters -Aft Avionics. **ALL** checklists below must be completed and verified by an inspector for Safety Officer’s signoff.
	______	**Tools Needed:** 1/8 in. hex key, 1.5 mm hex key, 7/16 in. socket, socket wrench, socket extension, flat-head screwdriver
	______	**Components Needed:** Aft Pressure Seal, Aft Altimeters Sleds, Aft Altimeters Bay Housing, Aft Avionics, 3x 10-24 bolts, 4x 4-40 bolts, 4x 4-40 nuts
S	______	**Safety Consideration: This checklist will deal with ejection charges. Ensure that all personnel are aware and wearing proper PPE. Remove all ignition sources from the area before continuing.**

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Table 40 – continued from previous page

#	Inspector Initials	Step Instructions
1	______	Install the aft avionics onto the bottom of the aft ejection bay housing using four 4-40 bolts and nuts.
2	______	Slide both altimeter sleds into the housing.
3	______	Ensure that no wires are disconnected or pinched while installing the sleds.
S	______	**Safety Consideration: Disconnected wires will result in an ejection charge failure.**
4	______	Check that the switches are accessible from the exterior of the housing.
5	______	Verify that locknuts have been installed on the eye bolts on the aft pressure seal.
6	______	Connect the housing to the aft pressure seal using four 4-40 bolts and a 1.5 mm hex key. The eye bolts should be oriented so that they are aligned with the switch mounts on the altimeter sleds. Ensure that no wires are pinched or disconnected during this process.
7	______	Check that the housing and pressure seal are flush together.
8	______	Loosen the pressure sealing bolts prior to installation.

Table 41: This checklist is used to assemble the BEAVS system.

		BEAVS Assembly
		Assembler Signature:________________ **Safety Officer Signature:** ________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: -Verify radial bolt tightness. -Verify system is powered on, verify blades fully retracted. **Prerequisite lists:** -Prefield Inspection -Preflight Inspection. **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** 1/8 in. hex key, flat-head screwdriver, micro flat-head screwdriver
	______	**Components Needed:** Aft airframe, BEAVS, 4x 10-24 bolts
S	______	**Safety Consideration: Failure to follow these steps in sequential order could result in mission failure.**
1	______	Ensure all screw terminals are fastened tightly and an SD card is installed in the Teensy 3.6.
S	______	**Safety Consideration: Failure to tighten screw terminals could result in power loss during flight.**
2	______	Ensure blades are fully retracted.
S	______	**Safety Consideration: Failure to ensure blades are not fully retracted before powering on will cause encoders to lose positional accuracy on blades.**
3	______	Plug in battery.
4	______	Ensure all wires are appropriately secured and none are strained.
S	______	**Safety Consideration: Strain on wires could cause them to come loose or break during launch.**
5	______	Ensure all radial bolts are removed from bulkhead.

Continued on next page

Table 41 – continued from previous page

#	Inspector Initials	Step Instructions
6	______	Locate notch in bulkhead and align with launch lug.
7	______	Slide BEAVS into fore end of aft airframe until notch passes launch lug.
8	______	Rotate 45° counter clockwise and continue sliding bulkhead down until it is aligned with radial bolt holes.
9	______	Install 4x 10-24 radial bolts using 1/8 hex key.
10	______	Verify system is still powered on.
11	______	Verify slots in airframe are aligned with blades.

Table 42: This checklist is used to assemble the af. ballast bayt

Aft Ballast Bay Assembly		
Assembler Signature:__________________		**Safety Officer Signature: __________________**
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: -Weight recorded -Nuts securing ballast bay are in place **Prerequisite lists:** -Prefield Inspection -Preflight Inspection -Canister Assembly. **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Scale, 9/16 in. crescent wrench, 1.5 mm hex key
	______	**Components Needed:** 4x 4-40 bolts, 1x 3/8 nut, ballast bay, ballast bay cap, aft canister, ballast material
1	______	Tare scale with no items on scale.
2	______	Place ballast container and cap on scale.
3	______	Fill ballast container with ___ lbf of ballast. (Ballast amount determined based on launch day conditions)
4	______	Recorded weight: ___ lbf.
S	______	**Safety Consideration: Failure to place correct amount of weight in ballast container could result in unstable launch vehicle.**
5	______	Place 4-40 bolts into ballast bay and secure with 4-40 nuts on cap.
6	______	Slide ballast bay onto threaded rod extending from canister.
7	______	Place 3/8-16 in. nut onto end of threaded rod and tighten with 9/16 in. crescent wrench until secure against bulkhead.

Table 43: This checklist is used to assemble the canister.

#	Inspector Initials	Step Instructions
		Canister Assembly
		Assembler Signature:__________ **Safety Officer Signature:** __________
	______	**Safety Officer Checklist:** -Ensure safety officer signed off on canister subsystems checklists (Aft Ejection Bay, Aft Avionics bay, Aft Recovery, Aft Ballast bay). **Prerequisite lists:** -Aft Ejection Unit -Altimeter Setup **ALL** steps below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Socket wrench screwdriver with 1/4 in. square drive, 1/8 in. Hex Key, 7/16 in. or 11mm Socket with 1/4 in. square drive, 1/4-to-1/4 in. square drive extension.
	______	**Components Needed:** Canister, 3/8-16 Threaded Rod, 3/8-16 Nut x3, Washer x3, GoPro Hero5, GoPro Hero3 x2, Yi 4K Action Camera x2, canister bulkhead, top camera mount, bottom camera mount, Aft Ejection Unit, 1/4-20 Nuts x6, 10-24 Button Hexagon Socket Bolts x6
S	______	**Safety Consideration: Inspect fillets on Canister base bulkhead.**
1	______	Turn on all five cameras and ensure the mode is set to "Video".
2	______	Place all five cameras in the correct mount location on aft mount. Next to each mounting location is either a V, III, or C. V is for the GoPro Hero5, III is for the GoPro Hero3, and C is for the Yi 4K action camera (GoPro clone).
3	______	Place fore camera mount on camera system.
4	______	Place camera system in canister, aligning camera lenses to camera lens holes.
5	______	Place fore bulkhead on threaded rod between two nuts. The fore nut flush with a washer against the fore end of the bulkhead, leaving as little rod fore of the bulkhead as possible. The aft nut butted up against a washer against the aft end of the bulkhead.
6	______	Place bulkhead/threaded rod assembly in canister.
7	______	Place washer and nut on threaded rod sticking out of the aft and of the canister.
S	______	**Safety Consideration: Ensure top and bottom nuts are tight against their corresponding bulkhead.**
S	______	**Safety Consideration: Ensure that ejection charge wires are not pinched while installing aft electronics bay.**
8	______	Install aft electronics bay into the canister aligning so that static port holes and radial bolt holes are visible from the exterior of the canister.
9	______	Partially install three 10-24 bolts into the aluminum bulkhead as a place holder.
10	______	Check that the switches are accessible from the exterior of the canister. (Rotate clockwise until a beep is heard, then rotate counterclockwise to disengage)
11	______	Tighten all six pressure sealing nuts to engage pressure seal.
12	______	Uninstall the radial bolts.
13	______	Press shutter button to begin recording on all five cameras through canister port hole. Do this right before installing canister into aft airframe.
14	______	***Move on to Aft Section Preparation/Assembly checklist.***

Table 44: This checklist is used to assemble the aft section.

Aft Section Assembly Assembler Signature:________________ Safety Officer Signature: ________________		
#	Inspector Initials	Step Instructions
	______	**Safety Officer Checklist:** -Ensure Recovery Harnesses are properly secured. **Prerequisite lists:** -BEAVS -Canister -Aft Ejection Unit -Aft Recovery Harness -Motor. **ALL** steps below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** 1/8 in. Hex Key, 10-24 Tap, Tap Wrench.
	______	**Components Needed:** BEAVS, Canister (Camera System and Aft Ejection Unit), Aft Recovery Harness, 10-24 Button Hexagon Socket Bolts x10
S	______	**Safety Consideration: Cover all skin on hands/arms to prevent fiberglass/carbon fiber splinters.**
1	______	Inspect Fins, Body Tube, Motor Retainer, Motor Tube, Launch Lugs, and Centering Rings for any visual imperfections that may impact flight/recovery.
2	______	Insert BEAVS into Fore end of the Aft Body Tube.
3	______	Rotate BEAVS such that the notch in the bulkhead is aligned with the launch lug and can get past it.
4	______	Once BEAVS is past the launch lug, rotate 90°to realign blades with slots.
5	______	Align BEAVS bulkhead bolt holes with clearance holes in body tube.
6	______	Insert 10-24 Button Hexagon Socket Bolts x4 into BEAVS bulkhead.
7	______	Tighten down bolts with 1/8" Hex Key.
8	______	Insert fully integrated Canister into body tube.
S	______	**Safety Consideration: The canister can ONLY be aligned one way.**
9	______	Align bulkhead holes and port holes in the canister with the matching holes in the body tube.
10	______	Insert 10-24 Button Hexagon Socket Bolts x6 into Aft Ejection Unit aluminum bulkhead.
11	______	Tighten down bolts with 1/8 in. Hex Key.

Table 45: This checklist is used to integrate the aft recovery systems into the airframe.

Aft Recovery Integration Assembler Signature:________________ Safety Officer Signature: ________________		
#	Inspector Initials	Step Instructions
	______	**Safety Officer Checklist:** - Safety Officer has all three Remove Before Flight (RBF) tags in his hand. **Prerequisite lists:** -Main Parachute Packing
		Continued on next page

Table 45 – continued from previous page

#	Inspector Initials	Step Instructions
		-Drogue Parachute Packing -Recovery Harness -Aft Altimeter Setup -Aft Ejection Unit Setup **ALL** steps below must be completed and verified by an inspector for Safety Officer's signoff.
	_____	**Tools Needed:** N/A
	_____	**Components Needed:** Aft fully assembled recovery harness
S	_____	**Safety Consideration: Ensure all sharp objects, heat sources, and corrosive materials are removed from work space. Work space should be clear of any items not related to harness and parachute prep. Failure to follow all steps will result in complete mission failure due to recovery failure.**
	_______	**Safety Officer Check Off:** There are three RBF tags on the [fore/aft] system.
1	_____	Ensure that the stitched loop Quick Link at the main end is attached to the two eye bolts on the [aft/fore] bulkhead. Ensure it is tight. Ensure two Tender Descender Quick Links are tight around the main Quick Link and the nylon/Kevlar harness.
2	_____	Ensure the deployment bag charges are sitting on the bulkhead. Ensure the primary and backup separation charges are hanging outside of the airframe.
3	_____	Spread cellulose insulation over the deployment bag charge.
4	_____	Take the Kevlar blast protector and spread it over the top of the airframe. Place a hand in it and push down so a cup is formed.
5	_____	Take the tape off of the parachute shrouds and remove the RBF tag and hand to safety officer.
6	_____	Take the tape off the deployment bag and remove the RBF tag and hand to safety officer.
7	_____	Grab the deployment bag and place the bottom of it in the cup formed by the Kevlar. Push this until it hits the bulkhead. Ensure the portion of the shock cord that the drogue pulls on remains taught outside of the airframe during this process.
8	_____	Grab all of the riser sections which are aft of loop #2 (the loop attached to the top of the deployment bag). Place this material on the side of the deployment bag which has the Tender Descenders.
9	_____	Grab the other Kevlar blast protector and set it on top of the airframe. Form a cup with this Kevlar as well. Place both of the separation ejection charges hanging outside of the airframe in the Kevlar cup. Place a handful of cellulose insulation inside the cup and close the Kevlar over it.
10	_____	Take the rest of the riser, which includes the drogue, and place it on top of the Kevlar.
11	_____	Take the tape off the drogue and remove the RBF tag and hand to safety officer.

4.2.4 Fore Launch Vehicle Assembly

Table 46: This checklist is used to assemble the fore hard point.

Fore Hard Point Checklist		
Assembler Signature:________________		Safety Officer Signature: ________________
#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Ensure radial bolts are not over torqued by visual inspection of airframe.
		- Ensure pass through bulkhead is clean.
		Prerequisite lists: N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	_____	**Tools Needed:** 1/8" hex key, 3/8" hex key, 7/16" wrench, Phillips screwdriver, paper towel, acetone
	_____	**Components Needed:** Fore airframe, FHP, 10-24 radial bolts x6, 3/8" eye hook x2
S	_____	**Safety Consideration: Over torquing hardware can cause airframe deformation and damage to components.**
1	_____	Clean pass through bulkhead and inside of airframe with acetone and towel.
2	_____	If FHP removed from airframe, clean with acetone and towel.
3	_____	If FHP removed from airframe, tighten 1/4 - 20 bolts and screws.
4	_____	If FHP removed from airframe, screw on eye hooks to bulkhead.
5	_____	If FHPremoved from airframe, slide into fore end of airframe, funnel side first, lining up bulkhead line to PLEC switch hole.
6	_____	Tighten radial bolts by hand, skipping every other while positioning FHP.
7	_____	Screw in remaining bolts, and tighten all with hex key. Do not tighten to point of airframe deformation.
8	_____	Remove eye hooks from FHP.
9	_____	Ensure pass through bulkhead is clean of any towel lint or other contaminant.
S	_____	**Safety Consideration: Failure to properly clean pass through bulkhead may result in failed payload ejection and black powder residue on PLEC.**

Table 47: This checklist is used to integrate the payload into the airframe.

Payload Integration Checklist		
Assembler Signature:________________		Safety Officer Signature: ________________
#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Ensure PLEC is disarmed.
		Prerequisite lists:
		-Payload Wrap Assembly Checklist
		-Fore Hard Point Checklist
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.

Continued on next page

Table 47 – continued from previous page

#	Inspector Initials	Step Instructions
	______	**Tools Needed:** Crimping tool, 3/8-16 nut and washer x2, 9/16 cut off wrench, flat head screwdriver
	______	**Components Needed:** PEARS assembly, guide rod, fore airframe, PLEC battery, battery mount
S	______	**Safety Consideration: Keep all ignition sources away from assembly process.**
S	______	**Safety Consideration: Ensure PLEC battery is Disconnected from Assembly.**
1	______	Using multimeter, ensure that each PLEC wire set has no voltage across them: Blue______V Red______V Green______V Yellow______V Black______V
S	______	**Safety Consideration: All voltages must be zero. Failure to ensure 0V will result in premature black powder ignition during assembly.**
2	______	Remove tape from one e-match lead, connect to the corresponding color on PLEC, and crimp.
3	______	Repeat for remaining 9 e-match leads, ensuring colors match.
4	______	Ensure rotary switch is in the shunting position.
S	______	**Safety Consideration: Failure to ensure circuit is shunted can result in premature black powder ignition during assembly.**
S	______	**Safety Consideration: Ensure ground station is not communicating with PLEC. Failure to ensure there is no communication will result in premature black powder ignition.**
5	______	Place battery into sled, and slide on threaded rod.
6	______	Secure battery sled with a nut, and tighten firmly against PLEC cover.
7	______	Connect battery to PLEC via Deans Connector, and verify a secure connection.
8	______	Turn switch, and ensure PLEC is able to arm.
9	______	Disarm switch by turning it back to the shunting position.
S	______	**Safety Consideration: Failure to return switch to shunting position could result in premature black powder ignition during further assembly.**
10	______	Lay airframe horizontally and pass guide rod from fore end of airframe through FHP hole that is not in the center. Pass rod until washers on rod hit FHP bulkhead.
11	______	Rotate Airframe until rod is on the top.
12	______	Begin inserting PEARS assembly threaded rod into aft side of airframe, lining up hole in the PLEC mount with the guide rod.
13	______	Keeping pressure on guide rod from fore side, insert bulkhead, making sure guide rod passes through PLEC mount.
14	______	Allowing guide rod to move, push PEARS until spacer is approximately 2 in. from end of airframe.
15	______	Stuff cavity with cellulose insulation and wrap Kevlar sheet around charges.
16	______	Continue pushing system into airframe until wrap touches end.
17	______	Rotate wrap so that Tender Descenders do not allow wrap to move more than 0.5" from assembly.
18	______	Push down edges of wrap, while applying force to insert wrap into airframe.
19	______	Once end of wrap is inserted all the way around, continue pushing on wrap, sliding zip ties along wrap, and off the end of airframe.
20	______	Continue pushing on wrap, keeping guide rod inserted, until threaded rod passes through FHP, and assembly is fully seated against pass through bulkhead.
21	______	Do not remove guide rod.
22	______	Check that the rotary switch on PLEC is accessible through hole in airframe.

Continued on next page

Table 47 – continued from previous page

#	Inspector Initials	Step Instructions
23	______	Keep pressure on guide rod.
24	______	Place a washer and 3/8 - 16 nut onto rod, and tighten down fully using cut off wrench.
S	______	**Safety Consideration: Ensure ground station is not communicating with PLEC. Failure to ensure there is no communication will result in premature black powder ignition.**
25	______	Again, check that switch is accessible by arming system with flat head screwdriver. Light should be visible.
26	______	Disarm the PLEC.
S	______	**Safety Consideration: Failure to disarm the system will result in loss of battery charge and failed payload ejection.**
27	______	Remove Guide Rod.

Table 48: This checklist is used to assemble the fore ballast bay.

Fore Ballast Bay Assembly		
Assembler Signature:__________________		Safety Officer Signature: __________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: -Weight recorded -Nuts securing ballast bay are in place. **Prerequisite lists:** -Prefield Inspection -Preflight Inspection -Payload Integration. **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Scale, 9/16 in. crescent wrench, 1.5 mm hex key
	______	**Components Needed:** 4x 4-40 bolts, 1x 3/8 nut, ballast bay, ballast bay cap, aft canister, ballast material
1	______	Tare scale with no items on scale.
2	______	Place ballast container and cap on scale.
3	______	Fill ballast container with ___ lbf of ballast. (Ballast amount determined based on launch day conditions)
4	______	Recorded weight: ___ lbf.
S	______	**Safety Consideration: Failure to place correct amount of weight in ballast container could result in unstable launch vehicle.**
5	______	Place 4-40 bolts into ballast bay and secure with 4-40 nuts on cap.
6	______	Slide ballast bay onto threaded rod extending from Fore Hard Point.
7	______	Place 3/8-16 in. nut onto end of threaded rod and tighten with 9/16 in. crescent wrench until secure against bulkhead.

Table 49: This checklist is used to integrate the fore avionics unit into the airframe.

Fore Avionics Integration		
Assembler Signature:__________________		**Safety Officer Signature:** __________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist:
		-Verify that pressure is engaged and all six 1/4-20 nuts are tight.
		-Verify that the locknut and washer are secure the pressure seal into the bay.
		Prerequisite lists:
		-Fore ATU.
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** 1.5 mm hex key, 7/16 in. socket, socket wrench, socket extension, 1/4 in. wrench, x2 11 mm wrench, flat-head screwdriver, ruler, measuring tape.
	______	**Components Needed:** Nosecone, Fore Avionics, Nosecone Pressure Seal, 4x 4-40 bolts
1	______	Install fore avionics to nosecone pressure seal (small side) using four 4-40 bolts and nuts.
2	______	Loosen all six pressure sealing nuts.
3	______	Check that the nosecone threaded rod has a washer with two nuts at the appropriate distance. The aft side of the washer should be 13.25 in. from the aft of the nosecone tip.
4	______	Ensure that the fore side of the black washer is 2 in. from the fore end of the threaded rod.
5	______	Place the threaded rod, without the tip, through the avionics and pressure seal and place the locknut just on the end of the threaded rod to keep the bulkhead in place. Do not tighten the locknut.
6	______	Install the pressure seal and avionics into the nosecone along the quarter in. threaded rod in the nosecone. Keep the seal as level as possible during integration.
7	______	Press the bay into the nosecone until the bulkhead is 6.5 in. from the end of the coupler.
8	______	Orient the pressure seal so that it is approximately level in the nosecone.
9	______	Tighten all six pressure sealing nuts using the socket and socket wrench.
S	______	**Safety Consideration: Be sure that the pressure seal is engaged securely.**
10	______	Tighten a locknut onto the nosecone threaded rod. Tighten until one thread extends past the nylon ring.
11	______	Tighten the tip onto the threaded rod, centering the tip to the nosecone in the process.

Table 50: This checklist is used to set up the fore ejection unit.

Fore Ejection Unit Assembly		
Assembler Signature:__________________		**Safety Officer Signature:** __________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist:
		-Verify that all six 10-24 radial bolts are properly and fully installed.
		-Verify that all ejection charges are appropriately tight and connected.
		-Verify that pressure is engaged and all six 1/4-20 nuts are tight.
		-Verify that both switches are accessible from static port holes.

Continued on next page

Table 50 – continued from previous page

#	Inspector Initials	Step Instructions
		Prerequisite lists: -Fore Altimeters -Payload Integration. **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** 1/8 in. hex key, 1.5 mm hex key, 7/16 in. socket, socket wrench, socket extension, flat-head screwdriver
	______	**Components Needed:** Fore Section, Fore Pressure Seal, Fore Altimeters Sleds, Fore Altimeters Bay Housing, 6x 10-24 bolts, 4x 4-40 bolts
S	______	**Safety Consideration: This checklist will deal with ejection charges. Ensure that all personnel are aware and wearing proper PPE. Remove all ignition sources from the area before continuing.**
1	______	Slide both altimeter sleds into the housing.
2	______	Ensure that no wires are disconnected or pinched while installing the sleds.
S	______	**Safety Consideration: Disconnected wires will result in an ejection charge failure.**
3	______	Check that the switches are accessible from the exterior of the housing.
4	______	Verify that locknuts have been installed on the eye bolts on the aft pressure seal.
5	______	Connect the housing to the aft pressure seal using four 4-40 bolts and a 1.5 mm hex key. The eye bolts should be oriented so that they are aligned with the switch mounts on the altimeter sleds. Ensure that no wires are pinched or disconnected during this process.
6	______	Check that the housing and pressure seal are flush together.
7	______	Loosen the pressure sealing bolts prior to installation.
S	______	**Safety Consideration: Ensure that ejection charge wires are not pinched while installing the fore ejection bay.**
8	______	Install fore ejection bay into the fore airframe aligning so that the static port holes and radial bolt holes are visible from the exterior of the airframe.
9	______	Verify that the switches are accessible from the exterior of the airframe.
10	______	Install all six 10-24 radial bolts aluminum ring.
11	______	Verify that the switches are accessible from the accessible from the exterior of the airframe.
12	______	Tighten all six pressure sealing nuts to engage pressure seal.

Table 51: This checklist is used to integrate the fore recovery systems into the airframe.

Fore Recovery Integration		
Assembler Signature:__________________		**Safety Officer Signature:** __________________
#	**Inspector Initials**	**Step Instructions**
	______	**Safety Officer Checklist:** - Safety officer has all three RBF tags in his hand. - The Quick Link at the drogue end of the recovery harness is attached to the 2 eye bolts in the nosecone. **Prerequisite lists:**

Continued on next page

Table 51 – continued from previous page

#	Inspector Initials	Step Instructions
		-Main Parachute Packing
		-Drogue Parachute Packing
		-Recovery Harness
		-Fore Avionics Integration
		-Altimeter Setup
		-Ejection Bay Setup
		ALL steps below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** N/A
	______	**Components Needed:** [Fore/Aft] fully assembled recovery harness
S	______	**Safety Consideration: Ensure all sharp objects, heat sources, and corrosive materials are removed from work space. Work space should be clear of any items not related to harness and parachute prep. Failure to follow all steps will result in complete mission failure due to recovery failure.**
	_______	**Safety Officer Check Off:** There are three RBF tags on the [fore/aft] system.
1	______	Ensure that the stitched loop Quick Link at the main end is attached to the two eye bolts on the [aft/fore] bulkhead. Ensure it is tight. Ensure two Tender Descender Quick Links are tight around the main Quick Link and the nylon/Kevlar harness.
2	______	Ensure the deployment bag charges are sitting on the bulkhead. Ensure the primary and backup separation charges are hanging outside of the airframe.
3	______	Spread cellulose insulation over the deployment bag charge.
4	______	Take the Kevlar blast protector and spread it over the top of the airframe. Place a hand in it and push down so a cup is formed.
5	______	Take the tape off of the parachute shrouds and remove the RBF tag and hand to safety officer.
6	______	Take the tape off the deployment bag and remove the RBF tag and hand to safety officer.
7	______	Grab the deployment bag and place the bottom of it in the cup formed by the Kevlar. Push this until it hits the bulkhead. Ensure the portion of the shock cord that the drogue pulls on remains taught outside of the airframe during this process.
8	______	Grab all of the riser sections which are aft of loop #2 (the loop attached to the top of the deployment bag). Place this material on the side of the deployment bag which has the Tender Descenders.
9	______	Grab the other Kevlar blast protector and set it on top of the airframe. Form a cup with this Kevlar as well. Place both of the separation ejection charges hanging outside of the airframe in the Kevlar cup. Place a handful of cellulose insulation inside the cup and close the Kevlar over it.
10	______	Take the Quick Link at the drogue end of the riser. Attach it to the two eye bolts in the nosecone.
11	______	Take the rest of the riser, which includes the drogue, and place it on top of the Kevlar.
12	______	Take the tape off the drogue and remove the RBF tag and hand to safety officer.

4.2.5 Payload Assembly

Table 52: This checklist is used to assemble the black powder charges used for payload ejection.

Payload Ejection Charge Checklist		
Assembler Signature:_________________ **Safety Officer Signature:** _________________		
Note: This checklist will be repeated for ejection charges of 1.6 g and 2.0 g.		
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: -Verify recorded e-match resistance for both charges. -Ensure charges are packed well by squeezing charge. -Ensure wires are taped. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** black powder vial, masking tape, multimeter, scale, scissors, sharpie, pliers, black powder funnel
	______	**Components Needed:** e-match x2, 4F Black Powder, Santoprene, surgical tubing, zip ties x4
S	______	**Safety Consideration: All steps to be carried out by HPR level 1 certified team member.**
S	______	**Safety Consideration: Process includes usage of black powder; follow Black Powder Handling for proper handling procedure.**
S	______	**Safety Consideration: Ensure all team members in close proximity wear safety glasses to avoid black powder contacting the eyes.**
S	______	**Safety Consideration: Ensure all ignition sources have been removed from the area.**
S	______	**Safety Consideration: Make sure the multimeter is set to measure Ohms before checking the e-match. Failure to do so may result in injury due to premature charge ignition.**
S	______	**Safety Consideration: Failure to correctly load charge may result in a failed ejection of payload.**
1	______	Verify e-match resistance is between 1.3 - 1.7 Ohms. Record Resistance Primary ____ Ohms Secondary ____ Ohms
2	______	Cover ends of e-match leads with masking tape.
3	______	Cut 4 pieces of Santoprene rubber rod into approximately 0.5 inch lengths using scissors.
4	______	Cut 2 pieces of surgical tubing into lengths of approximately 3 in. sections using scissors.
5	______	Insert a piece of Santoprene into one end of each piece of surgical tubing.
6	______	Secure Santoprene in each piece of surgical tubing by tightening a zip tie around the outside of the surgical tubing and Santoprene with pliers.
S	______	**Safety Consideration: Failure to measure in grams will result in wrong sizing of BP charges.**
7	______	Ensure the scale is measuring in grams. Ensure the scale has been zeroed.
8	______	Measure 1.2 g of black powder for the Primary charge. Record Mass: Primary: ____g
9	______	Insert funnel into the open end of a surgical tubing with zip tied end.
10	______	Pour approximately half of black powder into the Primary surgical tubing set-up.
11	______	Remove funnel.
12	______	Slide the red covering around the tip of the e-match down the blue and white wire about 12 inches.
13	______	Insert the tip of the e-match into the black powder in the surgical tubing set up.
Continued on next page		

Table 52 – continued from previous page

#	Inspector Initials	Step Instructions
14	______	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.
15	______	Pour the remaining black powder into the surgical tubing set-up.
16	______	Remove funnel.
17	______	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.
S	______	**Safety Consideration: Allowing extra room in black powder charges will result in failed ejection.**
18	______	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.
19	______	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.
20	______	Secure piece of Santoprene that has not been zip tied by tightening a zip tie around the outside of the surgical tubing and Santoprene with pliers.
S	______	**Safety Consideration: Failure to check zip tie tightness may result in failed ejection during recovery.**
21	______	Double check that the zip ties are secured as tightly as possible using pliers.
22	______	Remove zip tie tails using scissors.
23	______	Write "Primary" with the mass of the black powder on the outside of the surgical tubing in sharpie.
24	______	Cut e-match leaving approximately 6 in. outside the charge.
25	______	Separate wires and strip each 0.25 in.
26	______	Tape each wire separately.
27	______	Set aside away from all ignition sources. Ensure everyone in the vicinity knows the charge has been packed.

Table 53: This checklist is used to assemble the Tender Descenders used for payload retention

Payload Tender Descender Assembly Checklist		
Assembler Signature:__________________ **Safety Officer Signature:** __________________		
Note: This checklist will be repeated for the second Tender Descender.		
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: -Verify recorded e-match resistance for both Tender Descenders. -Ensure tape on back side of housing is fully secured. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** black powder vial, masking tape, multimeter, scale, scissors
	______	**Components Needed:** Tender Descender housing x2, e-match x2, 4F Black Powder
S	______	**Safety Consideration: All steps to be carried out by HPR level 1 certified team member.**

Continued on next page

Table 53 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: Process includes usage of black powder; follow Black Powder Handling for proper handling procedure.**
S	______	**Safety Consideration: Ensure all team members in close proximity wear safety glasses to avoid black powder contacting the eyes.**
S	______	**Safety Consideration: Ensure all ignition sources have been removed from the area.**
S	______	**Safety Consideration: Make sure the multimeter is set to measure Ohms before checking the e-match. Failure to do so may result in injury due to premature charge ignition.**
S	______	**Safety Consideration: Failure to correctly load charge may result in a failed ejection of payload.**
1	______	Verify e-match resistance is between 1.3 - 1.7 Ohms. Record Resistance Primary ____ Ohms
2	______	Install e-match into aluminum housing.
3	______	Tape e-match tail to backside of housing, ensuring hole is completely taped over.
4	______	Measure 0.3 g 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, and measure 0.3 g.
6	______	Pour measured 4F Black Powder into ejection canister.
S	______	**Safety Consideration: Confirm that Black Powder is sealed within the ejection canister.**
7	______	Ensure e-match is contacting black powder, and place strip of tape over canister hole.
8	______	Cut e-match tail approximately 6 in. from housing.
9	______	Separate wires and strip each 0.25 in.
10	______	Tape each wire separately.
11	______	Set aside away from all ignition sources. Ensure everyone in the vicinity knows the charge has been packed.

Table 54: This checklist is used to assemble the payload ARRD.

Payload ARRD Assembly Checklist **Assembler Signature:**_________________ **Safety Officer Signature:** _________________		
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Verify recorded e-match resistance. - Physically ensure the link is secured to body. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Black Powder Vial, Masking Tape, Multimeter, acetone, towel.
	______	**Components Needed:** ARRD, e-match, Black Powder.
S	______	**Safety Consideration: All steps to be carried out by HPR level 1 certified team member.**
S	______	**Safety Consideration: Process includes usage of black powder; follow Black Powder Handling for proper handling procedure.**
S	______	**Safety Consideration: Ensure all team members in close proximity wear safety glasses to avoid black powder contacting the eyes.**

Continued on next page

Table 54 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: Ensure all ignition sources have been removed from the area.**
S	______	**Safety Consideration: Make sure the multimeter is set to measure Ohms before checking the e-match. Failure to do so may result in injury due to premature charge ignition.**
S	______	**Safety Consideration: Failure to correctly load charge may result in a failed retention or ejection of payload.**
1	______	Verify e-match resistance is between 1.3 - 1.7 Ohms. Record Resistance ______ Ohms.
2	______	Unscrew base and push piston up to remove link. If piston and link are stuck, carefully hit on flat surface to remove piston before removing link.
3	______	Remove piston and remove the 5 1/4" ball bearings, careful not to dislodge spring..
4	______	Remove the cartridge from base.
5	______	Clean all components with acetone.
6	______	Place 5 1/4" ball bearings in red body.
7	______	Insert link into red body and push piston into body up to the end of the threads.
8	______	Measure black powder using black powder vial (0.3 g if vial is not available).
9	______	Thread e-match through cartridge and base.
10	______	Pour measured black powder into cartridge.
11	______	Place approximate 3/4" dia. tape over the end of the cartridge.
S	______	**Safety Consideration: Confirm that Black Powder is sealed within the ejection canister.**
12	______	Screw together base and body until firmly seated.
13	______	Grasp body and base and firmly pull on link while twisting.
14	______	If not fully secured, unscrew base, and repeat assembly process from the start.

Table 55: This checklist is used to set up the protoboard rover electronics.

Protoboard Rover Electronics Checklist

Assembler Signature:__________________ **Safety Officer Signature:** __________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: -All electronics are securely attached to the rover. -Loose wires have been secured to the rover body with use of zip ties so that none interfere with mechanical components. -Ensure exposed metal on all boards have been coated in an insulating material to avoid shorting between components. **Prerequisite lists:** -Rover Inspection. **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Wire strippers, Phillips head screwdriver, flat head screwdriver.
	______	**Components Needed:** assembled protoboard rover board, drive motor controller, 3 sonar modules, 1 2200mAh LiPo battery.
S	______	**Safety Consideration: Do not touch both terminals of the battery to any elecronics or body parts.**

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Table 55 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: Ensure all screw terminals are properly tightened and wires secured by pulling on each wire once tightened.**
1	______	Connect pins 1-5 from the protoboard to the corresponding pins on the drive motor controller according to the pictures in supporting document "Rover Electronics Connection Pictures (Protoboard)" 1: Black Wire 2-5: White Wire
2	______	Connect pins 6-7 from the protoboard to the corresponding pins on the sonar modules. 6, 7: White Wire
3	______	Connect pins 8-9 from the protoboard to the corresponding pins on the drive motor controller. 8: Orange Wire 9: Black Wire
S	______	**Safety Consideration: Pins 8 and 9 must be connected correctly, connecting them backwards will result in electrical shorting.**
4	______	Connect pins 10-11 from the protoboard to the corresponding pins on the auger motor. 10: Orange 11: Black
S	______	**Safety Consideration: Pins 10 and 11 must be connected correctly, connecting them backwards will result in the auger assembly tearing itself apart.**
5	______	Connect pins 12-15 from the protoboard to the corresponding pins on the soil retention motors. 12, 15: Orange 13, 14: Black
6	______	Connect pins 16-19 from the protoboard to the corresponding pins on the sonar modules. 16, 17: Black 18, 19: Orange
7	______	Connect pins 20-21 from the protoboard to the terminal which connect to the wire on the rover tail. 20, 21: Orange
8	______	Connect pins 22-25 from the drive motor controller to the corresponding pins on the drive motors. 22, 23: Orange 24, 25: Black
S	______	**Safety Consideration: Each of these pins must be connected correctly, failure to do so will result in the rover moving unpredictably.**
9	______	Wrap the rover tail and bridge the connection between pins 20 and 21.
10	______	Connect the battery while pins 20 and 21 are still bridged.
S	______	**Safety Consideration: Make sure pins 20 and 21 are connected for the entirety of rover integration. The rover will turn on if the connection is broken and the battery is plugged in.**

Table 56: This checklist is used to assemble the PEARS Removable system.

#	Inspector Initials	Step Instructions
		PEARS Removable Assembly Checklist
		Assembler Signature:________________ **Safety Officer Signature:** ________________
		Safety Officer Checklist:
		-Ensure a zero voltage was recorded for all PLEC leads.
		-Ensure ARRD is securely attached to bulkhead.
		-Ensure both Tender Descenders are securely liked to u-bolt.
		Prerequisite lists:
		-Payload Tender Descender Checklist
		-ARRD Assembly Checklist
		-Payload Ejection Charge Checklist
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** 3/16" hex key, 9/16" wrench, 9/16" cut off wrench, 1/2" wrench, 1/4" wrench, Measuring Tape, Phillips screwdriver, flathead screwdriver, tape, multimeter, small zip tie x2, crimping tool, crimping kit
	______	**Components Needed:** Packed Tender Descender x2, Tender Descender link x2, Assembled ARRD, Primary and Backup Ejection Charges, PEARS Removable Assembly
S	______	**Safety Consideration: Keep all ignition sources away from system**
1	______	Crimp on two Blue male crimps on to Primary Ejection Charge e-match ends, wrap crimped end with tape.
2	______	Crimp on two Red male crimps on to Backup Ejection Charge e-match ends, wrap crimped end with tape.
3	______	Crimp on two Green male crimps on to one Tender Descender e-match ends, wrap crimped end with tape.
4	______	Crimp on two Yellow male crimps on to other Tender Descender e-match ends, wrap crimped end with tape.
5	______	Crimp on two Black male crimps on to ARRD e-match end, wrap crimped end with tape.
6	______	Ensure battery is not connected to PLEC.
7	______	Ensure main bulkhead sits 4 in. from metal payload spacer; adjust nuts accordingly.
8	______	Tighten all nuts starting from spacer, to top of bulkhead, to bottom of bulkhead, to under PLEC, to on top of PLEC battery.
9	______	Tighten PLEC cover bolts.
10	______	Using multimeter, ensure that each PLEC wire set has no voltage across them: Blue______V Red______V Green______V Yellow______V Black______V
S	______	**Safety Consideration: All voltages must be zero. Failure to ensure 0V will result in premature black powder ignition during assembly.**
11	______	Screw in ARRD to bulkhead, ensuring rubber washer is between bulkhead and base. Use 1/2 wrench to tighten nut from bottom of bulkhead.
12	______	Carefully remove Tender Descender tape covering black powder.
13	______	Attach Tender Descender to link on u-bolt and with another loose link. Ensure top is fully compressed onto housing.

