OREGON STATE UNIVERSITY

2020 NASA SL TEAM

104 KERR ADMIN BLDG. # 1011

CORVALLIS, OR 97331

Flight Readiness Review

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Acronym Dictionary

AGL Above Ground Level. 14, 56, 66, 82, 192, 193

AIAA American Institute of Aeronautics and Astronautics. 223, 226, 245

APCP Ammonium Perchlorate Composite Propellant. 196

ATU Avionics Telemetry Unit. 7, 63–66, 228, 230, 231

BEAVS Blade Extending Apogee Variance System. 1, 3, 5, 6, 9, 13, 15, 20, 21, 24–26, 32–38, 40, 55, 78, 81, 82, 127, 131, 137, 138, 140, 147, 148, 179–181, 199, 238, 250, 265, 266

BP Black Powder. 5, 47–52, 55, 56, 73, 77, 82, 152, 154, 155, 180–182, 224–226, 231, 262, 266, 267

CAD Computer-Aided design. 7, 32, 54, 78, 79, 92, 265, 266, 273

CDR Critical Design Review. 1, 3, 13, 15, 48, 87, 89, 91, 100, 103, 196, 199, 201

CFD Computational Fluid Dynamics. 2, 67

CFR Code of Federal Regulations. 113

CG Center of Gravity. 234

CNC Computer Numerical Control. 18, 23, 138, 270

CO2 Carbon Dioxide. 225, 239

CST Central Standard Time. 82

CSV Comma Separated Value. 65, 230

DC Direct Current. 238

DMM Digital Multimeter. 35

DXF Drawing eXchange Format. 270

EDM Electrical Discharge Machining. 33

EMBERS Energetic Mid-flight Black powder Ejection Reserve System. 2, 7, 8, 47, 48, 51–55, 114, 124, 152, 180, 182, 231, 266, 267

ESD Electrostatic Discharge. 155, 226, 262, 266

FAA Federal Aviation Administration. 113, 126–128, 219, 223

FEA Finite Element Analysis. 33, 34, 179, 265, 266

FMEA Failure Mode Effects Analysis. 4, 5, 131, 133, 135, 137, 141, 222

FN Foreign National. 189

FOD Foreign Object Debris. 144

FRR Flight Readiness Review. 32, 77, 78, 82, 188, 190, 201, 204–206, 220

GLONASS Global Navigation Satellite System. 65

GNSS Global Navigation Satellite System. 65

GPS Global Positioning System. 29, 61–63, 65, 184, 227

GSE Ground Support Equipment. 195

GUI Graphical User Interface. 7, 61, 63–66, 111, 229

HPR High Powered Rocketry. 122

HPRSC High Powered Rocket Safety Code. 125–128

I2C Inter-Integrated Circuit. 62

IC Integrated Circuit. 35

ICE Innovative Composite Engineering. 16, 17, 20, 245

ID Internal Diameter. 17, 240

IDE Integrated Development Environment. 36, 65, 268

IMU Inertial Measurement Unit. 228

LiPo Lithium Polymer. 34, 35, 207, 238, 239, 276

LRR Launch Readiness Review. 220

MSDS Material Safety Data Sheet. 118, 119, 121, 222

NAR National Association of Rocketry. 113, 114, 123, 125–128, 148, 196, 219, 223

NASA National Aeronautics and Space Administration. 4, 45, 91, 113, 126–128, 188–192, 196, 204, 206, 207, 218, 219, 221, 223, 224, 245

NFPA National Fire Protection Agency. 113, 114, 119

NMEA National Marine Electronics Association. 65

NOAA National Oceanic and Atmospheric. 227

NTS not to scale. 6, 39

OD Outer Diameter. 240

OROC Oregon Rocketry. 69

OSGC Oregon Space Grant Consortium. 237, 245

OSRT Oregon State Rocketry Team. 8, 13, 16–19, 22, 25, 27, 32, 35, 37, 39–41, 43, 47, 51, 55–57, 69, 70, 73, 75, 77, 82, 83, 85, 89–91, 94, 99, 100, 107, 108, 112, 113, 115, 119, 123, 131, 134, 185, 186, 189, 190, 193, 194, 196, 210, 219, 220, 222–224, 229, 235, 236, 238, 239, 243, 245–249

OSU Oregon State University. 77, 78, 83, 90, 113, 114, 117, 223, 226, 228, 245

PCB Printed Circuit Board. 6, 7, 34, 35, 61, 77, 83, 87–93, 103, 105, 106, 140, 143, 162, 236, 238, 268

PID Proportional-Integral-Derivative. 37, 139

PLA Polylactic Acid. 90, 100, 239

PPE Personal Protective Equipment. 47, 119, 121, 122, 129, 148, 171, 173, 270, 273, 274

PST Pacific Standard Time. 69

PWM Pulse Width Modulation. 36

RAC Risk Assessment Chart. 5, 116–122, 125–130

RF Radio-Frequency. 17, 20, 29, 63, 122, 231

RIF Rotary Indexing Fixture. 6, 16

RPN Risk Priority Number. 133–145

RRC3 Rocket Recovery Controller 3. 7, 47, 48, 55, 56, 58, 60, 66, 70, 71, 75–77, 79, 180, 193, 200, 211

RSO Range Safety Officer. 113, 118, 120, 122–124, 126, 146, 168, 189, 190, 196, 197, 204, 207, 211, 223, 273, 274

SIFC Safe Integration Flow Chart. 173, 174

SO Safety Officer. 126, 207, 211, 221–224

SOE Standard Order of Events. 174

STEM Science, Technology, Engineering and Mathematics. 4, 189, 190, 221, 236, 249

STP Standard Temperature and Pressure. 265

TRA Tripoli Rocketry Association, Inc.. 113, 125–128, 196, 223

UART Universal Asynchronous Receiver-Transmitter. 62

USLI University Student Launch Initiative. 8, 39, 41, 46, 113, 124, 236, 249

UTS Unified Thread Standard. 44

UV Ultraviolet. 121

VM Verification Method. 188–236

1 General Information

1.1 Leadership Overview

Table 1: Adult Educator Summary Chart

Name of Mentor	Dr. Nancy Squires	Joe Bevier
Professional Title	Senior Instructor	OROC TRA TAP
Academic Institution	Oregon State University	Oregon State University
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TRA/NAR Number, Certification Level	TRA #15210 Level 3 NAR #97371 Level 3	TRA #12578 Level 3 NAR #87559 Level 3

2 Changes Made Since Critical Design Review (CDR)

2.1 Changes to Vehicle Criteria

There have been several changes to the launch vehicle since CDR. The location of the Blade Extending Apogee Variance System (BEAVS) blade airframe holes was moved. The lengths of both the fore and aft parachute bays were also reduced. The length of the payload bay was increased. Oregon State Rocketry Team (OSRT) also changed the nose cone include a lead screw mounting thread in order to attach the nose cone directly to the payload retention system. A handle was mounted to the BEAVS bay sealing bulkhead to enable easier removal of the BEAVS system. Other changes to the airframe include small changes to the fin sizes. The rear parachute mounting points were also reduced in size. The number of compression bolts on one of the sealing bulkheads was increased from 4 to 8. Mounting points that used to be on this ring are now 3D printed and bolted to the avionics mounting plates.

2.2 Changes Made to Payload Criteria

Changes made to payload since CDR are entirely auxiliary. There have been new mounts added, old mounts edited, and some new protective plastic cases to shield electronics. The payload as a whole is unchanged, seeing only slight refinements at the joints. These changes are discussed in detail in FRR section 4.3.

2.3 Changes Made to Project Plan

The biggest change made to the Project Plan was that the first Launch Vehicle and Payload Demonstration Flight, denoted as "Full Scale #1", was pushed back by two weeks due to the team's advisor recommending that the team should refine their design further before attempting their first Launch Vehicle Demonstration Flight. Therefore, the Payload, Launch Vehicle, and Recovery modify and repair times were changed to simply be "modify" times. However, the Full Scale Integration test still remained because the team felt that it would be valuable to still have an Integration of the launch vehicle and payload despite not being able to launch for a couple of weeks. Also, the second Launch Vehicle and Payload Demonstration Flight has been scheduled for Saturday, March 7th, 2020, after having acquired permission for a reflight by Mr. Fred Kepner on Monday, February 24th, 2020.

3 Vehicle Criteria

3.1 Launch Vehicle Summary

The final launch vehicle design is shown in Figure 1. The configuration as shown below in figure (insert fig here) is as follows from left to right. An ogive 5:1 nose cone attached to the for section by a 3.5 inch long coupler, then the fore body tube, main coupler with 6.25 inch long coupler sections, aft section, fore and aft rail guides, fins, thrust plate, and finally motor retainer.

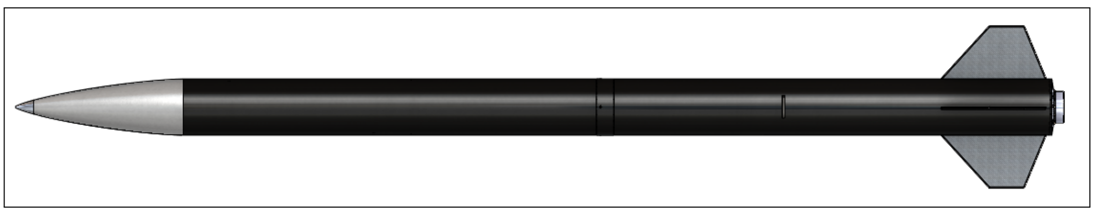

Figure 1: Final Launch Vehicle

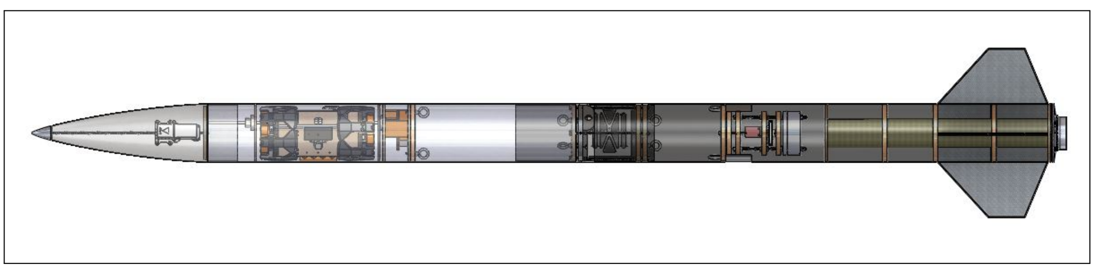

Figure 2: Final Launch Vehicle Layout

The various subsystems can be seen in Figure 2. From left to right, the nose cone tracking and avionics bay, payload and retention system, the main parachute bay, the coupler and recovery bay, the drogue bay, the parachute bay, and then the motor and fins bay.

3.1.1 Launch Vehicle Mission Statement

The launch vehicle will successfully deliver the payload to the specified apogee of 4000 ft Above Ground Level (AGL), deploy the drogue parachute at apogee, deploy the main parachute at 500 ft., and then deliver the payload to the ground within a 2,500 ft radius of the launch site.

3.1.2 Launch Vehicle Mission Success Criteria

The launch vehicle mission will be defined as a success when the following requirements have been met or exceeded:

- The launch vehicle performs the mission without damage to the payload during any point of the mission.
- The recovery system deploys and recovers the launch vehicle successfully.
- The launch vehicle ejects the payload successfully.
- The rocket is able to be readied for launch within two hours of arriving to the launch site.
- The launch vehicle is to remain reusable after launch, able to be readied for another launch the same day without major changes or repairs.

3.2 Design and Construction of the Launch Vehicle

3.2.1 Changes Made to the Launch Vehicle since CDR

There have been several changes to the launch vehicle since CDR. The location of the BEAVS blade airframe holes was moved in accordance with the design of BEAVS. The lengths of both the fore and aft parachute bays were also reduced after parachute test fitting revealed excess space available. This was done to reduce unnecessary length in the airframe and allow the extension of other bays in the launch vehicle to accommodate design changes. The length of the payload bay was lengthened to accommodate the payload size without having it extend into the nose cone coupler. This would reduce deployment complexity and potential failure points. Further changes to the nose cone include a lead screw mounting thread, in order to attach the nose cone directly to the payload retention system. This was determined to be necessary to reduce the chance of premature nose cone ejection during the recovery phase. A handle was mounted to the BEAVS bay sealing bulkhead to enable easier removal of the BEAVS system. Integration testing showed that this was necessary after removal of the system was difficult at best without one.

Other changes to the airframe include changes to the fins. In order to change the location of the center of pressure to be more favorable the fin height was reduced to be 5.5 in. The rear parachute mounting points were also reduced in size, to enable easier manufacturing, stemming from issues with capabilities of available end mills. This change did not significantly effect the capabilities of the mounts which maintained an acceptable factor of safety. The number of compression bolts on one of the sealing bulkheads was increased from 4 to 8 as it was found that there was significant flexing of the wooden compression ring. This was not deemed necessary on the opposing bulkhead as its sealing ring is aluminum and did not flex. Mounting points that used to be on this ring are now 3D printed and bolted to the avionics mounting plates to reduce manufacturing time and complexity.

3.2.2 Airframe

The launch vehicle airframe consists of three main sections, the nose cone, fore section, and aft section. The nose cone is a 5:1 ogive fiberglass nose cone that was modified from a commercial nose cone to fit OSRT's airframe. The fore section airframe is a fiberglass and the aft section is carbon fiber. Both of theses sections where manufactured by Innovative Composite Engineering (ICE). The tubes were modified by OSRT to cut them to size and place the necessary venting and mounting holes in the airframe. A tube cutting rig was constructed, shown in Figure 3, in order to ensure an even cut on the airframe. The tube was cut on this rig using a pneumatic handheld cutoff wheel.