Continued on next page

Table 56 – continued from previous page

#	Inspector Initials	Step Instructions
14	______	Repeat for second Tender Descender on other u-bolt link.
15	______	Zip tie an ejection charge to each u-bolt, laying it flat close to the threaded rod. Cut zip tie ends.
16	______	Set assembly away from any ignition sources until ready to attach to payload wrap.

Table 57: This checklist is used to assemble the payload wrap.

Payload Wrap Assembly Checklist

Assembler Signature:________________ **Safety Officer Signature:** ________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: -Ensure all Tender Descender links are secure. -Ensure ARRD link screw is tight. -Ensure payload sits firmly against PEARS spacer. **Prerequisite lists:** -PEARS Removable Assembly -Rover Mechanical Inspection -Protoboard Rover Electronics Checklists **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Zip ties x13, needle nose pliers, duct tape
	______	**Components Needed:** Fiberglass wrap, Kevlar harness, Tender Descender Links x 3, PEARS removable assembly, rover, rover bulkheads
S	______	**Safety Consideration: Keep all ignition sources away from assembly process.**
1	______	Connect zip ties until long enough to wrap rover (3x medium size, 4x small size). Make 3 separate zip tie chains.
2	______	Lay the fiber glass wrap flat, and ensure Kevlar harness is securely taped to wrap. (Add additional tape if needed)
3	______	Open Tender Descender links, and put two on one end of the harness, and one on the other.
4	______	Wrap tail under rover, plugging in delayed power activation wires.
5	______	Power on rover.
S	______	**Safety Consideration: If rover rotates and activates from the tail springing out, it will begin the soil collection process. If activated, quickly pick up rover by chassis and power off using the switch.**
6	______	Place rover on wrap along taped harness, ensuring the wheel notch is placed on harness, with the notched wheel on the side with harness links.
7	______	Place aft bulkhead on rover wheel without notch, ensuring harness is in bulkhead slot.
8	______	Stretch harness around aft bulkhead and pull along rover body.
9	______	Place fore bulkhead on notched wheel, ensuring harness is in bulkhead slot on top and bottom.
10	______	Zip tie harness ends together to help hold Kevlar harness in place.
11	______	Lift wrap around the rover from both sides, ensuring rover does not rotate, and arm.
12	______	Place zip tie chain around wrap just inside one of the wheels, tighten until wrap almost touches itself.

Continued on next page

Table 57 – continued from previous page

#	Inspector Initials	Step Instructions
13	______	Place zip tie chain around wrap just inside the other wheel, tighten until wrap almost touches itself.
14	______	Place final zip tie chain around center of wrap, again until wrap almost touches itself.
15	______	At this point, the wrap should be able to be let go of, and will not unfold. Ensure that the bulkheads are in place, the harness is in the bulkhead slots, and the harness ends are in the front wheel slots.
16	______	Tighten zip ties, allowing wrap to overlap itself. Continue squeezing wrap and tightening zip ties, using pliers if needed, until wrap overlaps itself by approximately 0.5 in., and the wheels are fully compressed.
17	______	Test that the leading side of the wrapped rover is compressed enough to fit within the fore airframe without much difficulty.
18	______	Stretch out Kevlar sleeve and patch to cover aft bulkhead
19	______	Cut zip tie holding harness end together.
20	______	Place rover on end, with harness ends pointing up.
21	______	Place removable PEARS assembly on top of wrapped rover..
22	______	Using the open harness links, connect one link from each end to a Tender Descender.
23	______	Turn the ARRD link screw to remove the ARRD link.
24	______	Place the remaining Tender Descender link around ARRD loop, place on the ARRD, and screw in link screw.
25	______	Ensure all links are tight, ARRD screw is tight, and payload sits firmly against PEARS spacer.

4.2.6 Launch Pad Procedures

Table 58: This checklist is used to set of the launch vehicle on the launcher.

Setup on Launcher Checklist		
Assembler Signature:__________________		**Safety Officer Signature:** __________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: -Ensure launch lugs are properly positioned on the launch rail. **Prerequisite lists:** -Final Assembly **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Small Flathead wrench, 2 adjustable wrenches, shop towels, flat head screwdriver, step stool, flashlight
	______	**Components Needed:** Assembled launch vehicle, Launch rail fixtures
S	______	**Safety Consideration: Inspect the launch area for any flammable material and remove if necessary.**
1	______	Four members bring launch vehicle to the launch pad.

Continued on next page

Table 58 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: The launch vehicle weighs more than 50 lbf, and must be supported by a minimum of two people at all times.**
2	______	Bring launch rail to a horizontal position using adjustable wrenches.
3	______	Use shop towel and vinegar to wipe down launch rail.
S	______	**Safety Consideration: Failure to align launch vehicle buttons with rail may cause the breaking of these components and failure in launch.**
4	______	Carefully slide launch vehicle onto the launch rail, ensure co-linearity with launch rail.
S	______	**Safety Consideration: Verify specified angle of launch rail before locking in place.**
5	______	Bring launch rail to specified angle as per RSO instructions and verify launch rail bolts are tight.
6	______	All but two team members leave launch pad for arming of altimeters.
S	______	**Safety Consideration: Only two team members shall be present for the arming of the altimeters to ensure no distractions during the process.**
7	______	Setup the step stool.
8	______	Turn on the bottom RRC3, ensure the sequence of beeps match up.
-	______	5 second long beep
-	______	10 second pause
-	______	Series of beeps (Battery voltage, should be > 9.1V)
-	______	8 Beeps (800 ft)
-	______	3 Beeps
-	______	Seven continuity beeps – repeats every 2 seconds
-	______	If one beeps (only drogue), two beeps (only main), or three beeps (drogue + main) – remove altimeters and inspect
9	______	Repeat steps for the second RRC3
10	______	Repeat steps for the third RRC3
11	______	Repeat steps for the fourth RRC3

Table 59: This checklist is used to insert the ignite into the launch vehicle.

Igniter Insertion Checklist

Assembler Signature:__________________ **Safety Officer Signature:** __________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: -Ensure continuity of wire. **Prerequisite lists:** -Setup On Launcher **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Wire strippers
	______	**Components Needed:** igniter, launch vehicle on launch rail, assembled motor, 2x Pyrodex pellets, cardboard tube, motor cap, rubber band

Continued on next page

Table 59 – continued from previous page

#	Team Lead Initials	Step Instructions
S	______	**Safety Consideration: All steps to be carried out by team mentor.**
1	______	Strip ends of wires.
2	______	Check continuity of wires.
3	______	Straighten wires.
4	______	Insert igniter through 2x Pyrodex pellets securing the pellets to the end of the igniter with a rubber band.
5	______	Feed the igniter through the cardboard tube so that the Pyrodex pellets are resting on top of the cardboard tube.
S	______	**Safety Consideration: Clear the area of all non-essential personnel before inserting igniter.**
6	______	Insert the end of the igniter with the Pyrodex pellets into the middle of the motor, feeding the cardboard tube up the motor.
7	______	Ensure the wire is fed all the way into the motor.
8	______	Place the plastic cap on the motor, securing the igniter in the motor.
S	______	**Safety Consideration: Ensure ignition system is not armed.**
9	______	Touch ignition system wires together ensuring no shock is produced from the wires. A spark indicated the ignition system is armed.
10	______	Clip and wrap the ignition system wires to the igniter.
11	______	Locate the clipped wires away from the motor exhaust.
12	______	Make sure the clips are not touching any metal.
13	______	Clear the area for launch.

Table 60: This checklist is used to launch the launch vehicle.

Launch Checklist

Assembler Signature:_________________ **Safety Officer Signature:** _________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: -Ensure visual and GPS tracking is maintained -Ensure no one approaches the launch vehicle until Range Safety Officer says range is open. **Prerequisite lists:** Setup On Launcher **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** N/A
	______	**Components Needed:** remote launch system
S	______	**Safety Consideration: Arming launch system before clearance is granted by the Range Safety Officer can lead to premature ignition.**
1	______	Confirm with the Safety Officer that six (6) Remove Before Flight tags have been removed.
2	______	Move all personnel to safe areas designated by the Range Safety Officer.
3	______	Wait for launch clearance from the Range Safety Officer.
4	______	Arm the remote launch system.
5	______	Wait for countdown from the Range Safety Officer.

Continued on next page

Table 60 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: Countdown must be loud enough to everyone in the vicinity is aware of launch. Do not press launch button if people are unaware of launch.**
6	______	Press the launch button on the remote launch system.

4.2.7 Rover Deployment

Table 61: This checklist is to be followed when ejecting the payload after recovery

Rover Deployment Checklist		
Assembler Signature:__________________		Safety Officer Signature: __________________
#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Ensure there is no danger of a fire from ejection charges. - Ensure Disarming PLEC and Payload Removal Checklist is followed if ejection is unsuccessful. **Prerequisite lists:** - Launch Checklist **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Fire extinguisher
	______	**Components Needed:** Ground Station
S	______	**Safety Consideration: Follow all directions from the Range Safety Officer. Ensure range is clear before approaching airframe.**
1	______	Ensure range is clear and no one is within 100 ft of side of the fore airframe, or within 300 ft of the end of the airframe.
S	______	**Safety Consideration: Ejection of payload can cause debris to be thrown in the air. Ensure all personnel in the vicinity are wearing safety glasses.**
S	______	**Safety Consideration: Potential for fire depending on ground conditions. Have fire extinguisher on hand and watch for fire after ejection.**
2	______	Wait for Range Safety Officer to approve ejection before initiating sequence.
S	______	**Safety Consideration: Charge sequence is 5 seconds long, with events one second apart. Three retention devices are released followed by a primary and back up charge. Do not approach airframe until all charges have been ignited.**
3	______	Arm ejection controller, and announce that it is armed.
4	______	Announce payload ejection countdown.
5	______	Press and hold ejection button.
6	______	Disarm ground station and ensure communication to PLEC has terminated.
7	______	Wait to approach launch vehicle fore 30 seconds after final charge is ignited.
8	______	Recovery all components: Wrap____ Kevlar Harness____, Fore Bulkhead____ Aft Bulkhead____

Continued on next page

Table 61 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: If ejection is not successful, proceed to Disarming PLEC and Payload Removal Checklist**

4.2.8 Post Flight Inspections

Table 62: This checklist is used to inspect the launch vehicle after it is recovered following a launch.

		Post Flight Launch Vehicle Checklist **Assembler Signature:**________________ **Safety Officer Signature:** ________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Any and all damage should be recorded and team members notified. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** acetone, paper towels
	______	**Components Needed:** Fire extinguisher
S	______	**Safety Consideration: Failure to notify team of damage to launch vehicle could result in unstable flight or full mission failure.**
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. Clean dirt with acetone and paper towels.
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	______	Record any damage below and notify the team. ____

Table 63: This checklist is used to inspect the rover after it is recovered following a launch.

		Post Flight Rover Checklist **Assembler Signature:**________________ **Safety Officer Signature:** ________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Any and all damage should be recorded and team members notified. **Prerequisite lists:** N/A
		Continued on next page

Table 63 – continued from previous page

#	Inspector Initials	Step Instructions
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** damp paper towel or cloth
	______	**Components Needed:** assembled rover
S	______	**Safety Consideration: Failure to notify team of damage to payload could result in injury or payload objective failure.**
1	______	Inspect for and remove obviously damaged or broken components.
2	______	Ensure chassis is structurally sound by manually applying tensile and compressive stress.
3	______	Ensure fasteners on motor mounts, shaft couplers, mounting blocks, and clamping hubs are tight and flush with surfaces.
4	______	Ensure fasteners on auger mounts and SCAR retention motor mounts are tight.
5	______	Inspect electrical components for detached wires.
6	______	Ensure sonar modules are mounted appropriately.
7	______	Clean camera lens with a damp paper towel or cloth.
S	______	**Safety Consideration: A damaged LiPo battery can ignite or explode spontaneously.**
8	______	Inspect rover battery for damage, warmth, or swelling. If any of these are present, dispose of the battery promptly and properly.
		____

4.2.9 Troubleshooting

Table 64: This checklist is used to disarm the launch vehicle following a misfire.

Disarming Misfired Launch Vehicle		
Assembler Signature:__________		**Safety Officer Signature:** __________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: -Launch vehicle firing system is disarmed -Firing system power source has been removed -Range Safety Officer has verified the range is open **Prerequisite lists:** -Launch Procedure **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** multimeter
	______	**Components Needed:** launch vehicle, ignition system, igniter, spare igniter
1	______	Wait 60 seconds after ignition system has malfunctioned in accordance with NAR Safety Code.
S	______	**Safety Consideration: Failure to ensure ignition system has been properly disarmed and power sources removed could result in unexpected ignition of launch vehicle.**
2	______	Disarm ignition system.
3	______	Disconnect power source from ignition system.

Continued on next page

Table 64 – continued from previous page

#	Inspector Initials	Step Instructions
4	______	Inform the Range Safety Officer of the misfire and disclose intent to approach launch vehicle.
S	______	**Safety Consideration: When approaching a misfired launch vehicle, a Safety Officer must be assigned to monitor the ignition system to ensure it remains disarmed and disconnected from all power sources until the igniter is removed or until all personnel have cleared the area.**
5	______	Upon approval to approach the launch vehicle from Range Safety Officer, only essential personnel are allowed to approach launch vehicle. Bring spare igniter to launch vehicle. Essential personnel is limited to a maximum of: Team Lead, a Safety Officer, Range Safety Officer, Igniter Insertion Assembler.
6	______	Disconnect igniter from ignition system and remove from motor. Team Lead, Safety Officer, Range Safety Officer, and Igniter Insertion Assembler are trained on how to remove the igniter.
7	______	Examine igniter for flaws or defect and check for continuity.
8	______	If the igniter is flawed or defective, follow Igniter Insertion Procedure (in Table 59) to replace with spare igniter.
9	______	If the igniter is not flawed or defective, disarm altimeters and PLEC.
10	______	If the igniter is not flawed or defective, use multimeter to test ignition system for 12 V DC when ignition is pressed. Troubleshoot ignition system if necessary.
S	______	**Safety Consideration: Risks should be considered for all unexpected plans of action. Postponing the launch is preferable to proceeding with unmitigated risks.**
11	______	If ignition system and igniter appear functional, develop plan of action with Range Safety Officer.

Table 65: This checklist is to be followed when unexploded recovery charges have to be handled after altimeters have been armed.

Disarming Unexploded Recovery Charges

Assembler Signature:__________________ **Safety Officer Signature:** __________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: -Ensure unnecessary personnel are clear of launch vehicle until unexploded charges are safely removed -Ensure x4 altimeters have been disarmed (x2 in Fore, x2 in Aft) -Ensure charges have been disconnected from altimeters. **Prerequisite lists:** -Setup on Launcher **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** Flathead screwdriver, wire cutters, 1/8 in. hex key, 1.5 mm hex key, 7/16 in. socket, 1/4 in. drive socket wrench, Phillips head screwdriver
	______	**Components Needed:** Fore launch vehicle section, aft launch vehicle section

Continued on next page

Table 65 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: Only essential personnel should approach the launch vehicle until all unexploded charges have been safely disarmed.**
1	______	If igniter has been installed, follow Disarming Misfired Launch Vehicle procedure (shown in Table 64).
2	______	Use flat-head screwdriver to turn off altimeters through static port hole. All altimeters in present section should be disarmed prior to proceeding with next step (x2 in Fore, x2 in Aft).
3	______	If dealing with the fore section after PLEC has been armed, follow Disarming PLEC and Payload Removal to disconnect power and discharge the capacitor (Shown in Steps 1-3 of Table 66).
4	______	If launch vehicle sections are not separated, separate the nosecone, fore, and aft section. Twisting the sections is the easiest way to shear the shear pins.
S	______	**Safety Consideration: Ensure no open flames, sparks, or ignition sources are present while ejection charges are exposed.**
5	______	Use wire cutters to snip e-match wire, remove ejection charge, store ejection charge in sealed container.
S	______	**Safety Consideration: Ensure all ejection charges have been removed from the section prior to moving the launch vehicle.**
6	______	Bring launch vehicle and unexploded charges back to assembly area.
7	______	Disassemble ejection charge and secure unused black powder in sealed container for disposal.
8	______	If cause of unexploded ejection charge is not apparent, troubleshoot cause by determining continuity of e-match, altimeter functionality, and analysis of altimeter data.
9	______	Use 1/8 in. hex key to remove x6 10-24 radial bolts that attach parachutes to airframe.
10	______	Use 7/16 in. socket to loosen x6 1/4-20 pressure seal bolts.
11	______	Slide parachutes and ejection bay out of airframe.
12	______	Disconnect Quick Link from eye bolts on bulkhead.
13	______	Use Phillips head screwdriver to remove the pressure sealing washer.
14	______	Use 1.5 mm hex key to remove x4 4-40 bolts from ejection bay and separate pressure seal.
15	______	Remove altimeter sleds and remove 9 V batteries.
16	______	Retrieve altimeter data, check that all e-matches and altimeter connections are properly attached.

Table 66: This checklist is to be followed when disarming the PLEC and removing the payload.

Disarming PLEC and Payload Removal		
	Assembler Signature:________________	**Safety Officer Signature:** ________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: -Ensure all black powder is sealed and away from ignition sources -Ensure e-match faults have been recorded **Prerequisite lists:** -Unexploded Recovery Charges

Continued on next page

Table 66 – continued from previous page

#	Inspector Initials	Step Instructions
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** 3/8 in. hex key, 9/16 in. cut off wrench, flat-head screwdriver, scissors, tape, sharpie
	______	**Components Needed:** Packed fore airframe, 3/8 in. eye hook x2, container for black powder
S	______	**Safety Consideration: Airframe contains live charges. Approach with caution and keep all ignition sources away from launch vehicle**
1	______	Ensure that the ground station is not communicating with PLEC.
2	______	Disarm PLEC by inserting screwdriver into arming hole and rotating until Light Emitting Diode (LED) has turned off.
3	______	Wait 30 seconds before continuing. Capacitor discharge required.
4	______	Follow Unexploded Recovery Charges checklist (shown in Table 65) to remove any unexploded recovery charges, as well as removal of the parachutes and fore ejection bay.
5	______	Remove nut retaining fore ballast bay, and remove bay.
6	______	Remove nut and washer on backside of FHP.
7	______	Screw on eye hooks to FHP.
8	______	Remove radial bolts on FHP.
9	______	Carefully remove FHP from airframe.
10	______	Disconnect PLEC battery from the PLEC from fore end of airframe.
11	______	From aft end of airframe, carefully pull on Kevlar harness of payload.
12	______	Continue pulling harness until payload wrap unfolds and removable assembly is at the end of airframe.
S	______	**Safety Consideration: Black powder charges and energetic retention devices are in removable assembly bay.**
13	______	Carefully cut e-match of primary ejection charge, and remove from airframe.
14	______	Cut e-match of backup ejection charge, and remove from airframe.
15	______	Cut e-match of first Tender Descender.
16	______	Cut e-match of second Tender Descender.
17	______	Cut e-match of ARRD.
S	______	**Safety Consideration: Ensure all ignition sources are removed from assembly station table.**
18	______	Remove assembly and return to assembly station.
19	______	Label each e-match with tape, indicating which ejection charge or retention device it was used on.
20	______	Disassemble both ejection charges, placing black powder in sealed container.
21	______	Open both Tender Descenders, placing black powder in sealed container.
22	______	Open ARRD, placing black powder in sealed container.
23	______	Check continuity of each e-match, and record name of any which fail. ____________
24	______	In a safe location away from all black powder, apply current to all e-matches which passed the continuity test. Record the name of any e-match which failed to spark. ____________

Table 67: This checklist is used when the avionics malfunction.

Malfunctioning Avionics Checklist		
Assembler Signature:________________		**Safety Officer Signature:** ________________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: -Inspect for loose electrical connections and components. -Verify that batteries are secure and in good condition. -Verify LiPo battery voltages are above 8 V. **Prerequisite lists:** -ATU Preparation Checklist -Ground Station Preparation Checklist **ALL** checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	_____	**Tools Needed:** Digital multimeter, electrical tape, micro-USB cable, laptop with Arduino IDE/Python 3.7/TeensyDuino installed
	_____	**Components Needed:** Prepared flight ATUs, prepared ATU ground station, LiPo battery for each ATU and 1-2 spares for troubleshooting, Yagi antenna, extra micro-SD cards
S	_____	**Safety Consideration: Use digital multimeter to ensure that battery are within maximum acceptable operating ranges before use (> 8 V).**
1	_____	Record ATU Battery Voltages: ____________________
2	_____	Open serial monitor on laptop connected to ground station.
3	_____	If serial monitor is not empty and shows packets labeled 'GPRMC' with mostly commas, the GPS units have not locked but the RF link is active. Unplug the flight ATU from the battery and plug it back in. Wait for up to a half hour for non-comma data to appear on the ground station serial monitor. Jump to step 11 if data appears within a half hour.
4	_____	If the serial monitor is empty, close the serial monitor, unplug the USB cable, plug the USB cable back into a different USB port, then open the serial monitor on the new port.
5	_____	If the serial monitor is still empty, unplug the flight ATU from the attached LiPo battery and unplug the micro-USB cable from the ground station.
6	_____	Plug the micro-USB cable into the flight ATU, plug the flight ATU back into its LiPo battery, and flash the diagnostic code to the flight ATU.
7	_____	Open the serial monitor for the flight ATU. If there is no data coming over the serial monitor, disconnect and reconnect the LiPo battery.
8	_____	If power cycling doesn't prompt data outputs on flight ATUs, try replacing the Teensy microcontroller and checking all electrical connections and continuity, then restart from step 6.
9	_____	If valid data can be read with the diagnostic code from both flight ATUs, flash the normal flight ATU code, disconnect them from the batteries and unplug the micro-USB cable.
10	_____	Plug micro-USB cable back into ground station and re-flash latest stable release of the ground station code. Repeat steps 3 through 10 until serial monitor on the ground station isn't empty (packets mostly composed of commas are fine).
11	_____	Once the RF lock is established and the ground station is receiving packets again, reconnect batteries and run through the ATU Preparation checklist (Table 38) and Ground Station Preparation Checklist (Table 32) to re-calibrate the systems as necessary.

Table 68: This checklist is used when the rover electronics malfunction.

Malfunctioning Rover Electronics		
Assembler Signature:_______________		**Safety Officer Signature:** _______________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist:
		-Ensure that no external hazards are present while retrieving the rover.
		Prerequisite lists: N/A.
	_____	**Tools Needed:** N/A
	_____	**Components Needed:** N/A
1	_____	Pick the rover up off of the ground.
S	_____	**Safety Consideration: Pick up the rover by the top of the chassis, the auger may activate at any time while the rover electronics are being unpredictable.**
2	_____	Toggle the switch on the protoboard.

Table 69: Checklist to follow when disarming the full launch vehicle and payload.

Disarming Full Launch Vehicle and Payload.		
Assembler Signature:_______________		**Safety Officer Signature:** _______________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist:
		-4x altimeters have been disarmed
		-PLEC has been disarmed.
		Prerequisite lists: N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's signoff.
	_____	**Tools Needed:** Flathead screwdriver
	_____	**Components Needed:** Launch vehicle
S	_____	**Safety Consideration: Failure to identify all explosive charges and disarm appropriately could cause significant injury. Black powder charges in the launch vehicle are contained within three sections: fore parachutes, PEARS, and aft parachutes. Motor may or may not be present.**
1	_____	If igniter has been inserted, follow Disarming Misfired Launch Vehicle checklist (shown in Table 64).
2	_____	If altimeters have been armed, follow Unexploded Recovery Charges checklist (shown in steps 1-5 of Table 65).
3	_____	If PLEC has been armed, follow Disarming PLEC and Payload Removal procedure (shown in steps 1-3 of Table 66).
4	_____	If launch vehicle has been placed upright on the rail, lower rail and bring launch vehicle back to assembly area.
5	_____	Separate nosecone and aft sections of launch vehicle.
6	_____	Proceed with remainder of the Unexploded Recovery Charges checklist (shown in Table 65).

Continued on next page

Table 69 – continued from previous page

#	Inspector Initials	Step Instructions
7	______	Proceed with remainder of the Disarming PLEC and Payload Removal procedure (shown in steps 4-23 of Table 66).

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 established on a previous mission. Once the rover arrives at the scientific base station, it will deposit the soil sample for analysis. The experiment will be 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 pH mapping would be to find candidate locations for a human colony to test plant growth. The primary function of the rover as a whole is to confirm proof-of-concept for a rover performing a similar mission on a different celestial body, like Mars.

5.2 Changes Since CDR

Changes made to the payload since CDR were minor, but important. Ejection tests using a placeholder payload convinced the team to change the PLA connecting rods in the drivetrain described in CDR documentation to an aluminum design for better strength and a thinner profile. Two notches were added to the rover's wheels to facilitate integration into the fore section of the airframe. They give clearance for PEARS' Kevlar harness to compress the tire tread and maintain the necessary cylindrical form once wrapped in fiberglass. The team carried out recovery ejection testing in the fore airframe section with the assembled rover integrated, and this made it clear that the PLA drive motor mounts were inadequate. A pair of modular replacement mounts were machined from aluminum and these held up well in payload ejection testing and during the full scale test flight.

Several components within the PEARS had minor changes as well, none of which affect the function or of the system or integration in the launch vehicle. The additively manufactured PLEC mount and cover were modified when the final PLEC was built, as it used a different size antenna. Finally, the PLEC battery mount was added to sit on top of the PLEC cover so that the battery can be disconnected from all systems easily should the FHP need to be removed.

5.3 Rover Mechanical

5.3.1 Unique Mission Success Criteria

In order for the rover to successfully complete the mission, several mechanical rover specific criteria have been developed. The chassis must be able to withstand all flight and ejection forces, while remaining lightweight. The SCAR must be able to drill into the ground to collect and seal soil samples in a variety of soil conditions. The drivetrain must allow the rover to travel away from the launch vehicle without getting stuck on small obstacles. Additionally, the rover must be able to sit securely within the airframe during flight. The chassis uses carbon fiber in a truss system to withstand atypical flight forces, and is very light. The drivetrain uses two coaxial independently-controlled wheels with vibration dampening hub assemblies to travel autonomously over slopes and small obstacles. Finally, the rover tires are compressible so the rover can effectively integrate into the fore airframe and create a pressure seal. The rover meets all competition and team derived requirements as verified in Tables 76 and 80, respectively.

5.3.2 Chassis

The chassis consists of machined aluminum blocks and carbon fiber rods to form two trusses connected by cross rods. The chassis assembly is shown in Figure 69.

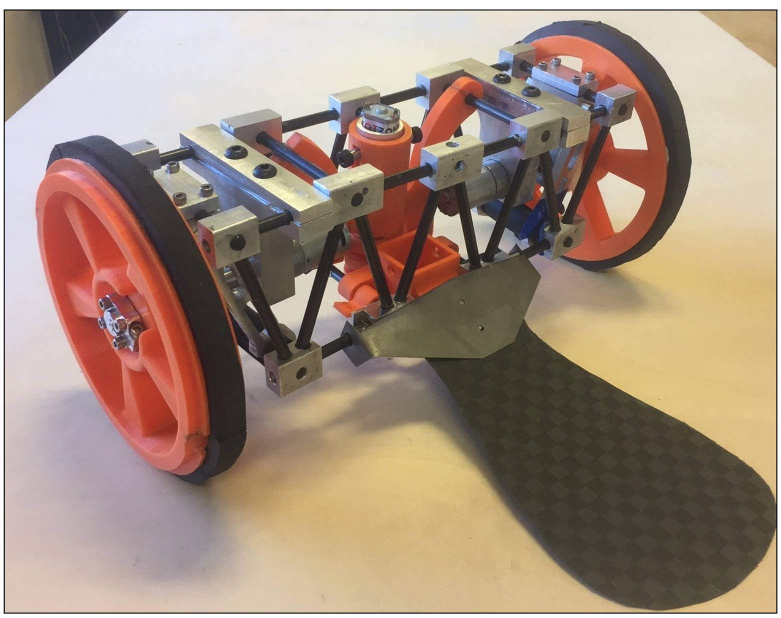

Figure 69: Rover Assembly

Each block has multiple holes drilled to fit the carbon fiber rods. The blocks were machined in the OSU

MPRL by members of OSRT using a compound angle vice set at 20° from level. The setup of the compound angle vice is shown in Figure 70.

Figure 70: Compound angle fixture used for block manufacturing

The set of chassis blocks used for the prototype rover contained through holes for all holes not at an angle and the rods were only held in place with epoxy. During ejection and parachute testing with the prototype rover, the horizontal truss rods broke the epoxy and the chassis length decreased by 0.7 in. To mitigate this for the final rover, the horizontal truss holes were not manufactured to be through holes, but machined to contain a wall of aluminum to press against when under compression. These internal walls for the rods are shown in the cross section view in Figure 71. The angled rods do not experience nearly the forces of the horizontal truss rods, thus do not need aluminum walls.

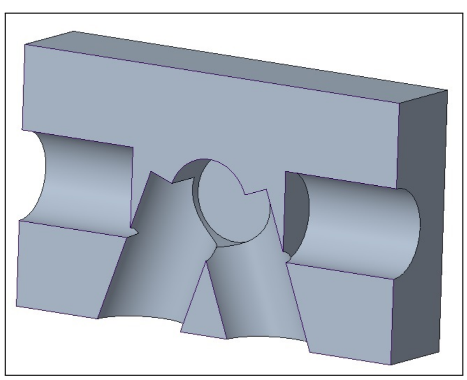

Figure 71: Connection block - cross section view

5.3.3 Rover Tail

The rover tail functions as a stabilizer and is made from three layers of carbon fiber Toray T700 weave. It is connected to the chassis by a sheet metal attachment. During integration, the tail wraps around the underside of the rover. Torsion springs force the tail to open into the mobility position shown in Figure 69. Attached to the tail is a quick release shunting circuit used to hold a relay open to keep the rover electronics powered off. When the rover is released from the PEARS and the tail springs into place, the shunting circuit breaks and the relay closes, allowing the rover electronics to power ON.

Figure 72: Carbon fiber tail

5.3.4 Drivetrain

The rover's drivetrain is a two-wheeled design with separate, mirrored subsystems. A general overview is shown in Figure 73.

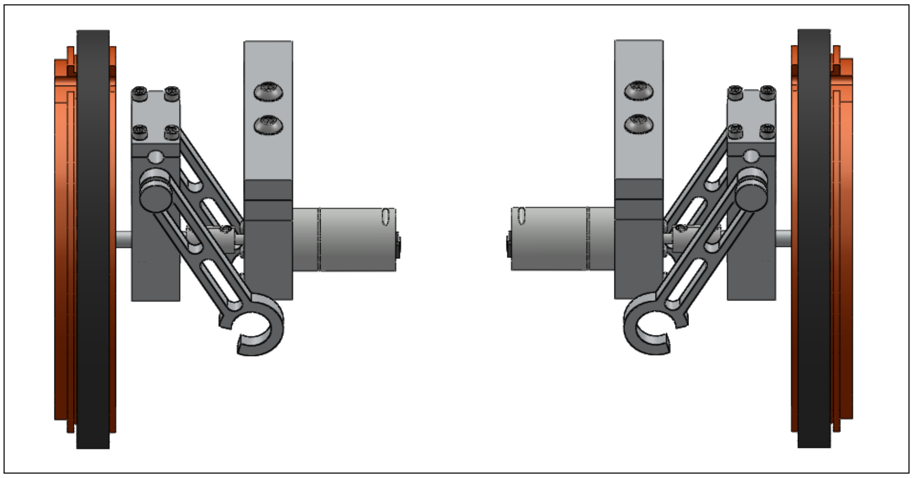

Figure 73: A render of the full drivetrain assembly

A brushed DC motor is the innermost component on each side, with terminals exposed for integration with the motor driver. The 170 RPM Econ Gear Motor was selected for this application because its torque output, in tandem, allows for 30° slope climbing and is conservative with respect to length and volume.

The motor is fixed at its front plate to an aluminum mount with two M3 screws. The mount is a two-piece modular design and is clamped together around two parallel chassis members with two 1/4-20 screws. At this point, the system has one (axial) degree of freedom.

The mounting block clamped to the outermost upper chassis cross rod fixes the entire subsystem. An aluminum drive shaft runs through this block, concentric with the output shaft of the motor and joined to it with a steel set screw coupler. The mounting block houses a pair of sealed ball bearings and a thrust washer. Each is permanently seated in the block. Both aluminum mounts have holes milled out to minimize unnecessary weight.

Two aluminum connecting rods are fixed to the sides of the mounting block and hook to the foam rubber-wrapped lower chassis cross rod, adding a semi-flexible attachment point that dampens vibrations. This design transmits axial forces through the chassis during launch, recovery, and ejection.

The outside end of the drive shaft runs through the center of a 6.00 in. diameter PLA wheel, shown in Figure 74. The wheel has a 0.250 in. bore clamping hub screwed to its far side which mounts the wheel to the drive shaft. The wheel has a 0.50 in. wide channel along its perimeter, into which a 0.375 in. thick length of PORON urethane foam is attached using epoxy.

Figure 74: The finished rover wheel

The foam plays an important role; it is sized such that it takes a considerable radial force to compress the fiberglass wrap around the wheel during integration with the PEARS. This allows for a tight seal with the interior of the airframe to be formed when the wrapped payload is slid inside. This allows the team to use a smaller black powder ejection charge, reducing the stress of ejection on all payload components. Once the rover ejects, the wrap falls away and the wheel tread quickly expands to provide more ground clearance for components like SCAR's auger which protrude from the chassis.

This drivetrain assembly underwent payload ejection testing on February 19th, 2019 and was included in the full scale Vehicle Demonstration Flight on February 22nd, 2019. These events represent the extent of expected stresses on the system, and all components were completely intact and reusable afterward.

Drivetrain manufacturing took place primarily in the OSU MPRL. For example, the mounting block assemblies were machined on a VMC (Figure 75) and drive shafts were turned to size on a lathe. Wheels were produced using additive manufacturing with PLA and finished with a drill press. Urethane foam strips were cut on a bandsaw and applied using a two-part epoxy.

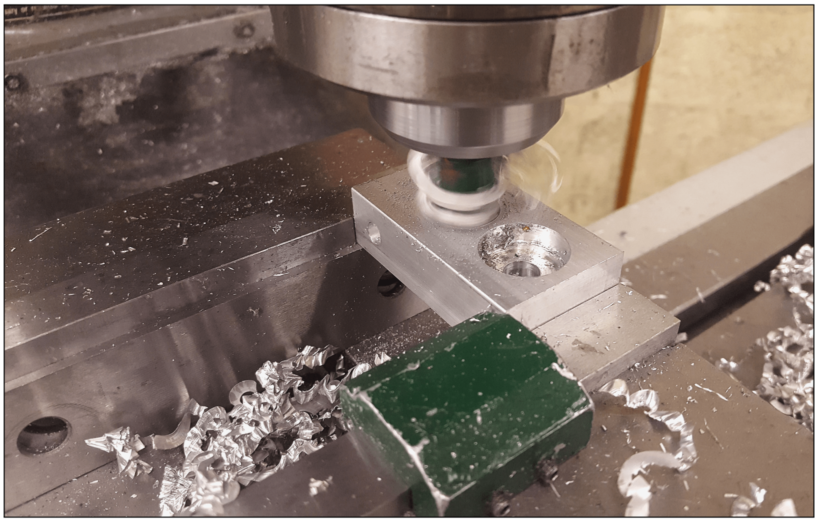

Figure 75: Machining a mounting block on a vertical mill

The drivetrain assembly can be removed and reattached without disassembling any other part of the rover. The process for integrating the drivetrain into the chassis is shown in a series of images below, starting with an overview of the components in Figure 76. It involves installing the motor into its mount (Figure 77), clamping this mount to the chassis (Figure 78), fitting the set screw coupler to the motor shaft (Figure 79), clamping the mounting block onto the outer crossbar (Figure 80), inserting the drive shaft and tightening its set screw (Figure 81), and finally attaching the wheel and tightening the clamping hub (Figure 82).

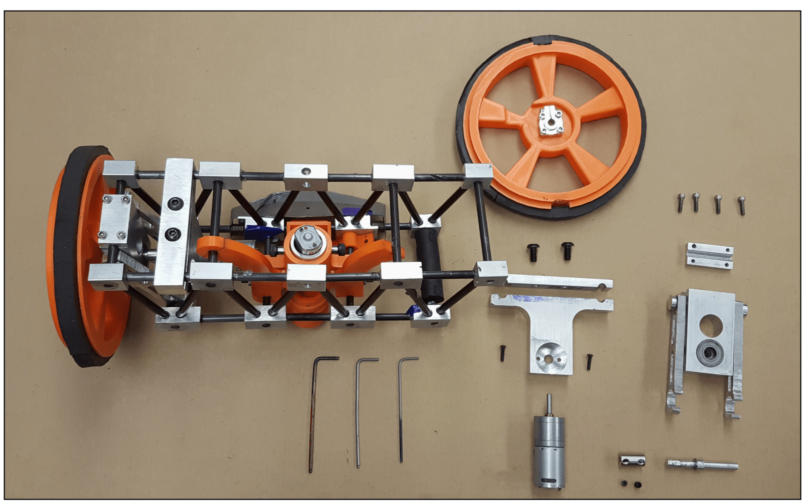

Figure 76: Drivetrain components and hardware

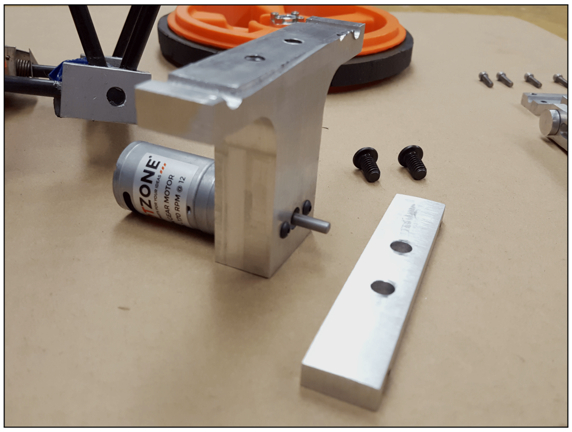

Figure 77: Fitting the motor to its mount

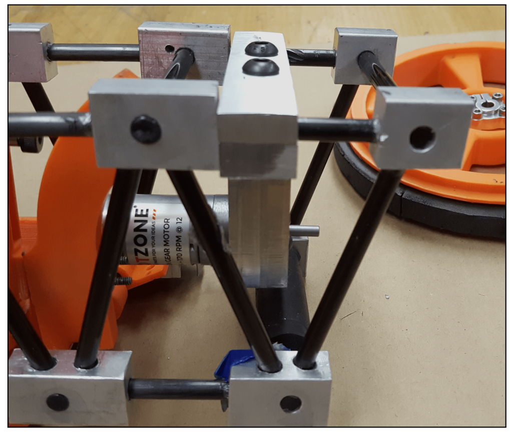

Figure 78: Clamping the motor mount to the chassis

Figure 79: Fitting the coupler to the motor shaft

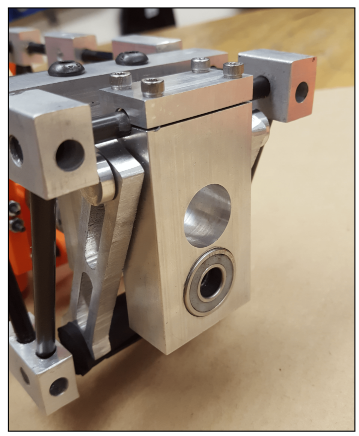

Figure 80: Clamping the mounting block assembly

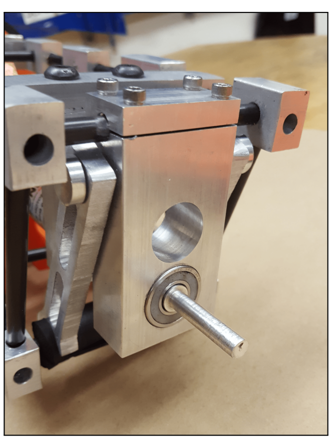

Figure 81: Fitting the drive shaft

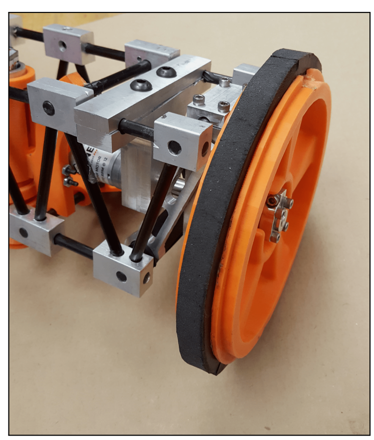

Figure 82: Fitting the wheel to the drive shaft

5.3.5 Soil Collection and Retention

The SCAR system consists of two separate subsystems: the soil collection and the soil retention system.

The soil collection assembly uses an additively manufactured auger made from PLA and is directly connected to a coupler and motor. A wrap is placed around the auger to retain the soil during extraction. A 1/8 in. aluminum rod is placed through the top of the auger and travels in a helical path within the PLA auger tube as shown in Figure 83, causing the auger to move in a helical path while the motor is powered ON.

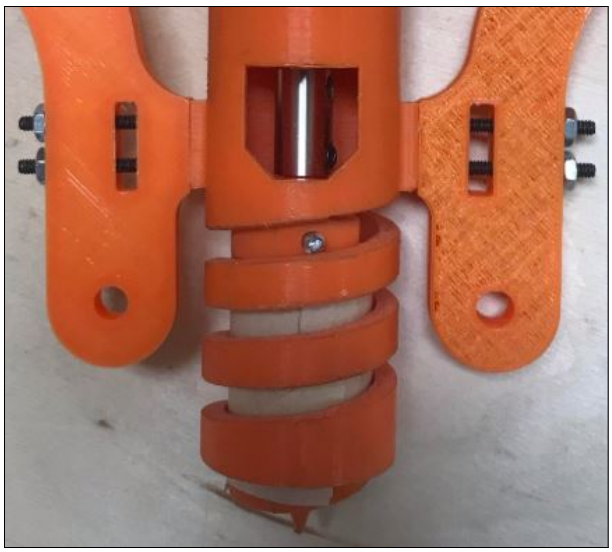

Figure 83: Auger placed within the auger tube

The auger motor is placed within a cylindrical aluminum motor mount and fastened with M2.5 screws. On the motor mount, two shoulder screws are placed at 180° from each other and limits the motor to only travel in a vertical motion, preventing wires from tangling while rotating the auger relative to the motor. The motor mount assembly is shown in Figure 84.

Figure 84: Auger motor, mount, and fasteners

After performing a FEA, the components most likely to break during mission operations are the soil collection mounting fixtures. The parachute ejection charges create the largest force upon the rover, calculated at 1,060 lbf. PLA has a yield stress of 8,840 psi and the FEA indicated a maximum stress on the component to be 4,100 psi. This results in a safety factor of 2.16. The FEA results are shown in Figure 85.

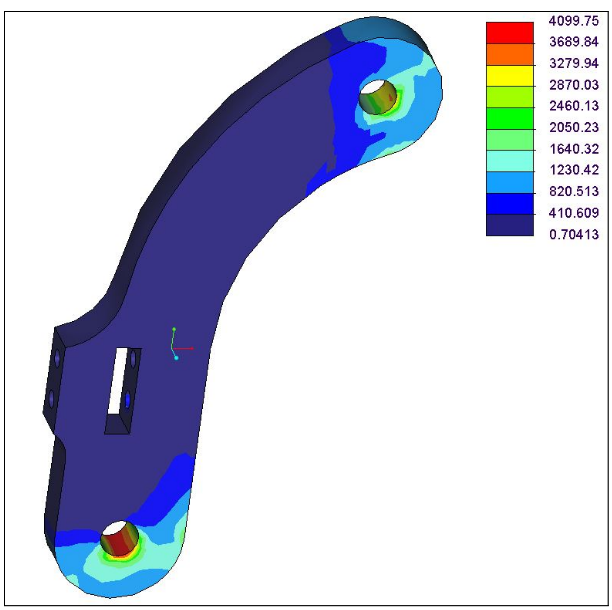

Figure 85: FEA of Soil Collection Mounting Fixture

The completed soil collection subsystem is shown in Figure 86.

Figure 86: Soil collection subsystem

The soil retention subsystem consists of a container with two separate doors. The doors are connected to aluminum rods that rotate using motors attached by couplers. The doors open and close independently to allow the soil to be sealed (top door closing) and deposited into the scientific base station (bottom door opening). The container and motor mounts are additively manufactured from PLA. The two doors are made of aluminum and sized to fit within the container with the ability to rotate without interfering with the walls or allowing soil to fall between the space between components. This subsystem is shown in Figure 87.

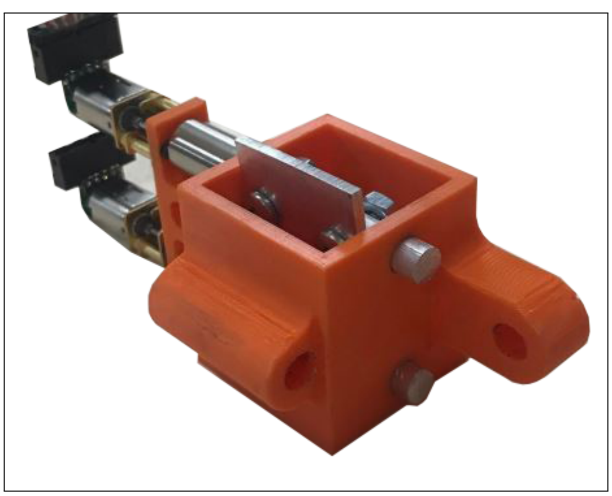

Figure 87: Soil retention subsystem

Most components within the SCAR were either additively manufactured from PLA or were purchased, such as the motor and couplers. The remaining components were made from aluminum within the OSU MPRL using a bandsaw and vertical mill.

5.4 Rover Electrical

5.4.1 Unique Mission Success Criteria

In order for the electrical systems of the rover to successfully complete the mission, several rover electrical specific criteria have been developed. Firstly, the rover must be able to avoid obstacles which, if hit, would result in the rover becoming stuck, rendering it unable to complete its mission. The rover must be able to detect when it is on a level surface before collecting soil to ensure that the soil collection routine is properly executed. The position of the auger motor must be known to the microcontroller to ensure the full range of motion is achieved by the auger. The position of both soil retention motors must also be sensed to ensure soil is in a sealed container upon collection, in accordance with NASA requirement 6.1.3.5. The rover must be able to detect its global position and successfully navigate from one position to another. RF transmissions must be received by the rover containing GPS coordinates of a scientific base station.

5.4.2 Microcontroller

The Teensy 3.6 microcontroller is responsible for analog and digital Inputs and Outputs (I/O) aboard the rover as well as higher level navigation algorithms pertaining to the mission. This microcontroller was chosen based on clock speed and extensive I/O capabilities. The inputs which the Teensy handles are an array of three sonar modules, an accelerometer and magnetometer module, a GPS unit, and an RF transceiver. A high level block diagram of the rover electronics is shown in Figure 88. The Teensy outputs to a motor controller which drives the dual drive motors and two smaller motor controllers which drive the auger motor and soil retention door motors. Additional inputs come from motor encoders on the auger and soil retention door motors which allow the Teensy sense the position of the motors.

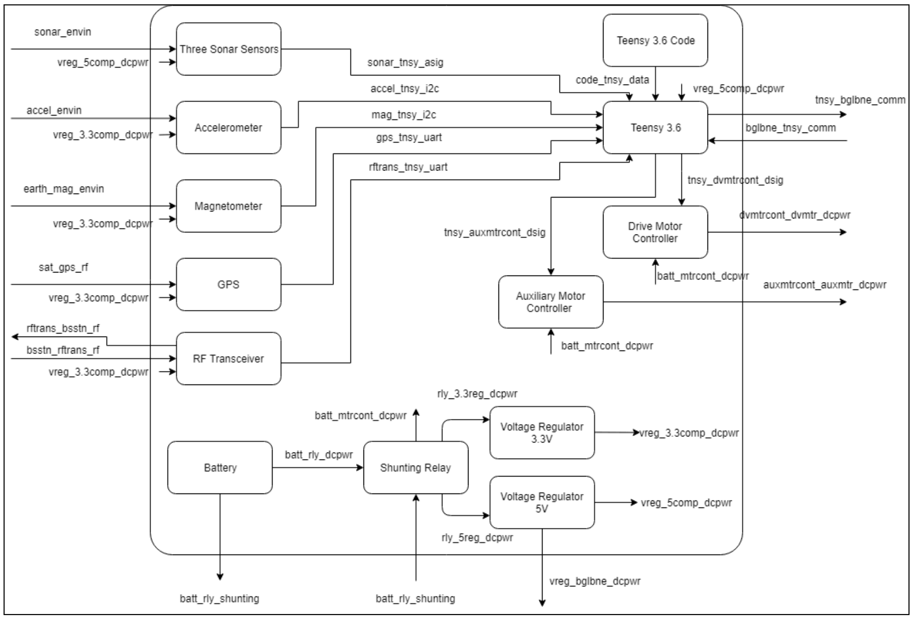

Figure 88: Top Level Rover Electronics Block Diagram

In OSRTs testing thus far the Teensy has proven capable of successfully running simple obstacle avoidance algorithms in conjunction with forward movement allowing the rover to move away from the launch vehicle. It also determines appropriate soil collection locations based on levelness of the ground which allows for a more reliable soil collection routine in the testing.

5.4.3 BeagleBone

The Beaglebone Black on the rover is responsible for running the computer vision. This is be powered by a 5 volt barrel connector connected back to the voltage regulator on the rover control board. The Beaglebone will be connected to an Logitech C920 camera capable of the h264 pixel format. The Beaglebone utilizes Universal Asynchronous Receiver-Transmitter (UART) in order to communicate with the Teensy microcontroller.

5.4.4 Sonar

An array of sonar modules, mounted at the front of the rover, is being used to detect obstacles. Because sonar works by measuring the time between emitting a sound and receiving it after reflecting off of a surface, these modules work very well in the case of detecting solid obstacles in front of the module. For this mission the only obstacles which need to be detected are large, solid objects which are insurmountable by the rover. In testing, the array of modules has successfully detected walls and trees directionally, allowing the rover to maneuver away from these obstacles.

5.4.5 Global Positioning System

A GPS module is implemented aboard the rover which is being used to track the location of the rover. This information is being used for two purposes in the mission. The GPS is first used to determine the starting location of the rover upon ejection from the airframe. This initial location is then compared to the current location of the rover to ensure the rover is 10 feet from any portion of the launch vehicle before soil collection, in accordance with NASA competition requirement 4.3.4 as described in Section 6.1.3.3. The second purpose of the GPS is to determine the locations where soil was collected to allow for plotting of data points on a map.

The specific GPS module being used, the u-blox MAX M8W, outputs information continuously upon being powered on. Eight different packet types are output on a loop. To filter the data, a parser was created to extract only useful coordinate and time data. This data is then written to a text file by the Teensy and, if pertinent to the mission, stored in an array of custom structs designated for useful coordinates.

5.4.6 Transceiver

Upon completing the NASA stated mission, the rover waits until a message is received to proceed to a scientific base station to deposit the soil for testing. A transceiver aboard the rover receives this RF signal. The message contains GPS coordinates where the base station is located. Once the rover has navigated to the base station, the transceiver communicates back to the base station the location at which the soil was collected. Using this information and the information collected by the base station, a plot was created showing the data points on a map of the surrounding area.

5.4.7 Accelerometer and Magnetometer

The accelerometer and magnetometer communicate with the Teensy via the I^2C protocol. While they are part of the same module, they do not share the same I^2C address, and therefore must be addressed individually through code.

Through testing, the accelerometer proved capable of detecting acceleration in three axes $\pm 1\%$. The accelerometer was configured to detect $\pm 2g$ on each axis. This decision was made due to a specific case where the accelerometer is functionally being used as a gyroscope to detect level ground for soil collection. It is only being read when the rover is at a full stop. The highest acceleration measured in this case is $\pm 1g$, which is due to gravity. OSRT is able to poll the accelerometer and perform the simple level calculation at a rate of 10 Hz which is far faster than the rover is able to relocate after failing to find level ground.

The magnetometer is configured to detect magnetic field ± 1.3 gauss, which is the proper threshold to detect the magnetic field of the earth. In testing, a raw value for the magnetic field across each axis was reliably produced in each direction. Through software, a heading is generated using these raw values which has allowed the rover to move in a specified direction.

5.4.8 Motor Controllers and Encoders

There are three motor controllers aboard the rover. One dual channel motor controller operates both drive motors, another controls both top and bottom retention door motors, and the remaining controller operates the auger motor. All motor drivers are bidirectional and have variable speed via Pulse Width Modulation (PWM).

Each motor aside from the drive motors are equipped with motor encoders. These encoders send a series of pulses back to the microcontroller to indicate distance travelled by the motor. In testing, the soil retention door motors were successfully and precisely turned 90°, and the auger motor completed 5 full rotations, during which it transverses from the top to the bottom of its movement range.

5.4.9 Rover Printed Circuit Board

Most of the electronic components are connected using a custom PCB. These components include the Teensy 3.6, accelerometer, magnetometer, transceiver, GPS unit, both auxiliary drive motors, both voltage regulators, and a relay. There will also be inputs/outputs for the battery, BeagleBone, drive motor, and sonar modules. The PCB is designed as a four layer board. The two middle layers consist of ground and 5 V plane, and the two outside layers are for a 3.3 V plane and communication traces.

A relay is held open to keep the rover electronics powered off until the rover is ejected from the airframe. When the relay is closed, the battery voltages are immediately stepped down to 5 V and 3.3 V. The transceiver and GPS module have an input voltage of 3.3 V. The sonar modules, accelerometer, magnetometer, and BeagleBone take an input voltage of 5 V. In addition to delivering power, the PCB serves to connect the Teensy 3.6 to each of the aforementioned components via traces for components on the PCB and screw terminals for components external to the PCB.

Design flaws preventing competition usage were discovered upon receiving the first iteration of the payload PCB. The first iteration of the PCB is shown in Figure 89. A second iteration is currently in development and will address the issues present in the first version.

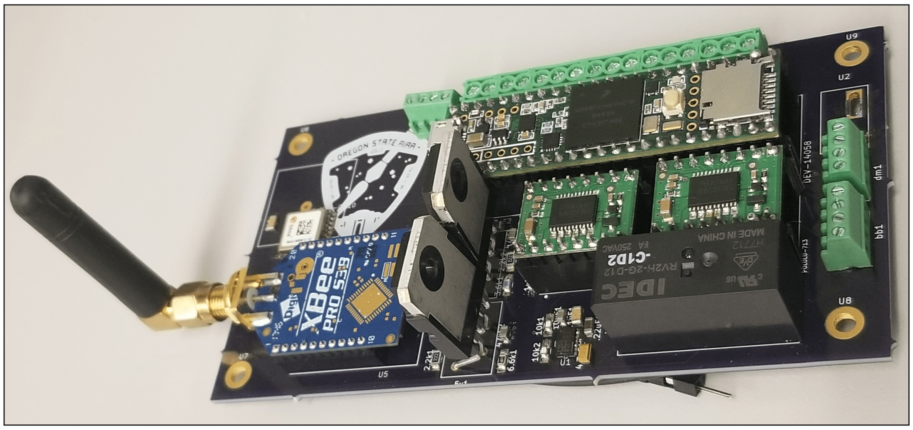

Figure 89: First Iteration of Rover PCB

An alternate control board was developed for testing using prototyping board, shown in Figure 90. This board is equipped with all elements of the PCB except for the GPS and RF transceiver modules. A small PCB has been developed which will sit atop this control board to introduce RF transceiver and GPS functionality, giving this control board the same functionality as the PCB.

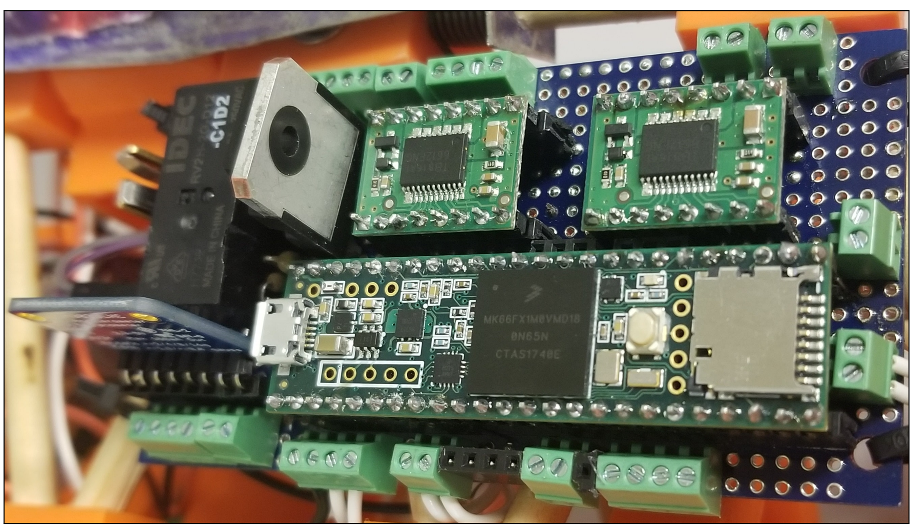

Figure 90: Prototype Control Board

5.5 Rover Software

5.5.1 Unique Mission Success Criteria

In order for the rover to successfully complete the mission, the rover must be set up with a complete set of instructions on what to do after deployment from the air-frame:

1) The rover must reliably move outside the launch vehicle's proximity without becoming stuck.
2) At least 10 mL of soil must then be collected and sealed inside a container on the rover. This will successfully conclude the requirements for the NASA competition.
3) A radio signal containing the GPS location data of the base station, and the number of samples to be collected, will be received by the rover.
4) The rover must travel in the direction of the coordinates given until the target is in range (Within 20 feet) and detected via computer vision.
5) The rover will use the combined functionality of the Beaglebone and the Teensy in order to dock the rover and deposit the sample into a collection chamber for analysis.
6) To collect additional samples, the rover will exit the station and set out to retrieve another soil sample from a different location.
7) The collection process will repeat a set number of times based on the current soil conditions.

5.5.2 Control Code

The Teensy is the primary controller for the rover. This will control the current phase of the rover and make logical decisions based on information feedback from the peripheral sensors in Section 5.4. The Teensy will be executing two main loops that are split into Phase 1 and Phase 2. Phase 1 is designed to navigate the rover away from the launch vehicle by moving away from GPS coordinates transmitted by the launch vehicle. Object avoidance is active during this process in order to safely guide the rover around any obstacles in the field. Phase 1 has been implemented on the rover. However, due to delays for rover fabrication and PCB manufacturing, Phase 2 is still under development. As soon as the PCB is completed, OSRT will have all of the sensors required to complete Phase 2. Phase 2 begins with a sequence of commands that operate an auger motor. During this process a small motor opens and closes the containment box lids for storing the sample. After collecting 10 mL, the rover will wait until it retrieves a GPS coordinate to where the soil sample is to be delivered. The Teensy has a magnetometer, which combined with the GPS coordinates, will allow the rover to find the scientific base station. Once found, the computer vision and the sonar will provide the Teensy with enough information to successfully dock and release the soil sample. The rover will then continue collecting the indicated number of soil samples following the same procedure.

5.5.3 Computer Vision

Computer Vision is implemented on a Beaglebone Black Wireless. An LG920 camera is connected to the Beaglebone via USB to capture and process frames of the surroundings. OpenCV is used to process each frame for circles reporting the center point in a single transmission. This is transmitted over UART1 to the Teensy to execute in an open loop docking process. The Beaglebone is able to process 0.33 frames per second and a single instruction is given for each processed frame. In order to correct the slow frame rate of the

Beaglebone, only 1 of every 5 frames is processed. This helps reduce the buffer lag from the camera, and keeps the measurements more precise.

5.6 Payload Ejection and Retention

5.6.1 Unique Mission Success Criteria

In order for the rover to successfully complete its mission, it must be fully retained within the launch vehicle during launch and recovery phases, and ejected when given a signal upon a safe landing. The system must be a fail-safe active retention system with the ability to remotely release and eject the rover. The system to retain and eject the payload, referred to as a whole as PEARS, meets all competition and team derived requirements as verified in Tables 76 and 80 respectively.

The PEARS features three subsystems to meet the requirements: the PEARS Removable Assembly, the Payload Wrap Assembly, and the PLEC. These systems are assembled together at every launch by following the checklists in Tables 56 and 57. Once assembled, the PEARS integrates into the fore section of the launch vehicle and is retained to the FHP.

5.6.2 PEARS Removable Assembly

The PEARS Removable Assembly is shown as designed using CAD in Figure 91, and as manufactured in Figure 92. The system consists of a 3/8-16 aluminum threaded rod that runs throughout the full subsystem. One end has a threaded spacer for the wrapped payload to sit against, and the other end is passed through the FHP funnel during integration, and the fore ballast bay will be secured on the section of threaded rod that sticks through the FHP.

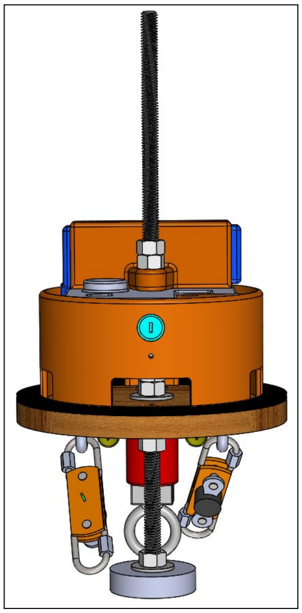

Figure 91: PEARS Removable Assembly CAD

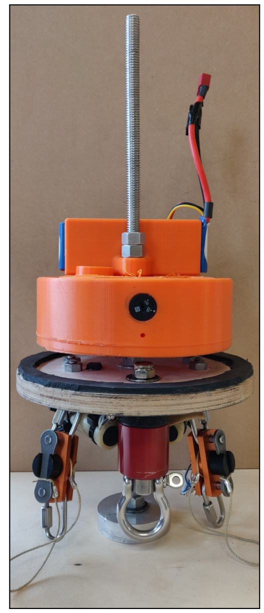

Figure 92: PEARS Removable Assembly

Attached to the main bulkhead are the retention devices. For retention redundancy, two L2 Tender Descenders and an ARRD were used. These devices all contain a small amount of 4F black powder, less than 0.3 g each, which are ignited via an e-match to separate and release the links of the devices when given the signal from the PLEC. Should the PLEC fail during flight, these retention devices cannot be separated, which actively keeps the payload secured within the airframe for the whole flight. The analysis done in Section 6.1.3.2 shows all components of the PEARS will not fail even under atypical flight forces.

Two 4F black powder ejection charges are located on the top side of the PEARS bulkhead. These charges are constructed exactly the same as the charges used in airframe separation and parachute deployment as described in Section 3.2.11. The primary charge is 1.2 g and the backup charge is 2.0 g. The ignition sequence of retention devices and ejection charges is detailed in Section 5.6.4. To get a pressure seal in the payload chamber to eject it, there is a Santoprene sheet on the backside of the main bulkhead. This seal is pressed against the FHP pass through bulkhead when the system is integrated.

The final unique feature of the removable assembly is the PLEC mounting assembly. The PLEC mount, shown in Figure 93, mounts the PLEC to the removable assembly, mounts the PLEC switch and LED, and contains the hole for clocking during integration. The inside of the cover shown in Figure 94 is lined with conductive tape and is used to protect the PLEC from physical impact as well as from RF signals. The PLEC antenna passes through a hole in the cover, allowing the PLEC to continue receiving a signal from the ground station when broadcast to initiate the ejection sequence. The PLEC battery is mounted on top the cover as seen in Figure 95. Keeping the battery separate in this manner allows the PLEC to be physically disconnected from the battery should an ejection charge not ignite during payload ejection. This safety procedure can be seen in the checklist in Table 66.

Figure 93: PLEC Mount on Removable Assembly

Figure 94: RF shielded PLEC Cover on Removable Assembly

Figure 95: PLEC Battery Case on Removable Assembly

5.6.3 Payload Wrap Assembly

To aid integration as well as retention and ejection, the rover is wrapped in a fiberglass sheet, capped with bulkheads on either end, and wrapped with a Kevlar harness as shown in Figures 96 and 97.

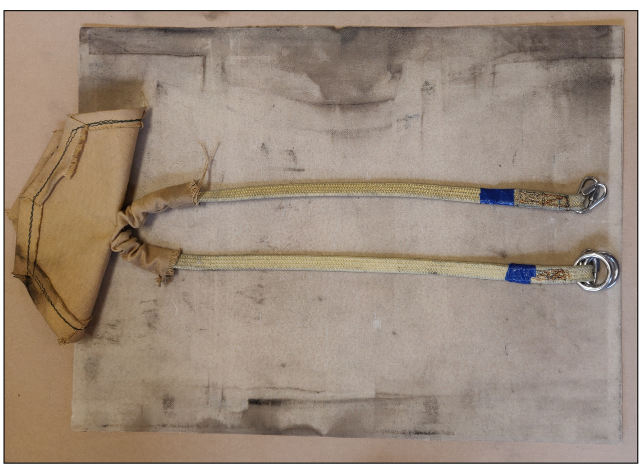

Figure 96: Rover ready to to be wrapped

Figure 97: Rover in fiberglass wrap assembly

The wrap is a four layer fiberglass layup manufactured by the OSRT. The layup schedule was $[0/90]_s$, which cured to be a flexible sheet, easily able to be wrapped and compressed around the rover foam tires but still rigid enough to spring flat after ejection. The aft bulkhead is the size of the compressed rover wheel and has small grooves for the Kevlar harness to lay within. The fore bulkhead has the same dimensions as the aft, but with an additional epoxied wood ring in the center that helps to align the wrapped assembly with the PEARS removable assembly spacer.

The Kevlar harness is 1/2 in. circular braided tubing. The loops on each end were hand sewn by the OSRT using 1/32 in. Kevlar thread and back-stitching a double box pattern. The pattern can be seen in Figure 98 after undergoing ejection testing and retaining the payload in the first full scale flight. The harness was then tested by hanging 300 lbf from one end while attaching the other end to an anchor point. The harness stretched slightly, but the threads held and the harness returned to original length when the weight was released. An analysis of the harness strength was also conducted, seen in Section 6.1.3.2, the results of which showed the harness withstands atypical flight accelerations well above 50 G.

Figure 98: Kevlar harness with Kevlar stitching

5.6.4 Payload Ejection Controller

The PLEC is a system which controls the ignition of e-matches to release and eject the rover from the fore airframe. The PLEC is armed via a DPST switch, accessible from outside of the airframe once the PEARS is fully integrated. The switch connects the positive terminal of the PLEC to ground through a resistor in one state. This configuration allows for the e-match igniting capacitor on the PLEC to discharge, disarming the system. The switch discharge analysis can be seen in Section 6.1.3.14, and discharges the controller in 2.72 seconds. The other state of the switch powers the PLEC, arming it, and turning on an indicator LED for verification of armed state.

While the PLEC is armed it is waiting to receive a key word which triggers the ignition sequence. This key word is send from the ground station once given clearance from the RSO. The ground station payload ejection sequence requires the switch on the PLEC to be armed, the arming switch on the ground station to be flipped, and the deployment button to be pressed for at least 0.5 seconds.

Once the trigger word is received, the PLEC ignites five e-matches sequentially at intervals of 1 second, for a total firing sequence of 5 seconds. The order of e-match ignition is Tender Descender, Tender Descender, ARRD, primary ejection charge (1.2 g) and backup ejection charge (2.0 g). This ejection sequence was verified through the team derived requirement Payload-14 shown in Section 6.1.3.20 with LEDs instead of e-matches. Implementing the PLEC with payload deployment was demonstrated as successful in Section 6.1.3.1. The PLEC was not flown in a live state during the Vehicle Demonstration Flight, and rover deployment was not attempted. The PLEC will be live and will be deployed after the Payload Demonstration Flight scheduled for March 16th.

The PLEC is powered by a 2200 mAh LiPo battery which can operate the PLEC for 20 consecutive hours while the system is in its armed state. A Teensy 3.6 microcontroller handles all I/O for the PLEC receiving input from an XBee 900HP transceiver. The Teensy outputs to an array of three Double Pole Double Throw (DPDT) electromechanical relays and five PNP transistors which control the current to each of the attached e-matches. Each e-match channel can only have current passing through it if the microcontroller toggles the state of both the transistor and the relay in series with that channel, providing safety through redundancy.

5.6.5 Payload Integration

Once the PEARS Removable Assembly and Payload Wrap Assembly have been assembled, they can be connected together via the links on the end of the Kevlar harness to the retention devices. This setup can be seen in Figure 99.

Figure 99: Fully assembled PEARS

Following the integration checklist in Table 47, the guide rod is used to clock the system as it is integrated. The PLEC mount goes through the pass-through bulkhead of the FHP and the seal is created between the Santoprene sheet on the pass PEARS bulkhead and the pass-through bulkhead face. As the system is integrated, the funnel on the FHP guides the threaded rod through the bulkhead. From the fore end of the airframe, the rod is retained to the bulkhead with a washer and 3/8-16 nut. Tightening this nut compresses the Santoprene sheet further, creating the pressure seal. The fore ballast bay, described in Section 3.1.16.2 is then slid on the threaded rod and sits against the wood bulkhead of the FHP. It is then retained with a 3/8-16 nylon lock nut. The fully assembled system can be seen outside the airframe, passing through the FHP and ballast in Figure 100. For clarity, the CAD model of the integrated system is shown in Figure 101.

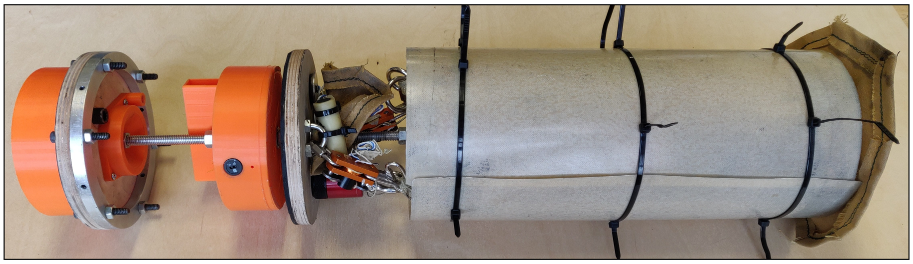

Figure 100: Fully assembled PEARS passing through FHP and fore ballast bay

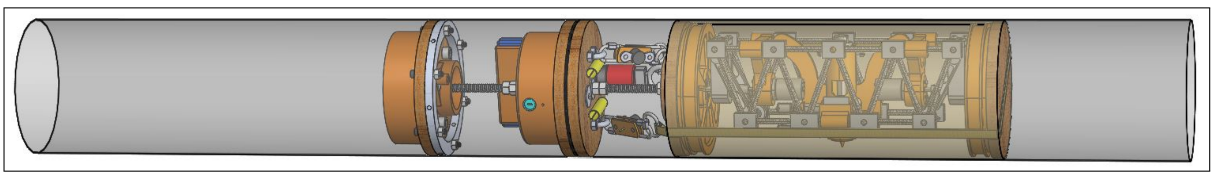

Figure 101: CAD of fully integrated PEARS

5.7 Payload Demonstration Flight

5.7.1 Planned Future Flight

The team's Payload Demonstration Flight has not yet been completed. The team plans on performing the payload demonstration flight on March 16th in Brothers, OR. The PEARS successfully retained the integrated rover during the team's Vehicle Demonstration Flight on February 22nd, 2019, though the payload ejection sequence was not included in this flight. The planned Payload Demonstration Flight will use the team's competition motor, the Cesaroni L2375-WT. This flight will also serve as a Vehicle Demonstration Re-Flight to validate maximum ballast conditions.

5.7.2 Success Criteria

In order for the payload demonstration flight to be considered successful, the team must launch and recover the full scale launch vehicle retaining the completed payload using the same motor as to be flown on launch day. Upon landing, the payload must be safely ejected from the airframe via a remote deployment signal sent from the ground station. During the mission, all retention mechanisms must function as designed and must not sustain damage requiring repair.

5.7.3 Results of Flight

Based on the successful retention during the Vehicle Demonstration Flight and successful ejection during ground demonstrations, the PEARS is expected to function properly during the upcoming Payload Demonstration Flight. All components were included in the launch vehicle during the Vehicle Demonstration Flight, so the flight trajectory will not be impacted by the rover or PEARS during the Payload Demonstration Flight.

5.7.4 Analysis of Payload Retention System Performance

The payload retention system did not sustain any damage from the Vehicle Demonstration Flight. The harness did not permanently deform from flight forces and all Kevlar stitching held as seen in Figure 102. The rover was properly protected protected from the recovery ejection charges by the Kevlar sleeve and blanket connected to the harness.

Figure 102: Damage-free Kevlar stitching after Vehicle Demonstration Flight

After the flight, all PEARS components were inspected for signs of wear or damage. No components sustained damage and there was no visible wear. This outcome was expected as the results from the analysis conducted in Section 6.1.3.2 showed all components are rated well above the maximum force they could potentially experience.

A more in-depth and documented post-flight analysis will be completed after the Payload Demonstration Flight.

5.8 Scientific Base Station

In addition to the rover completing the NASA SL stated mission goals, the rover will complete a scientific experiment with the collected soil. The experiment maps the pH levels of the soil near the base station. The base station was created to be modular to perform multiple types of tests. The base station simultaneously simplifies the requirements of the base station and the rover. This is designed to simulate a Mars or extraterrestrial mission. In the simulated mission, a previous launch could have established the base station that the rover uses to perform the scientific experimentation. The base station, shown in Figure 103, allows the rover to dock from four different sides. The base station has four pieces of cloth with circles suspended from the top of the frame, which the rover identifies with computer vision and drives straight towards.