Figure 3: Tube Cutting Rig

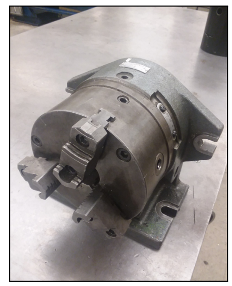

Figure 4: Rotary Indexing Fixture (RIF)

While this setup was used to cut the airframe tubes to length, a manual end mill was used to cut all holes and slots in the aft airframe. Seen in Figure 4, the RIF was used to mount the aft airframe to a manual milling machine along with a half circle support in order to accurately cut fin slots and mounting holes for various systems. This setup is shown in 5 where the fin slots were being milled. The end mill used was a 4 flute carbide bit, in order to ensure a smooth cut and reduce possible delamination of the composite tube stemming from a dulling end mill; due to the tendency of carbon fiber to dull cutting edges very quickly.

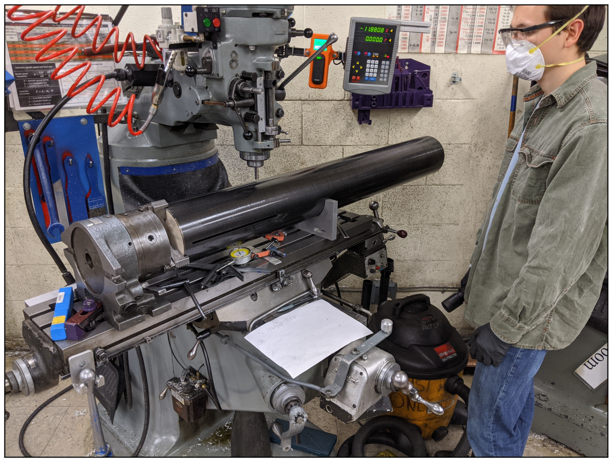

Figure 5: Mill Mounting method

The tube was indicated using a spindle mounted dial indicator to ensure straight cuts for fins, and to ensure the rail guides are in line when mounted through their respective mounting holes. In addition to computer simulations on airframe with forces beyond maximum expected forces components, the airframe and recovery systems functionality was confirmed on a full scale test flight of the launch vehicle.

3.2.3 Fore Section

The fore section of the launch vehicle houses the payload bay and the main parachute bay. This section is made out of a fiberglass and has been calculated to weigh 25 lbs. with the payload and parachutes installed. The airframe is 6.25 in. Internal Diameter (ID), 44.5 in. long. The main reason for selecting fiberglass over carbon fiber construction is to satisfy the need for Radio-Frequency (RF) transparency between the base station and the payload deployment system because of RF transmission blocking properties of carbon fiber.

While the fore tube was planned to be manufactured by ICE, processing and manufacturing errors determined that the OSRT timeline did not match what ICE could provide. The OSRT decided to re-manufacture a similar legacy tube that OSRT keeps in storage. The tube is the correct 6.25 inch in diameter fiberglass. Sanding was done on the tube in order to remove any finishes and paint. Small mounting and venting holes were filled using G5000 RocketPoxy. This was applied with a backing of release film and tape on the interior side of the holes, left to cure, then sanded down after the release film was removed. This allowed a uniform, smooth profile with the inner diameter of the tube only needing sanding on the exterior. Figure 6 shows a structures team member sanding down cured epoxy to match the fore tube profile.

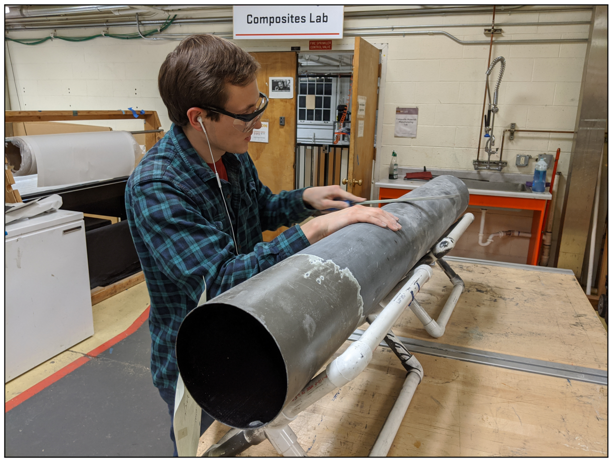

Figure 6: Fore Section Manufacturing

After the tube was sanded and patched, it was cut to size matching the required dimensions of the fore section. The pre-existing anti-zippering on the tube was preserved on the opening of the tube that would become the main parachute bay. This anti-zippering end consists of a section of the tube where the wall thickness is doubled in the last 3 in. of the tube during the layup process in order to decrease the likelihood of zippering in the event of a high velocity parachute deployment. A Computer Numerical Control (CNC) routed bulkhead was epoxied in place in the center of the tube with eye bolts tightened by locking nuts, separating the payload bay and main parachute bay. Lastly 4 - 3/8 in. static venting ports were placed towards the front of the fore section tube in order to vent the nose cone bay for the barometric pressure sensors to take readings.

3.2.4 Bulkheads and Centering Rings

The launch vehicle has several centering rings and wooden bulkheads separating several bays and serving as hard mounting points for recovery systems. Bulkheads and centering rings were constructed out of 0.5 in. 9 ply Baltic Birch plywood capable of withstanding torsion, axial, and bending forces that are experienced in the recovery sequence of flight. The plywood was not only readily available to OSRT, but has been used in legacy air frames, and has been tested as bulkheads in a 6.25 in. airframe to 2200 lbf before failure by previous OSRT teams [8]. The plywood withstood the forces during subscale and full scale testing with no visible deformations or splintering. All applicable mounting points are reinforced with fender washers to further distribute the forces of recovery across the bulkheads.

The bulkheads and centering rings were routed out of a plywood sheet using a CNC router as shown in Figure 7. The plywood sheet was mounted to a back board and then to the router table by general use wood screws. This was then indicated with an automatic indicating tool to indicate the part coordinate system. The CNC gcode was then verified by a dry run before actual routing of the bulkheads.

Figure 7: Bulkhead and Centering Ring Manufacturing

Several iterations of bulkheads were created until the fit tolerances were correct for the several bulkhead in the main airframe sections and the smaller bulkheads located in the center coupler and nose cone. There are 4 centering rings holding the motor tube in place with 2 permanently mounted bulkheads, and 4 non permanently mounted bulkheads in the fore and aft sections of the launch vehicle. Permanent centering rings and bulkheads are epoxied in place in the airframe using G5000 RocketPoxy; which is detailed in section (insert section).

3.2.5 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 producing very strong joints. The components that are epoxied to the airframe are the fins, the centering rings, the aft and fore parachute mounting points. 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 [4]. To do this, the OSRT used a scale to ensure a correct epoxy part 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. Black dye provided by the manufacturer was added to the mixture to enable identification of excess epoxy on wooden bulkheads while in the airframe. This also helps ensure that each exterior fillet on the fins are aesthetically pleasing. Figure 8 shows the fin fillets during curing after being applied.

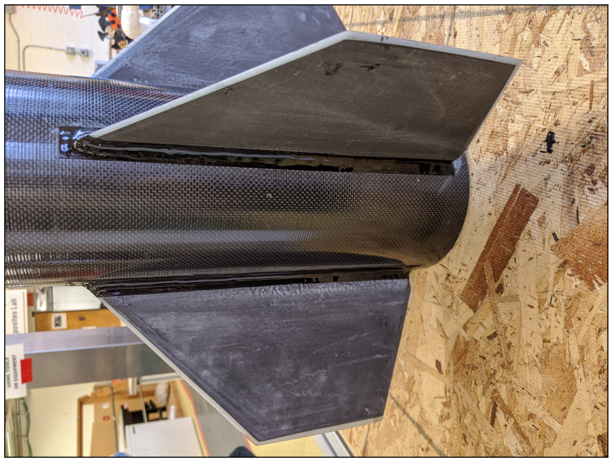

Figure 8: Fin Fillets After Application

3.2.6 Aft Section

The aft section of the launch vehicle includes the drogue parachute bay, the BEAVS bay, and the motor bay. The aft section is 49.2 in. long and weighs approximately 21.6 lbs.after motor burnout. The airframe tube itself is made out of carbon fiber tube manufactured by ICE. The aft section airframe is made entirely of carbon fiber and therefore will not have RF transparency, it is not needed in the aft section. Since the aft section houses the BEAVS system it will have two slots cut out for the blades to extend through. The BEAVS system is supported off of the BEAVS bulkhead, and 4 set screws bolted into bulkheads.

The aft section houses the majority of the airframe-to-part connections in the vehicle. Including two aft parachute mounts, an engine block bulkhead, four motor tube centering rings, the motor tube, four through wall style fins, and two rail buttons. Each of the aft section components required a different process of attachment of integration with the airframe. The completed aft airframe is shown in 9.

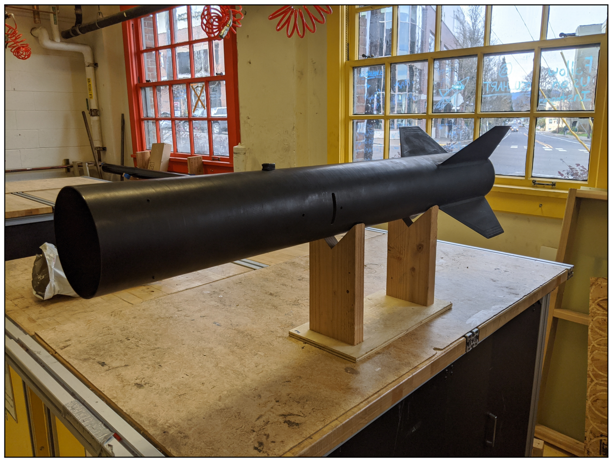

Figure 9: Aft Airframe Section

The aft parachute mounts were aligned by using the rail guide hole in the airframe as a reference as the forward rail guide is anchored in the aluminum mount. The holes are centered on the airframe as explained in section 3.2.2.

The motor bay bulkhead was mounted by applying a ring of epoxy to the inside of the airframe at the designated location. The block was then slid into the airframe onto said epoxy and allowed to cure. Each of the motor tube centering rings was epoxied to the motor tube by placing epoxy on the exterior of the tube and allowed to cure. Once all mounts on the motor tube had cured, epoxy was placed inside the aft airframe in the designated before inserting the motor tube along with the attached centering rings.

The through wall style fins were attached by first applying epoxy along the length of the root chord of the fin where the fin interfaces with the motor tube. Epoxy was also applied on the most fore and most aft tips where the fin contacts a centering ring on each end. Finally, epoxy fillets were applied to the exterior surface of the airframe around each side of each fin creating a strong rigid mount. After the epoxy fin fillets were applied, the aft section was placed in a wooden jig designed to hold the fins perpendicular to the airframe with 90 degree angles between each fin.

The rail buttons were attached to the airframe by first cutting centered holes in the airframe using the aforementioned end mill centering process 3.2.2. The foremost rail button and the aft rail button holes were placed by design directly on the BEAVS bulkhead and the aft most centering ring respectively so the rail button bolt attached internally. Once the rail buttons were bolted in place, they were aligned fore to aft with the length of the airframe section and epoxied in place. The rail guides are shown on the aft section in Figure 10.

Figure 10: Rail Guide Placement

3.2.7 Thrust Plate and Motor Retention

For the purpose of reducing loading of centering rings a thrust plate will be used. This thrust plate was manufactured by OSRT out of 6061 aluminum round stock sing a lathe and manual mill. The thrust plate was first roughed out to size with the lathe, then had a large chamfered edge finished on it and a centering edge on the back face for easier installation. Then it was mounted on a manual mill and notched out. Figure 11 shows the thrust plate on the manual mill.

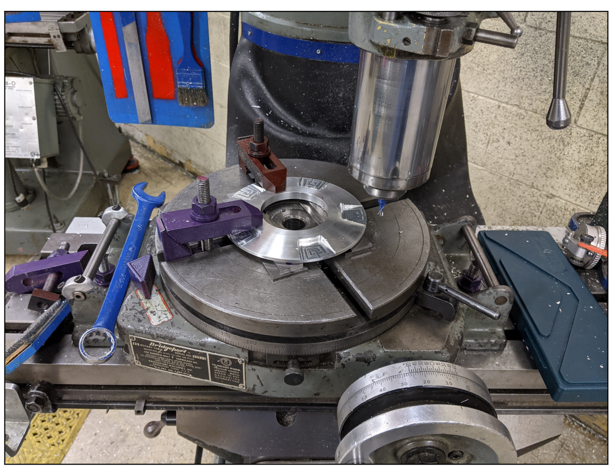

Figure 11: Thrust Plate Manufacturing

The motor retention system is a purchased commercial motor retainer from Aero Pack. This enables very quick motor changes and reduces the tools necessary to change the motor as it is a tool-less design. This is fastened through the thrust plate into the rear most centering ring where wood fastener inserts have been mounted. Figure 12 shows the thrust plate and motor retainer mounted with a motor installed.

Figure 12: Thrust Plate Mounting

3.2.8 Fins

The fin configuration is comprised of four trapezoidal fins with a sanded-down leading edge and no airfoil cross section. The configuration allows for a stability margin of 2.62, satisfying competition requirement 2.14.

The fins on the rocket are constructed with a FR4 and honeycomb core sandwiched between carbon fiber. The internal FR4 fiberglass is 0.125 in. thick with a unilateral four-ply layup of carbon fiber on each side of the fin leading to a total thickness of 0.25 in. The FR4 fiberglass center core of the fins were cut from a CNC router. The Nomex 0.125 in. thick honeycomb core provides lightweight while the carbon fiber provides additional strength. The layup schedule used is a quasi-isotropic symmetric layup consisting of [0/ 45/ -45/ 90/ Core/ 90/ -45/ 45/ 0]. This ensures a maximum strength in many directions for flight and landing fores. Laying Up Fins can be seen in Figure 13. The fin guide cut from a CNC router seen in Figure 14 was used to stabilize the fins while it cured to the motor tube and aft section. A post flight inspection of the fins was conducted, to asses the conditions of the fins after landing and being dragged through gravel and dirt of Oregon's high desert. The fins were dragged approximately 10 feet and Minimal wear was found with no significant damage, save for some scratches as seen in figure 15. This satisfied structural testing Project Planas described in section 6.1.2 .

Figure 13: Laying Up Fins

Figure 14: Fin Guide

Figure 15: Full Scale Fin Inspection After Landing

3.2.9 Motor Selection

The motor selected, the AeroTech L2200G, best fulfills the most important design requirements. This motor was selected for its ability to take the rocket to the predicted apogee, the fact that it will do so while maintaining safe loading of the rocket and a short enough motor burn time that BEAVS can function effectively. This assertion was verified in the first full scale launch vehicle test.

The selected motor AeroTech L2200G reaches the upper limit of the level 2 certification and is widely available. The thrust curve, a thrust-time graph of the motor's propellant burn sequence, can be seen in

Figure 16[5]. The thrust curve shows that over a burn time of 2.3 s the motor applies a maximum thrust of 697 lbf.

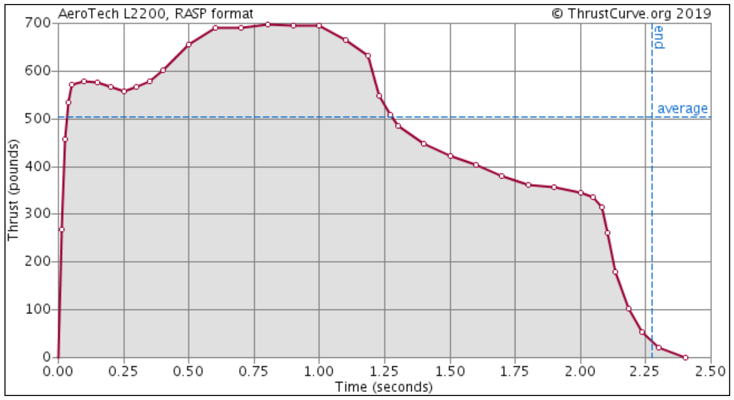

Figure 16: L2200G Thrust Curve

With the AeroTech L2200G, and no ballast, current simulations predict the launch vehicle will achieve an apogee of 4623 ft in zero wind launch conditions, and 4540 ft in 20 mph wind launch conditions. The respective apogees predicted by the wind boundaries give an expected apogee range assuming nominal flight. The range of the predictions is acceptable because the model in OpenRocket cannot delineate the actuation of the BEAVS system nor its effects on apogee. The active air brake system is expected to reduce apogee a few hundred feet, coupled with the use of ballast to guide the launch vehicle to apogee near the predicted value of 4000 ft.

Before assembling the motor, it was found that AeroTech, the manufacturer of the motor, had released an announcement editing and adding to the assembly instructions. The directive instructed the assembler to add "Elmers Glue Max" to the exterior of the grain casing to seal the grains in place. It was stated that particular motors, including the L2200G, had an increased likelihood of malfunction if propellant grain were left unsealed in the casing. OSRT followed this instruction supplement when assembling the motor, lightly applying the glue to each grain before placing them in the motor and allowing to dry an extra 12-14 hours before launch.

3.2.10 Aft Parachutes Mounts

The aft parachute mounts have been manufactured out of 6061 aluminum. Custom mill mounting was created so that rough cuts could be mounted to a manual mill rotary table, and mill the correct radius on the part. The part was rough cut on a band saw then milled to the correct outer diameter and inner diameter. The mount was then sandblasted on the side that is epoxied to the airframe. This ensures a rough surface for the epoxy to be able to better grab on too as smooth machined surfaces are not ideal for this application. The mounts were located off of the upper rail guide ensuring correct mounting inside the airframe. These mounts had the eye bolts attached before epoxying as the eye bolts cannot rotate completely due to the proximity to the airframe tube. Epoxy was then used to fill any gaps between the edges of the mounts and the airframe in an effort to reduce possible leak points. A large epoxy fillet was also applied to the lower side of the mounts to increase strength of the bond between mount and airframe.

3.2.11 Pressure Seals

Pressure seals are present in the launch vehicle on both sides of the main coupler and above the BEAVS bay. These area needed in order to seal pressurizing parachute bays of the airframe from open bays such as the BEAVS and recovery bays. These were constructed with a main bulkhead, sealing ring, sand witched on either side of square profile Buna-N O-Rings. One side of the coupler has a wooden compression ring, resulting in a need for more compression bolts in order to ensure proper compression of the bulkhead. The opposing side does not require more then 4 as the sealing ring is aluminum to accommodate radial bolts, and does not deform as the wooden compression ring does. The aft BEAVS sealing ring is smaller and also only requires 4 compression bolts for an adequate seal. This method for sealing has been tested to ensure parachute deployment. The compressing bolts to compress o-ring gasket sealing against inside of airframe as is seen in Figure **??**.

Figure 17: Pressure Seal

3.2.12 Pressure Seal Testing

Launch vehicle pressure seals were tested to ensure adequate sealing for parachute deployment. This was done with several methods. Parachute deployment of the aft BEAVS bulkhead was tested by installing the sealing bulkhead and main coupler assembly, then igniting a black powder charge sized for that particular bay. This was not successful; while the charge broke the shear pins, it did not manage to completely deploy the coupler as shown in Figure 18.

Figure 18: Sealing Bulkhead Test Deployment

By creating a white smoke with dry ice and water, the seal problem was able to be pinpointed, and a misaligned gasket was found. A second deployment test was then conducted and proved to be successful when the same charge that had previously only broken shear pins deployed the assembled coupler and recovery bay approximately 10 ft away from the aft end of the airframe.

3.2.13 Main Coupler

The main coupler of the launch vehicle is made of fiberglass with an outer diameter of 6.25 in. and inner diameter of 6.05 in. Fiberglass was chosen because it was both strong enough to withstand the forces of flight, and was readily available to OSRT. This coupler was manufactured by OSRT and laid up in a mold cut from excess airframe length. The fiberglass used was a unidirectional prepreg fiberglass using a NTC-301 resin system. Prior to layup the mold was prepared with 6 layers of locktite mold release to ensure no bonding between the coupler and mold. Because of the unidirectional weave type, the layup of the coupler was specified as [0/ 0/ -45/ 45/ 90/ 45/ -45/ 0/ 0]. This layup also has the benefit of an extra 0 layer which will help increase the couplers resistance to bending, which is desirable during flight. After the layup was complete then the layers were covered first with peel ply, ensuring the bagging material released from the coupler after curing. On top of the peel ply a layer of release film, then breather cloth, and finally bagging material was layered. Figure 19 shows the final bagged coupler prior to curing.

Figure 19: Coupler Layup Bagging

This combination of layers will ensure that excess resin will be drawn out of the coupler during the cure and be soaked up by the breather cloth. The part in the bagging material was held under vacuum the entire cure process to ensure that the excess resin is drawn out and decrease possible voids in the coupler. The coupler was then cured in an autoclave with a cure cycle designed for the resin system specified above. Figure 124 shows the completed coupler after the slip band has been epoxied in place

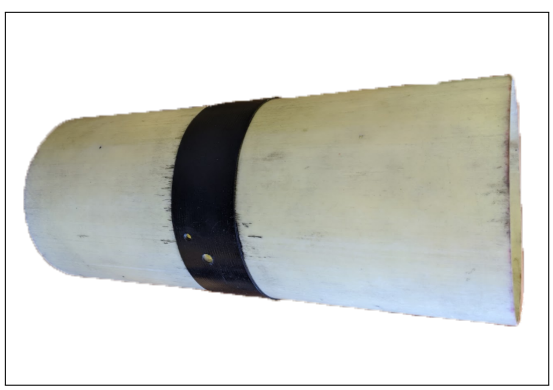

Figure 20: Coupler

The switch band is a section of carbon fiber airframe that was cut to size then epoxied to the center of the coupler using G5000 RocketPoxy. Set screw holes and the venting/arming ports were then drilled into the band so they could be accessible on the fully integrated launch vehicle.

3.2.14 Nose Cone

The nose cone of the launch vehicle is made of G12 fiberglass with an aluminum tip and a 5:1 ogive profile. The RF transparency allows for avionics to transmit radio frequencies to the ground station for tracking using Global Positioning System (GPS). No commercial vendor provides a nose cone that matches the size of the airframe, so a 7.5 in. diameter nose cone was purchased and cut down to fit the body diameter of the launch vehicle.

The process of re-manufacturing the the nose cone began by removing the aluminum tip. The nose cone was then placed in the tube cutting jig allowing the nose cone to rotate so that it would be cut with a grinder mounted on the tube cutting jig. The nose cone was cut oversized and sanded down to meet the size of the airframe to ensure a correct fit. After the nose cone was cut, the coupler was then layed up in the nose cone and a section of airframe as a mold as seen in 23.

The re-manufactured nose cone coupler included fourteen layers of prepreg 7781 E-Glass with a satin weave at a layup schedule of [0/-45/ 45/ 90/ 45/ -45/ 0]. This was then covered with layers of release film breather and vacuum bagging. It was cured in an autoclave under vacuum to draw out excess resin and reduce the possibilities of voids in the cure. This created a nose cone with a total height dimensions seen in Figure 24. This nose cone fits into the payload section and is secured in with nylon shear pins.

During the first full scale test flight, the nose cone sheared through the retaining pins during deployment of main parachute. As discussed in section this was the result of a high deployment velocity and more nose cone weight than was originally designed; along with a reduced shear pin size. This resulted in damage seen in Figure 21. The nose cone is in the process of being repaired using a scarf joint method, with a section replacement being cured out of the same material that the coupler was made from. This section will then be bonded into the coupler after both the coupler and section are sanded to angles on the edges. A layer of the composite will then be cured over the patch on the inner circumference of the coupler before sanding to ensure a uniform fit. Progress is seen in Figure 22.

Figure 21: Nose Cone Damage

Figure 22: Nose Cone Patch

To ensure that the nose cone will not detach again, an analysis was done and a solution was created. The nose cone will have a threaded mount created in order to thread the nose cone onto the payload retention system. The payload retention system was modified as well to reflect the added stresses. To asses the stresses on the retention system a maximum worst case scenario of 23.3 Gs was calculated at parachute opening. The payload lead screw is manufactured out of 1015 medium carbon cold rolled steel, with the payload and nose cone weight calculated to be 11.92 lbf. The retaining pin cross sectional area is 0.0122 in^2 with a tensile strength of 60 ksi. The 3 shear pins have been tested to hold 17 lbf before failure each, totaling 51 lbf that can be retained by them alone.

$$Maximumallowableloadonleadscrew = 60000 * 0.0122 = 732lbf; \tag{1}$$

$$Maximumimpulseload = 22.3G * 11.92lbf = 277.7lbf \tag{2}$$

Adjusting for shear pins and lead screw, we can determine the factor of safety on the retention system for the payload and nose cone.

$$Factorofsafety = 732lbf/227lbf = 3.2 \tag{3}$$

The aluminum tip was provided with the purchase of the nose cone and is secured to the tip of the fiberglass with a washer epoxied to the inside of the nose cone. The fully constructed nose cone can be seen in Figure 24.

Figure 23: Nose Cone Coupler Layup

Figure 24: Nose Cone With Coupler

3.2.15 Recovery Avionics Bay

The avionics bay that is located in the coupler responsible for the deployment of both the main and drogue parachutes. The bay consists of two sealing bulkheads connected by steel 5/16 threaded rods. A 3D printed mounting plate is mounted on two opposing rods on the bay for the electronics and battery cases to be mounted to. The switches are mounted to l shaped brackets that are in turn mounted to the plate as well. These are places to align with holes placed into the couplers outer band. Figure 25 shows the Recovery Avionics Bay, noting the switches for primary and backup charges are labeled "P" and "B" accordingly.

Figure 25: Recovery Avionics Bay

The recovery avionics bay is held in place in the coupler with 4 set screws set into the aluminum ring shown above. This ring also doubles as the compression ring for the forward sealing bulkhead. The bolts on the threaded rods are then tightened, compressing the gasket sealing the bay against the inside of the coupler. E-matches will be routed through the bay via sealing bolts on both bulkhead. these consist of large fender washer that compress o-rings over holes for both the main and drogue oriented bulkheads.

3.2.16 BEAVS 2.0 Mechanical

BEAVS 2.0 is an active airbrakes system that will control the projected apogee altitude of the launch vehicle by inducing drag force through an increase in cross-sectional area. Two blades housed inside the airframe will extend approximately an inch radially through slits cut in the airframe. This system will allow OSRT to hit the altitude challenge with accuracy.

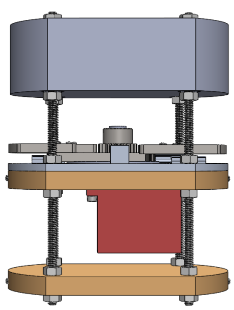

Figure 26: BEAVS 2.0 Assembly

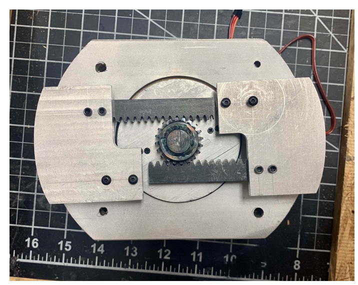

Figure 27: BEAVS 2.0 As Manufactured

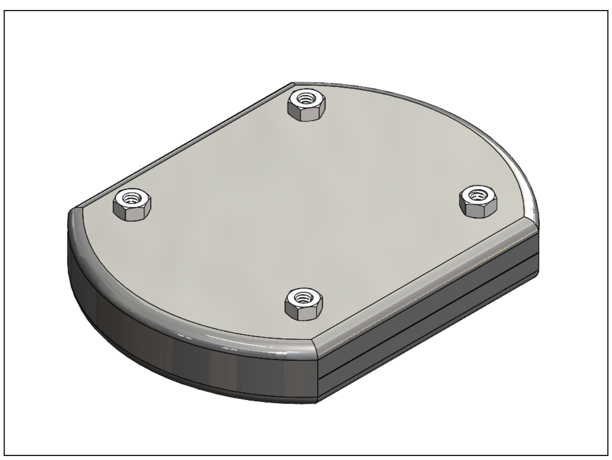

Figure 28: BEAVS 2.0 Ballast Bay

NOTE: Rail aligners were added to the Computer-Aided design (CAD) model and were not manufactured as of Flight Readiness Review (FRR) submission date.