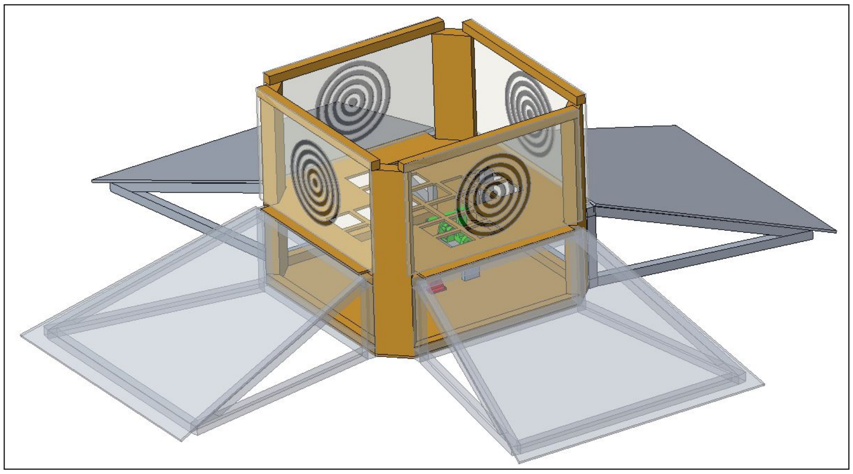

Figure 103: The CAD model of the scientific base station

The rover docks with the scientific base station by using its GPS coordinates to get within range, allowing computer vision to detect the base station. Once the base station is detected, it performs a docking procedure using the BeagleBone. The rover and base station communicate using a 900 MHz transmission frequency with identical communication protocol to the ATUs used for tracking the launch vehicle throughout flight and recovery. See Section 3.2.7 for more details on the ATU.

Once the rover has docked with the scientific base station, it deposits a soil sample into the setup shown in Figure 104. The soil sample is funneled into a beaker filled with deionized water, where a probe is then actuated into the soil sample. The pH of the mixture is measured for 90 seconds, due to the response time of the pH sensor being 60 seconds. The raw data is broadcast from the scientific base station back to the ground station where it can be processed. The raw data allows OSRT to determine the GPS coordinate and the pH of the sample at the collection location. The process is repeated numerous times, developing a pH map across the region surrounding the scientific base station.

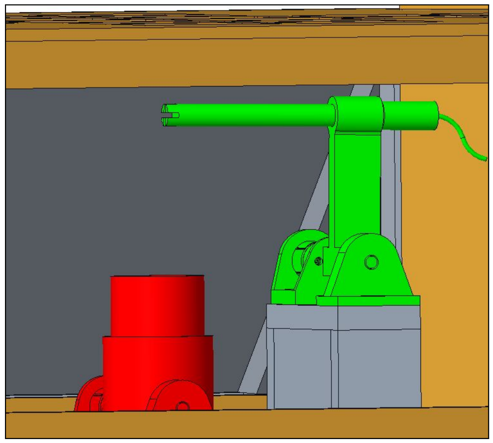

Figure 104: The beaker and probe assembly of the scientific base station

Throughout the Final Readiness phase of the project, the NASA SL competition requirements were prioritized above the scientific base station. This has delayed the scientific base station manufacturing, but will be completed and tested by the FRR Addendum.

6 Project Plan

6.1 Verification Procedures

Throughout the project, OSRT has developed and completed numerous procedures to ensure all competition requirements and team derived requirements are met. Each of these procedures can be of differing types: Test, Demonstration, Inspection, or Analysis. A Test is a procedure in which data is collected to determine the performance of a system. A Demonstration is a procedure which is completed that either passes or fails at meeting a set of success criteria. An Inspection is a procedure which verifies a requirement has been met through observation or detailed instructions. An Analysis verifies a requirement has been met based on calculations and simulations. Sections 6.1.1 - 6.1.3 contain details of the procedures performed by OSRT.

6.1.1 Launch Vehicle Verification Procedures

6.1.1.1 Launch Vehicle Demonstration Flight

This demonstration is to verify competition requirements 2.1, 2.7, 2.12, 2.18, 2.20, 3.8 in Tables 74 and 75.

Demonstration Objective: This demonstration is to assemble the launch vehicle with the fully manufactured weights and lengths to test all components prior to competition flight in Huntsville, AL.

Demonstration Description: The launch vehicle demonstration flight consisted of fully manufactured components. A simulated payload was retained in the fore airframe in the same manner it will be retained at competition in Huntsville, AL. The flight used the Cesaroni L2375-WT which will be used at competition with a 12 V direct current ignition system. Two independent sections fall from apogee using a 1.5 ft drogue parachute and an 8 ft main parachute for each section.

Success Criteria: The success criteria of the launch is as follows:

- Launch vehicle reaches an apogee altitude between 4,000 and 5,500 ft.
- Launch vehicle exits the launch rail above 52 ft/s.
- Two independent sections of the launch vehicle land with a kinetic energy less than 75 ft-lbf.
- The launch vehicle is reusable after flight.

Results: The results of the launch vehicle for each success criteria are as follows:

- The launch vehicle reached an apogee altitude of 5,079 ft.
- The launch vehicle had a rail exit velocity of 71.85 ft/s.
- The fore section of the launch vehicle landed with a kinetic energy of 38.45 ft-lbf. The aft section of the launch vehicle landed with a kinetic energy of 65.87 ft-lbf.

- The launch vehicle proved to be both recoverable and reusable following the Post Flight Launch Vehicle Checklist in Table 62.

6.1.1.2 Recovery Electrical Circuits Inspection

This inspection procedure is used to verify competition requirements 2.3, 2.4, 2.5, 2.6, 3.4, and 3.6, in Tables 74 and 75.

Inspection Objective: This inspection has six objectives.

- The electrical circuits for all recovery electronics will be separate from all payload circuits.
- It will be checked that at a minimum, 1 barometric altimeter will be included for recording the official altitude.
- All altimeters will be able to be armed by a mechanical switch which can be accessed from the outside of the launch vehicle on the launch pad, and this switch will be able to be locked in the on position.
- Each altimeter will have its own dedicated power supply.
- The launch vehicle will contain redundant, commercially available altimeters.

Inspection Description:

- Check that at a minimum, 1 barometric altimeter is included for recording the official altitude for competition. This altimeter will be one of the four RRC3 altimeters contained in the launch vehicle. This verifies competition requirement 2.3.
- Ensure that all altimeters are able to be armed by a mechanical switch which can be accessed from the outside of the launch vehicle on the launch pad. These switches are DPDT switches. Check that this switch can be be locked in the ”on” position. This verifies competition requirements 2.4 and 2.6.
- Ensure each altimeter has its own power supply. This is a 9 Volt battery, enclosed in a battery case. This verifies competition requirement 2.5.
- Ensure the electrical circuits for all recovery electronics are separate from all payload circuits. This verifies competition requirement 3.4.
- Ensure the fore and aft launch vehicle sections contain commercially available, redundant altimeters. This means two altimeters should be contained within both the fore and aft altimeter bays.

Success Criteria: The inspection is successful if all recovery circuits only include one commercially available altimeter operating barometrically, one DPDT switch, one 9 V battery, and none of the recovery electrical circuits are part of the payload recovery electrical circuits.

Results: Completed on the full scale launch vehicle. Competition derived requirements 2.3, 2.4, 2.5, 2.6, 3.4, and 3.6 have all been met with this inspection.

6.1.1.3 Full Scale Integration Demonstration

This demonstration is used to verify competition requirement 2.10 in Table 74 and the launch vehicle team derived requirement LV - 4, in Table 78.

Demonstration Objective: This demonstration will show that the OSRT can fully integrate all components of the launch vehicle in a timely manner.

Demonstration Description: The full scale launch vehicle is completely assembled including all components within the airframe. Black powder charges are replaced with blank charges so that there is no risk of an unexpected explosion. All other components are integrated as if preparing on launch day. All appropriate checklists are followed and marked simulating real launch day conditions. Once integration begins, a timer is started and is not stopped or paused until the launch vehicle is completely assembled and prepared to be placed on the launch rail.

Success Criteria: The demonstration is considered a success if the launch vehicle is fully assembled within two hours. If integration takes too long, the demonstration must be redone from the beginning until the entire launch vehicle is assembled within two hours.

Results: After several attempts, the launch vehicle, including all internal components, was able to be assembled in a time of 1 hour and 47 minutes. During the first two integration tests, the OSRT found several issues and the time constraint of two hours was not met. After fixing issues and finalizing checklists, the team was able to successfully complete the demonstration.

6.1.1.4 Launch Pad Stay Time Demonstration

This demonstration is used to verify competition requirement 2.11, as described in Table 74.

Demonstration Objective: The objective of this demonstration is to prove that the launch vehicle can sit on the launch pad for a minimum of two hours without losing functionality of any on-board, launch critical components.

Demonstration Description: All four altimeters are taken to a relatively sound insulated location. A new 9 Volt battery is placed in each battery case, and all switch and battery wires are connected to each altimeter. Once it has been verified that all altimeters are set up in the proper manner, turn on all four altimeters and start a stopwatch. Once this has been done, the altimeters are left on for two hours. The altimeters are checked after two hours to ensure they are still on. For the next two hours, ensure the altimeters are still on in intervals of 30 minutes. After three hours has passed, the altimeters can be shut off.

Success Criteria: The demonstration is successful if the altimeters can be left on for a minimum of two hours without running out of battery.

Results: The results for this demonstration were successful. The altimeters remained on throughout the duration of three hours, at which point they were shut off.

6.1.1.5 Static Stability Analysis

This analysis procedure is used to verify competition requirement 2.17 and team derived requirement LV - 2 as described in Tables 74 and 78.

Analysis Objective: The objective of this analysis is to verify that the static stability margin of the launch vehicle is above 2.0 calibers and below 3.5 calibers.

Analysis Description: The analysis began by creating an OpenRocket simulation with all designed weight and lengths of components in the launch vehicle. Fin dimensions were designed to locate the center of pressure of the launch vehicle 13.40 in. aft of the center of gravity, giving a static stability margin of 2.1 calibers. After completion of the fully integrated weight demonstration, the center of gravity as manufactured value is determined. With the as built center of gravity and center of pressure locations known, the static stability can be calculated.

Success Criteria: The center of pressure location must be more than 12.76 in. and less than 22.33 in. aft of the measured center of gravity location.

Results: The center of gravity was measured in the fully integrated weight demonstration to be 71.0 in. aft of the nosecone tip. The as built fin dimensions gave a center of pressure location of 84.7 in. aft of the nosecone tip. The static stability was calculated to be 2.14 calibers using Equation 1.

$$Stability = \frac{Cp - Cg}{OD} = \frac{84.7in. - 71.0in.}{6.38in.} = 2.14calibers \tag{1}$$

6.1.1.6 Steel Threaded Rod Analysis

This analysis procedure is to verify team derived requirement LV - 8 in Table 78.

Analysis Objective: The goal of this analysis is to show that all threaded rods relating to parachute deployment can withstand the force at an acceleration of 50 G.

Analysis Description: Due to the design change of radial bolted rings, there is only one threaded rod that is directly attached to the parachutes. This remaining rod is threaded with 1/4-20 threads, made of grade 8 steel, and is located in the nosecone. At a 1/4 in. diameter, the cross-sectional tensile strength area is 0.031 in^2. The weight of the fully assembled nosecone is 5.07 lbs. By using the stress equation, the maximum expected stress in the threaded rod is calculated. This is then compared to the tensile strength of rod to find a safety factor.

Success Criteria: The threaded rod must be able to withstand a minimum of 1.5 times the expected maximum stress.

Results: The threaded rod was calculated to have a safety factor of 18.34 using Equation 2 and Equation 3. This is well above the necessary 1.5 and the analysis can be considered successful.

$$ExpectedMaximumStress = \frac{Mass * Acceleration}{Area} = \frac{5.07lbm * 50G}{0.031in^2} = 8,200psi \tag{2}$$

$$SafetyFactor = \frac{TensileStrength}{ExpectedMaximumStress} = \frac{150,000psi}{8,200psi} = 18.34 \tag{3}$$

6.1.1.7 Aluminum Threaded Rod Analysis

This analysis procedure is to verify team derived requirement LV - 8 in Table 78.

Analysis Objective: The goal of this analysis is to show that aluminum threaded rods can withstand the force at an acceleration of 50 G.

Analysis Description: There is one aluminum threaded rod that is used in the launch vehicle. This rod is threaded with 1/4-20 threads, made of grade 6061 aluminum, and is located in the canister. This rod holds the camera system in place as well as retains the aft ballast bay. At a 3/8 in. diameter, the cross-sectional tensile strength area is 0.11 in^2. The weight of the fully assembled camera system is 2 lbs and the maximum weight of the aft ballast bay is 2 lbs. By using the stress equation, the maximum expected stress in the threaded rod is calculated. This is then compared to the tensile strength of the rod to find a safety factor.

Success Criteria: The threaded rod must be able to withstand a minimum of 1.5 times the expected maximum stress.

Results: The threaded rod was calculated to have a safety factor of 22 using Equation 4 and Equation 5. This is well above the necessary 1.5 and the analysis can be considered successful.

$$ExpectedMaximumStress = \frac{Mass * Acceleration}{Area} = \frac{4lbm * 50G}{0.11in^2} = 1,818psi \tag{4}$$

$$SafetyFactor = \frac{TensileStrength}{ExpectedMaximumStress} = \frac{40,000psi}{1,818psi} = 22 \tag{5}$$

6.1.1.8 Fin Design and Positioning Analysis

This analysis verifies the team derived requirement LV-9.

Analysis Objective: This analysis was done to ensure the fins do not break during recovery by impacting the ground first. By making sure the fins are not the first component to impact the ground, they are far less likely to fracture.

Analysis Description: The descent time and impact velocity upon landing in Section 6.1.1.15 were used in conjunction with the maximum allowable wind speed to calculate the maximum angle of impact, using trigonometry.

Success Criteria: The fins are not the first component to impact the ground first.

Results: The maximum angle of descent was found to be 25.8° for the aft section. The fins were designed with a 22.4° trailing edge angle and positioned 2 in. from the aft end of the body tube. This creates a 45° angle from the aft end of the body tube to the tip of the fins, ensuring the fins do not impact first. Additionally, this was demonstrated during the February 22nd launch vehicle demonstration flight.

6.1.1.9 Radial Bolt Test

This test verifies team derived requirements LV - 6 and LV - 7 in Table 78.

Test Objective: This test is to determine the number and size of machine screws needed to retain the recovery attachment bulkhead in the airframe.

Test Description: This test uses an Instron machine to determine the failure point of the radially bolted ring and bulkhead. There are several points that can break in this configuration: the wooden bulkhead, the aluminum ring, the radial bolts, or the airframe itself. All of these components need to withstand a test at 50 G, the worst case scenario for recovery forces. The aft section, after full motor burn, weighs 23.1 lbs, leading to a maximum expected force of 1,155 lbf. The test procedures are as follows:

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

1) Cut a small section of excess airframe for destructive testing.
2) Machine radial bolt holes in airframe test section.
3) Assemble bulkhead into airframe test section with six machine screws, equally spaced radially along the bulkhead.
4) Prepare Instron machine for testing.
5) Mount assembly into Instron machine. Pictured in Figure 108.

- Safety Consideration: Ensure all body parts, long hair, and loose clothing or jewelry are secure and away from the Instron machine.

6) Conduct compression test using the Instron machine to measure the force required to cause failure in any component present in the system (airframe, bulkhead, retention ring, or machine screws).
7) Record maximum force data.
8) If the force required to cause failure is less than the worst case expected recovery force of 50 G, the test is considered a failure. Modifications of the design must be made and tested again.

Success Criteria: All components involved are able to hold up to a minimum of 1,155 lbf without any permanent damage.

Results: The first method that was tested used six radially mounted 8-32 bolts, that were 3/4 in. long, around the body tube of the launch vehicle. These bolts were mounted into a 9 ply 1/2 in. Baltic Birch Plywood bulkhead. This test was unsuccessful, as the bolts were mounted in such a way that the plies began to separate at a mere 520 lbf, as seen below in Figure 105 and Figure 110. The airframe and bolts had no visual defects from the test.

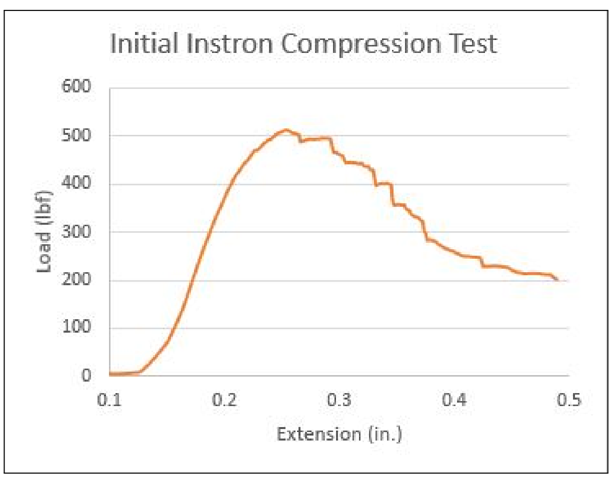

Figure 105: Plywood Bulkhead Failure due to Splitting

A second method tested an aluminum ring mounted on the face of the plywood bulkhead. With this design, the force on the plywood is spread out more evenly across the ring and bulkhead. Additionally, the force will be truly compressing the bulkhead rather than attempting to separate the glue. The ring measured 3/8 in. thick with an outer diameter of 6.25 in. and an inner diameter of 5.00 in. Six bolts were utilized again, but this time they were sized up to 10-24 and were 3/4 in. long. Simulating the forces that the plywood bulkhead would see during recovery, this method held up to 2,212 lbf. Each ply's breaking point is seen in Figure 106. The results show that a bulkhead can withstand up to 95 G, which is well above the requirement of 50 G.

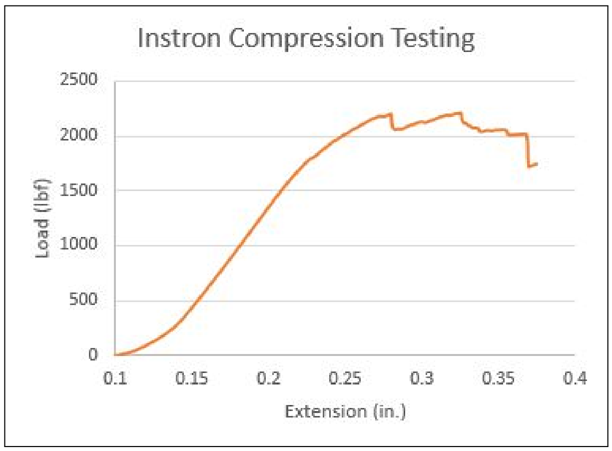

Figure 106: Plywood Bulkhead Failure

Lastly, the airframe was tested to failure. The whole aluminum ring was pushed on, instead of just the center of the plywood. This test resulted in the bolts tearing through the carbon fiber section at an applied force of 3,524 lbf. The results of this test can be seen in Figure 107 and Figure 109. Both of the tests with the aluminum ring show that this method will hold up to the worst case expected forces during recovery.

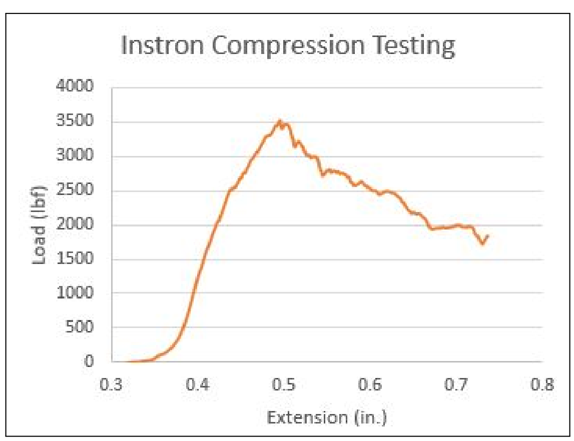

Figure 107: Carbon Fiber Airframe Failure

Figure 108: Instron Test

Figure 109: Body Tube Failure

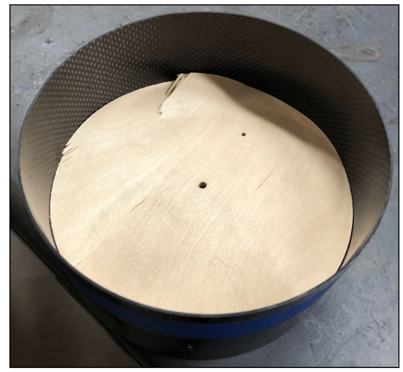

Figure 110: Bulkhead Failure

6.1.1.10 Airframe Compression Test

Test Objective: This test is to determine the structural integrity of the airframe with maunfactured holes and slots.

Test Description: This test uses an Instron machine to determine if the airframe can withstand the expected load during launch without buckling at stress factors. There are several holes within the airframe, including 7/8 in. holes for the camera system, and the BEAVS slots. All of these stress factors need to withstand a test at 15 G, the highest load scenario for ascension forces. The test procedures are as follows:

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

1) Cut small section of excess airframe for destructive testing.
2) Machine holes and slots into airframe section.
3) Prepare Instron machine.
4) Mount assembly into Instron machine. Pictured in Figure 112.

- Safety Consideration: Ensure all body parts, long hair, and loose clothing or jewelry are secure and away from Instron machine.

5) Conduct compression test using the Instron machine to measure the force required to cause failure in the airframe.
6) Record maximum force data.
7) If the force required to cause failure is less than the worst case expected recovery force of 15 G, the test is considered a failure. Modifications of the design must be made and tested again.

Success Criteria: The airframe section is able to hold up to a minimum of 678 lbf without any permanent damage.

Results: The fiberglass airframe held up to 2,700 lbf. The test was not conducted until failure. This applied force value results in a safety factor of over 4, so the test was stopped to prevent fiberglass shrapnel.

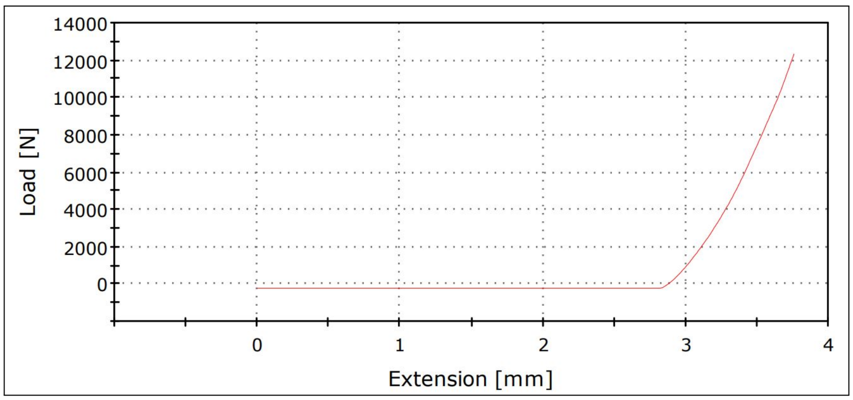

Figure 111: Fiberglass Airframe Section Under Compression

Figure 112: Fiberglass Airframe Section in Instron Machine

6.1.1.11 Fully Integrated Weight Demonstration

This demonstration is to verify competition requirement 2.17 in Table 74.

Demonstration Objective: This demonstration is to calculate the weight of the fully integrated launch vehicle, and find the center of gravity location with respect to the nosecone tip.

Demonstration Description: Before this demonstration can begin, the launch vehicle must be fully assembled with all integrated components in the launch vehicle. When the fully integrated launch vehicle is ready, the fully assembled motor is inserted into the motor tube.

Safety Consideration: Only NAR Level-2 certified personnel are to handle the assembled motor and insert motor into motor tube. Ensure there are no possible ignition sources in the area and that everyone in the area is aware of the packed motor.

When the launch vehicle is fully assembled, as if ready to be placed on the launch rail, place the assembled launch vehicle on a scale to measure the full weight. After the full weight is recorded, have two people hold the launch vehicle from each end. Place a section of nylon shock cord around the airframe at approximately where the center of gravity location will be. Loop the nylon shock cord around a steel bar so that by holding the steel bar the launch vehicle will be retained.

Safety Consideration: The launch vehicle weighs more than 50 lbf; have two people sharing the weight of the launch vehicle at all times.

Hold the entirety of the launch vehicle by the nylon shock cord section. Adjust the location until the launch vehicle is balanced on each side of the shock cord. Mark each side of the shock cord, and then mark the center of these two marks to be the center of gravity location. Using a tape measure, measure the location relative to the nosecone tip. Figure 113 shows two members of OSRT completing this demonstration.

Figure 113: Fully Integrated Center of Gravity Demonstration

Success Criteria: The weight of the launch vehicle is recorded as if it was located on the launch rail ready to launch. The center of gravity location is determined with equally balanced sections on each side of this location.

Results: The final weight of the fully integrated launch vehicle was measured to be 56.9 lbf. The center of gravity location was measured to be 71.0 in. aft of the nosecone tip.

6.1.1.12 Rail Exit Velocity Analysis

This analysis procedure is to verify competition requirement 2.18 as described in Table 74.

Analysis Objective: This analysis will ensure that the launch vehicle will be designed to exit the launch rail at more than 52 ft/s.

Analysis Description: The 52 ft/s minimum rail exit velocity requirement is with a 12 ft 1515 rail. The OpenRocket simulation calculates the velocity of the launch vehicle upon rail exit. For test flights, OSRT uses a 8.08 ft 1515 rail. The velocity off of a 8.08 ft rail will be less than a 12 ft rail because the launch vehicle continues to accelerate after leaving the launch vehicle. Exit velocities off of both launch rails will be designed to be above the minimum required 52 ft/s.

Success Criteria: The simulated launch vehicle exit velocities are above 52 ft/s for both a 8.08 ft 1515 rail and 12 ft 1515 rail.

Results: The launch vehicle had a rail exit velocity of 71.85 ft/s off of a 8.08 ft rail for the launch vehicle demonstration flight. The launch vehicle is simulated to have a rail exit velocity of 83.4 ft/s off of a 12 ft rail at SL competition.

6.1.1.13 Subscale Launch Vehicle Demonstration

This demonstration is to verify competition requirement 2.19, 2.20, 3.3, 3.9, and 3.10 in Tables 74 and 75.

Demonstration Objective: This demonstration is to assemble a subscale launch vehicle and launch it to verify that the simulations and processes used by the OSRT are accurate and will work for the full scale flight.

Demonstration Description: The subscale launch vehicle flight consisted of fully manufactured components. There was no payload in this demonstration flight. Simulations used to predict full scale flight characteristics were altered to reflect the specifications of subscale. Current recovery layout and methods will be used in this demonstration flight.

Success Criteria: Simulations used are verified by subscale launch and recovery results.

Results: Two subscale flights were conducted. These launches took place in Brothers, Oregon on December 8th, 2018 and January 4th, 2019. On the first subscale flight, the main parachute slipped out at apogee. On the second flight the drogue parachute deployed at apogee, but the main parachute failed to be deployed. Using data from both flights, recovery simulations were able to be verified. Extra redundancy features were added to the recovery design to ensue a successful recovery.

6.1.1.14 Structural Protuberance Analysis

This analysis is used to verify competition requirement 2.22 in Table 74.

Analysis Objective: This analysis is to verify that the BEAVS is located aft of the center of gravity. BEAVS is the only structural protuberance on the launch vehicle.

Analysis Description: The first step in the analysis is to find the burnout center of gravity of the launch vehicle. This can be done with an OpenRocket simulation. The final step is to locate the BEAVS slots in the aft airframe aft of the burnout center of gravity.

Success Criteria: The BEAVS slots are aft of the burnout center of gravity.

Results: The burnout center of gravity is located 66.522 in. aft of the nosecone tip at motor burnout. The BEAVS slots are located 95.875 in. aft of the nosecone tip.

6.1.1.15 Descent Trajectory Analysis

This analysis is to verify competition requirement 3.9 and 3.10 in Table 75 and team derived requirement LV - 5 in Table 78.

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

Analysis Description: Certain characteristic of the launch vehicle must be input such as weight, parachute type and size, predicted apogee and altitude of main parachute deployment. The analysis will calculate the cross sectional area of each parachute used in order to measure the drag force each parachute provides. This is used to calculate the acceleration of the launch vehicle during descent which can be used to calculate the velocity and location of the launch vehicle. Using this, the descent time and kinetic energy of each recovered section at the time of landing can be calculated. Drift radius is calculated using the descent time and a range of wind speeds. It should be noted that this simulation does not include weather cocking and assumes apogee is directly above the launch rail.

Success Criteria: A combination of drogue and main parachutes are selected that will yield a recovery with a descent time no more than 90 s, a landing kinetic energy no more than 75 ft-lbf, and a drift radius no more than 2,500 ft.

Results: The analysis was performed and the OSRT decided to use a 8 ft toroidal parachute for the fore and aft main parachutes and a 1.5 ft cruciform parachute for the fore and aft drogue parachutes. These parachutes will result in a landing kinetic energy of 64.1 ft-lbf, 62.7 ft-lbf and 17.9 for the fore, aft and nosecone sections, respectively. These are both under the maximum allowable landing kinetic energy of 75 ft-lbf. The drift radius at 20 mph is 1,967 ft and 2,077 ft for the fore and aft sections, respectively. This is the maximum wind velocity that the OSRT will launch in, so these values will be the largest drift radius. Both these values are under the maximum drift radius of 2,500 ft. The simulation yielded a descent time of

67.07 seconds and 70.83 seconds for the fore and aft sections, respectively. Both these values are under the maximum allowable descent time of 90 seconds.

6.1.1.16 Thrust to Weight Ratio Analysis

This analysis procedure is to verify team derived requirement LV - 3 as described in Table 78.

Analysis Objective: This analysis will verify that the thrust to weight ratio of the launch vehicle is at least six to one to ensure safety upon rail exit. Motor will be selected for a thrust to weight ratio of at least ten to one.

Analysis Description: The thrust to weight ratio of the launch vehicle is determined by dividing the maximum thrust of the motor by the fully integrated weight of the launch vehicle. A higher thrust to weight ratio is beneficial to counteract weather cocking and achieve a higher apogee altitude. A thrust to weight ratio below six leads to safety concerns of the launch vehicle not able to properly exit the launch vehicle for stable flight.

Success Criteria: The thrust to weight ratio of the launch vehicle is at least six to one.

Results: The fully integrated weight measured in the fully integrated weight demonstration determined the launch vehicle to be 56.9 lbf. The maximum thrust of the Cesaroni L2375-WT is 586 lbf. The thrust to weight ratio of the launch vehicle is therefore 10.30.

6.1.2 Recovery Verification Procedures

6.1.2.1 Heat and Pressure Effects Inspection

This inspection verifies team derived requirement LV - 1 in Table 78.

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

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

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

Results: Inspection was completed after ground ejection demonstrations and full scale flight on February 22nd, 2019. The ejection components did not cause not cause noticeable damage or melting to recovery components.

6.1.2.2 Recovery Integration Order Demonstration

This demonstration verifies team derived requirement Recovery - 10 in Table 79.

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 Descenders are not attached to the harness. Ensure all components have been appropriately packed into the airframe. Pull on the butterfly knot the drogue parachute is attached to until the deployment bag has left the airframe. Continue pulling until the main parachute is completely extracted from the deployment bag.

Success Criteria: All recovery components are extracted untangled, and in the desired order. The force required required to pull the parachute out of the deployment bag should be little to none once the deployment bag has exited the airframe.

Results: The recovery integration order demonstration was completed for the full scale launch. All recovery components were extracted untangled, and in the correct order. No force was required to extract the parachute out of the deployment bag once the deployment bag was outside the airframe.

6.1.2.3 Recovery Staging Demonstration

This demonstration is used to verify competition requirements 3.1, 3.1.1, and 3.1.2 in Table 75.

Demonstration Objective:

The purpose of this demonstration is to prove that the drogue parachutes can be deployed at apogee with a delay less than two seconds and that the main parachutes can be deployed above 500 ft.

Demonstration Description:

The full scale launch vehicle has been assembled according to checklists. The full scale launch vehicle has been flown, including the payload. At apogee, the altimeters caused the two separation events, deploying the drogue parachute. The primary altimeters were set to have a delay of zero seconds, and the backup altimeters were set to have a delay of one second. The main parachutes were retained in the airframe sections by two Tender Descenders in parallel until an altitude of 700 ft AGL. After the parachutes were released, the backup charge forced the deployment bag from the airframe.

Success Criteria:

The drogue parachutes must be deployed within two seconds of reaching apogee, and the main parachutes must be deployed above 500 ft AGL.

Results:

At the full scale launch, all check lists were followed in order to assemble the launch vehicle correctly. The launch vehicle was flown to an apogee of 5,079 ft, where both separation events occurred. The launch vehicle sections fell under drogue to an altitude of 700 ft AGL, where the Tender Descenders were released. 1 second later, the backup charges expelled the main parachutes. Both were deployed above 500 ft. However, due to the close proximity to 500 ft when the parachutes were deployed, the Tender Descenders will be released at 800 ft AGL, and the backup charges blown 0.5 and 1 second later.

6.1.2.4 Parachute Ejection Demonstration

This demonstration is used to verify competition requirements 3.2 and 3.8 in Table 75 and team derived requirement Recovery - 1 in Table 79.

Demonstration Objective:

This demonstration is associated with recovery integration. It is necessary to ensure that only the drogue section of the recovery harness leaves the airframe at apogee. 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 necessary to successfully separate the launch vehicle sections at apogee.

Demonstration Description:

Listed below is the procedure which has been 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. Ensure the e-match holes are uncovered.
2) Take the long wire and thread about 12 in. through the recovery bay bulkhead.
3) Follow the checklist for fore or aft ejection bay integration, which are described in Sections 43 and 44. Start with the step where the bulkhead is being pushed into the fore airframe or aft coupler, and follow the whole checklist.

4) Take the assembly to the propulsion lab, which is the location OSRT has available to ejection test.

- Safety consideration: Handle the charge with care. Static electricity can set off a charge.

5) Attach extension leads to the e-match leads.
6) Follow recovery integration procedure in Tables 45 and 51 to ensure the assembly is integrated correctly. After the recovery components have been integrated, slide the fore and aft, or the fore and nosecone, sections together. Place three nylon shear pins in the assembly.
7) Place towels over the cinder blocks. This is to keep the airframe from being scratched during the demonstration.
8) Strap down the airframe with ratchet straps to cinder blocks.

- **Note:** It is important for the fin section to be immobile during this demonstration.

9) Move safe distance away from airframe.
10) Ensure the ignition system is in the off position.
11) Plug extension into the ignition system.
12) Attach a 9 V battery to the ignition system.

- Safety Consideration: Ensure all participants are aware that the ignition system is ready. Announce that you are about to set off the charge. Ensure no one is within 50 ft the airframe before the charge is set off. Ensure everyone is behind a protective barrier/shield.

13) Flip the switch.
    a. If successful, repeat until 5 consecutive tests are successful.
    b. If unsuccessful, determine why: Did **zero/one** charges ignite?
       i) **Zero:** Disassemble full scale launch vehicle. Check the following potential causes in the order listed until the problem is solved: improper battery and e-match combination used, leading to a current over 6 A; charges are likely not wired correctly; the e-matches have a broken lead; the e-matches are faulty.
       ii) **One:** If one ignited, charge was sized incorrectly, or a pressure seal was not formed.
14) Inspect the recovery assembly. Ensure the deployment bag has been contained within the airframe.
    - **Note:** If the deployment bag has left the airframe, the recovery system demonstration is considered a failure.
15) Repeat this process until five consecutive, successful tests have been performed.

Success Criteria: This demonstration is considered successful if 5 consecutive separation events fully separate the launch vehicle sections, expel the drogue parachute, and retain the deployment bag within the airframe.

Results: Ejection demonstrations have successfully been performed to size charges and view the events which would occur at apogee on the full scale launch vehicle. Figure 114 displays a successful separation of the full scale launch vehicle sections. These demonstrations were further proven at the full scale launch, when all sections separated successfully. These demonstrations resulted in sizing of all recovery charges. The charge sizes are listed in Table 70

Figure 114: Ejection Demonstration

Charge Name	Charge Size [g]
Fore Primary	4.0
Fore Secondary	6.0
Fore Deployment Bag Primary	4.0
Fore Deployment Bag Secondary	4.0
Aft Primary	5.5
Aft Secondary	8.0
Aft Deployment Bag Primary	4.0
Aft Deployment Bag Secondary	4.0

Table 70: Recovery Charges Sizing

All secondary, separation charges have been sized to be roughly 1.5x the primary ejection charge size. This was done per recommendations from OSRT mentors. The deployment bag charge size is not changed because a 4 gram charge was proven to expel the deployment bag from the airframe with a high velocity. If the bag does not come out because of ignition of the first charge, it is not because of the sizing of the charge. Instead, it is likely because neither Tender Descender separated. In the case the primary charge does not ignite, but one or both Tender Descenders fire, the backup will still expel the bag with a 4 gram charge.