The active mechanical system is a rack and pinion design housed aft the center of gravity shown in Figure 26. The two blades sit on a set of 7 mm linear guide rails. The gear is driven by a high torque servo motor, discussed further in the BEAVS electrical system section. The 20-pitch spur gear is made of hardened carbon steel with a 20 degree pressure angle which has been welded onto an aluminum attachment piece. The racks, also made from hardened carbon steel, were ordered from McMaster-Carr and machined down to size on a wire Electrical Discharge Machining (EDM) to match the pressure angle and pitch of the gear. The blades were machined from 1/4 in. 6061 aluminum and are attached to the rack and linear guide rails via vibration resistant screws. Vibration resistant screws were selected for the assembly when dimensions and sizing permitted.

The gear is driven by a servo motor, attached to the servo arm by a piece machined from 6061 aluminum. The attachment piece acts as a motor shaft through the gear and then attaches to a platform located between the gear and the servo, similar to a plate. That plate is connected to the servo arm via screws.

The passive system pictured in 28 was 3D printed and filled with sand and various small weights made from aluminum or steel. This is a coupled system with one bay located below the active portion of BEAVS, and one bay located in the nose cone. The bottom ballast bay will attach to the four threaded aluminum rods pictured 26. The ballast bay in the nose cone will attach to the single threaded aluminum rod located within the nose cone.

3.2.17 BEAVS 2.0 Mechanical Manufacturing

The manufacturing of BEAVS 2.0 consisted of:

- Plywood Bulkheads (x3)
- Aluminum Bulkhead Reinforcement
- Servo-Gear Connecting Piece
- Aluminum Blades (x2)

The components that were ordered and assembled into the system consisted of:

- Linear Guide Rails (x2)
- Linear Carriages (x2)
- Pinion Gear
- Rack (x2)
- Threaded Rods (x4)
- Other: Various Nuts and Bolts

3.2.18 BEAVS 2.0 Mechanical Testing

Finite Element Analysis (FEA) tests were performed to ensure that the blades would withstand flight forces. The blades will only activate after motor burnout, however, in the event they deploy *during* burnout, tests were run with the highest flight forces possible. The highest flight forces occur at max velocity and can be calculated using the drag equation:

$$D_{max} = C_d * \rho * V_{max}^2 * \frac{A}{2} \tag{4}$$

With a maximum velocity of 541.8 m/s simulated from OpenRocket, and a cross-sectional area of each blade being 0.0016 m^2:

$$D_{max} = 0.42 * 1.225 * 541.8^2 * 0.0016 \tag{5}$$

$$D_{max} = 765.3N \tag{6}$$

The FEA simulations showed that the blades could withstand these max forces with a factor of safety of over 3, fulfilling the team requirement.

3.2.19 BEAVS 2.0 Electrical

The electrical system for BEAVS will use sensors that control the high torque servo motor which is responsible for moving the blades of the mechanical system. The sensors will collect data such as: three axis orientation, acceleration, barometric pressure, and altitude. After filtering the environmental data received, the values are sent into an algorithm which will calculate the projected apogee altitude.

The electronics are consisted of a custom designed Printed Circuit Board (PCB) shown in Figures 29 and 30; complementary components: accelerometer sensor, barometric pressure sensor, buck voltage regulator, capacitors and resistors, and microcontroller; 7.4V Lithium Polymer (LiPo) battery; and high torque servo motor.

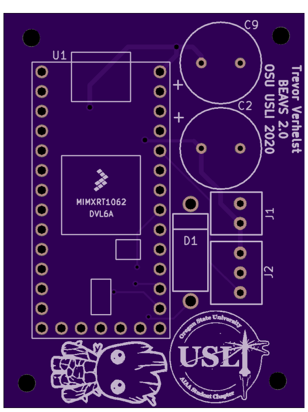

Figure 29: Front Side of PCB

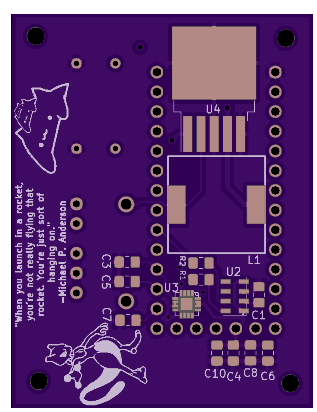

Figure 30: Back Side of PCB

The PCB is a two-layer, 1.53 x 2.00 in. fiberglass board. Once designed with KiCad, the PCB was ordered and manufactured from OSH Park. Mechanical holes were included in the four corners of the board for mounting onto the bulkhead easily. The complementary components were ordered from DigiKey and attached to the PCB using solder paste and a reflow oven infrared Integrated Circuit (IC) heater. The microcontroller, which is attached via female pin headers to the PCB, is a Teensy 4.0 that was ordered alongside the PCB from OSH Park. The servo motor is a 1/4 scale servo ordered from Aloft Hobbies. The motor attaches to the gear with a servo horn and screws. The LiPo battery drives the motor directly with no voltage regulation and uses the voltage regulator to step-down the voltage to 5V for the microcontroller. To ensure that all electrical components stay secure and connected to each other during launch, screw terminals are used to clamp the power wires from the battery as well as the power and signal wires for the servo motor.

3.2.20 BEAVS 2.0 Electrical Manufacturing

The manufacturing of BEAVS 2.0 Electrical consisted of:

- PCB

The components that were ordered and assembled into the system consisted of:

- 7.4V LiPo Battery
- 1235MG High Torque Motor
- ADXL377 Accelerometer
- MPL3115A2 Barometric Pressure Sensor
- LM2576 Voltage Regulator
- Other: Various Capacitors and Resistors

3.2.21 BEAVS 2.0 Electrical Testing

To ensure the quality and functionality of the PCB, OSRT electrical team members used a Digital Multimeter (DMM) and oscilloscope to measure voltage and current draws as well as signals going to the microcontroller from the environmental sensors. After plugging in the battery to the screw terminals, 5V was measured in the appropriate locations to ensure no short circuits or unexpected voltages. With the assurance that the microcontroller would not be fried, the oscilloscope was used to probe the signal lines coming from the sensors and to the microcontroller to show that appropriate signals and voltages were being sent. From proving the functionality of the hardware of the BEAVS electronics, we moved onto the code.

Code for the accelerometer and pressure sensor were tested under many different conditions to ensure precise functionality. The accelerometer needed to be accurate enough to detect motor burnout and start calculating projected apogee altitude like discussed in the BEAVS 2.0 Controls section. The pressure sensor and accelerometer are then to be used constantly to measure acceleration, altitude, and, from there, velocity.

To be able to get accurate readings from the sensors, code was sourced from well-documented examples on Sparkfun.com with slight alterations to better fit our applications. Using the Aruindo Integrated Development Environment (IDE) software with the Teensyduino extension, environmental information from the sensors was printed to a serial monitor to determine functionality and to find bugs or errors.

Initial tests had shown large discrepancies between measured and assumed or known values. As shown in Figure 31 for the accelerometer and Figure 32 for the pressure sensor, values were far out of expected range. For example, the temperature for the pressure sensor reading was ~75 degrees Fahrenheit, which is accurate given the testing conditions were a well air conditioned building, but within the same sensor, the altitude reading was ~25560 meters above sea level which was expected to be closer to ~71 meters above sea level from online altitude tool through Google Maps. From these results, it was clear that some calibration was necessary and changes were made to the code with offsets to the environmental data to compensate for the extreme values. With these offsets we were able to more accurately read realistic environmental data so that our control system for BEAVS would be able to better calculate a projected apogee altitude.

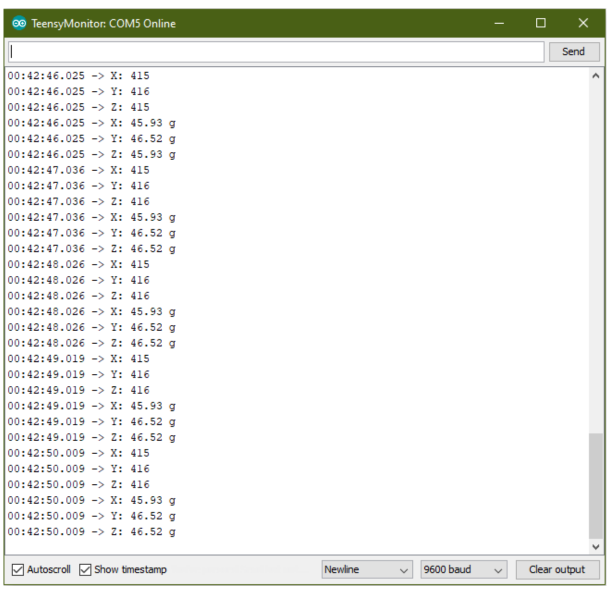

Figure 31: Accelerometer Serial Monitor Output

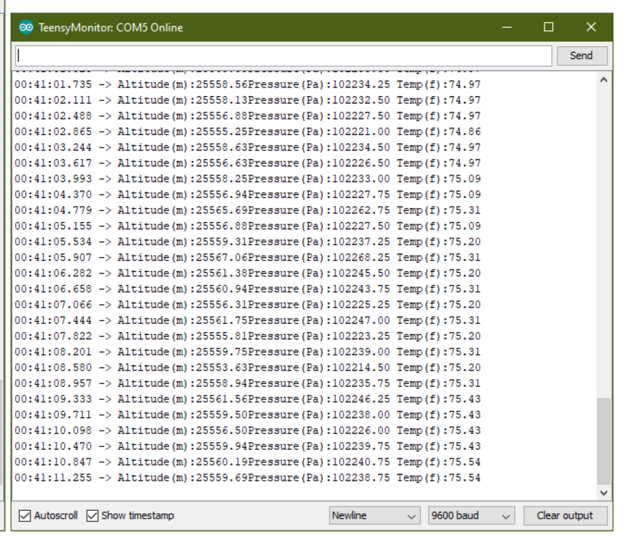

Figure 32: Pressure Sensor Serial Monitor Output

After sensor testing, we moved to testing the motor and making sure that it would move quickly and smoothly enough with the mechanical system as to not strain or break any components within BEAVS. The motor used is a servo motor as detailed above and therefore is controlled with Pulse Width Modulation (PWM) signals that tell the motor at what angle to rotate. As the blades in the system will either be fully extended or fully retracted, there is no need for tracking of intermediate positioning. The use of precise motor angle rotations allowed us to ensure that the racks that move along the gear atop the motor would always stay in contact with each other and neither over-extend or over-retract which could cause both structural damage as well as compromise the functionality of the entire system. After putting the motor through different rotation patterns, we were sure that there would be no issue with moving the gear. An issue was discovered when the rail was added to the system as the linear guides were not rigid enough as to ensure constant teeth alignment of the gear and the rail. This made it so the gear was spinning but the rail was constantly bouncing off instead of moving the blades in and out. To overcome this issue, rail aligners were added that compressed the rail to increase the mesh of the teeth between the two components.

3.2.22 BEAVS 2.0 Controls

OSRT is approaching the controls system with preventative measures to ensure no controls or electrical failures are experienced on launch day. The controls will have fail-safes implemented that prevent the brakes from activating during motor burn, this will ensure that the blades absolutely will not be deployed under the flight forces which occur during motor burn. Teams in the past have had this happen and have suffered from airframe damage and compromised mission assurance. The airbrakes will also automatically deploy at 4,000 ft. If the change in position from the current altitude of the launch vehicle to the previous is negative (meaning it has reached apogee), BEAVS 2.0 will not deploy. If the expected apogee altitude is projected to be less than 4,000 ft from the launch rail, BEAVS 2.0 will not deploy but will continue to collect and store flight data from the sensors.

The BEAVS controls system relies on the sensors mentioned above to read the launch vehicle's current altitude and rate of deceleration. The sensor data is filtered to ensure accurate values. Given these metrics, an algorithm embedded into the microcontroller will calculate the projected apogee altitude and determine whether to drive the motor. This control scheme will work on a 1 second duty cycle, recalculating the projected altitude each second of the coast phase. A Proportional-Integral-Derivative (PID) control scheme is utilized to ensure low steady state error and a quick response time from the system.

An overview of the controls schematic is pictured below:

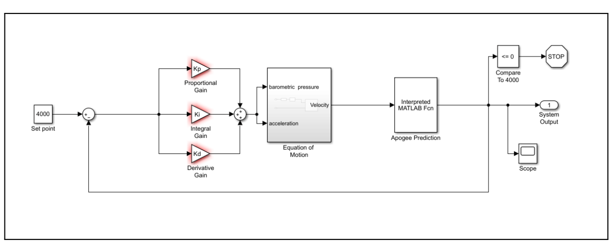

Figure 33: BEAVS Controls System

3.2.23 BEAVS 2.0 Controls Testing

Simulations for subscale and fullscale were built and compared against OpenRocket before launch and altimeter data post launch. These simulations calculated motor burnout time, velocity and altitude. They also calculated predicted apogee altitude using various methods. The first method used a set of equations which took in the launch vehicle and motor parameters and values, and output the altitude of motor burnout and the coast phase altitude. For the fullscale predictions, this gave an error of 4047 ft or x percent.

Due to the large margin of error in the coast phase altitude, the second approach used basic physics to calculate the coast phase altitude gain with the following equation:

$$dh = v_{BO} * t - \frac{1}{2} * (g + \frac{D}{mB}) * t^2 \tag{7}$$

Where dh = altitude gain (ft), v_{BO} is velocity at motor burnout, g is the gravitational constant and D is drag, calculated iteratively throughout the coast phase.

This equation combined with the motor burnout velocity and mass gave a much more accurate value for apogee altitude compared to altimeter data, which was 15 ft or 0.33 percent off.

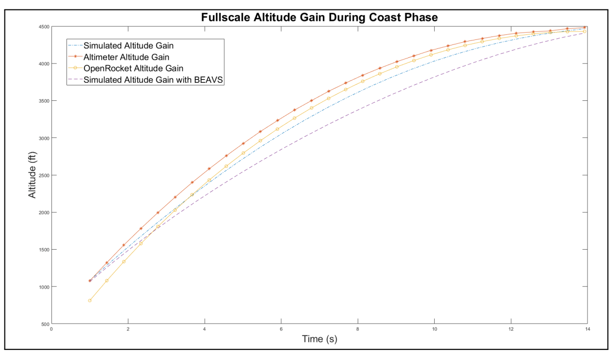

Figure 34: Coast Phase Altitude Gain

Algorithm Output

Coast Phase Time: 14 s

OpenRocket apogee altitude: 4430 ft

Altimeter apogee altitude: 4481 ft

Matlab simulated apogee altitude: 4466 ft

Matlab simulated apogee altitude w/ BEAVS extended: 4408 ft

The reduced altitude with the blades extended is due to the increase in drag force that is produced by the increased cross-sectional area, thus decreasing the apogee altitude by a total of 58 ft. This system is intended to "fine-tune" the apogee altitude. Ballast will be the major source of altitude reduction, as it can reduce the altitude by approximately 100 ft per lb added.

3.3 Recovery System

3.3.1 Mission Success Criteria

The OSRT main mission success requirements for the 2020 University Student Launch Initiative (USLI) competition state that the launch vehicle must separate at apogee and release a drogue parachute. The launch vehicle separates at 600-500 ft and releases a main parachute. Once these processes are met, they then must fall in the Student Launch Handbook requirements. These requirements are as follows:

- A drift radius no more than 2500 ft in winds up to 20 mph.
- A descent time of no more than 90 s.
- A landing kinetic energy of no more than 75 $ft - lbs$ per section.

3.3.2 Recovery Layout and integration

The final layout of the recovery system will involve a single main parachute and a single drogue parachute with three separate sections.

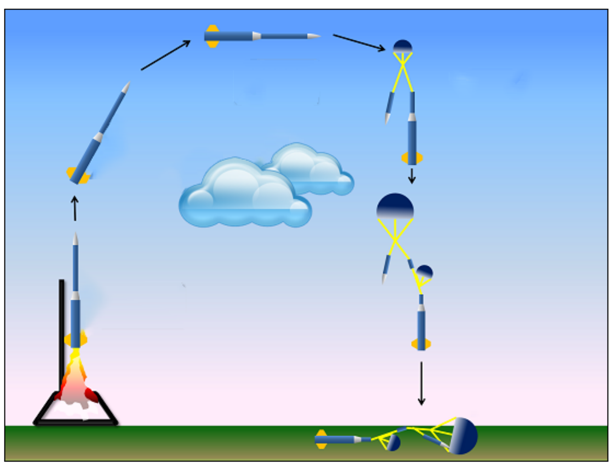

Figure 35: Rocket Simulated Flight Path (not to scale (NTS)) [9]

The final layout of the recovery design will involve three separate sections connected by a tether, fore (frontal section), aft (motor and back section), and coupler as the vehicle descends. The fore and aft layout are almost identical save for a few small changes.

The dual-compartment dual-recovery systems layout involves a single drogue parachute at apogee and a single large main parachute at 600-500ft.

The layout is as follows. There is a bulkhead in the aft body tube that can withstand 15 G's with a factor of safety of 12, and fore body tube that can withstand 10 G's with a factor of safety of 6. These bulkheads are secured with high strength epoxy to the sides of the body tube. The bulkheads have eyebolts that can withstand 1000 lbf upon deployment of the parachute and tether system. This tether system from the aft bulkhead to the coupler is a length of shock cord spanning 10 m or 32.8 ft. Connected to both sides with two 2100 lbf quick links. On that tether 2/3 of the way to the section connecting to the coupler, at 11 ft to the end, is a butterfly knot connecting the drogue parachute shock cord (18 ft) to the tether (33 ft). The shock cord connected to the butterfly knot is the main attachment point for the drogue parachute. The drogue is attached to the shock cord with a 600 lbf rated swivel and a 1200 lbf quick link. The coupler is the main attachment point for the parachute tether system, the coupler itself has two eyebolts on either side, each with a 2100 lbf quick link attachment. In the fore section of the launch vehicle, there is a tether connecting from the coupler to the fore bulkhead via four 2100 lb quick links, two on either side. 1/3 of the way down this section of the tether from the coupler side is a butterfly knot connecting the 18ft nylon shock cord to the tether. On this 18ft shock cord is another 2100 lbf quick link and 2000 lbf swivel attached to the 144 in main parachute. In both of these sections, the tethers and shock cords will be artificially zippered together using blue masking tape to reduce the shock of the initial deployment. Underneath both parachute connections will be a Nomex/kevlar hybrid fire blanket to reduce any burning or damage done to the parachutes due to heat. The layouts can be seen in Figures 36 and 37.

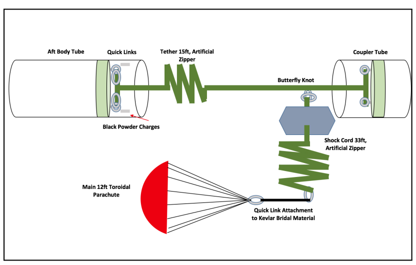

Figure 36: Main Parachute Recovery Layout

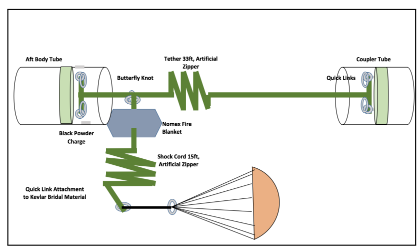

Figure 37: Drogue Recovery Layout

3.3.3 Bulkhead Attachment Points

The OSRT has 1 traditional bulkhead in the fore, 1 in the aft section and 2 attachment "bulkhead" points in the coupler section. Each bulkhead in the body-tube can withstand up to 15G's with a factor of safety of 12. They have each been expoxied with high strength 2000 lbf epoxy. The bulkheads themselves consist of 2 forged steel eyebolts each inserted into the bulkhead. Two eyebolts were used for redundancy in case one failed. The aft bulkhead has a different layout than the fore bulkhead. The aft bulkhead has to accommodate for the BEAVS system. So the two stainless steel eyebolts are mounted on 1 in. thick steel blocks and epoxy'd to the sides of the carbon fiber body tube. These are rated for 15G's and a factor of safety of 12. They have been successful in both full-scale and subscale recoveries. The aft body bulkhead can be seen in figure
The fore bulkhead is a traditional birch wood bulkhead with steel inserts and 2 forged eyebolts epoxy'd to the sides of the carbon fiber body tube. This bulkhead has a factor of safety of 15 and can withstand up to 20G's of force. The fore body bulkhead can be seen in figure

The coupler itself has a total of four forged steel eyebolts that can withstand 500 lbf of static force each and 1000 lbf working load. Two eyebolts are on either side of the coupler and attach to 2100 lbf quick links for the recovery system. These are held together on steel rods threaded through plywood boards with a tensile strength of 4000 lbf which can survive the extreme shock forces felt from the recovery system. The coupler bulkhead attachment points can be seen in figure

3.3.4 Parachutes

Figure 38: X-Form Drogue Parachute

Figure 39: Toroidal Main Parachute

The OSRT decided to use a 3 ft (36 in.) X-Form chute as the drogue parachute. This parachute was chosen for its high stability and high coefficient of drag at high speeds 0.7. These parachutes are easy to pack, and are inexpensive; so if damaged it can be replaced easily. A cruciform parachute is seen in figure 38

The OSRT does not have the equipment or ability to manufacture parachutes from usable materials. The complexity and time required were not available to the students. Therefore the OSRT decided to use a reputable manufacturer to purchase the main parachute.

For the main parachute, the team decided to go with a toroidal-shaped parachute. This parachute has a larger coefficient of drag at 2.2, requiring a smaller parachute to slow the launch vehicle down to the kinetic energy and velocity requirements. This parachute is known for its high coefficient of drag and its high performance/stability rating. This parachute will ensure that the recovery system meets the requirements that the USLI handbook lays out. Ranging parachute sizes can be seen in figure

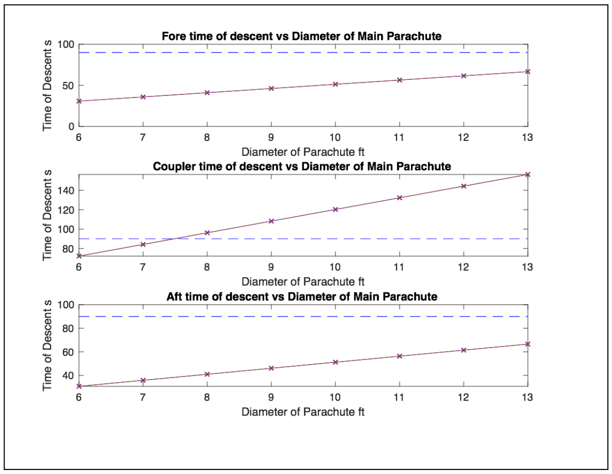

Figure 40: Time of Descent vs Parachute Size.

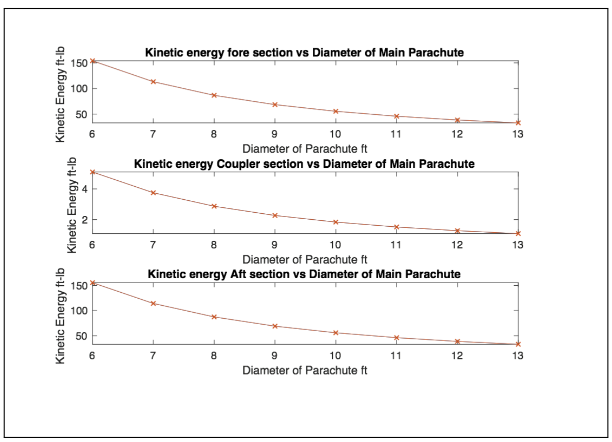

Figure 41: Kinetic Energies vs Main Parachute Size.

3.3.5 Recovery Protection

For this years competition, the team decided to use black powder as its means of ejection. 4F black powder burns at at a range of 400-800F and the parachutes melt well below this at 220F. To ensure the parachutes do not burn, the team will be making and using a nomex/kevlar hybrid fire blanket to wrap the parachutes and lines in. This blanket is 24x24in for the main parachute and 18x18 for the drogue parachute.

Figure 42: Nomex and Kevlar Blanket.

The shock cord is a 1 in. wide nylon cord from fruity chutes. Nylon loses functionality after experiencing thermal damage and burns at 500F. The team has sewn nomex sleeves for the shock cords and tethers, connecting to the nomex/kevlar blanket via stitching. Even with this protection, the blankets and sleeves have been burnt and charred and have become unusable, as seen in fig42, they will be replaced prior to competition to ensure a functional recovery system.

3.3.6 Parachute Packing

The drogue and main parachutes will both be packed independently and in their own separate compartments. Both sections will be packed nearly the same. The packing method follows similarly to the Fruity Chutes toroidal parachute packing method as listed on their website with some slight differences, such as folding the gores in, instead of out. The main parachute will be folded with its shroud lines, tether, and shock cord into a Nomex blanket. This packed blanket will then be loaded into the fore tube of the rocket with the Nomex sleeve facing towards the bottom of the tube. The drogue parachute will similarly be folded with its shroud lines, tether, and shock cord into a Nomex blanket. This packed blanket will then be loaded into the fore tube of the rocket with the Nomex sleeve facing towards the bottom of the tube.

3.3.7 Shock Cord and Tether Materials

The bridal, or shroud, lines for each parachute are long, flat Kevlar lines that attach from the swivel to the nylon parachute. The OSRT decided to go with Kevlar for its strength and durability under high dynamic loads. The shock cord and tethers will be made of the same material, a 1 in. width nylon webbing. Nylon was chosen for its durability under high loads and its elasticity during a snatch load. The elasticity is crucial as it reduces zippering into the body tube dramatically, as opposed to its counterpart Kevlar. Nylon is easily burnt and has a low flame retardance, therefore Nomex fire blanket material will be sewn into a sleeve and wrapped around the nylon cords to protect from charring and burning from the black powder charges.

Figure 43: Shock Cord and Tether Materials

3.3.8 Connection Points

Between the Tether, spanning from bulkhead to bulkhead, will be a butterfly knot. Butterfly knots are used in rock climbing supporting high impact loads from falling climbers. We chose the butterfly knot because it is extremely versatile and has many unique uses. The team needed loops on specific points on the tether and risers meaning a knot would be needed to be placed in a precise location the butterfly knot provides just that. The butterfly knot reduces the Unified Thread Standard (UTS) of the tether to 70% of its rated load. While 30% reduction of maximum force from 4000lbs to 2800lbs allowed on the tether is significant, the tether was already rated for 50G's of acceleration and had a safety factor of 7. It now has a safety factor of 5, and will still hold the entirety of the launch vehicle during descent. You can see the knot in 44

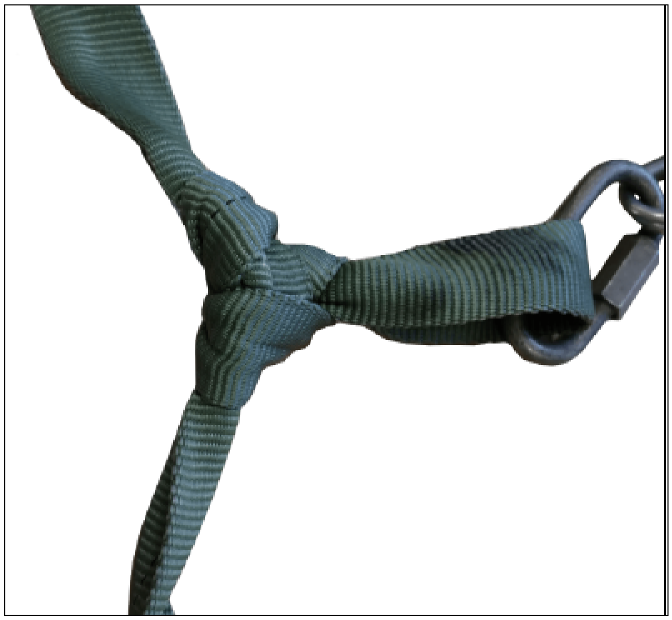

Figure 44: Butterfly knot

3.3.9 Sizes and Descent Rates

This section outlines the process for determining parachute sizing for the launch vehicle.

$$KE = F_{impact} = \frac{1}{2}mv^2 \tag{8}$$

kinetic energy in ft-lbf, m is in slugs, and v is in ft/s.

$$D = \frac{1}{2}C_d \rho_{air} v^2 A_r \tag{9}$$

From the National Aeronautics and Space Administration (NASA) website [1], drag can be calculated using Equation 9. In this equation, D is drag of the parachute in lbf, C_d is the coefficient of drag on the parachute dependent upon its shape. These calculations assume the use of toroidal parachutes for the main and cruciform chutes for the drogue. ρ_{air} is the density of the air in Huntsville, Alabama, v is the velocity in ft/s, A_r is the area of the parachute canopy in ft^2, and W_{lv} is the weight of the launch vehicle in lbf.