6.1.2.5 Static Port Hole Sizing Analysis

This analysis is used to verify team derived requirement Recovery - 6 in Table 79.

Analysis Objective: Two different mission critical altimeters have been flown in the full scale launch vehicle: RRC3 and StratoLoggerCF. Both of these altimeter's manuals describe an appropriate static port hole sizing procedure.

Analysis Description: The analysis procedure for the Missile Works RRC3 and the PerfectFlite StratoLoggerCF are as follows:

Missile Works RRC3

1) Calculate the altimeter bay volume with Equation 6

$$Volume = \pi R^2 L \tag{6}$$

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 7 if Volume ≤ 100 in^3 or Equation 8 if Volume ≥ 100 in^3.

$$D = \frac{Volume}{400} \tag{7}$$

$$D = 2\sqrt{\frac{Volume}{6397.71}} \tag{8}$$

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 9.

$$Area = \pi(\frac{D}{2})^2 \tag{9}$$

4) Lastly, calculate the diameter of each port with Equation 10

$$D_{multi-port} = 2\sqrt{\frac{Area/N}{\pi}} \tag{10}$$

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

Success Criteria: This analysis is considered once the static port holes are drilled into the full scale launch vehicle airframe and measured to ensure they are sized correctly.

Results: Four static port holes have been used for both altimeter bays. Based off the calculations, each static port hole will be sized to 0.185 in. in diameter.

6.1.2.6 E-match Resistance Demonstration

This demonstration is used to verify team derived requirement Recovery - 7 in Table 79.

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 Ω. Repeat for all e-matches needed.

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

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

6.1.2.7 Altimeter Pressure Reading Demonstration

This demonstration is used to verify team derived requirements Recovery - 8 and Recovery - 9 in Table 79.

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, labeled ”primary drogue,” ”secondary drogue,” ”primary main,” ”secondary main,” ”primary deployment bag,” and ”secondary deployment bag.” The checklist in Table 39 is followed to set up the altimeter sleds. Slide the sleds into their respective altimeter bay. Ensure the e-match leads are hanging over the edge of the altimeter bay and place the bulkhead over the top of it. Tape over all holes, excluding one altimeter arming hole to create a makeshift pressure seal. Arm the altimeter. Secure the head of a shop vacuum hose to the altimeter bay. This is to simulate flight, dropping the pressure in the altimeter bay. Turn the vacuum on and wait until the drogue charge ignites. Shut the vacuum off and the main e-match should ignite. The auxiliary e-match should then ignite a set time after the main. For the primary RRC3, it will be 0.5 seconds. For the secondary, it will be 0.85 seconds. Repeat this for the other RRC3 altimeter. The main parachute e-matches will ignite, the primary deployment bag e-match will ignite 0.5 seconds after, and the secondary deployment bag e-match will ignite 1 second after the main e-matches. Pull the altimeters out of the altimeter bay 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 parachute's e-matches were ignited at the highest altitude sensed. Ensure the main parachute's e-matches were ignited near 800 ft AGL (if not near, ensure the altitude was higher than 500 ft AGL). Ensure the deployment bag charges were ignited with the correct spacing from the main e-matches.

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

Results: E-matches were ignited in the correct sequence at the expected times during this demonstration for full scale. Figure 115 shows the setup for this demonstration.

Figure 115: Sealed altimeter bay with e-matches prior to the Altimeter Pressure Reading Demonstration

6.1.2.8 Ejection Charge Rupture Inspection

This inspection is used to verify team derived requirements Recovery - 11 in Table 79.

Inspection Objective: This inspection has been implemented to ensure consistency in the rupturing of the ejection charges.

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

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

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

Results: All ejection charges used properly detonated, causing the explosion to rupture through the wall of the surgical tube. Figure 116 displays how the charges should appear after successfully firing. Ejection charge demonstrations have been performed for all tests and launches involving ejection charges.

Figure 116: Ejection charges exploding through the wall of the surgical tubing.

6.1.2.9 Vehicle Ascent Security Analysis

Analysis Objective: The objective of this analysis is to ensure the nosecone stays secured to the airframe during ascent.

Analysis Description: The atmospheric pressure in Huntsville, Alabama is estimated to be 14.40 psi, and the pressure at apogee is estimated to be 11.97 psi. This results in a difference of pressure of 2.43 psi. The surface area of the bulkhead at the nosecone is 30.68 in^2. The force applied to the nosecone due to the change in pressure is solved for using Equation 11.

$$F = PA \tag{11}$$

Where P is the pressure difference and A is the area of the bulkhead. Assuming no friction, the force required to remove the nosecone due to a pressure buildup would be 74.33 lbf.

The nosecone is attached to the fore section with three 2-56 nylon shear pins. This nylon has a shear strength of 10,000 psi. The area of each shear pin is .0058 in^2. This results in a force pf 58.1 lbf to shear one of these pins. Since three pins are being used to attach the nosecone, the minimum force required to shear these pins is 174.3 lbf.

Success Criteria: This analysis was considered successful if the provided safety factor was greater than 2.

Results: The provided safety factor of these shear pins is 2.34. The nosecone will not pop off from a pressure buildup inside the fore recovery bay due to a change in altitude. This was proven during the full scale launch. The launch vehicle remained in one section during the ascent, not separating until the ejection charges fired. This is discussed in section 3.4.2.2

6.1.2.10 Altimeter Arming Switch Analysis

This analysis verifies team derived requirement Recovery - 12 in Table 79

Analysis Objective: This analysis is used to determine the amount of time it takes to discharge the capacitors located in the pressure sensor on the MissileWorks RRC3 altimeters. This analysis is necessary in order to determine the amount of time it is necessary to wait for it to be safe to handle ejection charges after altimeters have been switched off.

Analysis Inputs:

- Value of all capacitance of the altimeter
- Value of resistor between the positive terminal of the altimeter and battery ground

Analysis Outputs:

- Time for full discharge of altimeter capacitors

Analysis Description: The circuit has been designed to ground both terminals of the e-match in one switch position, while in the other switch position the altimeters are armed for flight. Figure 117 shows the wiring diagram for the switch that powers the altimeters.

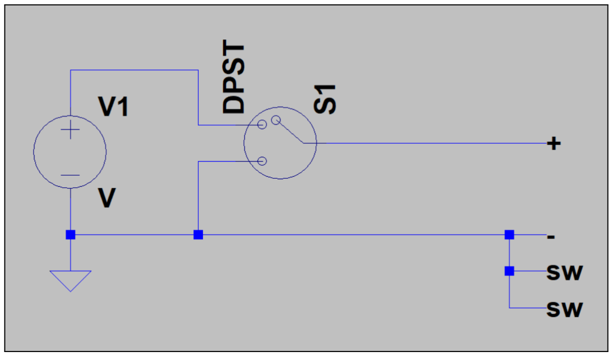

Figure 117: Altimeter Electrical Schematic

The point at which the capacitor is fully discharged will be determined by using the Equation 12.

$$V_C = V_0 * e^{-t/RC}. \tag{12}$$

Solving the equation for time, Equation 13 is produced.

$$t = -RC * ln(\frac{V_C}{V_0}). \tag{13}$$

For this analysis, a discharge rate of 99% to be a fully discharged system will be used. This is done by setting V_C/V_0 equal to 0.01 and plugging in values for resistance and capacitance.

Success Criteria: This analysis is considered successful when live charges are not handled after any altimeter is turned off until all capacitors have been fully discharged.

Results: The amount of time needed to fully discharge the capacitors of the altimeters is 461 nS, which is a negligible amount of time. There is no need for a resistor between the positive terminal of the altimeter and battery ground due to the small value of the capacitor on the altimeter. The resistance was estimated to be 1 Ω, giving a calculated discharge time result higher than the likely discharge time in practice. Upon disarming the altimeter there will be no risk of accidental capacitor discharge igniting a charge.

6.1.2.11 RF Shielding Inspection

This inspection is used to verify competition requirement 3.12, 3.12.1, 3.12.2, 3.12.3, and 3.12.4 in Table 75.

Inspection Objective: This inspection is intended to show that the altimeter bays and PLEC are RF shielded from outside signals.

Inspection Description: The inner walls of the fore and the aft altimeter housings, and PLEC bay are lined with conductive tape and the resistance across several points is measured using a digital multimeter. The full bay includes the fore and aft sides of the bay as well, so that no signals can enter from above the bay. This means that the aft of the pressure seals must be covered in tape as well. Each bay will have a minimum of 20 set of points tested to ensure that the whole bay is RF shielded.

Success Criteria: The maximum resistance between any two points is 1 Ω. If any set of points fails this inspection, the bay must be wrapped and inspected again until 20 consecutive and successful readings are recorded.

Results: The fore and aft altimeter housings are properly RF shielded so that no unwanted signals can enter the bay. The average resistance across two points within the bay is 0.243 Ω with a maximum of 0.516 Ω in the fore housing. Additionally, the altimeters have not been affected by foreign signals during either subscale launch or the first full scale launch. This method of RF shielding was used in all of these flights. The inner wall of the PLEC had a maximum of 0.623 Ω and an average of 0.272 Ω. Figures 118 and 119 show some of the multimeter readings for the aft altimeter housing.

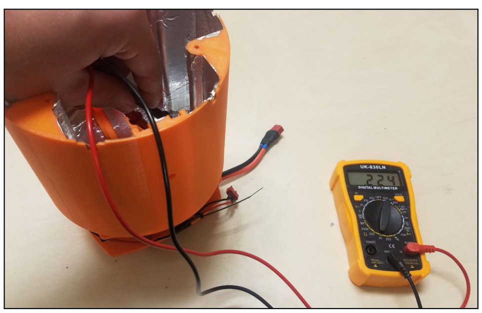

Figure 118: Aft RF Shielding Inspection

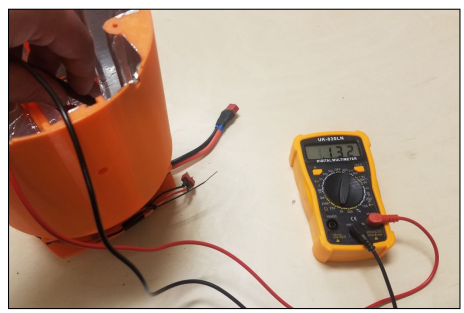

Figure 119: Aft RF Shielding Inspection

6.1.2.12 Battery Life Test

This test verifies competition requirement 2.11 in Table 74 and team derived requirement Recovery - 5 in Table 79.

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

Test Description: Due to the indeterminate duration that the ATU will be required to operate, the system must have a competition-compliant uptime ability. 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 of the flight. Each ATU should be capable of 8 hours of concurrent operational time, with 10 hours being the ideal target.

The procedure is as follows:

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

1) Charge battery pack to full capacity using a smart charger.
2) Check and verify that the battery voltage of battery under test is > 7.7 V.

- Safety Consideration: Do not continue the test if voltages are not within acceptable range.

3) Follow ATU Preparation Checklist in Section 38 (for flight unit) or Section 32 (for ground station) 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 Teensy displays solid orange light.
5) Leave ATU on until light from Teensy goes out. Record time.
6) Unplug ATU from battery.
7) Remove micro-SD card from ATU and transfer data to computer.
8) Compare time stamps between first lock (and recorded start time) and record termination (and recorded end time) and determine total operational time.

Success Criteria: ATU remains powered on for 8 hours while system is in fully operational standard configurations - 900 MHz at 250 mW and 433 MHz at 40 mW.

Results: Lab testing of both 900 MHz and 433 MHz systems have demonstrated operational up-time of over 8 hours (900 MHz, for instance, worked for 9 hours during first subscale launch).

6.1.2.13 Avionics Inspection

This inspection verifies competition requirement 3.11 and 3.11.1 in Table 75.

Inspection Objective: Ensure that active electronic tracking devices (rocket-locating transmitters) 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 and ATU ground station checklist have been completed (see Sections 38 and 32) and that electrical components are all taped down and secured. Make sure that ATUs have achieved GPS lock using ground station serial monitor. During integration, ensure that flight ATUs are armed and one is placed in the aft and fore sections of the launch vehicle. Check that avionics sleds are secure inside the bays. Check components holding the launch vehicle together to confirm that separation will occur as expected. Confirm that transmission from ATUs inside launch vehicles is operational and that data stream on the ground station is stable through the launch vehicle body.

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

Results: ATUs have performed successfully for both full scale and subscale launches.

6.1.2.14 Avionics Operation Demonstration

This demonstration verifies competition requirement 3.11.2 in Table 75 and team derived requirement Recovery - 3 in Table 79.

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

Demonstration Description: ATU checklist (see Section 38) is to be completed prior to launch vehicle assembly. Ground station checklist is then completed (see Section 32). Ground station will indicate coordinates via serial monitor when GPS lock has been attained on flight ATUs and RF link is active. Operation and connection are verified in the same method once ATUs have been placed in aft and fore sections of launch vehicle (see Section 6.1.2.13). Ground station will continue to receive transmitted data and output to serial monitor as long as flight ATUs are operational.

Success Criteria: Ground station ATU outputs positional data to serial monitor on attached PC before, for the duration of, and after the flight. Serial monitor not displaying a large quantity of empty GPS packets indicates successful RF link and GPS lock, and hence successful operation.

Results: The ATU has successfully tracked the subscale and full scale launch vehicles during flight. See Sections 3.4.2.3 and 3.4.2.6.

6.1.2.15 Transmission Range and Continuity Test

This test verifies team derived requirements Recovery - 3 and Recovery - 4 in Table 79.

Test Objective: To determine the effective reliable distances for the ATU and ensure hardware being implemented on ATUs can remain in constant contact with the ground station.

Test Description: The ATU must be able to communicate with the ground station continuously at a significant range to allow for tracking of the launch vehicle after flight. According to the SL handbook, the maximum allowable drift radius of the launch vehicle is 2,500 ft. Continuous tracking can be defined as providing accurate tracking data in intervals no greater than 5 seconds.

The testing procedure is as follows:

- Safety Consideration: Weather conditions must be good to ensure circuit safety. Do not perform test in poor weather such as rain, snow, or even fog.
- Safety Consideration: Walking tester must be alert and aware of potential hazards or obstructions such as traffic.
- Safety Consideration: Battery leads must not be touched to ensure circuits do not short.
- Safety Consideration: Ground station operator should be careful not to touch any exposed circuitry or Integrated Circuit (IC)s during operation in case of damaging equipment.

1) Perform ATU and ground station preparation checklists prior to testing (see sections 38 and 32).
2) Configure RF transceiver on ATU to communicate with ground station at minimum rate of 5 Hz, gain GPS lock on flight unit and RF link between flight unit and ground station.
3) Hold flight unit 10 ft away from ground station without visual obstruction and confirm that flight unit is communicating with ground station.
4) Once RF link is confirmed, begin walking away from ground station and continue until flight unit and ground station are 1 mi apart.
5) Unplug flight unit and return to ground station.
6) Remove SD card, transfer data to PC, rename and save.
7) Reinsert SD card and power flight unit back up. Repeat steps 3-5 until 5 iterations of the test have been performed.
8) Analyze data to determine effective transmission ranges.

Success Criteria: A reliable operating range of at least 1 mi with packets arriving every five seconds for the duration of the test

Results: Tests on 900 MHz band prior to CDR indicate successful operation over 1 mi. Recent tests, however, have given a maximum operational distance of 0.6 mi, which is still within competition drift range requirements. Poor performance may have been due to electrical interference from infrastructure. Tests with 433 MHz equipment are currently inconclusive at significant ranges, thus the 900 MHz will be used for verification and competition until the 433 MHz band can be demonstrated to work consistently under test conditions.

6.1.3 Payload Verification Procedures

6.1.3.1 Rover Deployment Demonstration

This demonstration is used to verify competition requirement 4.3.1 and 4.3.3 as described in Table 76.

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 was wrapped and attached to the PEARS which was integrated into the fore section of the launch vehicle by retaining to the FHP as seen in the payload assembly checklists in Tables 57, 56 and 47. The PLEC was armed through the airframe, and then from a safe distance the OSRT used the ground station to send the remote signal to the PLEC which released the three retention devices sequentially, and then ignited the black powder charges sequentially, ejecting the rover from the airframe.

Success Criteria: The rover must be fully contained within the launch vehicle in flight configuration, and the remote signal sent to release retention devices and ignite ejection charges. The demonstration is successful if the rover is deployed clear of the airframe.

Results: The demonstration was conducted at the Oregon State Propulsion Lab (OSPL) and was successful. The rover was integrated in launch configuration with two Tender Descenders and an ARRD retaining the rover, and a 1.2 g primary 4F black powder charge and a 2.0 g secondary 4F black powder charge. From a safe distance, the ground station sent the remote signal to the PLEC which successfully released and ejected the rover using the primary 1.2 g charge. The backup charge ignited after the rover was deployed. The rover came to a stop 10 ft away from the airframe, and the wrap and two bulkheads successfully fell away from the rover, allowing it to complete its mission. The ejected rover can be seen in Figure 120

Figure 120: Ejected rover after ground testing. Measured at 10 ft. from airframe.

6.1.3.2 PEARS Component Strength Analysis

This analysis is used to verify competition requirement 4.3.2 as described in Table 76.

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 the OSRT to use the component in full scale launches. This is to ensure the system is fail-safe and can maintain control of the payload even under atypical flight forces.

Analysis Description: The first step of the analysis was 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 and PEARS component weight is distributed though the system via each linking component. The next step was finding the rated strength of each component. These rated values are all based on product specifications and and material properties and dimensions. Finally, G acceleration rating is found by dividing the rated strength of a component by the applied force. These weights and rated strengths are seen in Table 71.

Success Criteria: The test is considered successful if all components are able to withstand greater than 50 G of acceleration.

Results: The results can be seen in Table 71. 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 and under the assumption the full weight acts as a point load in the center of the harness. The analysis conducted shows that the payload retention system will not fail due to structural reasons even under atypical flight forces.

Table 71: PEARS Component Strength

Component	Weight on Component (lbf)	Rated Strength (lbf)	Acceleration Able to Withstand (G)
Kevlar Harness	6.01	550	91.5
Quick Link	3.38	2,000	591.7
Threaded Rod	8.70	4,418	507.8
ARRD	1.69	2,000	1186.4
Tender Descender	3.40	2,000	588.2
U Bolt	3.49	425	121.8
Nut 3/8 - 16 Threads	8.70	9,300	1069.0
Fore Hard Point	8.70	2,213	254.4

6.1.3.3 Rover Mobility Demonstration

This demonstration procedure is used to verify competition requirement 4.3.4 as described in Table 76.

Demonstration Objective: The Rover Mobility Test is used to demonstrate that the rover will move more than 10 feet away from any portion of the airframe in accordance with competition requirement 4.3.4.

Demonstration Description: The rover will be ejected from the bottom of the fore airframe, as it is described in Section 6.1.3.1. The behavior of the rover will be observed until the soil collection portion of the program is reached. At this point the distance to the nearest point of the launch vehicle will be measured.

Success Criteria: In order for the demonstration to be considered a success, the measured distance from the rover to the nearest part of the airframe will be greater than or equal to 10 ft. The rover must be stabilized by a tail attached to the back of the rover to succeed in this demonstration.

Results: Demonstration will be conducted during payload demonstration flight after FRR, pending FRR Addendum approval.

6.1.3.4 Soil Collection Test

This testing procedure is used to verify competition requirement 4.3.5 as described in Table 76 and team derived requirement Payload - 1 in Table 80.

Testing Objective: The Soil Collection Test was used to determine the number of cycles required to collect 10 mL of soil, and whether the auger shape or material needed to be changed.

Testing Description:

Listed below is the procedure that should be followed when performing this test:

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

1) Ensure SCAR is properly assembled within the testbed.
2) Ensure electrical components are properly secured to the motor.
3) Place the rover on a location consisting of soil.
4) Power ON the electrical system and allow the auger to extend and retract from the soil once.
5) Repeat this process until 10 mL of soil is collected.
   - The auger shape/material may need to be changed to successfully complete testing.
6) Record the rover weight and number of cycles required to collect 10 mL of soil.

Success Criteria:

The test is considered successful if the auger can collect 10 mL of soil and deposit it from the deposit slot within the auger tube.

Results:

The results of this test were successful. Shown in Figure 121 is the successful soil collection test, collecting 15 mL of soil in 15 cycles and depositing it in the measurement beaker placed in the location of the soil retention container.

Figure 121: Results from soil collection test

6.1.3.5 Soil Retention Demonstration

This demonstration procedure is used to verify competition requirement 4.3.6 as described in Table 76.

Demonstration Objective: The objective of this demonstration is to ensure the soil retention subsystem can seal and retain 10 mL of soil. Additionally, soil needs to be deposited from the bottom of the soil container to be analyzed by the scientific base station.

Demonstration Description: Listed below is the procedure that has been followed when performing this test:

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

1) Ensure the soil retention container bottom door is closed and the top door is open.
2) Deposit soil from the location of the soil deposit slot within the auger tube until the 10 mL has been added.
3) Actuate the top door to close, sealing the soil.

4) Inspect whether any soil has falling through the cracks between the doors and container.
5) Actuate the bottom door to deposit the soil.
6) Measure the amount of soil deposited.
7) Repeat the process with increasing volumes of soil determine the maximum soil volume that can be sealed within the soil retention subsystem.

Success Criteria:

This test is considered successful if the soil container can seal, retain, and deposit 10 mL of soil.

Results:

The results of this test were successful. The soil retention container successfully sealed and deposited 10 mL of soil. Figure 122 and Figure 123 show the doors in the open and closed position during the test.

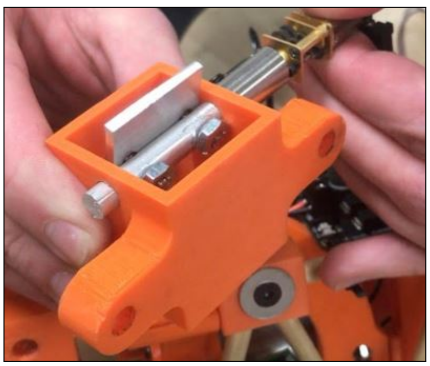

Figure 122: Soil Retention Doors (Open)

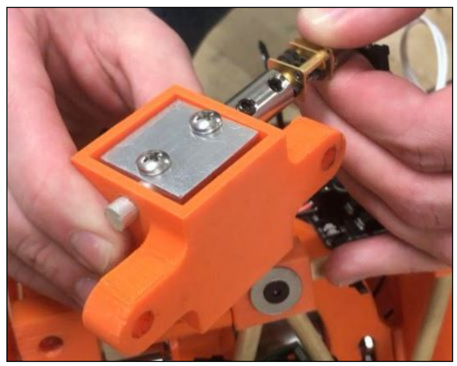

Figure 123: Soil Retention Doors (Closed)

6.1.3.6 Rover Battery Impact Protection and Marking Inspection

This inspection procedure is used to verify competition requirement 4.3.7 and 4.3.8 as described in Table 76.

Inspection Objective: The objective of this inspection is to verify the rover batteries are handled according to the regulations set by NASA and the University Student Launch Initiative (USLI) competition.

Inspection Description: The inspection procedure is as follows:

1) Verify that the rover battery has brightly colored duct tape (different from the orange of the rover components) on both the front and back.
2) Inspect the battery case to verify that it is labeled with the word "Battery".
3) Verify that the rover battery has no way of falling off of the rover upon ejection.
4) Verify that the battery has at least one layer of protection in every direction in case the rover lands on uneven ground.

5) Turn the rover and look down the axis of the wheels to verify that the battery and its casing is held well within the diameter of the wheels.

Success Criteria: The inspection is successful if the battery is both properly identified and protected from impact.

Results: This inspection has been completed. It will be verified again prior to every launch through Step 4 in the rover checklist in Table 28.

6.1.3.7 Rover Weight Demonstration

This demonstration procedure is used to verify the team derived requirement Payload - 1 as described in Table 80.

Demonstration Objective: The objective of this test is to ensure the rover is lightweight enough to reach the target altitude, but durable enough to withstand all mission operations and heavy enough to successfully collect soil.

Demonstration Description:

The completed rover will be retained during a full scale launch and ejected upon landing. Additional testing specified in Section 6.1.3.4 will determine if the rover has sufficient weight to collect soil.

Success Criteria:

The demonstration is successful if the rover is retained within the launch vehicle during flight, the target altitude is reached, and 10 mL of soil is collected.

Results:

The results of this test were successful. The rover was retained within the airframe during flight and reached an altitude above the team's target altitude. The SCAR system collected over the required 10 mL of soil. The final rover weight was 6.01 lbf.

6.1.3.8 Rover Ejection Battery Life Analysis

This analysis is used to verify team derived requirement Payload - 2 as described in Table 80.

Analysis Objective: Show that the rover can be held in the wrapped position for 2 hours and complete its mission upon ejection.

Analysis Description: The current draw of the rover will be measured. The capacity of the battery will then be divided by the measured value to find the total time the battery can keep the rover relay open.

Success Criteria: If the rover battery is not discharged after two hours with the rover in its wrapped state.

Results: The current drawn by the relay while being held open by the battery is 23 mA. The capacity of the battery is 2,200 mAh which, when divided by the current draw of the relay, shows that the rover can remain within the airframe for 95 hours without losing charge. The analysis is considered a success because the calculated time is greater than 2 hours.

6.1.3.9 Ejection Charge Protection Inspection

This inspection procedure is used to verify team derived requirement Payload - 3 as described in Table 80.

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 Description: The inspection procedure is as follows:

- 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 is considered successful if all components do not show damage or significant wear.

Results: The results of this test were successful. After several ejections, all components were cleaned and inspected. The ejection wadding and Kevlar blankets in the system were successful in protecting all components, and all components can withstand extensive ejection events without any loss in component integrity.

6.1.3.10 Collision Avoidance Demonstration

This demonstration procedure is used to verify team derived requirement Payload - 4 as described in Table 80.

Demonstration Objective: The purpose of this demonstration is to show that the rover is capable of detecting large, solid obstacles and steering away from them.

Demonstration Description: The rover will be set down greater than one yard from a wall and allowed to proceed towards the wall. The behavior of the rover will be observed.

Success Criteria: The demonstration will be considered a success if the rover steers away from the wall before coming in contact with the wall.

Results: The rover has demonstrated the ability to detect an object which must be avoided and steer away from it as shown in Figure 124.

Figure 124: Payload Detecting a Wall and Steering Away

6.1.3.11 Expandable Wheels Inspection

This inspection procedure is used to verify team derived requirement Payload - 5 as described in Table 80.

Inspection Objective: The objective of this inspection is to ensure that the rovers wheel's can be forcibly compressed to be smaller than their nominal size. This is necessary to create a pressure seal which facilitates payload ejection by PEARS.

Inspection Description: The inspection procedure is as follows:

- Safety consideration: Ensure rover is powered down to prevent unintentional motion.

1) Prepare three zip tie chains measuring at least 20 in. in length.
2) Place fiberglass wrap on a flat surface.
3) Ensure Kevlar harness is taped securely lengthwise to fiberglass wrap.
4) Place rover, centered, on fiberglass wrap with notches in wheels aligned with Kevlar harness.
5) Measure the nominal diameter of each wheel with a ruler and record.
6) Place aft bulkhead against one wheel, ensuring harness is in bulkhead slot.
7) Stretch Kevlar harness around aft bulkhead and pull along rover body.
8) Place fore bulkhead against other wheel, ensuring harness is in bulkhead slot.
9) Run a zip tie through the ends of the harness and tighten until secure.
10) Envelop rover in fiberglass wrap, holding it closed, and cinch one zip tie chain around the wrap just inside one wheel, taking care to prevent it from sliding off.
11) Repeat the process for the other two zip tie chains, positioning one just inside the other wheel and one in the center of the wrap.
12) Tighten each zip tie chain by hand until it becomes too difficult to continue.
13) Measure the diameter of each end of the wrapped rover and record.

Success Criteria: The inspection is considered successful if both ends of the wrapped rover have a diameter smaller than both of the wheels' nominal diameters.

Results: The wheels' nominal diameters were measured to be 6.50 in. (16.5 cm) and 6.54 in. (16.6 cm) (Figures 125 and 126). Note that the camera perspective distorts the position of the ruler. When compressed inside the fiberglass wrap, both measurements read 6.34 in. (16.1 cm) (Figures 127 and 128). This requirement has been verified.

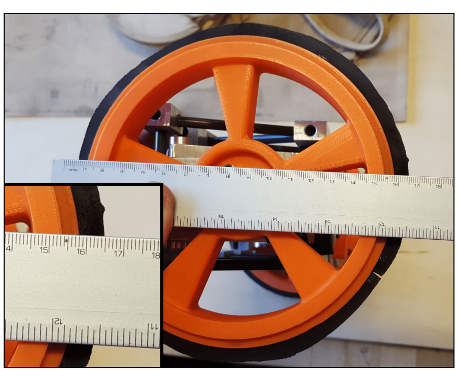

Figure 125: Wheel 1 measured uncompressed

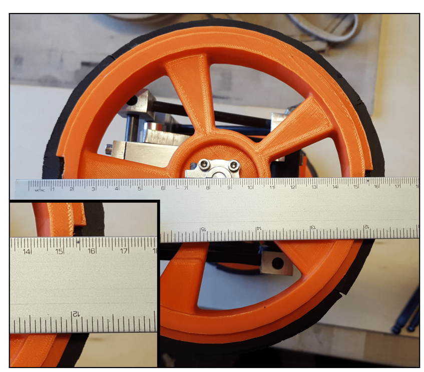

Figure 126: Wheel 2 measured uncompressed

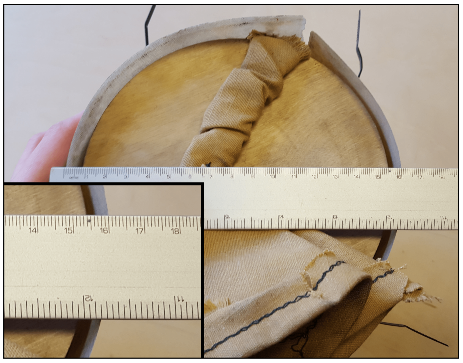

Figure 127: Wheel 1 measured within payload wrap

Figure 128: Wheel 2 measured within payload wrap

6.1.3.12 Rover Battery Life Analysis

This analysis verifies team derived requirement Payload - 6 in Table 80.

Analysis Objective: In order to determine how long the rover will be able to continuously operate, an analysis of the current draw of each component has been performed. This test took into account current draw from the battery adjusted with the assumption made of 85% efficiency for both voltage regulators.

Analysis Description: For each component aboard the rover the number of that component will be multiplied by the current draw measured for that component. This product will then be multiplied by the quotient of the voltage supplied to the component over the battery voltage. The resulting value of these calculations will then be divided by the efficiency of the voltage divider to give the current draw from the battery with each component on at all times. To find a more accurate representation of the current draw over time, the value calculated in the preceding steps will then be multiplied by a duty cycle which is defined via code. The result will be the average current the component draws from the battery. The sum of these currents for all components is then the average current draw from the battery of the whole system. Dividing the capacity of the battery, in mAh, by this calculated value will yield the total operating time of the rover.

Success Criteria: The average current draw is lower than the rated continuous current of the battery and the duration for which the rover can operate is greater than 45 minutes.

Results:

Table 72: Rover Power Budget

Component	Qty	Current (mA)	Voltage (V)	Battery Current (mA)	Duty Cycle	Battery Draw with Duty Cycle
LSM303DLHC	1	0.11	5.0	0.08	1	0.08
Teensy 3.6	1	70	5.0	49	1	49
C920 Camera	1	80	5.0	56	1	56
BeagleBone Black	1	500	350	0.08	1	350
Drive Motor	2	200	8.4	470	0.7	330
Transceiver	1	215	3.3	99	0.1	9.9
Auxiliary Motors	3	100	8.4	350	0.3	110
u-blox MAX M8W	1	67	3.3	31	1	31
MB1230 XL-MaxSonar-EZ3	3	34	5.0	71	1	71
Totals				**1481 mA**		**1003 mA**

The average current draw from the battery is 1,003 mA, which is far lower than the 25 A continuous current rating of the battery. Dividing the capacity of the battery, 2,200 mAh, by the average current draw yields an operating time of 2 hours and 11 minutes, more than 45 minutes. Both analyses were successful and therefore the analysis is a success.

6.1.3.13 Rover Low Power State Demonstration

This demonstration procedure is used to verify team derived requirement Payload - 7 as described in Table 80.

Demonstration Objective: The objective of this demonstration is to show that the rover will not unnecessarily use battery while integrated into the airframe.

Demonstration Description: The rover will be wrapped with two terminals bridged by a jumper attached to the wrapped tail. The rover will then be wrapped in a fiberglass cover as it is when integrated into the launch vehicle to keep the tail of the rover in place and the terminals bridged. This is shown in Figure 129. The rover will be observed to ensure no navigation or soil collection functions are taking place.

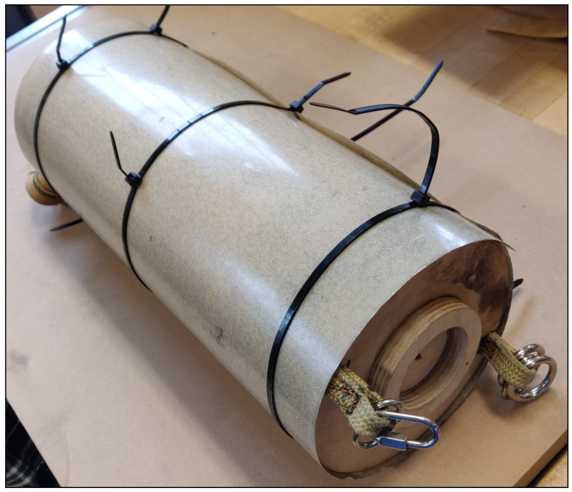

Figure 129: Payload in Wrapped Position with Relay Held Open

Success Criteria: If no navigation or soil collection functions take place while the payload is in its wrapped state, the demonstration will be considered a success.

Results: The rover does not demonstrate navigation or soil collection behavior while in its wrapped state. The demonstration is considered a success.

6.1.3.14 Payload Ejection System Arming Switch Analysis

This analysis verifies team derived requirement Payload - 8 in Table 80.

Analysis Objective: In order to determine the appropriate amount of time to wait before handling the PLEC with live charges attached, an analysis of how long it will take to discharge the capacitors on the PLEC must be performed.

Analysis Description: The point at which the capacitor is fully discharged is determined by using the equation $V_C = V_0 * e^{-t/RC}$. Solving the equation for time yields $t = -RC * ln(V_C/V_0)$. For this analysis, a discharge rate of 99% was used as a fully discharged system. This is done by setting V_C/V_0 equal to 0.01 and plugging in values for resistance and capacitance.

Success Criteria: The time between disarming the PLEC and the capacitor being fully discharged is under 60 seconds to allow for the team to reasonably wait many times the full discharge time before handling the launch vehicle.

Results: The amount of time needed to fully discharge the capacitors of the PLEC is 2.72 s, with a resistor value of 100 Ω and a capacitor value of 5,900 µF.

6.1.3.15 Prototype Rover

This demonstration verifies team derived requirement Payload - 9 in Table 80.

Demonstration Objective: The objective of this demonstration is to show that a rover prototype was able to be developed and was able to be used for electronic testing.

Demonstration Description: The rover electronics will be attached to the rapid prototype and will be tested by performing the same tasks the final rover must perform, such as object avoidance and hill climbing.

Success Criteria: The demonstration is considered successful if a prototype rover is developed which can be used to test the electrical functions of the final rover.

Results: The demonstration was successful as the rapid prototype with electronics was able to be used for testing of the electrical systems. The prototype rover can be seen in Figure 130 and seen in Figure 131 climbing a slope of 30°.

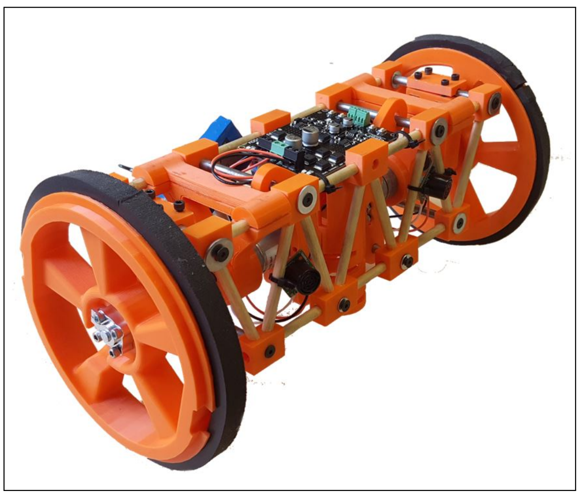

Figure 130: Rapid Prototype Rover

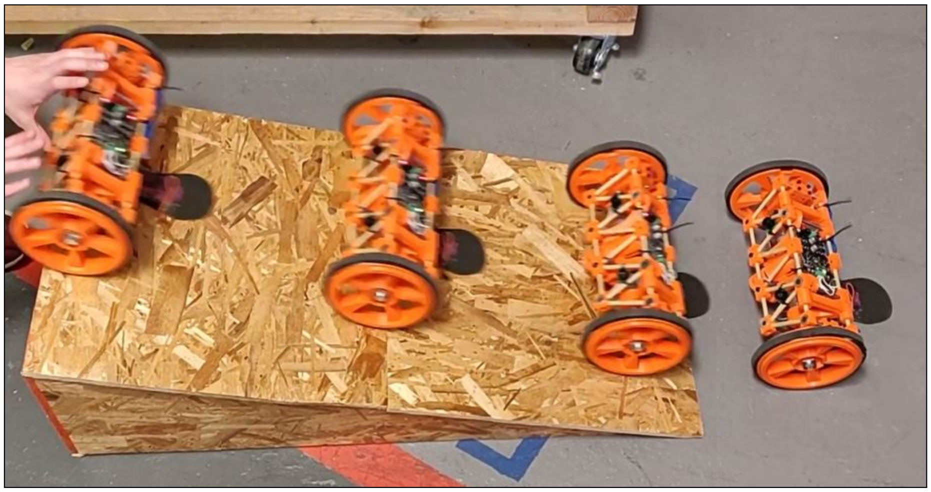

Figure 131: Successful Ramp climb of 30°

6.1.3.16 Prototype Rover Electronics

This demonstration verifies team derived requirement Payload - 10 in Table 80.