Expanding Equation 8 into Equation 9 results in

$$D = W_{lv} = \frac{1}{2}C_d \rho_{air} v^2 A_r \tag{10}$$

A_r can be calculated from Equation 11

$$A_r = \frac{1}{4}\pi(d_o^2 - d_i^2) \tag{11}$$

For a toroidal parachute, there is an inner and outer diameter defined. Using the Fruity Chutes website, the ratio between the two is 5:1 [2]. Equation 12 the simplified equation of area with this ratio.

$$A_r = \frac{6}{25}\pi d_o^2 \tag{12}$$

Combining Equation 10 with Equation 12 results in Equation 13

$$d_o = \sqrt{\frac{25W_{lv}}{3\pi C_d \rho_{air} v^2}} \tag{13}$$

With the current weight, the parachute diameter required for the launch vehicle is 12 ft. This will result in the descent speeds of the launch vehicle being 14.1 ft/s. The impact force of the main vehicle is 73.19 ft-lbf. The drogue chute calculation resulted in a 36 in diameter X-Form parachute. With a coefficient of drag of 0.7, the speed from the drogue is 150.2 ft/s.

Using the above equations and MATLAB code, the impact speeds and kinetic impact energies found are:

Measurements	**Tethered body sections**
Dry Weight	61.1 lbf
Max Impact Velocity with Parachutes	14.1 ft/s
Max Impact Energy with Parachutes	73.19 ft-lbf

Table 2: Vehicle Descent Rates and Energies

3.3.10 *Parachute Kinetic Energy, Descent time, and Drift*

A MATLAB script was created that generated the kinetic energies for the fore, aft, and coupler sections. This took into account the changing air density as the rocket fell and the changing velocity as the main parachute and drogue parachute opened. It can be seen from the table 3 that the maximum kinetic energies felt stay well below the requirements given in the USLI student handbook.

Table 3: Kinetic Energy Analysis

Measurement	Fore Section	Coupler	Aft section
Weight	24.05	6.4	24.7
Velocity Main and Drogue	14.1 ft/s	14.1 ft/s	14.1 ft/s
Kinetic energy with Main and Drogue	73.19 ft-lb	19.47 ft-lb	74.9 ft-lb
Velocity with only Drogue	161.1 ft/s	161.1 ft/s	161.1 ft/s
Kinetic Energy with only Drogue	2054 ft-lb	648.4 ft-lb	2060 ft-lb
Velocity no parachutes	150.9 ft/s	150.9 ft/s	150.9 ft/s
Kinetic energy no parachutes	9255 ft-lb	304.8 ft-lb	9283 ft-lb

Table 4: Drift Calculations

Wind Speed (mph)	0	5	10	15	20	Descent time (s)
Drift MATLAB (ft)	0	459	1100	1682	2100	82
Drift OpenRocket (ft)	12.4	125	565	990	1467	76.6

3.3.11 Recovery Protection Testing

The OSRT used proper Personal Protective Equipment (PPE) and safety equipment before testing all recovery systems. The team went out to the nearby airport and used a makeshift test stand to eject the parachute and the recovery harness in its entirety. This test was to ensure all fire retardant material would be suitable and functional for a fullscale launch. Figure 42 shows the successful test ejection the nomex blanket and sleeves absorbed 99% of the black powder heat and discharge. However it was not 100% success full as seen in fig where the parachute is charred and burned having a number of holes in the nylon from the blast. More tests are being conducted on a kevlar nomex material for the launch in Huntsville, AL, that will be more successful than 99%.

Figure 45: The scorch marks from the test launch.

3.3.12 Parachute Ejection System

Overall, the parachute ejection system will feature four 9 V batteries, four switches, four Missile Works Rocket Recovery Controller 3 (RRC3) altimeters, four Black Powder (BP) charges, and two Energetic Mid-flight Black powder Ejection Reserve System (EMBERS). Since there are two areas where ejection events need to occur, within the drogue parachute bay, and within the main parachute bay, these components will be split in half so that each bay has two 9 V batteries, routed through a switch to two RRC3 altimeters. The primary RRC3 altimeter will be connected directly to the primary BP charge while the backup RRC3 altimeter will be connected to an EMBERS, which will be connected to another battery through another switch, and to the backup BP charge, as shown in Figure 46, for the main parachute, and Figure 47 for the drogue parachute.

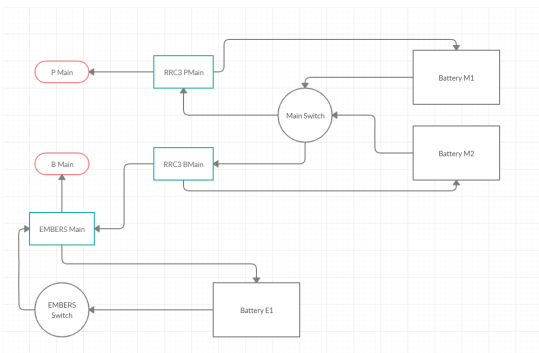

Figure 46: Main Parachute Ejection System Layout

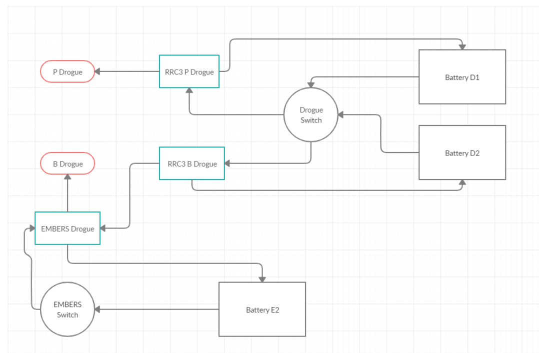

Figure 47: Drogue Parachute Ejection System Layout

3.3.13 Ejection Charge Sizing

Similar to what was documented in CDR, in order to calculate the initial necessary size of the charges for the full scale launch vehicle, the following equation was used:

$$BP = 0.006 * l_{compartment} * d^2_{compartment} \tag{14}$$

$l_{\text{compartment}}$ for the full launch vehicle is the length of the parachute bay. The length of the main parachute bay is 20.2 in. and the length of the drogue parachute bay is 8 in. $d_{\text{compartment}}$ is the diameter of the parachute bay, which is 6.25 in. To ensure that the parachute bays stay connected to the main coupler for as long as intended, the team used 1/4-in. long #2-56 shear pins for both the drogue and main parachute bays. According to the High Power Rocketry Strength of Materials guide from CDR, it takes an average total of 84.44 lbf to break the four pins, as shown in Figure 48 [7]. Since the bulkheads are approximately 30.68 in.^{2} in area, it takes approximately 2.75 psi on the bulkheads to break the four shear pins.

#2 Nylon Screws				#4 Nylon Screws		
# of Pins	Peak Load (lbs)	Peak Load (Each Pin)		# of Pins	Peak Load (lbs)	Peak Load (Each Pin)
2	53.123	26.56		2	81.304	40.65
2	45.952	22.98		2	85.148	42.57
2	50.848	25.42		2	75.944	37.57
2	51.799	25.90		2	80.391	40.20
2	47.924	23.96		2	80.908	40.45
Avgs	***49.93***	***24.64***			***80.75***	***40.30***
3	62.637	20.88		3	119.273	39.76
3	60.569	20.19		3	110.999	37.00
3	64.395	21.47		3	99.969	33.32
3	62.413	20.80		3	113.554	37.85
3	68.760	22.92		3	116.208	38.73
3	66.643	22.21		3	121.121	40.37
				3	123.689	41.23
Avgs	***64.24***	***21.41***			***114.97***	***38.32***
4	86.699	21.67		4	143.405	35.85
4	86.855	21.71		4	152.368	38.09
4	78.771	19.69		4	142.026	35.51
4	84.269	21.07		4	160.489	40.12
4	85.617	21.40		4	153.302	38.33
4	90.402	22.60		4	154.766	38.69
				4	160.368	40.09
Avgs	***84.44***	***21.36***			***152.38***	***38.21***

Figure 48: Nylon Shear Pin Breaking Forces [7]

The coefficient of .006 in the BP equation is meant to allow the calculated amount of BP to create a pressure of 15 psi within a given space [3]. This coefficient was calculated by deriving it from the coefficient of .006 which hales a pressure of 15 psi. The coefficient of .006 was used because it gives the parachute ejection system a safety factor of 5.455. However, while this seems to be a overkill for the ejection system, in the first full scale flight, the team experienced some ejection issues involved with getting the drogue and main parachutes to leave the airframe with the charges sized to produce a pressure of 15 psi on the bulkheads, and, therefore, the next primary charge for the drogue parachute will be the size of the Full Scale #1 backup drogue charge, and the main parachute charge will be sized up by half a gram due to how large it is already. The charges are being sized like this because the team is trying to ensure that the shear pins break when they are supposed to, and that the parachutes are able to leave their respective bay in a reasonable amount of time. A summary of the size of the Full Scale #1 flight charge sizes and Full Scale #2 flight charge sizes is detailed in 5.

Table 5: Calculated BP Sizing

BP Charge	Size (g)
Full Scale #1 Main Parachute Primary Charge	4.734
Full Scale #1 Drogue Parachute Primary Charge	1.875
Full Scale #2 Main Parachute Primary Charge	5.234
Full Scale #2 Drogue Parachute Primary Charge	2.4

On the lower end, based off of how the coefficient of 0.006 produces 15 psi, in order to produce 2.75 psi, the coefficient is 0.0011, and therefore, the minimum size the charges need to be is detailed in Table 6.

Table 6: BP Minimum Sizing

BP Charge	Minimum Size (g)
Full Scale Main Parachute Primary Charge	0.87
Full Scale Drogue Parachute Primary Charge	0.34

For the simplicity of measuring the charges, the charge sizes were rounded up to cleaner numbers from the sizes calculated from 15 psi, so the actual charge sizes what were used, and will be used are listed in Table 7.

Table 7: Rounded BP Sizing

BP Charge	Size (g)
Full Scale #1 Main Parachute Primary Charge	4.8
Full Scale #1 Drogue Parachute Primary Charge	1.9
Full Scale #2 Main Parachute Primary Charge	5.3
Full Scale #2 Drogue Parachute Primary Charge	2.4

These charge sizes were then tested via the testing procedure outline seen in the Black Powder Parachute Ejection Testing.

For back-up charge sizing, the charge sizes were scaled to 1.25 times the size of the primary charges, so that the back-up charges were sized as follows in Table 8 for the first full scale flight, and will be sized as follows for the second full scale flight.

Table 8: BP Back-up Sizing

BP Charge	**Size (g)**
Full Scale #1 Main Parachute Back-up Charge	6.0
Full Scale #1 Drogue Parachute Back-up Charge	2.4
Full Scale #2 Main Parachute Back-up Charge	6.7
Full Scale #2 Drogue Parachute Back-up Charge	3.0

OSRT realizes that these charges are quite large, and, therefore, the team has enacted certain safety practices and protocols in order to ensure that no mishaps will occur that will cause injury to personnel or equipment. The first safety protocol is to enact the use of an ammunition box to store live BP charges after they have been made at the launch site. Since the team would like the ammunition box to be able to protect the charges from outside influences, the ammunition box will be modified to contain fire and prevent any static charge from reaching the charges from the outside by covering the inside in a 1/4-inch thick, flame-retardant polyurethane foam sheet with an adhesive backing and then lining the flame-retardant foam with 1/4-inch anti-static polyurethane foam so that the charges sit on the anti-static polyurethane foam. While polyurethane is naturally insulating, OSRT wanted to ensure that no static electricity would be able to reach the charges, which prompted the double-layering of the foams. Therefore, all of this will prevent static electricity from reaching the charges, cushion the charges, and help extinguish any flames that could result in the event of a BP charge detonation. In the event of a BP charge detonation, venting holes will be drilled into the ammunition box to ensure that any explosions that do occur will not turn the ammunition box into shrapnel. This will also help the box to vent heat, which, when exposed to extreme temperatures, is how BP is ignited. Therefore, holes will be drilled at the top and bottom of the box to allow both pressure and heat to escape. To add to the safety, this ammunition box will be clearly labeled that it contains live charges to ensure that no unauthorized personnel choose to venture near it or open the box.

3.3.14 EMBERS Design

The EMBERS system was created to protect the launch vehicle's parachutes in the air, and team personnel on the ground. With the current layout of the launch vehicle, where the altimeter bay is surrounded by the parachute bays, the BP charges have to be routed down each bay and behind the parachutes to ensure that the parachutes can get pushed out via the BP. However, if the primary charges are successful with deploying the parachutes, this means that the back-up charges will be pulled out of the airframe, and are allowed to swing freely in midair around the parachutes until they are given the voltage to detonate. While this was not a problem in the first subscale launch, the team is concerned that the back-up BP charges run the risk of colliding with a parachute in the air and blowing a hole in it, and this proved to be a very real issue with the parachute in Full Scale Launch 1, as the main parachute sustained some damage due to the backup ejection. Because of this, the EMBERS was created to keep the back-up BP charge in the bay, which is where it will detonate in midair without causing any safety threats to the parachutes or to the people handling the recovery system.

The original design, shown in Figures 49 and 50, featured a 3D-printed housing that would hold a 9 V battery with the leads pointing toward the BP charge, and a sliding chamber in which a 3D-printed plastic slider was housed that had two leads attached to it. This slider would be pushed into the leads of the 9 V battery via a spring that was attached to be back wall of the sliding chamber, which would then touch the leads on the slider to the leads on the battery. Because the ematch for the BP charge would be wired to the leads that are attached to the slider, the BP charge would be connected to the 9 V battery, instantaneously detonating the charge. This system would be attached to the bulkhead before the parachute was installed via heavy duty Velcro that would permanently remain within the airframe and on the charge.

Figure 49: First EMBERS Design, Armed

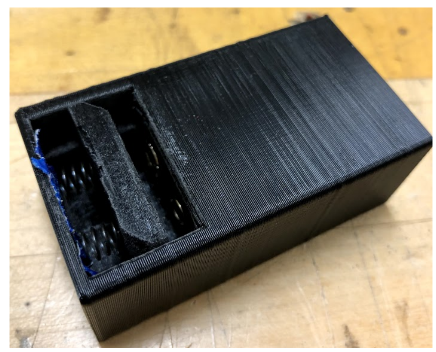

Figure 50: First EMBERS Design, After Pull

While this design worked quite well when conducting the EMBERS Assemble and Pull Test, the team was concerned primarily about the safety of it, because the way that the system was integrated into the launch vehicle was completely assembling it outside the vehicle, installing a live charge on it, and then installing the entire system with the live charge into the launch vehicle with nothing but a 1/4-inch thick piece of plastic separating a live 9 V battery from the leads to a live either 2.4 or 6.0 g BP charge. This created an enormous safety hazard because, while someone would be monitoring the wire while another individual would be installing EMBERS to ensure that the wire would not get pulled while it was being installed, since the parachutes were fitting so tightly into their respective bays, if the team had to remove the parachutes once they had been integrated for some reason, there would be nothing stopping EMBERS from being pulled and detonating the BP charge while the launch vehicle was still being integrated.

Therefore, the team went back to the drawing board to integrate a switch into the system so that the system could be turned on from the outside of the launch vehicle, and installed with no risk of the BP charge being detonated by the EMBERS prematurely. In order to accomplish this, the team designed two different EMBERS. The first was a shorter and wider design that would take up less vertical space within the parachute bay, and can be seen in Figure 51 and was designed to fit to the inner diameter of the air frame to ensure that it could attach to the inside of the air frame and that there would be a good seal between the switch and the access port in the air frame. This particular design houses the switch in the middle of structure, with the battery on the right-hand side so that modifications to get it out could be made easily, and the sliding chamber on the left so that the switch wires could be easily routed to the chamber and that the person who is integrating the system can easily access everything within the system.

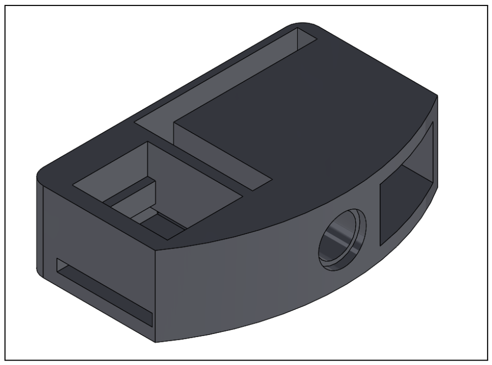

Figure 51: Second EMBERS Design, Version 1

The second EMBERS was also designed to fit to the inner diameter of the air frame to ensure that it could attach well to the inside of the air frame. From the first EMBERS design, the 9 V battery was moved to the back of the system so that it would stand on end, and the switch was placed underneath the sliding chamber, since the chamber needs to be open to the parachute bay in order to be able to be assembled. The sliding chamber was extended, to allow more room for a bigger spring, and then Figure 52 was 3D printed, as seen in Figure 53.

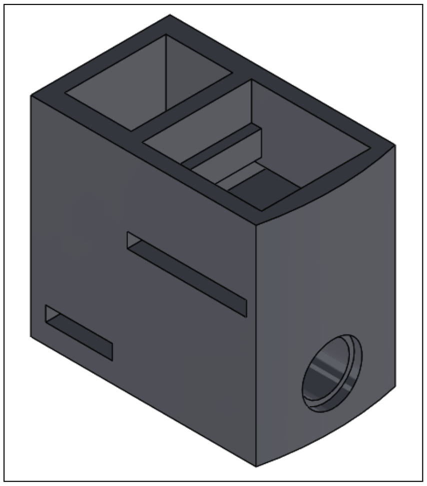

Figure 52: Second EMBERS Design, Version 2 CAD

Figure 53: Second EMBERS Design, Version 2 Printed

This taller EMBERS design with a smaller footprint on the bulkhead turned out to be the better design because of how the 9 V battery had issues fitting into the system without conflicting with the curvature of the airframe in the flatter design, and also, the taller design was able to sit between the nuts that connected items on the other side of the bulkhead to the bulkhead, and therefore, the system did not have to be designed to incorporate the nuts, which would have not only caused issues for the person designing the system, but would have also caused issues for the person who was integrating the items on the other sides of the bulkheads, as the nuts would have to be in a very specific orientation to ensure that the EMBERS could sit flat against the bulkhead.

After printing the second EMBERS, it was found that the switch did not quite fit into the switch hole, and that the battery would not fit completely in the battery chamber height-wise with the incorporation of the 9 V battery connector. It was also discovered that battery fit the battery slot exactly width- and length-wise, and, therefore, was quite difficult to remove, portions of the walls around the battery were removed to give more space to grasp the battery better. Holes were explicitly printed for the screws this time as well to ensure that the screws would have the maximum amount of surface area to grip onto. The overall final design can be seen in Figure 54.

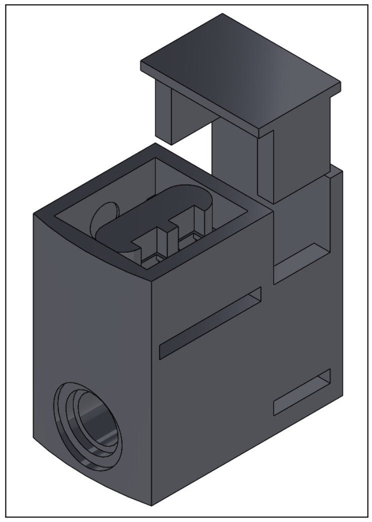

Figure 54: Third EMBERS Design

3.3.15 Ejection Charge and EMBERS Testing

Ejection Charge and EMBERS Testing has been completed as seen in section 6.1.3. The ejection charge test was ultimately successful once the drogue parachute bay was both dry and well sealed from the BEAVS 2.0 bay. The EMBERS testing was quite successful, with minimal pressure escaping from around the port to the EMBERS switch and the screw holes for EMBERS attachment to the airframe.

3.3.16 Altimeters

OSRT will be using a total of four Missile Works RRC3 altimeters within their launch vehicle in order to have one altimeter for each BP detonation event. The team made the decision to have one altimeter per charge as opposed to one altimeter for the primary charges and one altimeter for the backup charges because of altimeter challenges the team faced in the first full scale launch, where the drogue parachute did not appear to deploy within the required, nor the planned, time frame, and neither did the main parachute. This way, if there are any issues with the RRC3s, then it will only impact one charge, and, by giving each charge its own altimeter, this should effectively solve all remaining deployment issues because the primary charges should separate the main coupler from the respective parachute bay. If there is a malfunction with one of the primary charges, then the backup charge will be able to separate the coupler from the bay, but if the primary works and the backup malfunctions, then the backup charge will still detonate because of the EMBERS.

3.3.17 Altimeters Testing

Due to deployment issues in the first full scale launch, OSRT wanted to ensure that the RRC3 altimeters did not have issues reading barometric pressure. Initially, to test the functionality of the altimeters, the altimeters were put into the altimeter bay, and were wired so that they could detonate e-matches, as opposed to full

BP charges. From there, the altimeters, the bay, and the e-matches were all placed in a vacuum chamber, which was vacated of pressure to simulate launch, suction was stopped to simulate apogee and to pop the primary and backup drogue parachute e-matches, and then pressure was slowly allowed back into the chamber to simulate descent, where, around the pressure for 600 ft and 500 ft AGL causes the altimeters to pop the primary and backup e-matches for the main parachute. However, given that this particular vacuum chamber is not built for small pressure differences, and does not have marks for pressure changes such as going from 0 to 600 ft AGL, it is extremely difficult to know if the altimeters are popping the e-matches at the correct altitudes. Therefore, the team came up with eleven different ideas in order to reliably test the altimeters that allowed the altimeters to gain an altitude of at least 400 ft before descending in a safe manner, was easily attainable, and were put into a decision matrix to figure out which test the team should pursue. The first idea was to launch a small model rocket that had an inner diameter of at least 1 inch so that an RRC3 altimeter could fit in it, as well as a 9 V battery, and then 3D print custom housing for the altimeter and 9 V battery, make a very small BP charge, and launch the rocket to approximately 400 ft in altitude. While this would be great for protecting the altimeters from any extraneous forces, and would be quite low in cost, since OSRT's advisor has quite the collection of model rockets along these lines, it would be nice if the test had a more controlled way of getting to and from 400 ft in altitude, as, if the parachute does not deploy, or melts because of the BP, then the RRC3 could be severely damaged by crashing into the ground from 400 ft. The second option is what the team has dubbed "UP 2.0". What this is is using a certain amount of helium balloons to lift the RRC3, 9 V battery, and ematch in a small housing, and have the entire system attached to a heavy duty kite string or fishing line to ensure that the balloons can be reeled back in. The team liked this testing idea because it could be controlled fairly readily, altitude-wise, and reach altitude and descend quite safely. It could be a tricky experiment to do, however, since one balloon can lift approximately 5 g, and the RRC3 weighs approximately 17 g and a standard 9 V battery weighs roughly 45 g. Therefore, if one were to create a housing for the altimeter and the battery, and needed to account for the weight of the kite string, the entire system would need approximately 30 balloons, which is a lot of balloons to acquire. However, this system would take the altimeters straight up and straight down, which would reduce the extraneous impacts on the altimeters that could mess with the barometric pressure readings. This testing method could also be on the more expensive end of things, as, balloons alone would cost a total of $30.

The third option the team came up with was to try to charter a helicopter to take the altimeters up to approximately 400 ft, and then land, While this would take the altimeters to an altitude quite reliably, and would allow for a safe ascent and descent, along with not causing any extraneous errors in the barometric pressure readings, this method of testing would be quite expensive, and would be difficult to do, since the altimeter hooked up to a battery and to an ematch could potentially cause some serious safety hazards while in a helicopter. Taking an elevator or running the stairs of a tall building were also considered in order to get the altimeters to the correct altitude, however, running the stairs for 400 vertical feet would likely mean that the person who is running the stairs would need to take breaks, and the stairs have landings, which would cause an "apogee" to be reached. Similarly, while riding an elevator does not have the same cardiovascular impacts on a person, the team could not control if someone called the elevator on another floor, which could cause the elevator to stop and reach an "apogee" before it hit 400 ft. The good thing about both of these tests, though, is that the altimeters would be able to ascend and descend safely, and would be free of extraneous impacts that could cause errors to occur with the barometric pressure readings. It also would be low cost. However, this would be extremely difficult to accomplish because most tall buildings are office buildings in the middle of cities, and, with the way the altimeter bay is set up, it is likely that no one would appreciate the team running up and down their stairs or elevator a couple of times.

Riding a ski lift was the team's sixth idea, as ski lifts definitely can ascend over 400 linear feet up a mountain side, however, ski lifts are prone to making stops in the middle of the ride, and, therefore, could create a false apogee. It would also be difficult to accomplish this test because the team would have to get the ski lift operator to agree to allow them to ride both up and down the mountain on the lift, which, if the team could manage to accomplish this, it would likely end up being quite expensive. On the positive side, however, the altimeters would be able to ascend and descend safely, and would not have any strange air impacts that would affect the success of the barometric pressure sensor. Driving to the top of a nearby mountain was also considered, which was a great idea for a test in the sense of its ability to allow the altimeters to ascend and descend safely, it is easy to do, since multiple members on the OSRT have cars, and therefore, it would not be very expensive either, and it would allow the barometric pressure sensor to work how it is supposed to work. The only downside to this is that the road on the nearby mountain has dips in it as it ascends, and therefore, it would create a false apogee.

Along the same lines as running to the top of a tall building, the team thought that lowering the altimeter off of the roof of a tall building could be an option, as someone could stand at the bottom, switch the altimeters on, and then the person at the top could pull them up and drop them down to simulate a launch. This was a great idea in the sense that the altimeters could ascend and descend pretty safely, and would not be impacted by any extraneous air flows. The downside to this test is that, if the altimeters are being manually pulled up the side of a building, it is likely that the altimeters would experience some bounce, as the hand-over-hand pulling technique can result in rope bouncing. Similarly, the issue of taking the altimeter bay into a building like the one that the team would need still exists, and rope would likely be needed to lower and raise the altimeters, which is not inexpensive at over 400 ft in length. The team also thought about driving to an outlook in the Columbia River Gorge and lowering the altimeters off of that in a style similar to the lowering-off-of-a-building idea. While this would be much easier to accomplish than the building option, reaching the altitude reliably would be nearly impossible since no one could stand at the bottom of the outlook, meaning that the altimeters would have to fly in an upside-down flight path. Also, since there is a lot of vegetation around the outlook, getting the altimeters down and back safely would be difficult.

The last two options were to tow the altimeters with a drone or get a colleague to fly the altimeters around in a small plane. The drone idea was a great one until the team tried to lift the altimeter bay with one of their drones and discovered that the drone could not give enough lift. Then, when the team tried simply strapping the bare RRC3 with a 9 V battery to the struts of the drone, the airflow from the propellers caused too much airflow over the barometric pressure sensors on the altimeters, otherwise dubbed "extraneous impacts", which caused faulty readings. Getting a colleague to fly in the altimeters in a small plane was the final idea the team came up with, and it was great in the sense that the altimeters could reach the altitudes that they needed reliably and safely, and that the pressure sensors would be safe from any extraneous airflow. However, while this would be easier to conduct in a plane than a helicopter, very similar concerns still exist when it comes to the safety of the team on board the aircraft, and also, chartering a plane can be expensive.