Demonstration Objective: The objective of this demonstration is to show that the prototype rover performs as the final rover will perform and therefore provides a viable test bed for experimentation with electronic and mechanical elements alike.

Demonstration Description: The rover with prototype electronics will be flashed with code developed to allow it to drive for a set amount of time and collect soil thereafter. The rover will then be powered on, set facing towards a wall, and observed. Following this observation the rover will be allowed to go through its entire routine up to and including soil collection. Instead of the SCAR components being functional aboard the rover, LEDs will be used to indicate when soil collection is occurring.

Success Criteria: For the test to be successful, the rover must approach the wall and turn away before making contact with the wall. The rover must also stop to collect soil upon detecting level ground using the IMU.

Results: The rover detected the wall using sonar modules, turned away before making contact, and proceeded onward, as shown in Figure 132. Upon being reset in a hallway, the rover navigated for 15 seconds without colliding with any obstacles present and stopped three times upon detecting a level surface. Both demonstrations are successful as described above.

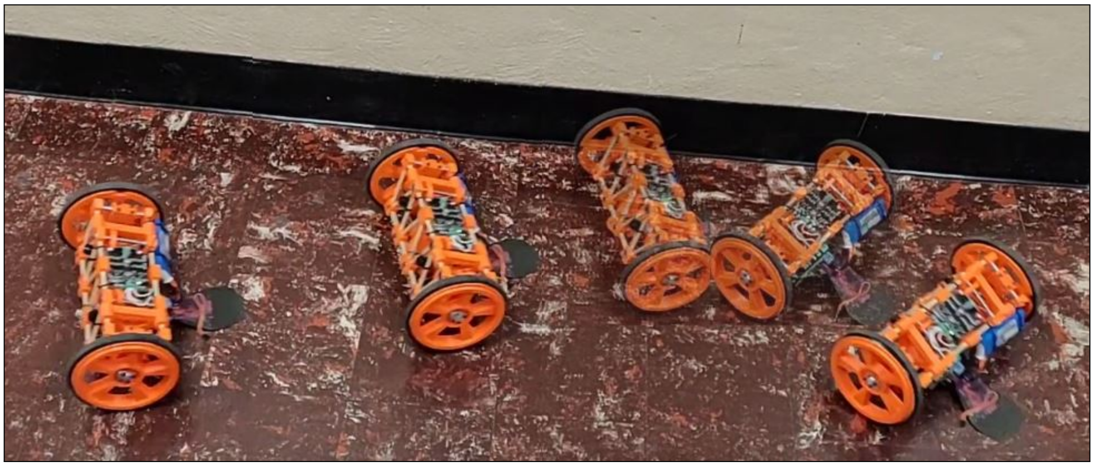

Figure 132: Rover Detecting a Wall and Steering Away

6.1.3.17 GPS Navigation

This demonstration verifies team derived requirement Payload - 11 in Table 80.

Demonstration Objective: This demonstration is used to show that the rover is capable of navigating its way to a set GPS coordinate autonomously which will allow for competition requirement 6.1.3.3 to be verified as complete.

Demonstration Description: Upon ejection from the fore airframe, the rover will wait for GPS lock. Once lock is achieved the rover will begin to move, intermittently checking its current location against its starting location.

Success Criteria: If the distance between starting and soil collection locations is greater than 10 ft, as confirmed by GPS coordinates recorded by the rover, the demonstration will be considered a success.

Results: Incomplete - demonstration will be performed by FRR Addendum.

6.1.3.18 Rover RF Communication

This demonstration verifies team derived requirement Payload - 12 in Table 80.

Demonstration Objective: The objective of this demonstration is to show that the rover can receive accurate information via an onboard RF transceiver.

Demonstration Description: RF communications will be sent to the rover which will record everything it receives to a text file on an onboard storage device.

Success Criteria: The demonstration will be considered a success if the information recorded in the text file matches the information sent to the rover.

Results: Incomplete - demonstration will be performed by FRR Addendum.

6.1.3.19 Scientific Base Station Docking

This demonstration verifies team derived requirement Payload - 13 in Table 80.

Demonstration Objective: This demonstration will show the capability of the rover to navigate to, and dock with, the scientific base station.

Demonstration Description: Upon completion of the soil collection and retention mission, the rover will wait for an RF signal to arrive containing the GPS coordinates of a scientific base station. The rover will then navigate as near to this base station as possible. Once as close as GPS will allow, the rover will begin using Computer Vision (CV) to navigate atop the base station.

Success Criteria: This demonstration will be considered a success if the rover navigates from its location after soil collection to a specified GPS coordinate and then positions itself using CV in such a way that the collected soil is deposited for testing.

Results: Incomplete - demonstration will be performed by FRR Addendum.

6.1.3.20 PLEC LED Demonstration

This demonstration verifies team derived requirement Payload - 14 in Table 80.

Demonstration Objective:

The objective of the demonstration is to show that the proper payload retention release and ejection sequence can be triggered remotely.

Demonstration Description: Five LEDs were each attached in series with a small resistor on a breadboard, and attached to PLEC as if each LED was an e-match. The PLEC battery was connected and the DPST switch was armed. Finally the signal was sent to the PLEC from the ground station.

Success Criteria: This demonstration is considered successful if the PLEC is armed with the DPST switch and none the of LEDs light up. Once the signal is sent from the ground station, the LED corresponding to terminal one must light up for half a second, then shut off. After light one has shut off for half a second, the LED connected to terminal two must light up for half a second. This sequence must continue down the line to terminal three, four, then five.

Results: The demonstration conducted was completed successfully. The wiring set up used can be seen in Figure 133. The ignition order was correct, and a relay was opened or closed every half second. It took a total of 5 seconds for the sequence to complete.

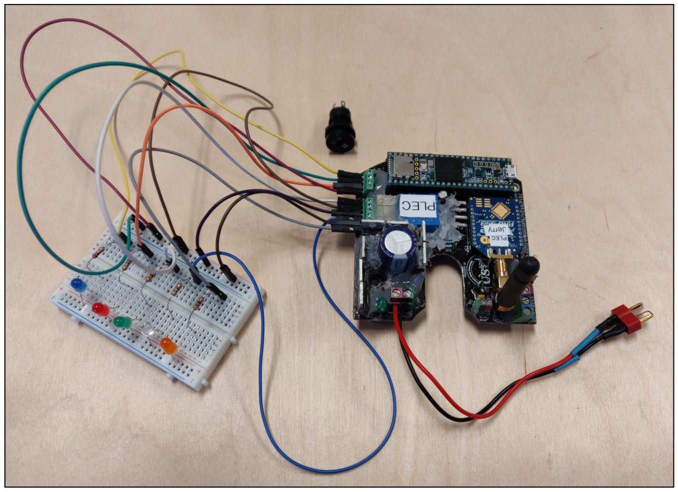

Figure 133: PLEC LED Demonstration

6.1.3.21 Rover Directional Navigation

This demonstration verifies team derived requirement Payload - 15 in Table 80.

Demonstration Objective: This demonstration will show the ability of the rover to maintain a consistent direction while moving between two set points. **Demonstration Description:** The rover will be programmed to move in a specified direction indefinitely. The rover will be powered on and observed. **Success Criteria:** After travelling for 50 feet the rover will have deviated no more than 10 degrees as measured from the original position. **Results:** Incomplete - demonstration will be performed by FRR Addendum.

6.2 Requirement Compliance

The following sections summarize the methods that the OSRT is using to comply with all requirements in the NASA SL handbook and all requirements which have been derived by the team. The purpose of the team derived requirements is to develop requirements which are specific to the OSRT designed launch vehicle and payload, which allow us to ensure the systems will perform safely and meet the mission goals. The team derived requirements may additionally go above and beyond the stated competition requirements in the NASA SL handbook.

Each of these methods are verified with procedures of differing types: Test, Demonstration, Inspection, or Analysis. Test indicates a procedure in which data is collected to determine the performance of a system.

Demonstration indicates a procedure which is completed that either passes or fails at meeting a set of success criteria. Inspection indicates a procedure which verifies that a requirement has been met through observation or detailed instructions. Analysis verifies a requirement has been met based on calculations and simulations. The method of Test, Demonstration, Inspection, or Analysis is denoted in Tables 73 - 81 with the letters T, D, I, or A respectively.

6.2.1 Competition Requirements

6.2.1.1 General Requirements

Table 73: 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 project work.	Complete - Students did all project work to date, and will continue to do so through FRR addendum, competition, and Post Launch Assessment Review (PLAR).	N/A
1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, Science, Technology, Engineering and Mathematics (STEM) engagement events, and risks and mitigations.	I	OSRT will provide and maintain a project plan throughout the project.	Complete - OSRT has provided and maintained a project plan throughout the competition. The remaining events after FRR will continue to be tracked with a project plan.	N/A
1.3	Foreign National (FN) team members must be identified by PDR and may or may not have access to certain launch week activities during launch week due to security reasons. In addition, FNs may be separated from their team during certain activities.	I	OSRT will identify FN students by PDR.	Complete - No FNs are a part of the current OSRT roster.	N/A
1.4	The team must identify all team members attending launch week by the CDR.	I	OSRT will identify all members attending launch week by CDR.	Complete - All team members attending launch week activities were identified.	N/A

Continued on next page

Table 73 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
1.4.1	Students actively engaged in the project throughout the entire year.	I	OSRT will identify all members attending launch week by CDR.	Complete - All team members attending launch week activities were identified.	N/A
1.4.2	One mentor (see requirement 1.13).	I	OSRT will identify all members attending launch week by CDR.	Complete - All team members attending launch week activities were identified.	N/A
1.4.3	No more than two adult educators.	I	OSRT will identify all members attending launch week by CDR.	Complete - All team members attending launch week activities were identified.	N/A
1.5	The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics STEM activities, as defined in the STEM Engagement Activity Report, by FRR. To satisfy this requirement, all events must occur between project acceptance and the FRR due date and the STEM Engagement Activity Report must be submitted via email within two weeks of the completion of the event.	D	OSRT will engage a minimum of 200 participants in STEM lessons before FRR.	Complete - OSRT engaged 3,362 participants in STEM lessons.	N/A
1.6	The team will establish a social media presence to inform the public about team activities.	D	The team will establish social media presence on Facebook, Twitter, Instagram, and Snapchat.	Complete - Social media presence has been established. Posts include manufacturing updates, launch days, and STEM Engagement events.	N/A
1.7	Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach in an email, inclusion of a link to download the file will be sufficient.	D	The team will submit all deliverables appropriately.	Complete - All documentation has been and will continue to be submitted appropriately via direct email and the OSRT website.	N/A

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Table 73 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
1.8	All deliverables must be in PDF format.	I	The team will submit all deliverables appropriately.	Complete - All documentation has been and will continue to be submitted in the appropriate format.	N/A
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	I	The team will include a table of contents with all reports.	Complete - A table of contents has been included on all documentation, and will be included for all future documentation.	N/A
1.10	In every report, the team will include the page number at the bottom of the page.	I	The team will include a page number on all pages.	Complete - Page numbers have been on all documentation and will continue to be included for all future documentation.	N/A
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes but is not limited to, a computer system, video camera, speaker telephone, and a sufficient internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	I	The team will use a conference room with necessary capabilities.	Complete - Two OSU conference rooms have been selected for use in teleconferences. These rooms have all necessary equipment.	N/A
1.12	All teams will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted on the field. Eight foot 1010 rails and 12 foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on launch day. The exact cant will depend on wind conditions.	I	The team will make use of a 1515 rail for all designs.	Complete - The vehicle launched off of a 8.08 ft 1515 rail during the Vehicle Demonstration Flight and will use a 12 ft 1515 rail at SL competition.	N/A
1.13	Each team must identify a mentor.	I	Team will identify a mentor.	Complete - Joe Bevier has been identified as the OSRT mentor.	N/A

6.2.1.2 Launch Vehicle Requirements

Table 74: Launch Vehicle Verification Matrix

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
2.1	The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 ft AGL.	D	The motor selection is based on OpenRocket simulation to reach the required AGL range.	Complete - Launch vehicle reached an apogee altitude of 5,079 ft with a simulated payload on February 22nd, 2019 in Brothers, OR.	Section 6.1.1.1
2.2	Teams shall identify their target altitude goal at the PDR milestone.	I	The target AGL goal of 4,500 ft apogee altitude will be set at PDR.	Complete - Launch vehicle will target 4,500 ft AGL.	N/A
2.3	The vehicle will carry one commercially available, barometric altimeter.	I	The launch vehicle will contain a commercially available barometric altimeter.	Complete - Multiple commercially available altimeters have been obtained. Commercially available barometric altimeters were used in the subscale and full scale launch vehicles.	Section 6.1.1.2
2.4	Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	I	The location of the altimeter housing will allow for each altimeter arming switch to be activated from the exterior of the launch vehicle.	Complete - Arming switches are accessible from the exterior of launch vehicle. Externally armed mechanical switches are present in all designs.	Section 6.1.1.2
2.5	Each altimeter will have a dedicated power supply.	I	All altimeters will have their own dedicated power supply.	Complete - Each altimeter has a dedicated power supply in design.	Section 6.1.1.2
2.6	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	I	All arming switches will have a mechanical locking system.	Complete - Arming switches are armed through the use of hex key which maintains ON position throughout flight.	Section 6.1.1.2

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Table 74 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
2.7	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	D	The launch vehicle will be designed to survive launch and recovery without needing repairs or modifications prior to an additional same day launch.	Complete - Launch vehicle is designed to withstand all expected forces of launch and recovery. Reusability of designs was demonstrated on Vehicle Demonstration Flight, and properly following checklists ensures reusability.	Section 6.1.1.1
2.8	The launch vehicle will have a maximum of four (4) independent sections.	I	The launch vehicle will have no more than four independent sections.	Complete - Launch vehicle is designed to have three independent sections.	N/A
2.9	The launch vehicle will be limited to a single stage.	I	The propulsion system will consist of only one motor.	Complete - Only one motor is used.	N/A
2.10	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the FAA flight waiver opens.	D	The team will perform preparation drills to practice assembling and readying the launch vehicle within two hours.	Complete - OSRT fully integrated the full scale launch vehicle in 1 hour and 47 minutes.	Section 6.1.1.3
2.11	The launch vehicle will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.	T, D	The batteries selected will have a minimum battery life of 2 hours.	Complete - Batteries consistently work far longer than 2 hours under full load in tests, and worked for required duration during full scale flight.	Sections 6.1.2.12 and 6.1.1.4
2.12	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.	D	The launch vehicle will have a separate launch system that is powered by an external 12-volt system.	Complete - The Cesaroni L2375-WT was ignited with a standard igniter and 12 V direct current firing system on the Vehicle Demonstration Flight.	Section 6.1.1.1

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Table 74 – 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.	Complete - No external circuitry is used.	N/A
2.14	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant Ammonium Perchlorate Composite Propellant (APCP) which is approved and certified by NAR, Tripoli Rocketry Association, Inc. (TRA), and/or the Canadian Association of Rocketry (CAR).	I	The launch vehicle will be designed to use a commercially available motor that is approved and certified by the NAR, TRA, and/or the CAR.	Complete - The Cesaroni L2375-WT motor meets these requirements.	N/A
2.15	Pressure vessels on the vehicle will be approved by the RSO and will meet the provided criteria.	I	Pressure vessels will not be integrated into the launch vehicle.	Complete - No pressure vessels are used in the launch vehicle or payload.	N/A
2.16	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	I	The motor selection will be limited to using a L-class or lower as to not exceed 5,120 Newton-seconds of impulse.	Complete - The Cesaroni L2375-WT is 4905 Newton-seconds as specified by the manufacturer.	N/A

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Table 74 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
2.17	The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit.	A	Fin dimensions will be designed to locate the Center of Pressure aft of the Center of Gravity location at a distance at least twice the diameter of the airframe. After manufacturing, measure actual Center of Gravity location and calculate stability with simulated Center of Pressure location. If stability margin is below 2.0 calibers, a fore ballast bay will be used to locate the Center of Gravity towards the fore end of the airframe until a stability of 2.0 calibers is achieved.	Complete - Center of Gravity of the launch vehicle was measured to be 71.0 in. from the tip of the nosecone. Simulations locate the Center of Pressure 84.7 in. from the tip of the nosecone. The static stability margin is 2.14 calibers.	Sections 6.1.1.5 and 6.1.1.11
2.18	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	A, D	The selected motor will be simulated to achieve over 52 fps off of a 12 ft rail provided by NASA SL.	Complete - Rail exit velocity is simulated to be 82 fps off of a 12 ft rail. The full scale flight data on February 22nd, 2019 showed a rail exit velocity of 71.85 ft/s off of a 8.08 ft launch rail.	Sections 6.1.1.12 and 6.1.1.1
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.	D	The team will successfully create, launch, and recover a subscale launch vehicle prior to submitting the CDR.	Complete - The subscale launch vehicle was flown on both December 8th, 2018 and Januray 4th, 2019.	Section 6.1.1.13

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Table 74 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
2.20	All teams will complete demonstration flights.	D	The team will launch a subscale and full scale launch vehicle with retained payload included in the full scale, eliminating the need of a simulation mass. Both vehicles will be built with resources available at OSU and fully equipped with chutes and avionics. The launch vehicle will not be modified after final vehicle demonstration flight. If re-flight is necessary, proper documentation will be filed for an extension which would be done before the FRR addendum deadline.	Complete - A full scale launch with a retained payload was launched and recovered on February 22nd, 2019.	Sections 6.1.1.13 and 6.1.1.1
2.21	An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR.	D	If the team fails to complete a Payload Demonstration Flight prior to the FRR, the team will follow the proper procedure for re-launch.	Incomplete - An FRR Addendum will be filed by the specified deadline which details the results of the Payload Demonstration Flight.	N/A
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.	Complete - Analyses has been conducted to show all protuberances in design are aft of center of gravity.	Section 6.1.1.14
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 is contact information clearly labeled on the fore and aft sections of the launch vehicle.	Complete - Contact information was placed on both independent sections of the launch vehicle.	N/A

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Table 74 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
2.24	Vehicle prohibitions	I	None of the NASA SL provided prohibitions will be implemented.	Complete - All of the vehicle prohibitions are appropriately followed.	N/A

6.2.1.3 Recovery Requirements

Table 75: Recovery System Verification Matrix

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
3.1	The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.	D	Demonstrations will be performed to ensure staging events occur in the correct order and at the correct time.	Complete - The recovery system was successfully demonstrated during ejection demonstrations and during the full scale launch on February 22nd, 2019.	Section 6.1.2.3
3.1.1	The main parachute shall be deployed no lower than 500 feet.	D	Demonstrated during both subscale flights and the full scale flight that the Tender Descenders separated at the altitude expected (700 ft AGL).	Complete - The recovery system successfully staged the drogue and main parachutes. The main parachutes were deployed 700 ft AGL.	Sections 6.1.2.3 and 3.4

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Table 75 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	D	Demonstrated during both subscale flights that both altimeters fired the drogue ejection charges within two seconds of sensing apogee. Demonstrated that the delay on both altimeters were set to less than two seconds.	Complete - Primary charge ignition occurred with no delay and secondary charge ignition occurred with a one second delay. This was successfully demonstrated in the full scale launch.	Sections 6.1.2.3 and 3.4
3.2	Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.	D	Ground ejection tests will be performed with the subscale and full scale launch vehicles to demonstrate proper ejection of drogue and main parachutes.	Complete - Ejection demonstrations have been completed for all subscale and full scale launches.	Section 6.1.2.4
3.3	At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	A, D	It was demonstrated during the first subscale launch that each launch vehicle section will land under with a kinetic energy under 75 ft-lbf.	Complete - Parachute sizes have been selected based off analyses which have been verified through the results of the full scale launch.	Sections 6.1.1.13 and 3.4
3.4	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	I	Each recovery circuit will be inspected to ensure they are separate from all payload circuits.	Complete - The final full scale launch vehicle has completely independent circuits for payload and recovery.	Section 6.1.1.2
3.5	All recovery electronics will be powered by commercially available batteries.	I	Recovery electronics will be inspected to ensure they are powered by commercially available batteries prior to both subscale launches and the full scale launch.	Complete - All batteries have been purchased through reputable vendors.	N/A
3.6	The recovery system will contain redundant, commercially available altimeters. The term ”altimeters” includes both simple altimeters and more sophisticated flight computers.	I	Each altimeter bay will be inspected prior to both subscale launches and the full scale launch to ensure it contains redundant altimeters.	Complete - Redundant, commercially available altimeters have been selected and were tested on both subscale flights and the full scale flight.	Sections 6.1.1.2 and 3.2.6

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Table 75 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	I	The motor and motor retainer will be inspected to ensure the motor will not be ejected during recovery.	Complete - Motor ejection was not used for recovery during the full scale flight.	N/A
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	D	Once the full scale launch vehicle has been fully assembled, the vehicle will be inspected to ensure it is held together with removable shear pins. The OSRT will ensure nylon shear pins are used at separation points.	Complete - Both couplers use 3x 2-56 nylon shear pins. These shear pins were successfully used on the ejection demonstrations and full scale launch.	Sections 6.1.2.4 and 6.1.1.1
3.9	Recovery area will be limited to a 2,500 ft radius from the launch pads.	A, D	Recovery area will be demonstrated in subscale and full scale flights and simulations for maximum drift radius in ideal scenarios.	Complete - The full scale launch vehicle sections landed within the maximum drift radius, and multiple simulations have been performed which demonstrate recovery of all sections will fall within 2,500 ft radius.	Sections 6.1.1.15, 6.1.1.13 and 3.4.2.3
3.10	Descent time will be limited to 90 seconds (apogee to touch down).	A, D	Descent time will be demonstrated in simulations for ideal scenarios and all subscale and full scale flights.	Complete - Multiple simulations have been performed which demonstrate recovery of all sections within 90 seconds. The full scale launch verified these results.	Sections 6.1.1.15, 6.1.1.13 and 3.4
3.11	An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	I	While the fore and aft avionics bays are being assembled, an inspection will be performed to ensure the tracking system links with the ground receiver.	Complete - Design has accounted for the inclusion of tracking systems in the fore and aft sections of the launch vehicle. Tracking system linked with ground receiver prior to and during full scale launch.	Section 6.1.2.13

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Table 75 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
3.11.1	Any launch vehicle section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.	I	While assembling the launch vehicle, an inspection will ensure a tracking device is placed in each section that will land independently of the rest of the launch vehicle.	Complete - Design includes one avionics system on each independently recovered section of the launch vehicle. The full scale vehicle sections which landed untethered from each other both contained an active electronic tracking device.	Section 6.1.2.13
3.11.2	The electronic tracking device(s) will be fully functional during the official flight on launch day.	D	Functionality will be demonstrated on launch day by turning tracking systems on and ensuring they link with the ground receiver.	Complete - System was tested and functional during full scale launch.	Section 6.1.2.14
3.12	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	I	An inspection will be performed to ensure recovery electronics are properly shielded from any electronics which may adversely affect them.	Complete - Design has accounted for appropriate shielding and protection of electronics. The full scale altimeter bays properly protect altimeters. The recovery electronics have not been affected by unwanted signals during any flights.	Section 6.1.2.11
3.12.1	The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other RF transmitting device and/or magnetic wave producing device.	I	An inspection will be performed during the full scale launch vehicle assembly to ensure recovery system altimeters are located in a separate compartment from all other RF transmitting devices and/or magnetic wave producing devices.	Complete - Design has accounted for appropriate shielding and protection of electronics. The recovery electronics have not been affected by unwanted signals during any flights.	Section 6.1.2.11

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Table 75 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
3.12.2	The recovery system electronics will be shielded from all on-board transmitting devices to avoid inadvertent excitation of the recovery system electronics.	I	An inspection will be performed to ensure recovery system electronics are properly shielded from all on-board transmitting devices.	Complete - Design has accounted for appropriate shielding and protection of electronics. The recovery electronics have not been affected by unwanted signals during any flights.	Section 6.1.2.11
3.12.3	The recovery system electronics will be shielded from all on-board devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	I	An inspection will be performed to ensure all recovery components are properly shielded from all on-board devices which may generate magnetic waves.	Complete - Design has accounted for appropriate shielding and protection of electronics. The recovery electronics have not been affected by unwanted signals during any flights.	Section 6.1.2.11
3.12.4	The recovery system electronics will be shielded from any other on-board devices which may adversely affect the proper operation of the recovery system electronics.	I	An inspection will be performed to ensure the recovery system electronics are properly shielded from any other on-board devices which may adversely affect the proper operation of the recovery system electronics.	Complete - Design has accounted for appropriate shielding and protection of electronics. The recovery electronics have not been affected by unwanted signals during any flights.	Section 6.1.2.11

6.2.1.4 Payload Requirements

Table 76: 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	The demonstration will be conducted by showing that the rover can be fully contained within and remotely ejected from the internal structure of the launch vehicle.	Complete - The demonstration was conducted showing that the payload could be fully integrated and remotely ejected.	Section 6.1.3.1
4.3.2	The rover will be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the rover if atypical flight forces are experienced.	A	An analysis of all structural components will be 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 6.1.3.2
4.3.3	At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the rover from the rocket.	D	A demonstration will be conducted by showing that the rover can be deployed remotely from a signal sent from the ground station.	Complete - The demonstration was conducted which showed the payload was able to be remotely deployed.	Section 6.1.3.1
4.3.4	After deployment, the rover will autonomously move at least 10 ft. (in any direction) from the launch vehicle. Once the rover has reached its final destination, it will recover a soil sample.	D	Demonstration will be conducted showing the rover will drive itself away from the launch vehicle after ejection from the airframe.	Incomplete - Demonstration will be conducted during Payload Demonstration Flight prior to FRR Addendum submission.	Section 6.1.3.3
4.3.5	The soil sample will be a minimum of 10 milliliters (mL).	T	Tests will be performed using the full rover assembly to assess the auger system.	Complete - The auger collected 10 mL of soil.	Section 6.1.3.4

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Table 76 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
4.3.6	The soil sample will be contained in an on-board container or compartment. The container or compartment will be closed or sealed to protect the sample after collection.	D	Demonstration will be conducted by showing the soil retention container can sealed, retain, and deposit 10 mL of soil.	Complete - The soil container can seal, retain, and deposit 10 mL of soil.	Section 6.1.3.5
4.3.7	Teams will ensure the rover's batteries are sufficiently protected from impact with the ground.	I	Battery module will be completely enclosed in a protective casing.	Complete - Battery pack is mounted such that they are retained entirely within a 3D printed protective casing that is secured within the radius of the rover wheels.	Section 6.1.3.6
4.3.8	The batteries powering the rover will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts	I	Battery modules are marked with colored electrical tape.	Complete - Batteries are bright blue and marked as fire hazards. The case protecting the battery has the word "Battery" on its side.	Section 6.1.3.6

6.2.1.5 Safety Requirements

Table 77: 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 sub-team will create a checklist of their required items. Checklists will be compiled and verified by the SO. All team members will verify checklists and comply with them at launch.	Complete - Checklists have been developed and completed for all launches.	Section 4.2

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Table 77 – continued from previous page

Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
5.2	Each team must identify a student SO who will be responsible for all items in section 5.3 of the NASA USLI Handbook.	I	The team SO will be selected.	Complete - The team SO is Jon Verbiest.	N/A
5.3	The role and responsibilities of each SO will include, but are not limited to:	I	SO will manage all roles outlined within requirement section 5.3. There are two additional SOs for the launch vehicle and payload. These two sub-team SOs report to the SO and are responsible for maintaining safe practices in the case that the SO cannot be at the event.	Complete - The SO is currently, and will continue to be responsible for team safety in all aspects.	N/A
5.3.1	Monitor team activities with an emphasis on safety during:	I	Lead SO or sub-team SO will be present during all team activities which pose a safety risk.	Complete - SOs have been and will continue to be present at present during team activities with safety risks.	N/A
5.3.1.1	Design of vehicle and payload	I	The Lead SO or one of the sub-team SOs will be at all internal design reviews to make sure all design decisions follow all safety requirements. The SO has final say over a design when the safety of a design is in question.	Complete - SOs are present at all design reviews to provide safety input when necessary.	N/A
5.3.1.2	Construction of vehicle and payload	I	Before construction begins, the SO will inform all team members of potential hazards and mitigation plans. The SO will make sure that JHA forms are filled out prior to any manufacturing. One of the SOs will stand by to assist in fulfilling safety protocols. Manufacturing safety rules are set in place by the OSU MPRL	Complete - SOs have given safety briefings to team and taught a lesson on filling out JHA forms.	N/A

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Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
5.3.1.3	Assembly of vehicle and payload	I	Before assembly begins, the SO's informed all team members of potential hazards and mitigation plans. One of the SOs stood by to provide assistance in fulfilling safety protocols. One of the SOs verified checklists with their respective sub-team leads before assembly began.	Complete - All checklists require a signature from the SO to verify proper assembly procedures have occurred and all safety steps are followed.	N/A
5.3.1.4	Ground testing of vehicle and payload	I	Before ground testing begins, the SO will inform all involved team members on potential hazards and mitigation plans. The lead SO or one of the sub-team SOs will stand by to provide assistance in fulfilling safety protocols.	Complete - the OSRT has safely ground tested vehicle and payload.	N/A
5.3.1.5	Subscale launch test(s)	I	During launch assembly, the SO is responsible for monitoring checklists, use of PPE, and troubleshooting steps. The SO ensured that the team was in compliance with safety restrictions set by the RSO.	Complete - the OSRT launched the subscale launch vehicle on January 4th.	N/A
5.3.1.6	Full-scale launch test(s)	I	Before full scale launch the SO completed the master launch readiness checklist in Section 25 The SOs informed 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 was carried out by the SO.	Complete - the OSRT launched the full scale launch vehicle on February 22nd, 2019.	N/A

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Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
5.3.1.7	Launch day	I	Before launch day, the SO will complete a checklist for launch with the help of the OSRT members taking part in the launch. The SO 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 SO. The Lead SO or one of the sub-team SOs will stand by to make sure all safety regulations are followed throughout the duration of the launch activities.	Complete - Subscale and full scale launches have been completed.	N/A
5.3.1.8	Recovery activities	I	The SO will work closely with the appropriate range officers to determine the appropriate time to collect the launch vehicle. The SO will inform all team members of potential hazards and mitigation plans.	Complete - Subscale and full scale launches have been completed safely through collaboration with range officers.	N/A
5.3.1.9	Educational Engagement Activities	I	SO will approve all engagement activities for safety.	Complete - The SO has been present for engagement activities and approved lesson plans.	N/A
5.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	I	The SO will verify all checklists and make sure all team members are informed of them. The SO will be in charge of making sure all checklists are followed.	Complete - Procedures have been developed and will continue to be developed or revised, as necessary.	N/A
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	I	The SO will collect all required forms and analyses and make sure that they are available to all team members. New versions will replace older editions.	Complete - The SO is managing and maintaining current hazard analyses and FMEAs.	N/A

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Requirement Number	Description Requirement	Verification Method	Verification Plan	Status	Report Location
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	I	The SO will be in charge of collecting, compiling and reviewing all hazard analyses, failure mode analyses and procedures.	Complete - The SO assists with and reviews all hazard analyses and FMEAs.	N/A
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 SO 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.	Complete - The team has been briefed on OROC launch site rules and has worked with the OROC RSO to ensure rule compliance during all launches thus far and during all future launches.	N/A
5.5	Teams will abide by all rules set forth by the FAA.	I	The team has knowledge of all appropriate FAA regulations and has followed them. The SO is responsible for verification that regulations are adhered to and will be assisted by the sub-team SOs.	Complete - The team has followed FAA rules for all launches.	N/A

6.2.2 *Team Derived Requirements*

6.2.2.1 Launch Vehicle Team Derived Requirements

Table 78: Launch Vehicle Team Derived Verification Matrix

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
LV - 1	All components will be able to withstand the heat and pressure from ejection charges.	The heat and pressure from ejection charges could potentially harm components located within the parachute bays. Any component not capable of handling the heat or pressure should be shielded with Kevlar or other protective material.	I	All components will be inspected after ground tests are completed for damage or burning.	Complete - Ejection demonstrations and launches of the full scale launch vehicle did not damage any sensitive components.	Section 6.1.2.1
LV - 2	Launch vehicle will not be over stable or susceptible to weather cocking.	Too much stability will result in more significant weather cocking, reducing consistency of launches.	A	Static stability will be limited to maximum of 3.5 calibers through design choices.	Complete - Measured center of gravity location and simulated center of pressure locations have determined the launch vehicle to have a static stability margin of 2.14 calibers.	Section 6.1.1.5
LV - 3	Motor will provide a minimum 10 to 1 thrust to weight of launch vehicle ratio.	A high thrust to weight ratio helps prevent weather cocking during the ascension of the launch vehicle. A high thrust from the motor quickly accelerates the launch vehicle, creating a high rail exit velocity.	A	Using OpenRocket simulations, the OSRT will be able to test the thrust output of the motor acting on the launch vehicle.	Complete - The thrust to weight ratio of the launch vehicle is 10.30.	Section 6.1.1.16

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
LV - 4	The launch vehicle will accommodate all interior components.	All components and systems should be able to be integrated within the launch vehicle. Additionally, the launch vehicle needs to be RF transparent where necessary to accommodate avionics.	D	Launch vehicle will have specific areas to accommodate the payload and avionics system in the payload bay and avionics bay, respectively.	Complete - The launch vehicle has been fully integrated during the integration demonstration as well as at the first full scale launch. All components were able to fit and both avionics bays as well as the payload bay are RF transparent.	Section 6.1.1.3
LV - 5	MATLAB scripts will be used in conjunction with all OpenRocket simulations.	Redundant simulations will ensure descent velocities, descent trajectory, and landing energy of the launch vehicle will maintain safe values.	A	Descent velocities, descent trajectory, and landing energy will be calculated using MATLAB scripts. All simulations will be checked to ensure no values disagree by more than 15%.	Complete - MATLAB code has been developed for necessary mission calculations.	Section 6.1.1.15
LV - 6	Bulkheads will be able to withstand up to a 75 G applied force with respect to the maximum forces experienced during separation.	The bulkheads provide the mounting points for the parachutes. In the case that a bulkhead were to dislodge from the launch vehicle, there would be nothing to slow the descent of the airframe. It is important that the bulkheads are able to withstand forces at least twice the magnitude of those expected.	T	Bulkheads are to be tested to withstand all expectant forces during flight..	Complete - Bulkheads have been successfully verified to exceed expected yield strength during flight.	Section 6.1.1.9

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
LV - 7	Radial bolts will withstand the worst case scenario anomalous recovery forces of 50 G.	Failure of the radial bolts would result in the parachutes separating from the launch vehicle, thus radial bolts need to be directly tested for their maximum holding capacity.	T	An Instron compression test will be used to determine the failure mode and maximum force of a bulkhead retained with radial bolts in a small section of excess airframe.	Complete - The compression testing first resulted of the bulkhead failing at 2,200 lbf followed by the airframe failing at 3,500 lbf, well above the required 50 G.	Section 6.1.1.9
LV - 8	All threaded attachments have a strength greater than 1.5 times the minimum shear strength of the selected threads.	This will prevent any failure of threaded rods at attachment points.	A	All purchased threaded components will be compliant, all manufactured components will be compliant so that a minimum safety factor of 1.5 is achieved.	Complete - The nosecone and canister threaded rods are able to withstand much more stress than what is applied and have a safety factor of 18.3 and 22, respectively.	Section 6.1.1.6 and 6.1.1.7
LV - 9	Fins must be designed and positioned to not be the first thing that hits the ground.	This will prevent any significant structural damage to the fins.	A	Maximum descent angle of the aft section under main parachute at 20 mph wind speed is 25.8°. Fins must be designed and positioned to not impact at that angle of descent.	Complete - The fins were designed with a 22.4° trailing edge angle and positioned 2 in. from the aft end of the body tube. This creates a 45° angle from the aft end of the body tube to the tip of the fins.	Section 6.1.1.8

6.2.2.2 Recovery Team Derived Requirements

Table 79: 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 going ballistic. Reliability has been confirmed through five consecutive tests at one size.	D	Ejection demonstrations will be performed successfully prior to all launches.	Complete - Ejection testing was completed prior to the subscale and full scale launches.	Section 6.1.2.4
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.	I	Deployment of payload from open end of launch vehicle will be demonstrated.	Complete - The fore airframe is open on the aft end which allows for payload ejection.	N/A
Recovery - 3	Avionics will be able to track the launch vehicle during and after the flight, broadcasting GPS information to a ground station.	The avionics communicating GPS coordinates to the ground station is critical to being able to locate the launch vehicle after landing.	T, D	This will be tested and demonstrated prior to and during all launches.	Complete - The avionics system was tested on both subscale launches and the full scale launch. Avionics functioned as intended for all but the first subscale launch.	Sections 6.1.2.15 and 6.1.2.14

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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 transmission upon landing.	T	The avionics system will be ground tested to ensure capability of communication with the ground station at maximum allowed drift radius. The inclusion of multiple ATUs provides redundancy for full-flight tracking.	Complete - The avionics system was tested on both subscale launches and the full scale launches.	Section 6.1.2.15
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 communicates 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 flight.	T	The battery life of the system will be tested during all subscale and full scale flights, and through on-ground duration testing.	Complete - battery life has been tested during both subscale and full scale flights and via on-ground duration testing.	Section 6.1.2.12
Recovery - 6	Recovery system will have appropriately sized static port holes.	This verification ensures the altimeters will correctly sense the pressure outside of the launch vehicle. Under or oversized static port holes will cause early or late separation events respectively.	A	Analyses will be performed to determine the correct sizing and number of static port holes.	Complete - The port hole calculations have been performed, and the port holes were drilled to specifications.	Section 6.1.2.5

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Recovery - 7	E-match wires will have a resistance within nominal range.	E-matches with an incorrect wire resistance will deliver incorrect current to the igniter leads, raising the chance for lead ignition to fail. Ensuring that resistance is in the nominal range will provide the highest chance to ignite ejection charges.	D	Correct resistance will be demonstrated prior to all ejection demonstrations and launches. Only e-matches verified to be within the nominal operating range will be used for testing and launches.	Complete - Ejection charge manufacturing process includes verification of e-match resistance.	Section 6.1.2.6
Recovery - 8	Altimeters will be verified to be pressure sensitive prior to each launch.	The team determined it was necessary to verify that the altimeters would react to a change in pressure prior to being used.	D	Demonstrations proving the altimeters which are going to be flown are pressure sensitive will be performed prior to all launches.	Complete - This process is included in the altimeter demonstration procedures.	Section 6.1.2.7
Recovery - 9	Altimeters will be verified to be capable of firing e-matches.	The altimeters used should be capable of firing e-matches for the drogue and main parachutes. Without this capability, the launch vehicle will never operate safely.	D	The altimeters will be verified to be capable of firing drogue, main, and auxiliary e-matches by firing the e-matches on the ground during a vacuum test.	Complete - This process is included in the altimeter demonstration procedures and has been performed prior to every launch.	Section 6.1.2.7
Recovery - 10	Pack method will allow components to be ejected in correct order.	The team determined it is necessary to verify that any new pack method and recovery configuration will result in an untangled and ordered ejection for reliability and safety of recovery components.	D	The recovery section will be separated by hand by pulling on the shock cord to ensure the components come out in the correct order, without tangles.	Complete - This has been successfully tested with a pull demonstration.	Section 6.1.2.2

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Recovery - 11	Ejection charges will consistently rupture through surgical tubing rather than 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	The failure point of all ejection charges will be photographed 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 6.1.2.8
Recovery - 12	All ejection charge firing systems will be capable of being disarmed and shunted. Capacitors contained on firing systems must be discharged.	All altimeters are wired to ejection charges which could cause injury to personnel. Shunting as a redundant safety measure ensures safety during assembly and disassembly process.	A	A DPST switch has been implemented for the altimeters, which connects both the positive and the negative terminals of the altimeter to ground in one position and connects positive to battery voltage and negative to ground in the other position. The ejection charge disarming procedures in Sections 66 have been developed for any case in which the ejection charges must be handled after arming of the systems.	Complete - DPST switches have been implemented, and analysis of capacitor discharge time has been determined.	Section 6.1.2.10

6.2.2.3 Payload Team Derived Requirements

Table 80: 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 for the launch vehicle to reach its target altitude with the selected motor. The rover, however, must be robust enough to survive flight and ejection stresses and heavy enough to be able to use its auger reliably.	T	Design weight will be based upon ideal flight simulations. A test will occur prior to test launches and payload test missions.	Complete - The final rover has been constructed and was flown during the first full scale launch. The launch vehicle apogee altitude exceeded the target altitude, indicating that the rover was of appropriate weight. Auger testing was performed and successfully collected 10 mL of soil.	Sections 6.1.3.4 and 6.1.3.7
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, the payload requires power to maintain GPS lock throughout flight to allow for expedited mission completion and to hold a relay open, ensuring no navigation or soil collection functions occur.	A	Analysis will be conducted to ensure the battery has charge left upon being ejected from the airframe.	Complete - The battery of the payload is capable of remaining charged for over 2 hours.	Section 6.1.3.8

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Payload - 3	All components will be able to withstand the 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 from both apogee separation and payload ejection without any wear.	I	After each ejection all components in the ejection bay will be inspected. The inspector will look for any damage found from heat, residue, or pressure.	Complete - Inspection has occurred after each ejection test, both ground testing and the full scale launch. Inspection will continue to occur after each ejection.	Section 6.1.3.9
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 and thus must be actively avoided.	D	The rover will have three front mounted sonar sensors facing in slightly different directions to scan a wide field of view. The rover will demonstrate the ability to steer to avoid large, solid objects in its path.	Completed - 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 6.1.3.10
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 demonstrated to expand upon release of radial pressure.	Complete - Wheels were additivly manufactured and foam tires used to compress and form pressure seal.	Section 6.1.3.11
Payload - 6	The rover's battery will have sufficient capacity to power all of its electrical systems for at least 45 minutes.	The mission, including requirements set forth by NASA and those derived by the team, may take up to 45 minutes to complete.	A	The power budget for the rover will be analyzed to ensure the battery will be sufficient for 45 minutes of continuous operation.	Completed - The power draw of the payload has been calculated and the battery will last for 45 minutes of continuous operation.	Section 6.1.3.12

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Payload - 7	The rover will remain in a low power state until it has been ejected.	Because of the amount of time that 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 will show that the rover can remain in a low power state while inside a fiberglass wrap.	Completed - The payload does not perform any navigation or soil collection functions while in its wrapped state.	Section 6.1.3.13
Payload - 8	All payload ejection charges will be capable of being disarmed and all capacitors discharged.	Capacitors containing charge pose a risk of discharging through an e-match and triggering a live charge.	A	A DPST switch is implemented for the PLEC, which connects both the positive and negative terminals of the PLEC to ground in the disarmed position and positive to battery voltage and negative to ground in the armed position. The payload ejection charge disarming procedure in Section 66 has been developed for any case in which the ejection charges must be handled after arming the system.	Complete - DPST switches have been implemented and analysis of capacitor discharge time has been performed.	Section 6.1.3.14
Payload - 9	A rapidly prototyped rover will be developed.	A prototype rover allows the electrical and software systems to be developed and tested while the mechanical systems of the rover are being machined.	D	The final rover design will be prototyped utilizing additive manufacturing of PLA for the components to be rapidly manufactured.	Complete - A prototype rover was manufactured and used to rover testing.	Section 6.1.3.16

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Payload - 10	A prototype of the rover electronics will be developed to verify functionality.	The rover PCB is complex and requires testing to ensure the final PCB will function as intended. A prototype circuit with breakout boards mounted can be used to test sensors and code performance.	D	Functionality of the motor drivers, sonar sensors, and IMU will be demonstrated via prototype hardware.	Complete - A protoboard was constructed and has been used to perform numerous rover tests.	Section 6.1.3.15
Payload - 11	The rover will be capable of driving to a specified GPS coordinate.	The rover must be capable of driving a minimum of 10 ft from the launch vehicle, which OSRT is measuring using GPS.	D	Demonstration will show that the rover is capable of using GPS to confirm the distance travelled from its starting location.	Incomplete - demonstration will be performed by FRR Addendum.	Section 6.1.3.17
Payload - 12	The rover will be capable of RF communication with the scientific base station and the ATUs.	Receiving GPS data from the scientific base station and launch vehicle are important to rover navigation.	D	Demonstration will show that the rover is capable of RF communication with the scientific base station and the launch vehicle ATUs.	Incomplete - demonstration will be performed by FRR Addendum.	Section 6.1.3.18
Payload - 13	The rover will be capable of autonomously docking with a scientific base station.	The OSRT is pursuing an additional scientific experiment to be performed after the conclusion of the SL mission. In order to perform the scientific experiment, the rover must be capable of bringing the sample to the scientific base station.	D	Demonstrate will show that the rover is capable of using CV and GPS to navigate to the base station.	Incomplete - demonstration will be performed by FRR Addendum.	Section 6.1.3.19

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Payload - 14	The PLEC will demonstrate proper sequencing of charges prior to using e-matches or black powder.	The proper sequencing of charges is critical to safe deployment of the rover. Functionality testing is required before any black powder charges can be wired to the system.	D	An LED and a small resistor will be used to simulate each e-match on the PLEC ports. The sequencing of charges should release the three retention devices prior to proceeding with the ejection charges.	Complete - The test LEDs lit up in the desired sequence when given the signal from the ground station.	Section 6.1.3.20
Payload - 15	The payload will demonstrate the ability to maintain a set heading without deviating more than 10 degrees in either direction	A direction of travel will be calculated from the GPS coordinates of the rover to the coordinates of the scientific base station. In order to navigate to the scientific base station the rover must be able to follow a heading.	D	A magnetometer will be used to determine the orientation of the rover relative to the earths magnetic field.	Incomplete - demonstration will be performed by FRR Addendum.	Section 6.1.3.21

6.2.2.4 Safety Team Derived Requirements

Table 81: Team Derived Safety Verification Matrix

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

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Safety - 4	The team will follow all safety rules and guidelines set by the NAR, TRA, and OSU.	The rules and guidelines set by the NAR, TRA, and OSU are made to protect all individuals involved. Following these rules is beneficial for all parties.	D	The SO will understand both NAR and 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.	Complete - All team members have followed all safety regulations as of FRR submission and will continue to do so.	N/A
Safety - 5	The team will have written checklists with instructions on how to safely assemble the rover, recovery systems, and launch vehicle.	Written checklists ensure that all safety considerations are taken into account and that all steps are followed when assembling components. Correct assembly is crucial and can easily go wrong if the checklist is not followed. Additionally, the checklists mean that the assembler must work with a qualified partner, further promoting safety.	I	Each team member or sub-team responsible for designing a part on any assembly pertaining to the launch vehicle or payload will write a formal checklist to ensure that any team member can assemble the part without the presence of the designer of the part. All checklists will be verified by an assembler, inspector, and safety officer.	Complete - Checklists have been written for assembly of the rover, recovery systems, and launch vehicle.	Section 4.2
Safety - 6	The team will create a comprehensive list of FMEAs for each subsystem of the project to mitigate as many failure modes as practical.	FMEAs help the team identify potential failure points. If possible, the failure point will be completely eliminated. If elimination is not possible, steps will be taken to minimize the risk of the failure mode.	I	Each team member will write a FMEA for each and every part of the project they are working on. These will be organized by sub-team and subsystem so they can be easily referenced.	Complete - FMEAs for all parts have been created.	Section 4.1.1

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Safety - 7	The team will charge all LiPo batteries with a smart charger to prevent nonuniform or over charging of the batteries.	Properly charging the batteries allows for the avionics system and payload to run for the required duration. If the batteries charge poorly GPS tracking can fail.	D	The team will only buy smart chargers, so that non-smart chargers are never used for charging the batteries.	Complete - The team is using a smart charger under a 'balanced charge' profile for all LiPo batteries.	N/A
Safety - 8	The team will not short circuit any of the batteries while installing them into systems requiring batteries.	Short circuiting a battery could result in damage to the avionics or the battery itself.	I	Batteries will have keyed, female connectors which cannot be shorted accidentally or connected in the wrong orientation. Heat shrink and insulation will cover all live electrical wiring. Terminals will be insulated.	Complete - All batteries are equipped with female, keyed headers which eliminate the risk of electrical shorting. Batteries and terminals are insulated.	N/A
Safety - 9	The team will use appropriate PPE when handling and machining composite materials.	Improper PPE will result in injury to the user. Using the correct PPE will minimize this risk.	D	Safety briefings will be conducted. JHAs will be filled out as necessary.	Complete - All team members have used appropriate PPE and JHAs have been filled out as necessary as of FRR submission.	N/A
Safety - 10	There will be no sharp edges on the external portion of the payload.	Sharp edges on the external portion of the payload could cause damage to the airframe or other components. More importantly, a sharp edge could cause personnel injury.	I	Any sharp edges on payload will be machined off or will be completely encased in a safe container. See Section 5.3.5 for auger encasing.	Complete - Machined components were inspected upon completion. Preflight inspections are performed for every launch.	N/A

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Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Safety - 11	There will be a light to indicate the payload ejection charges are armed.	It is important to know if the ejection charges are armed so that extra precautions can be taken. All present individuals should be aware of armed charges.	I	A blinking LED indicator was connected to the PLEC. The LED blinking is inspected to be visible upon arming PLEC.	Complete - The LED was implemented and was inspected to be flashing when armed.	N/A
Safety - 12	The PLEC will have an Single Pole Double Throw (SPDT) arming switch accessible while on the launch rail, as well as a remote arming switch on the ground station.	Being able to arm the payload ejection charges after they are fully integrated in the airframe and having a secondary remote arming switch will minimize the risk of injury due to premature ejection charge firing.	I	This requirement is inspected by turning the PLEC switch and verifying that the LED is blinking to indicate armed status. The ground station payload ejection switch can then be armed.	Complete - the PLEC was able to be armed via the connected switch as well as from the ground station.	N/A
Safety - 13	The Mentor and Educational Advisor will have the final say in safety decisions on all activities and designs.	The Mentor and Educational Advisor have much more experience than the rest of the team and are more qualified to assess the risk involved. If either of these individuals are uncertain about a method or component, their opinion should be accounted for.	I	If the safety of an event or activity is disputed, whatever the Mentor or Advisor decides will be the final decision.	Complete - All team members have followed this rule throughout the project, and will continue to follow this rule for the duration of the project.	N/A

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Table 81 – continued from previous page

Requirement Number	Description Requirement	Justification	Verification Method	Verification Plan	Status	Report Location
Safety - 14	All team members must remain attentive and at safe distances from the launch area during subscale and full scale launches.	The majority of injuries are due to neglect or ignorance of one's surroundings. If all individuals are aware of potential hazards before, during, and post launch, the risk of injury is substantially decreased.	I	Each team member will be responsible for having awareness of their surroundings during all launch-related activities. All three safety officers will oversee team members' safety.	Complete - Implemented at first three launch events and will be maintained through all future launches.	N/A

6.3 Budgeting and Timeline

6.3.1 Budget

Tables 82, 83, and 84 are itemized lists of components and materials necessary to realize this design. These tables represent a breakdown of components and raw materials which the OSRT has used in the manufacturing and launching of the launch vehicle and payload. Costs associated with testing are included in this budget in the appropriate sub-team table.

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

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

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

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

Table 82: Structures Bill of Materials

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
01	Structures	01-001	Cesaroni L2375-WT	3	$331.99	$995.97	Wildman	PR75-4G-WT	
01	Structures	01-002	Motor Casing	1	$415.22	$415.22	Apogee Rockets	71043	
01	Structures	01-003	75 mm Fore Closure	1	$70.99	$70.99	Wildman	P75-CL	
01	Structures	01-004	75 mm Retainer	1	$48.89	$48.89	Apogee Rockets	24054	
01	Structures	01-005	Centering Ring	3	$0.54	$1.62	Spaeth Lumber	-	
01	Structures	01-006	Fiberglass Motor Tube	1	$111.99	$111.99	Apogee Rockets	-	
03	Cameras	03-001	Top Camera Case	1	n/a	n/a	Club Resources	-	$5.00
03	Cameras	03-002	Bottom Camera Case	1	n/a	n/a	Club Resources	-	$5.00
03	Cameras	03-003	Portable Camera	5	n/a	n/a	OSU Valley Library (rental)	-	
03	Cameras	03-004	Threaded Rod	1	$6.80	$6.80	McMaster-Carr	93225A961	
03	Cameras	03-005	Notched Bulkhead	2	$5.00	$10.00	Spaeth Lumber	-	
04	Structures	04-001	Aft Plywood Blkhd	1	$0.54	$0.54	Spaeth Lumber	-	
04	Structures	04-002	Aft Body Wall	1	n/a	n/a	Club Resources	-	$1.25
04	Structures	04-003	Altimeters Mount	2	n/a	n/a	Club Resources	-	$0.87
04	Structures	04-004	Switch Mount	1	n/a	n/a	Club Resources	-	$0.12
04	Structures	04-005	Battery Casing	2	$1.69	$3.38	LEDSupply	BH-9V-SWITCH	
04	Structures	04-006	Spacer	12	$0.07	$0.84	Alliedelec	901-605	
04	Structures	04-007	9V Battery, 4 ct.	1	$12.96	$12.96	Walmart	MN16RT4Z	
04	Structures	04-008	Board Screws, 100 ct.	1	$5.29	$5.29	McMaster-Carr	91772A081	
04	Structures	04-009	Battery Screws, 100 ct.	1	$5.82	$5.82	McMaster-Carr	90471A215	
04	Structures	04-010	Sealing Washer, 10 ct.	1	$8.58	$8.58	McMaster-Carr	93303A102	
08	Structures	08-001	Battery Casing	2	$1.69	$3.38	LEDSupply	BH-9V-SWITCH	
08	Structures	08-002	Spacer	8	$0.07	$0.56	Alliedelec	901-605	
08	Structures	08-003	9V Battery	2	n/a	n/a	Club Resources	MN16RT4Z	

Continued on next page

Table 82 – continued from previous page

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
08	Structures	08-004	Sealing Washer, 10 ct.	1	n/a	n/a	Club Resources	93303A102	$0.75
08	Structures	08-005	Seal Washer Bolt, 50 ct.	1	n/a	n/a	Club Resources	92620A564	$2.57
08	Structures	08-006	Lower Avionics Mount	1	n/a	n/a	Club Resources	-	$1.00
08	Structures	08-007	Upper Avionics Mount	1	n/a	n/a	Club Resources	-	$1.00
08	Structures	08-008	Avionics Battery Case Bottom	1	n/a	n/a	Club Resources	-	$0.23
08	Structures	08-009	Avionics Battery Case Top	1	n/a	n/a	Club Resources	-	$0.23
10	Structures	10-001	Avionics Mount	2	n/a	n/a	Club Resources	-	$2.50
10	Structures	10-002	Mount Topper	1	n/a	n/a	Club Resources	-	$0.75
10	Structures	10-003	Mount Feet	2	n/a	n/a	Club Resources	-	$0.50
10	Structures	10-004	Black-Oxide 4-40 Socket Bolt 100 ct.	1	$8.84	$8.84	McMaster-Carr	91251A113	
10	Structures	10-005	Low-Strength Steel 4-40 Hex Nut 100 ct.	1	$0.89	$0.89	McMaster-Carr	90480A005	
11	Structures	11-001	Nosecone	1	$184.95	$184.95	Madcow Rocketry	FWNC75M	
12	Structures	12-001	3 x 3 ft Carbon Fiber Fin Stock	1	$295.00	$295.00	Tim McAmis Performance Parts	TMC-1290-0125	
13	Structures	13-001	Aft Body Tube	1	n/a	n/a	Innovative Composite Engineering	-	$1,500.00
13	Structures	13-002	RocketPoxy (2 pints)	1	n/a	n/a	Club Resources		$43.75
13	Structures	13-003	6.25 in. Outer Diameter (OD) Canister	1	n/a	n/a	Club Resources	-	$100.00
14	Structures	14-001	Fore Body Tube	1	n/a	n/a	Innovative Composite Engineering	-	$1,500.00
14	Structures	14-002	Fore Coupler	1	n/a	n/a	Club Resources	-	$50.00
14	Structures	14-003	Prepreg 7781 E-Glass (5 yd roll)	1	n/a	n/a	Fiberglast	2100-C	$241.95
			STRUCTURES TOTAL			**$ 2,442.51**			

Table 83: Aerodynamics and Recovery Bill of Materials

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
02	Mech. BEAVS	02-001	1/8 in. Aluminum Plate (2 x 24 in.)	1	n/a	n/a	Club Resources	-	$11.08
02	Mech. BEAVS	02-002	1/4-20 Fasteners	4	$0.19	$0.76	McMaster-Carr	-	
02	Mech. BEAVS	02-003	Aft Plywood Blkhd	1	$0.54	$0.54	Spaeth Lumber	-	
02	Mech. BEAVS	02-004	PLA 3D Printer Filament (1 kg)	7	$19.99	$139.93	Monoprice	10551	
02	Mech. BEAVS	02-005	M2 Fasteners, 100 ct.	1	$13.26	$13.26	McMaster-Carr		
02	Mech. BEAVS	02-006	7 mm Linear Guide Block/Rail	4	$14.99	$59.96	CNC Machine Shops	B018KFFIAI	
02	Electrical BEAVS	02-007	SparkFun Venus GPS	1	$49.95	$49.95	SparkFun	GPS-11058	
02	Electrical BEAVS	02-008	Teensy 3.6	1	$31.25	$31.25	Digi-Key	MK66FX1-M0VMD18	
02	Electrical BEAVS	02-009	MPL3115 Barometer	1	$4.87	$4.87	Mouser	MPL3115	
02	Electrical BEAVS	02-010	Absolute Orientation IMU	1	$34.95	$34.95	Adafruit	BNO055	
02	Electrical BEAVS	02-011	Turnigy 2200mAh LiPo	1	$10.99	$10.99	HobbyKing	B07CHVCNF5	
02	Electrical BEAVS	02-012	OSRT Designed PCB	1	$92.90	$92.90	DFRobot	-	
02	Electrical BEAVS	02-013	Xbee Pro 900hp	1	$39.00	$39.00	Digi-Key	XBP9B-DPST-021	
02	Electrical BEAVS	02-014	7 in. Reverse Polarity Sub-Miniature Version A Connector (RPSMA) Whip Antenna	1	$4.29	$4.29	Amazon	NSKI SRH805s	
02	Mech. BEAVS	02-015	Retention Ring	1	n/a	n/a	Club Resources	-	$0.10
02	Mech. BEAVS	02-016	Retention Link	4	n/a	n/a	Club Resources	-	$0.40
02	Mech. BEAVS	02-017	3/8 in. 4-40 Bolt	8	$0.30	$2.40	McMaster-Carr	91255A108	
02	Mech. BEAVS	02-018	24 Pitch 14.5 deg Pressure Angle	1	$19.22	$19.22	Amazon	B004LDIYEO	
02	Mech. BEAVS	02-019	Lynxmotion 5.2:1 Brushed Direct Current (DC) Motor	1	$45.92	$45.92	RobotShop	RB-Wtc-19	
02	Mech. BEAVS	02-020	10 GA Steel Plate	10	$2.37	$23.70	OnlineMetals	14695	
04	Recovery	04-012	MissileWorks RRC3 Sport Altimeter	2	$69.95	$139.90	MissileWorks	90905	
04	Recovery	04-013	PerfectFlite StratoLogger CF	4	$57.50	$230.00	PerfectFlite	A1247	

Continued on next page

Table 83 – continued from previous page

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
04	Recovery	04-014	4f Black Powder (1 lb)	1	$36.54	$36.54	Graf and Sons	SC4FG	
04	Recovery	04-015	Santoprene (1 ft)	5	$2.43	$12.15	McMaster-Carr	86215K54	
04	Recovery	04-016	Surgical Tubing (10 ft)	2	$36.00	$72.00	McMaster-Carr	88210	
04	Recovery	04-017	E-Match	80	$0.75	$60.00	Australian Rocketry	J-TEK LF	
05	Recovery	05-001	Main Parachute	2	$404.00	$808.00	FruityChutes	IFC-96-S	
05	Recovery	05-002	Drogue Parachute	2	$19.99	$39.98	Top Flight Recovery	XTPAR-18	
05	Recovery	05-003	Eye bolt	6	$6.65	$39.90	Grainger - Ken Forging	35Z511	
05	Recovery	05-004	Nyloc	6	$5.67	$34.02	Zoro	G5360591	
05	Recovery	05-005	Nylon Shock Cord	2	$34.60	$69.20	FruityChutes	SCN-1000	
05	Recovery	05-006	Quick Link	7	$4.10	$28.70	Apogee Rockets	29621	
05	Recovery	05-007	Swivel	4	$9.00	$36.00	FruityChutes	SWIV-3000	
05	Recovery	05-008	Nylon Harness	2	$18.00	$36.00	FruityChutes	-	
05	Recovery	05-009	Kevlar Sleeve	4	$28.75	$115.00	BlackCat Rocketry	HK-S-250	
05	Recovery	05-010	Deployment Bag	2	$43.00	$86.00	FruityChutes	CDB-4	
05	Recovery	05-011	Tender Descender	4	$81.43	$325.72	TinderRocketry	-	
05	Recovery	05-012	Wide Mouth Quick Link	5	$4.76	$23.80	McMaster-Carr	3711T23	
05	Recovery	05-013	Shear Pins	3	$3.22	$9.66	Apogee Rockets	29615	
05	Recovery	05-014	Cellulose Insulation	-	n/a	n/a	Club Resources	-	
05	Recovery	05-015	Parachute Blast Protector	4	$11.95	$47.80	Madcow Rocketry	NB-9	
			AERODYNAMICS AND RECOVERY TOTAL			**$2,824.26**			

Table 84: Payload Bill of Materials

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
06	PEARS	06-001	Threaded Rod	1	$8.44	$8.44	McMaster-Carr	90322A121	
06	PEARS	06-002	Aft PEARS Bulkhead - Loose	1	$0.92	$0.92	Club Resources	-	
06	PEARS	06-003	Rod Cap - Spacer	1	n/a	n/a	Club Resources	-	$3.00
06	WRAP	06-004	Aft Payload Bulkhead	1	$0.92	$0.92	Club Resources	-	
06	WRAP	06-005	Fore Payload Bulkhead	1	$0.92	$0.92	Club Resources	-	
06	WRAP	06-006	Kevlar Harness	1	$11.67	$11.67	Giant Leap Rocketry	-	
06	PEARS	06-007	Advanced Retention Release Device	1	n/a	n/a	Club Resources	-	$119.00
06	PEARS	06-008	Tender Descender	2	n/a	n/a	Club Resources	-	$158.00
06	Soil Collection	06-009	Auger	3	n/a	n/a	Club Resources	-	$9.00
06	Drivetrain	06-010	Clamping Hub (0.25 in. bore)	6	$5.99	$35.94	ServoCity	RB-Sct-582	
06	Soil Collection	06-011	High-Strength 1045 Carbon Steel Rod	1	$6.60	$6.60	McMaster-Carr	8279T16	
06	Soil Collection	06-012	Carbon Fiber Auger Wrap	1	n/a	n/a	Club Resources	-	$10.00
06	SCAR	06-013	Set Screw Shaft Coupler	3	$4.99	$14.97	ServoCity	625118	
06	SCAR	06-014	26 Revolutions per Minute (RPM) Mini Econ Gear Motor	2	$9.99	$9.99	ServoCity	638830	
06	Soil Collection	06-015	Short-Thread Alloy Steel Shoulder Screw	6	$4.10	$24.60	McMaster-Carr	94361A112	
06	Soil Collection	06-016	Auger Tube	3	$5.00	$15.00	McMaster-Carr	89955K919	
06	Soil Retention	06-017	Low-Carbon Steel Rod	2	$1.20	$2.40	McMaster-Carr	8920K115	
06	Soil Retention	06-018	Psvtd 18-8 Stainless Steel (SS) Pan Head Phillips Screw, 100 ct.	1	$7.54	$7.54	McMaster-Carr	91772A194	
06	Chassis	06-019	Carbon Fiber Tail	1	n/a	n/a	Club Resources	-	$10.00
06	Chassis	06-020	Torsion Spring	1	$6.19	$12.38	McMaster-Carr	9271K182	
06	Chassis	06-021	Aluminum Tail Mount	1	n/a	n/a	Club Resources		$3.00
06	Drivetrain	06-022	Wheel	6	n/a	n/a	Club Resources	-	$40.00

Continued on next page

Table 84 – continued from previous page

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
06	Drivetrain	06-023	8 x 10 in. Urethane Foam Sheet	4	n/a	n/a	Rogers Corporation	-	$10.00
06	Drivetrain	06-024	.25 x .75 x 12 in. 6061 Aluminum Bar	3	$2.14	$6.42	McMaster-Carr	8975K594	
06	Drivetrain	06-025	.75 x 1.5 x 12 in. 6061 Aluminum Bar	2	$11.42	$22.84	McMaster-Carr	8975K45	
06	Drivetrain	06-026	.5 in. dia, 1 ft. 6061 Aluminum Rod	2	$2.66	$5.32	McMaster-Carr	8974K28	
06	PEARS	06-027	PLEC Mount	1	n/a	n/a	Club Resources	-	$4.00
06	PEARS	06-028	SPDT Switch	8	$10.33	$82.64	Apogee Components	-	
06	PEARS	06-029	1 in. Steel Ring	3	$1.20	$3.60	McMaster-Carr	-	
06	PEARS	06-030	Santoprene Rubber (12 x 24 x 1/16 in.)	1	$23.80	$23.80	McMaster-Carr	86215K54	
06	PEARS	06-031	U Bolt	2	$0.80	$1.60	McMaster-Carr	8880T954	
06	PEARS	06-032	Nylon Locknut	5	n/a	n/a	Club Resources		$2.00
06	PEARS	06-033	Sealing Washer	5	n/a	n/a	Club Resources		$2.00
06	Electronics	06-034	Teensy 3.6 Development Board	1	$29.25	$29.25	SparkFun	RB-Pjr-08	
06	Electronics	06-035	Solid-Core Wire Spool (25 ft, 22 American Wire Gauge (AWG))	1	$2.95	$2.95	Adafruit	288	
06	PEARS	06-036	Quick Link	3	$1.20	$3.60	McMaster-Carr	29621	
06	PEARS	06-037	Kevlar Thread	15	$0.34	$5.10	Giant Leap Rocketry	-	
06	Drivetrain	06-038	3/8 in. Ball Bearing	4	$16.94	$67.76	McMaster-Carr	4648K5	
06	Drivetrain	06-039	3/8 in. Ball Bearing	2	n/a	n/a	Club Resources	4648K5	$33.88
06	Drivetrain	06-040	1/4 in. Ball Bearing	4	$12.13	$48.52	McMaster-Carr	2342K164	
06	Drivetrain	06-041	1/4 in. Ball Bearing	2	n/a	n/a	Club Resources	2342K164	$24.26
06	Drivetrain	06-042	1/4" High Load Fe-Cu Thrust Bearing	6	$2.02	$12.02	McMaster-Carr	3750K1	
06	Drivetrain	06-043	Steel Shaft Coupling (0.25 in. to 4 mm)	6	$4.99	$29.94	ServoCity	625118	

Continued on next page

Table 84 – continued from previous page

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
06	Drivetrain	06-044	170 RPM Econ Gear Motor	6	$14.99	$89.94	ServoCity	638354	
06	Drivetrain	06-045	6-32 Unified National Coarse (UNC) Screw, 50 ct.	1	$10.60	$10.60	McMaster-Carr	97763A144	
06	Drivetrain	06-046	M3-0.5 Screw, 100 ct.	1	$8.38	$8.38	McMaster-Carr	92095A182	
06	Drivetrain	06-047	10-32 Unified National Fine (UNF) Screw, 100 ct.	1	$7.55	$7.55	McMaster-Carr	92949A267	
06	Drivetrain	06-048	6-32 Locknut, 100 ct.	1	$7.54	$7.54	McMaster-Carr	90101A007	
06	Soil Collection	06-049	1 in. OD Mirror-Like 6061 Al Round Tube	1	$21.32	$21.32	McMaster-Carr	7785T11	
06	Soil Retention	06-050	3 x 3/32 in. 6061 Aluminum Sheet	2	$4.35	$8.70	McMaster-Carr	8975K343	
06	Soil Retention	06-051	1000:1 Micro Metal Gearmotor High-Power Carbon Brush (HPCB) 12V	2	$24.95	$49.90	Pololu	3046	
06	Soil Retention	06-052	Soil Retention Container	2	n/a	n/a	Club Resources	-	$6.00
06	Soil Collection	06-053	Blk-Ox Steel Hex Drive Flat Head Screw, 10 ct.	1	$7.36	$7.36	McMaster-Carr	91253A119	
06	Soil Collection	06-054	Low Strength (LS) Steel Nylon-Insert Locknut, 100 ct.	1	$2.79	$2.79	McMaster-Carr	90631A005	
06	Soil Collection	06-055	Auger Mount	6	n/a	n/a	Club Resources	-	$9.00
06	Soil Retention	06-056	Soil Retention Motor Mount	3	n/a	n/a	Club Resources	-	$5.00
06	Electronics	06-057	PLEC	1	n/a	n/a	Club Resources	-	$35.00
06	Electronics	06-058	PLEC Battery	1	n/a	n/a	Club Resources	-	$5.00
06	Electronics	06-059	PLEC DPST Switch	1	n/a	n/a	Club Resources	-	$5.00
06	Electronics	06-060	Dual Channel DC Motor Driver	1	$19.25	$19.25	RobotShop	RB-Cyt-153	
06	Electronics	06-061	2200mAh LiPo Battery Pack	1	$15.01	$15.01	HobbyKing	T2200.3S.40	
06	Electronics	06-062	Dual Motor Driver Carrier	1	$2.11	$2.11	Digi-Key	TB6612FNG	
06	Electronics	06-063	Voltage Regulator	1	$2.73	$2.73	Mouser	595-TPS54383PWP	
06	Electronics	06-064	Accelerometer/Magnetometer	1	$14.95	$14.95	Adafruit	LSM303	

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Table 84 – continued from previous page

Section	Assembly	Identifier	Description	Qty	Unit Cost	Cost	Vendor/Source	SKU	Value
06	Electronics	06-065	RF Transceiver	1	$39.00	$39.00	Symmetry Electronics	XBP9B-DMST-002	
06	Electronics	06-066	Logitech High Definition (HD) Webcam	1	$27.84	$27.84	Amazon	960-000585	
06	Electronics	06-067	Relay	1	$8.57	$8.57	Digi-Key	RV2H-2G-D12-C1D2	
06	Electronics	06-068	Sonar Module	3	$39.95	$119.85	MaxBotix	MB1230	
06	Electronics	06-069	GPS Module	1	$27.00	$27.00	Digi-Key	MAX-M8W-0	
06	Electronics	06-070	Antenna	1	$5.10	$5.10	Taoglas	GP.1575.18-4.A.02	
06	Chassis	06-071	1/4 in. dia, 2 ft Carbon Fiber Rod	10	$14.09	$140.90	McMaster-Carr	2153T52	
06	Chassis	06-072	0.5 in. x 0.75 in. x 6 ft 6061 Aluminum Bar	1	$16.32	$16.32	McMaster-Carr	8975K618	
06	Drivetrain	06-073	3.5 x .75 x 12 in. Aluminum Bar	1	$22.08	$22.08	McMaster-Carr	8975K625	
07	Fore Hard Point	07-001	Fore Bulkhead	1	n/a	n/a	Club Resources	-	$0.35
07	Fore Hard Point	07-002	Fore Funnel	1	n/a	n/a	Club Resources	-	$5.00
07	Fore Hard Point	07-003	Pass-Through Bulkhead	1	n/a	n/a	Club Resources	-	$0.35
			PAYLOAD TOTAL			**$ 1,172.44**			

6.3.2 Finance Plan

The OSRT is supported in part through NASA/Oregon Space Grant Consortium (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. This a minimum 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 is be done through sponsorships, discounts, and materials donations from other companies and resources. Table 85 shows the funding plan. The OSU chapter of American Institute of Aeronautics and Astronautics (AIAA), OSGC, and ICE represent the primary funding sources for OSRT.

Table 85: Major funding contributions breakdown.

	Total Cost	**OSGC Contribution**	**Matching Contribution**	**Matching Sources**
Structures	$5,899.98	$2,442.51	$3,457.47	ICE, Fiberglast, Club Resources
Aerodynamics and Recovery	$2,835.84	$2,824.26	$11.58	Club Resources
Payload	$1,671.20	$1,172.44	$498.76	Club Resources
Outreach	$300.00	-	$300.00	AIAA
Travel	$12,000.00	-	$12,000.00	AIAA, Student Expenditure
Lodging	$6,300.00	$4,560.79	$1,739.21	AIAA, Student Expenditure
Total	**$29,007.02**	**$11,000.00**	**$18,007.02**	
		Matching Ratio: 1.64		

The OSRT 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) and Home Comfort have both agreed to a $500.00 donation. The airframe tube is being donated by ICE and is valued at $3,000.00. All of these donations and discounts will go towards the matching. Additionally, any student expenditures, such as materials purchased by team members and travel, will also be put to reach the matching amount required by OSGC.

Other companies that are contacted by more than one rocketry team at OSU 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 134: Special thank you to OSGC!

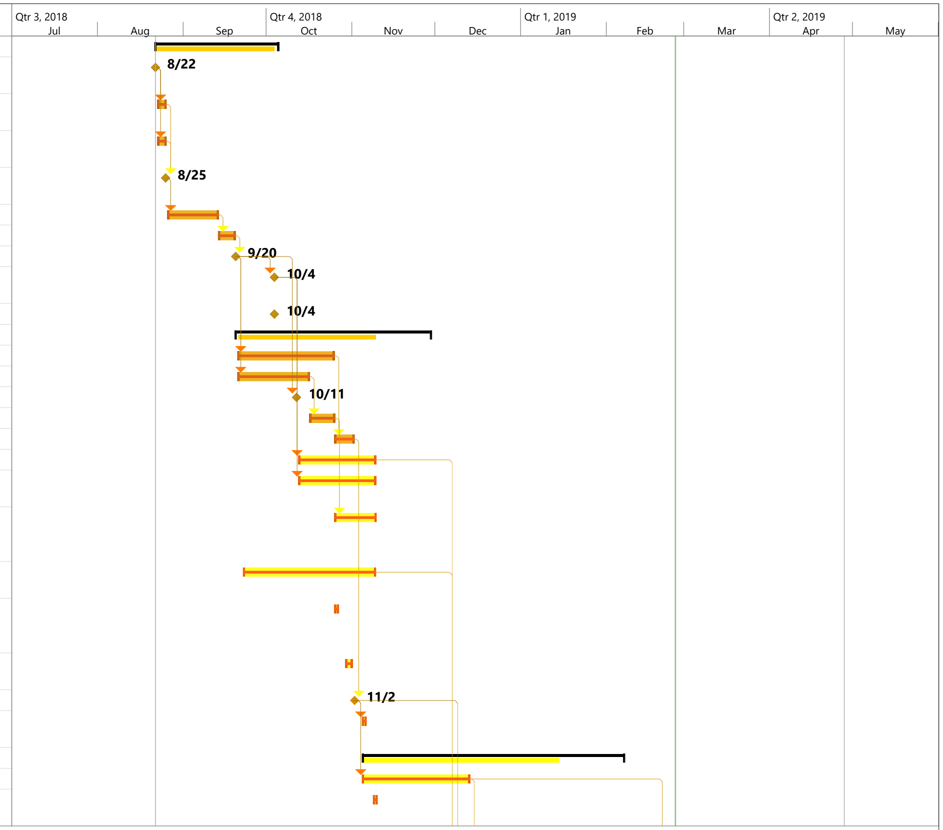
6.3.3 Timeline

The OSRT has broken the competition down into five distinct phases. The phases are closely aligned with key project milestones outlined by the SL Team. The key phases are: Preliminary Design Phase, Critical Design Phase, Final Readiness Phase, Competition Phase, and Post Launch Phase. The Preliminary Design Phase, Critical Design Phase, and Final Readiness Phase are accompanied by design review reports and teleconferences with the SL Team in the PDR, CDR, and FRR. The Competition Phase features the final launch and payload demonstration for the team. The project concludes in the Post Launch Phase, which primarily consists of an analysis of the launch and payload mission in the PLAR.

There are several notable milestones OSRT has met during the project life cycle. The subscale launch vehicle was launched two times, first on December 8th, 2018 which resulted in the main parachute deploying at apogee. Based off of the first subscale launch, changes were made and it was relaunched on January 3rd, 2019 which resulted in the drogue parachute deploying at apogee but the main parachute failing to deploy. Both subscale flights were used to inform the design of the full scale launch vehicle, which was launched on February 22nd, 2019 and resulted in successful deployment of the drogue and main parachutes. In addition to technical project milestones, numerous outreach events have culminated in OSRT teaching lessons in STEM to over 3,362 people in the community during the duration of the project.

Currently, OSRT is completing the Final Readiness Phase of the competition, as shown in Figures 135 - 137. Completion of the Final Readiness Phase allows the team to launch in the competition at Marshall Space Flight Center in Huntsville, Alabama. The team is working to complete a few outstanding tasks to be ready for launch at competition.

ID	Task Name	Duration	Start	Finish	% Complete
1	**Proposal Phase**	**45 days**	**Wed 8/22/18**	**Fri 10/5/18**	**100%**
2	Competition Rules Released	0 days	Wed 8/22/18	Wed 8/22/18	100%
3	Launch Vehicle Concept Development	3 days	Thu 8/23/18	Sat 8/25/18	100%
4	Payload Concept Development	3 days	Thu 8/23/18	Sat 8/25/18	100%
5	Team Decisions and Kickoff Meeting	0 days	Sat 8/25/18	Sat 8/25/18	100%
6	Compile Proposal	18 days	Sun 8/26/18	Thu 9/13/18	100%
7	Edit Proposal	6 days	Fri 9/14/18	Wed 9/19/18	100%
8	Submit Proposal	0 days	Thu 9/20/18	Thu 9/20/18	100%
9	Proposal Admittance Announced	0 days	Thu 10/4/18	Thu 10/4/18	100%
10	AIAA Presentation	0 days	Thu 10/4/18	Thu 10/4/18	100%
11	**Preliminary Design Phase**	**72 days**	**Thu 9/20/18**	**Thu 11/29/18**	**100%**
12	Compile PDR	35 days	Fri 9/21/18	Thu 10/25/18	100%
13	Research Design Choices	26 days	Fri 9/21/18	Tue 10/16/18	100%
14	Kickoff and PDR Q&A	0 days	Thu 10/11/18	Thu 10/11/18	100%
15	Complete CAD Models	9 days	Wed 10/17/18	Thu 10/25/18	100%
16	Edit PDR	7 days	Fri 10/26/18	Thu 11/1/18	100%
17	Manufacture Subscale	28 days	Sat 10/13/18	Fri 11/9/18	100%
18	Ground Test Subscale Systems	28 days	Sat 10/13/18	Fri 11/9/18	100%
19	Manufacture BEAVS Prototype and Test Airframe Modifications	15 days	Fri 10/26/18	Fri 11/9/18	100%
20	Build L1/L2 Certification Rockets	48 days	Sun 9/23/18	Fri 11/9/18	100%
21	Yamhill-Carlton High School Rocketry Team Outreach Even	1 day	Fri 10/26/18	Fri 10/26/18	100%
22	Discovery Days Outreach Event	2 days	Tue 10/30/18	Wed 10/31/18	100%
23	Submit PDR	0 days	Fri 11/2/18	Fri 11/2/18	100%
24	PDR Video Teleconferences	1 day	Mon 11/5/18	Mon 11/5/18	100%
25	**Critical Design Phase**	**96 days**	**Mon 11/5/18**	**Thu 2/7/19**	**100%**
26	Compile CDR	39 days	Mon 11/5/18	Thu 12/13/18	100%
27	Veneta Elementary School Outreach Event	1 day	Fri 11/9/18	Fri 11/9/18	100%



Project: FRR Schedule
Date: Tue 2/26/19

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

Page 1

Figure 135: The OSRT project schedule (1 of 3).

ID	Task Name	Duration	Start	Finish	% Complete
28	Women's Basketball Game Outreach Event	1 day	Wed 11/14/18	Wed 11/14/18	100%
29	Honors Colloquium Outreach Event	1 day	Tue 11/27/18	Tue 11/27/18	100%
30	Certification Rocket Launch Day	2 days	Sat 12/8/18	Sun 12/9/18	100%
31	Subscale Launch	2 days	Sat 12/8/18	Sun 12/9/18	100%
32	Launch Analysis	1 day	Sun 12/9/18	Sun 12/9/18	100%
33	Design Updates and Testing	25 days	Mon 12/10/18	Thu 1/3/19	100%
34	Edit CDR	3 days	Thu 12/13/18	Sun 12/16/18	100%
35	Evergreen Air and Space Museum Outreach Event	1 day	Sat 12/15/18	Sat 12/15/18	100%
36	Westview High School Outreach Event	1 day	Wed 12/19/18	Wed 12/19/18	100%
37	Subscale Relaunch	1 day	Thu 1/3/19	Fri 1/4/19	100%
38	Launch Analysis	1 day	Fri 1/4/19	Sat 1/5/19	100%
39	Submit CDR	0 days	Fri 1/11/19	Fri 1/11/19	100%
40	CDR Video Teleconferences	0 days	Tue 1/15/19	Tue 1/15/19	100%
41	**Final Readiness Phase**	**106.88 days**	**Mon 12/10/18**	**Mon 3/25/19**	**91%**
42	Compile FRR	41 days	Wed 1/16/19	Mon 2/25/19	100%
43	Cub Scout Lock-In Outreach Event	1 day	Sat 1/19/19	Sat 1/19/19	100%
44	Western University of Health Sciences Outreach Event	1 day	Sat 1/26/19	Sat 1/26/19	100%
45	Manufacture Full Scale Launch Vehicle	60 days	Mon 12/10/18	Wed 2/6/19	100%
46	Manufacture Payload	60 days	Mon 12/10/18	Wed 2/6/19	100%
47	Integration Testing	60 days	Mon 12/10/18	Wed 2/6/19	100%
48	Ground Test Full Scale Systems	60 days	Mon 12/10/18	Wed 2/6/19	100%
49	Lenox Elementary School Outreach Event	1 day	Fri 1/18/19	Fri 1/18/19	100%
50	Evergreen Air and Space Museum Outreach Event	1 day	Sat 1/26/19	Sat 1/26/19	100%
51	Payload Ejection Testing	1 day	Sat 2/16/19	Sat 2/16/19	100%
52	Franklin Elementary Outreach Event	1 day	Tue 2/19/19	Tue 2/19/19	100%
53	Vehicle Demonstration Flight	1 day	Fri 2/22/19	Fri 2/22/19	100%

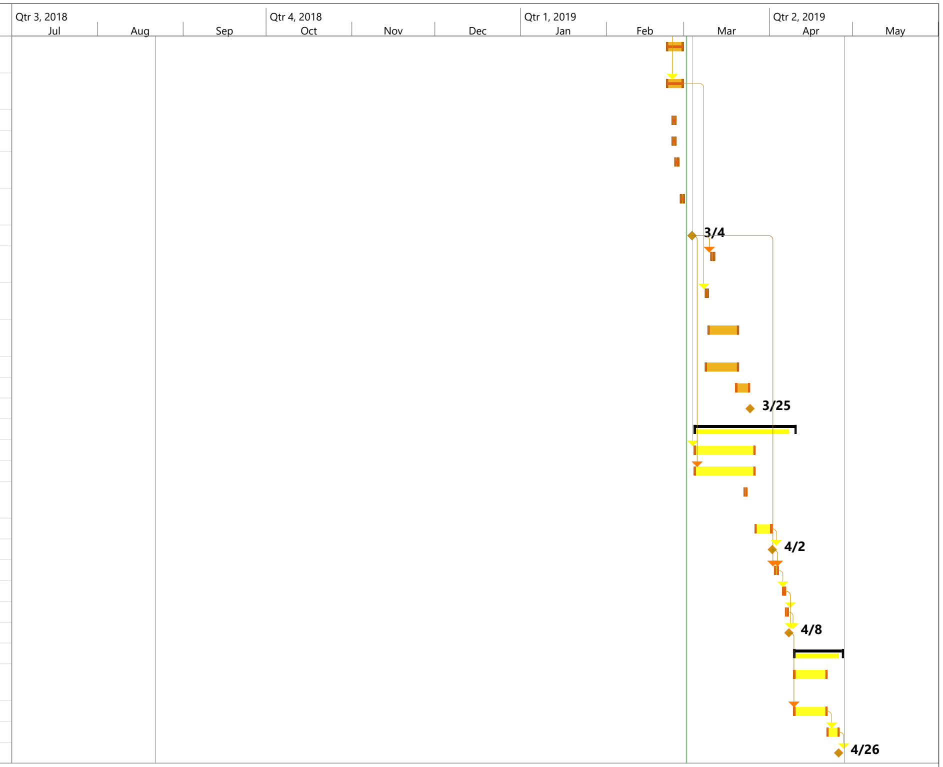
Project: FRR Schedule
Date: Tue 2/26/19

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

Page 2

Figure 136: The OSRT project schedule (2 of 3).

ID	Task Name	Duration	Start	Finish	% Complete
54	Analyze Vehicle Demonstration Flight	6 days	Sat 2/23/19	Thu 2/28/19	100%
55	Design Updates and Testing	6 days	Sat 2/23/19	Thu 2/28/19	100%
56	SCAR Testing	1 day	Mon 2/25/19	Mon 2/25/19	100%
57	Drivetrain Testing	1 day	Mon 2/25/19	Mon 2/25/19	100%
58	Obstacle Avoidance Testing	1 day	Tue 2/26/19	Tue 2/26/19	100%
59	Philomath Middle School Outreach Event	1 day	Thu 2/28/19	Thu 2/28/19	100%
60	Submit FRR	0 days	Mon 3/4/19	Mon 3/4/19	100%
61	FRR Video Teleconference	1 day	Mon 3/11/19	Mon 3/11/19	0%
62	Payload Demonstration Flight	1 day	Sat 3/9/19	Sat 3/9/19	0%
63	Analyze Payload Demonstration Flight	11 days	Sun 3/10/19	Wed 3/20/19	0%
64	Compile FRR Addendum	12 days	Sat 3/9/19	Wed 3/20/19	0%
65	Edit FRR Addendum	5 days	Wed 3/20/19	Sun 3/24/19	0%
66	Submit FRR Addendum	0 days	Mon 3/25/19	Mon 3/25/19	0%
67	**Competition Phase**	**37 days**	**Tue 3/5/19**	**Wed 4/10/19**	**0%**
68	Paint Rocket	22 days	Tue 3/5/19	Tue 3/26/19	0%
69	Develop Displays	22 days	Tue 3/5/19	Tue 3/26/19	0%
70	Evergreen Air and Space Museum Outreach Event	1 day	Sat 3/23/19	Sat 3/23/19	0%
71	Motorpool Departure	6 days	Wed 3/27/19	Mon 4/1/19	0%
72	Arrive in Huntsville	0 days	Tue 4/2/19	Tue 4/2/19	0%
73	LRR	1 day	Wed 4/3/19	Wed 4/3/19	0%
74	Launch Day	1 day	Sat 4/6/19	Sat 4/6/19	0%
75	Backup Launch Day	1 day	Sun 4/7/19	Sun 4/7/19	0%
76	Depart from Huntsville	0 days	Mon 4/8/19	Mon 4/8/19	0%
77	**Post Launch Phase**	**18 days**	**Wed 4/10/19**	**Sat 4/27/19**	**0%**
78	Analyze Competition Flight	12 days	Wed 4/10/19	Sun 4/21/19	0%
79	Compile PLAR	12 days	Wed 4/10/19	Sun 4/21/19	0%
80	Edit PLAR	4 days	Mon 4/22/19	Thu 4/25/19	0%
81	Submit PLAR	0 days	Fri 4/26/19	Fri 4/26/19	0%



Project: FRR Schedule - FINAL.m
Date: Sat 3/2/19

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

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Figure 137: The OSRT project schedule (3 of 3).

6.4 STEM Engagement

Throughout the entirety of the competition, OSRT completed STEM engagement events with 3,362 community members around Oregon. Events included education and outreach activities with young students as ranging as early as preschool to adults in our community. The major portion of the events included elementary to high school aged students. Lesson plans generally included a presentation about our NASA SL team, and what general engineering is about. Figure 138 is of OSRT presenting to science classes at Philomath Middle School. We also performed several STEM events with the students including drawing the solar system, making slime, and building bridges. The activity we enjoyed the most with the students was making straw rockets and launching them across their gymnasium using a compressed air launcher. We did this for many events, ranging from Kindergartners to high school students.

Figure 138: OSRT at Philomath Middle School

The general premise was that students were given a straw, in which they were to use duct tape to create a nosecone and fins before placing their rockets on the compressed air launcher. With the older students, we challenged them to attempt different designs in order to fly the farthest possible rocket. First graders at Franklin Elementary can be seen launching their straw rockets in Figure 139. Students experimented with adding weight to different sections, changing the length of their straw bodies, fin shape, number of fins, and fin locations. All the students were invested in the engineering process of designing their own rockets and testing that design. They then discussed what they thought worked and what didn't work with their design with members of OSRT, their teachers, and their peers to redesign and improve their rockets. After completion of all the STEM engagement events this year, OSRT believes that we inspired a lot of students in the area to consider engineering as a career path and specifically the aerospace engineering path.

Figure 139: OSRT Launching Straw Rockets at Franklin Elementary

OSRT has scheduled a few events after the STEM engagement competition deadline. One event is with two fifth grade classes in Springfield, OR. which needed to be rescheduled after the deadline due to a school closure from a snow storm. OSRT has also scheduled another event with Evergreen Aviation and Space Museum to present on the NASA SL mission and the engineering process that our team has gone through the course of the project. OSRT has also scheduled other AIAA rocket teams to speak at this event about their mission and how they have designed and engineered their project to accomplish their goals. STEM engagement in our community will continue throughout the year with more events to be scheduled. This year's team has made many connections and lesson plans to help next year's team reach more community members than this year in the competition time frame.

APPENDIX A

DRAWINGS AND SCHEMATICS

A.1 Drawings and Schematics

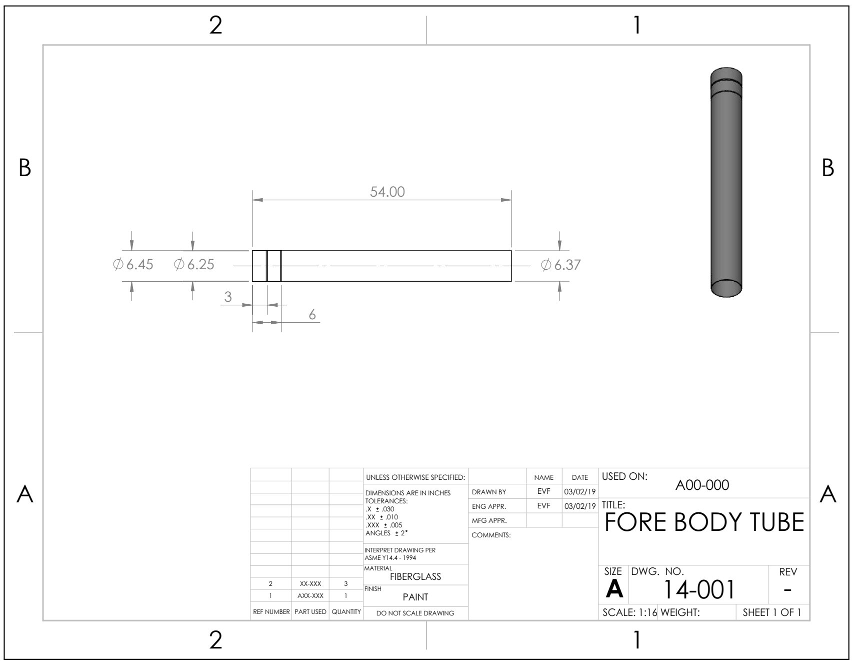

Figure 140: Fore Body Tube Drawing

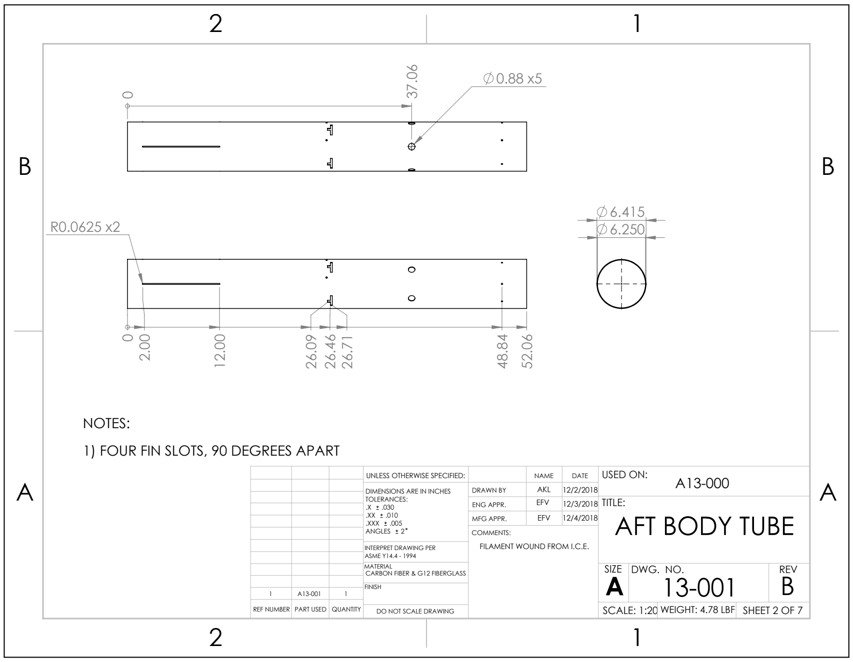

Figure 141: Aft Body Tube Drawing

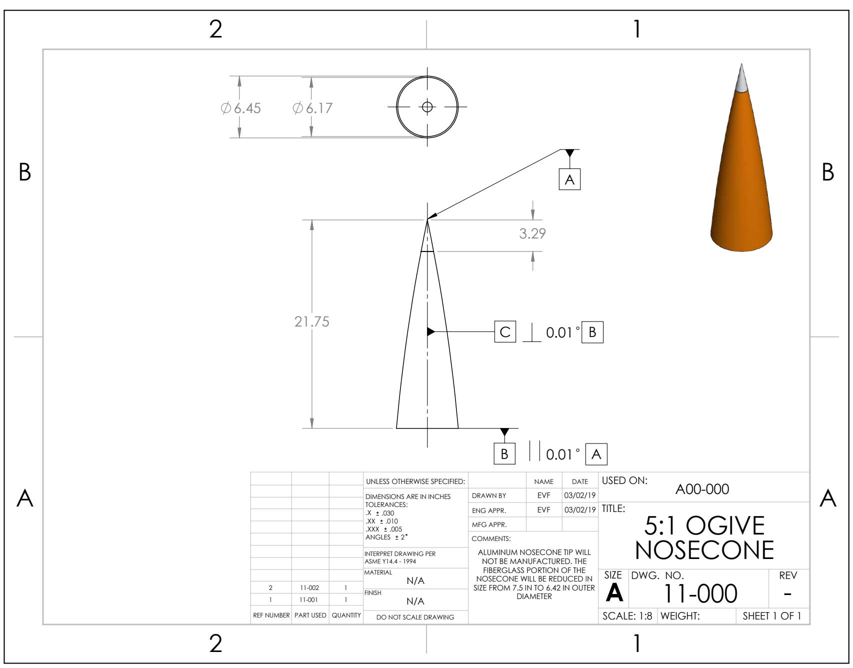

Figure 142: Nosecone Drawing

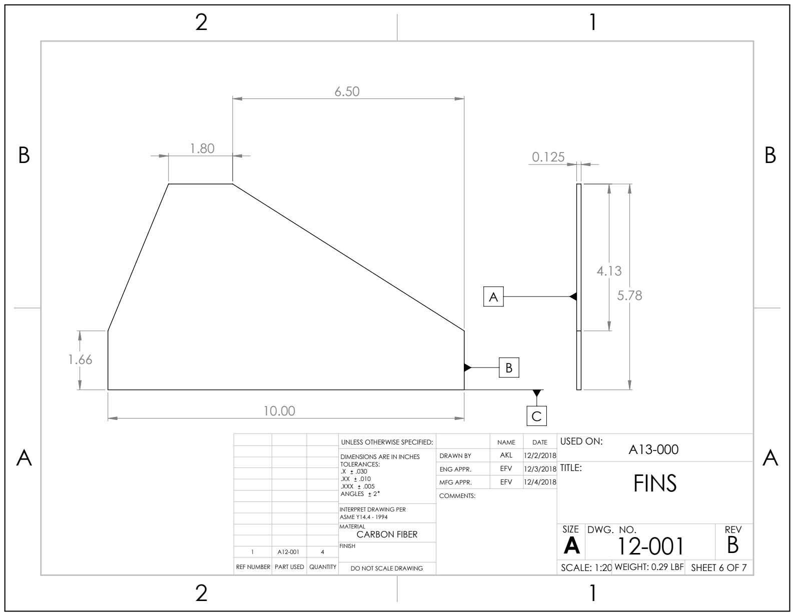

Figure 143: Fin Drawing

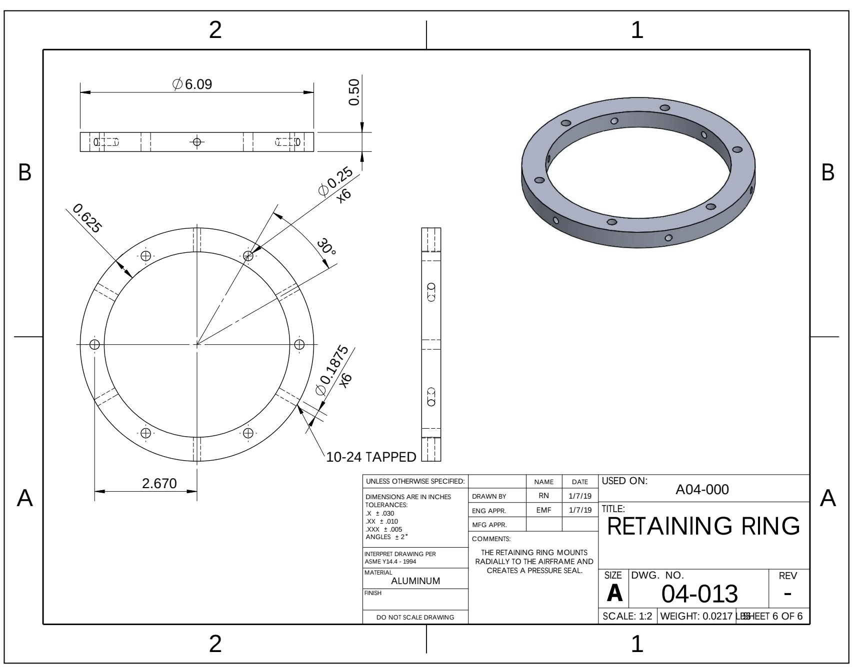

Figure 144: Retaining Ring

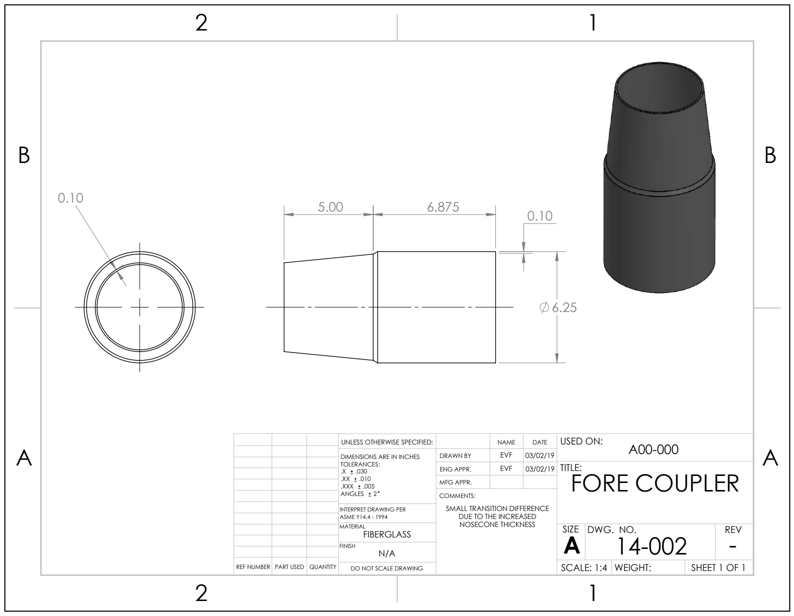

Figure 145: Fore Coupler

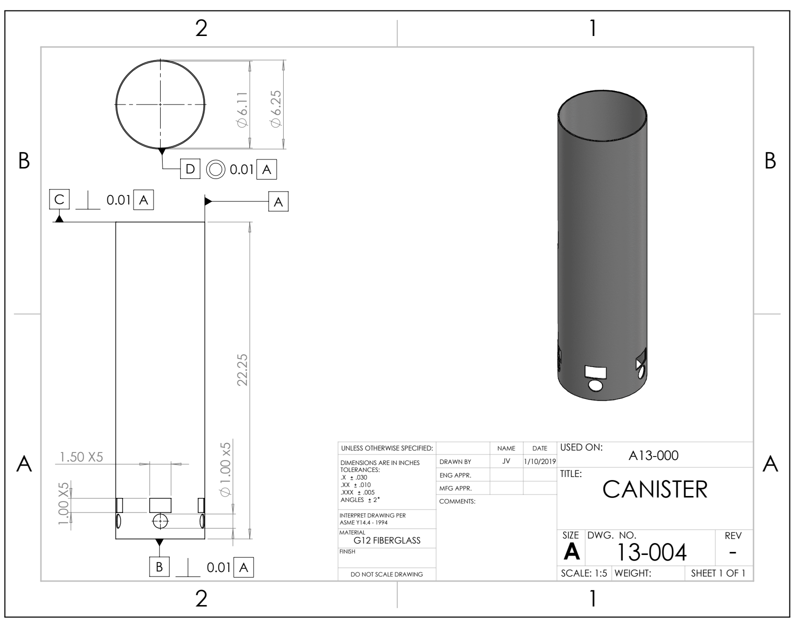

Figure 146: Canister

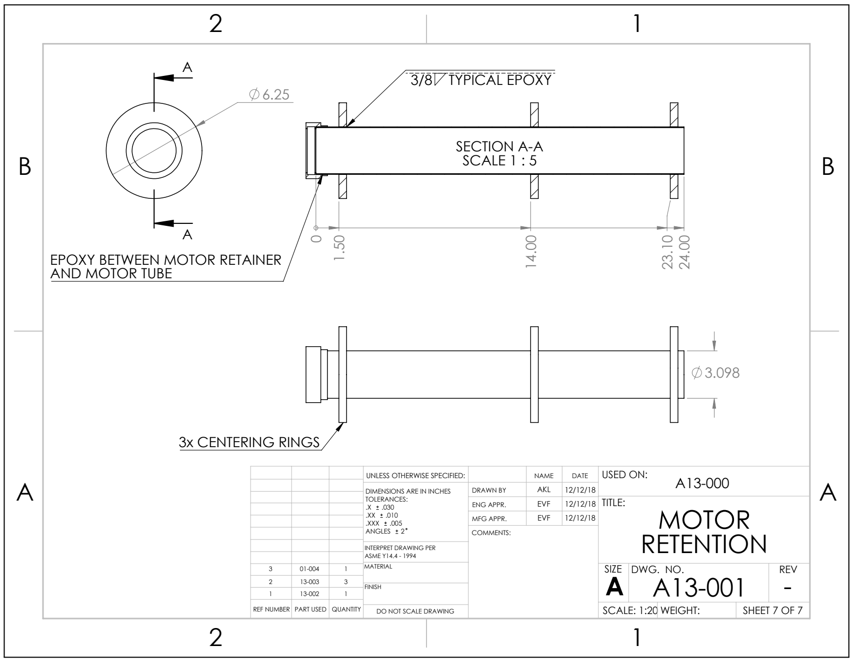

Figure 147: Motor Retention Drawing

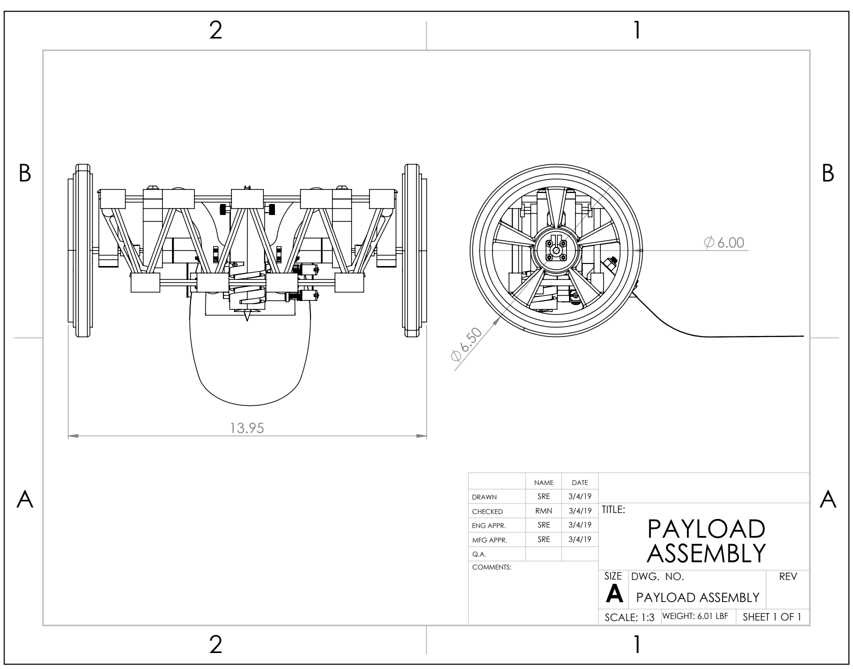

Figure 148: Rover Assembly

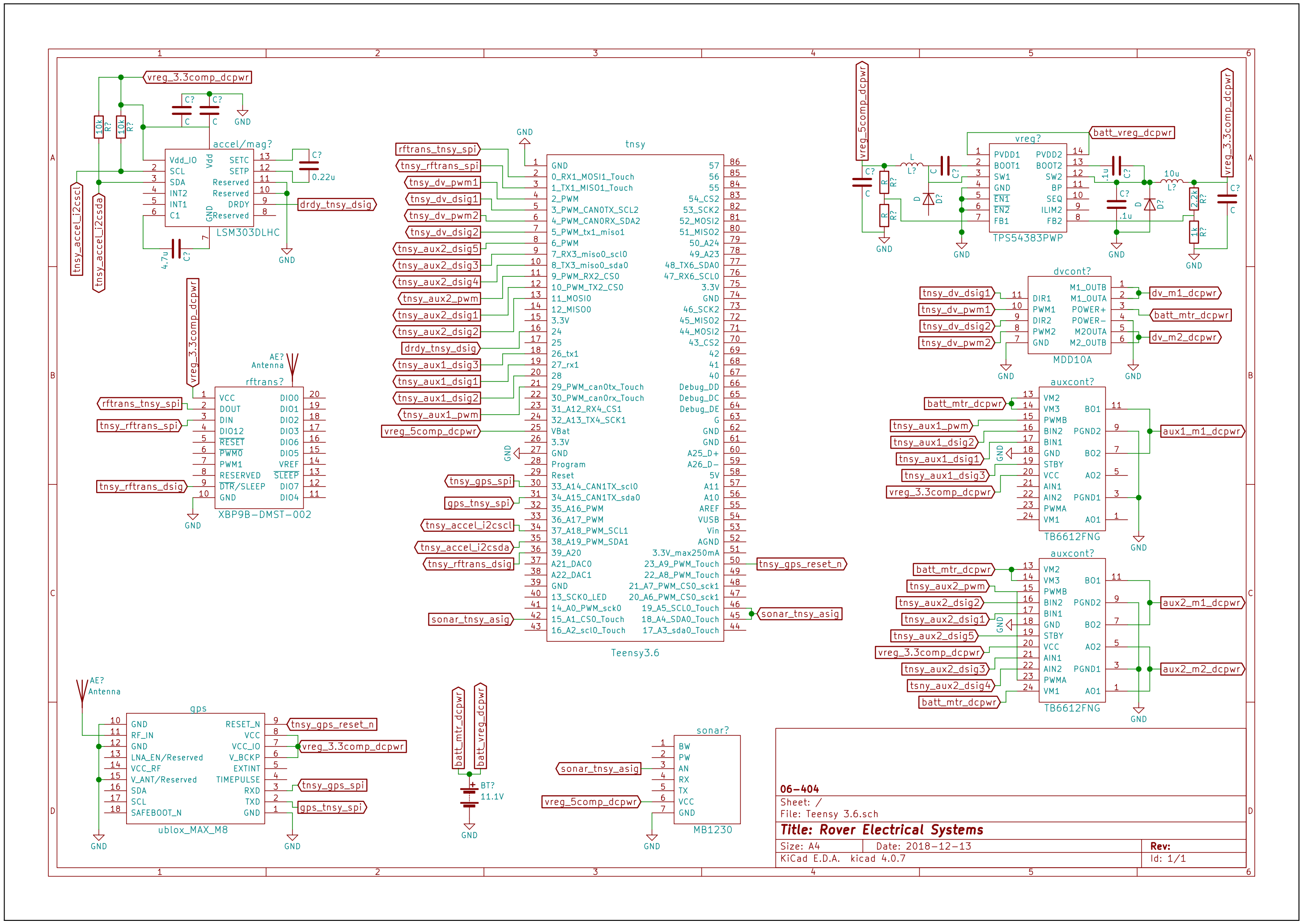

Figure 149: Schematic of Payload Electronics