From all of these testing options, a decision matrix was created, and can be seen in Table 9.

Table 9: Altimeter Testing Decision Matrix

		Option 1		**Option 2**		**Option 3**		**Option 4**		**Option 5**		**Option 6**		**Option 7**	
		Small Rocket		**UP 2.0**		**Charter a Helicopter**		**Run the Stairs to the Top of a Tall Building**		**Take the Elevator to the Top of a Tall Building**		**Ride a Ski Lift**		**Drive to the Top of a Mountain**	
Criteria	Weight	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Can Reach Altitude Reliably	2.5	3	7.5	5	12.5	5	12.5	1	2.5	3	7.5	3	7.5	1	2.5
Can Reach Altitude and Descend Safely	3	3	9	5	15	5	15	5	15	5	15	5	15	5	15
Is Easy to Do	2	3	6	3	6	1	2	1	2	1	2	1	2	5	10
No Extraneous Impacts	1.5	5	7.5	5	7.5	5	7.5	5	7.5	5	7.5	5	7.5	5	7.5
Low Cost	1	5	5	3	3	1	1	5	5	5	5	1	1	5	5
Total:	**10**		**35**		**44**		**38**		**32**		**35**		**33**		**40**

		Option 8		**Option 9**		**Option 10**		**Option 11**	
		Lower the Altimeters Off the Top of a Tall Building		**Lower the Altimeters Off an Outlook in the Gorge**		**Tow the Altimeters to the Needed Altitude with a Drone**		**Get a Colleague to Fly the Altimeters Around the Airport in a Small Plane**	
Criteria	Weight	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Can Reach Altitude Reliably	2.5	3	7.5	1	2.5	5	12.5	5	12.5
Can Reach Altitude and Descend Safely	3	5	15	1	3	5	15	5	15
Is Easy to Do	2	1	2	5	10	5	10	3	6
No Extraneous Impacts	1.5	5	7.5	5	7.5	1	1.5	5	7.5
Low Cost	1	1	1	1	1	5	5	1	1
Total:	**10**		**33**		**24**		**44**		**42**

From Table 9, it was clear that either the UP 2.0 test method or the towing the altimeters with a drone method would be the best options out of the 11 presented here. The drone one was attempted, however, the drone, which is a DJI Phantom 4, was unable to lift the altimeter bay in its entirety. Therefore, the team affixed the altimeters and batteries onto the struts of the drone, and then situated the e-matches away from the drone in a way that the camera on the drone could see the e-matches and relay the feed back to the iPad connected to the controller. This was also attempted, as seen in Figure Y, however, the airflow from the propellers caused too much air to flow over the barometric pressure sensors, and therefore, the e-matches did not go off at the apogee of 400 ft for drogue, nor 300 ft for main.

Figure 55: Altimeter Testing Via Drone

Instead of trying to fashion a cover for the altimeters that would add weight to the system, the team opted for the UP 2.0 test, and therefore created a sled that could be attached to 30 balloons and a heavy duty kite string. This testing will be completed before launching again on Saturday, March 7th, and will feature 30 helium balloons, since the standard balloon can lift approximately 5 g of weight, the RRC3 altimeters are 17.01 g each, and a 9 V battery is, on average, about 45 g. Therefore, with 150 g of lift, this would leave approximately 88 g of weight for a sled to attach the altimeter, 9 V battery, balloons, and kite string to. The kite string will be measured out to 600 ft, and will be attached to the sled on the free end of the string. When the test is conducted, at least two people will be present to run it to be able to have one person pilot the balloons, and have another person run string length calculations.

3.3.18 Avionics Overview

The avionics system will have an accelerometer, GPS sensor, and an altimeter. It will compile this data and transmit it over 915 MHz. This data will be turned into packets as will be described in Section 3.3.22. It will also be displayed in a Graphical User Interface (GUI), this is designed such that the rocket will have active GPS, altitude, and acceleration tracking. If the rocket is lost or if it is damaged in any way, it will be easier to locate and there will still be useful data from the launch. The avionics system will also have an on-board microSD card to act as a black box with all garnered data stored.

3.3.19 Avionics Electrical and Transmitters

The electrical system for avionics involves all of the direct sensors and their connections. The electrical system itself involved several blocks including the sensors and transmitter. It also includes the hardware on the ground station. The electrical system includes two transmitters on the rocket. One is located in the nose cone, and the other is located at the beginning of the payload bay. These both include GPS units. The nose cone transmitter is attached to the avionics and is 68 in from the altimeters. The other transmitter in the payload bay controls payload ejection and is 19 in away. They are both surrounded by a ground plane, and the altimeters are surrounded by a slightly conductive carbon fiber frame.

The Avionics PCB can be seen in Figure 56. The Avionics PCB can be seen in Figure 57. These were manufactured from schematics and layout seen in the Appendix Figures, 113, 114, 115, and 116.

The largest concern for the Avionics is the ability to accurately transmit the data and the overall accuracy of the sensors. To increase the reliability as much as possible, separate analog and digital grounds were used. Additionally, the sensors were powered from a linear regulator. This enabled the output power to have minimal noise on the lines which would eliminate the noise on the signal lines if it was induced from the power supply.

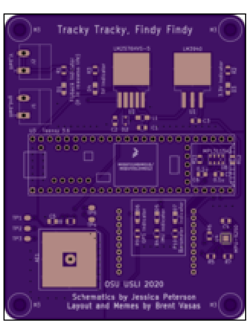

Figure 56: The top of the Avionics PCB

Figure 57: The bottom of the Avionics PCB

To consider some of the factors in the designs, a block diagram was used to visualize the system and the necessary connections. This can be seen in Figure 58.

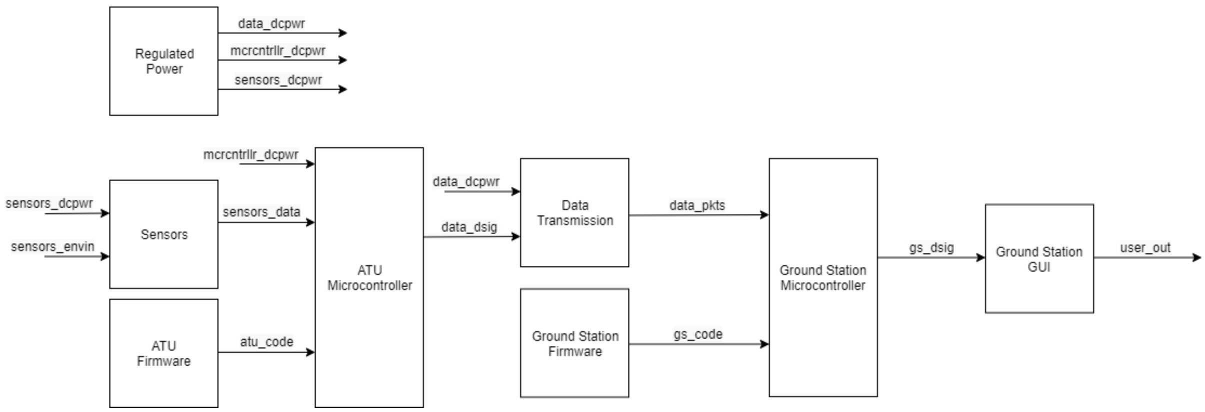

Figure 58: Avionics Electrical Block Diagram

3.3.20 Avionics Electrical Testing

The electrical testing involved separate testing of the different hardware blocks, and then system level testing. The general tests that were done included power consumption, signal integrity, and overall system accuracy. Each sensor was tested to ensure that the power supplied would be enough, and would not harm the sensor in the long term.

Additionally the GPS sensor was tested for accuracy according to known geodetic survey markers. These geodetic survey markers provide absolute coordinates to compare against. Standing near one allows for testing the GPS sensor since any deviations from the actual coordinates can be observed. The barometric pressure sensor was also tested at launch, which the firmware calculates the altitude from. These altitude values were compared with altimeters.

Signal integrity was tested by measuring all of the Universal Asynchronous Receiver-Transmitter (UART) and Inter-Integrated Circuit (I2C) signals appeared as expected. The rise times were recorded.

3.3.21 Recovery System Sensitivity to On-Board Devices

To ensure that there was no problems with interference, the devices were tested with and without the transceivers. The transceivers did not effect the results of the avionics pressure sensor as measured at ground level.

To further ensure that there was no interference between the transceiver and GPS as well as the altimeters, the transceiver and GPS are covered with a ground plane on the bottom, and via stitched on the side. This forms a Faraday cage like structure. This structure combined with the carbon fiber body structure surrounding the altimeters, will serve to isolate the altimeters from the radio signals. The carbon fiber is slightly conductive, and blocks RF signals from testing.

3.3.22 Avionics Software

Avionics software encompasses the firmware code that instructs both the Avionics Telemetry Unit (ATU) and the ground station microcontrollers, as well as the application code that displays telemetry data on the ground station GUI.

3.3.22.1 ATU Firmware

The ATU serves as the remote point from which sensor data is collected and transmitted through telemetry back to the ground station. Here, the operations are driven by a Teensy 3.6 microcontroller. After polling the GPS, barometric pressure sensor, and accelerometer, the set of data is packaged and logged onto the on-board microSD card. Finally, the data packet is sent out from an XBee transceiver. The firmware logic can be visualized in Figure 59 sub-figure "A".

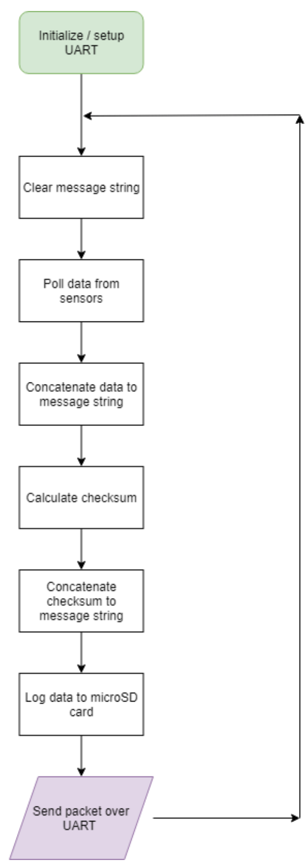

Figure 59: ATU Firmware Flowchart

On erroneous transmission, the packets sent may contain unusual symbols and characters. To rectify this, a checksum calculation was added to both the ATU firmware and avionics ground station firmware. For each packet, a checksum is calculated as follows:

1) Collect sensor values into a string.
2) Obtain the ASCII value for each character.
3) Sum the ASCII values of the string.
4) Modulo the sum by 256.

The ending value is considered the checksum, which is added as the last field within the data packet.

3.3.22.2 Avionics Ground Station Firmware

Like the ATU firmware described in Section 3.3.22.1, the avionics ground station firmware also programs a Teensy 3.6 microcontroller. At the avionics ground station endpoint of the avionics system, the overall logic proceeds according to Figure 59 sub-figure "B".

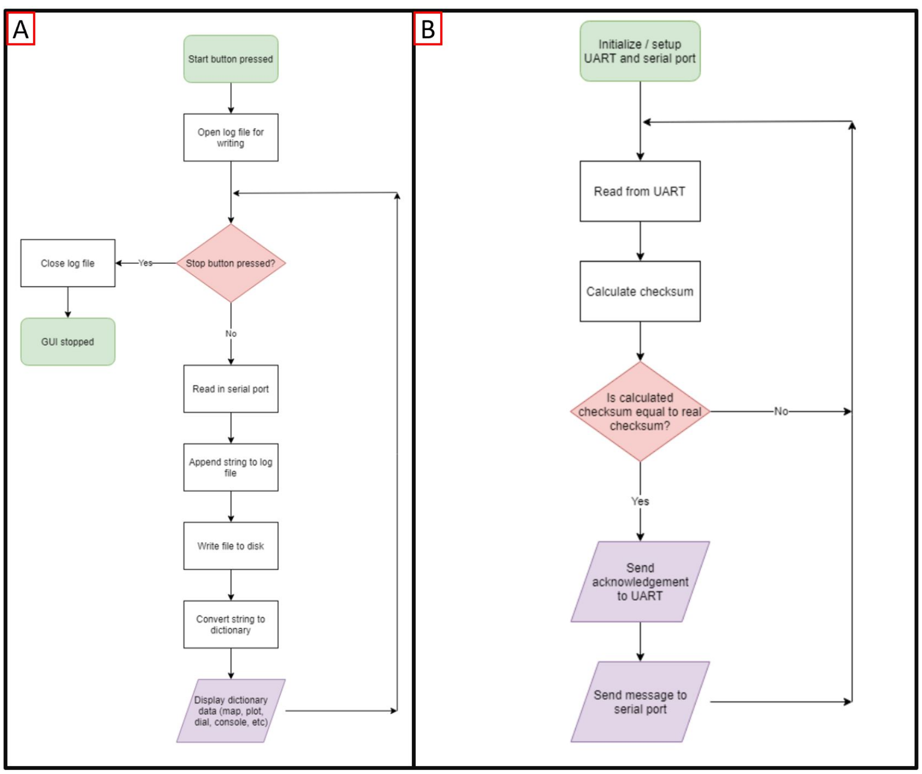

Figure 60: Avionics Flow Charts

"A" shows avionics ground station firmware flowchart; "B" shows avionics ground station GUI Flowchart

At the avionics ground station, the firmware parses every field but the actual checksum value. The checksum is calculated again using the parsed fields and compares the expected checksum to the actual. If the two are equal, the transmission is successful and the data packet is logged. The ground station firmware will additionally reply to the ATU with an acknowledgement message containing the packet number that was just successfully received.

3.3.22.3 Avionics Ground Station GUI

The avionics ground station GUI displays the data received at the ground station end of telemetry. While the Arduino IDE has a built-in serial monitor, the GUI serves its functions and more. The serial monitor displays messages when they are printed; this functionality is easily translated to the GUI as the Python application prints incoming data out to the GUI's console log. The data is also saved to a local Comma Separated Value (CSV) file, which must be forcibly saved to ensure the file's contents stay up to date even in the event of failure. Figure 61 web application prototype of the GUI. The general logic is observed in Figure 59 sub-figure "B".

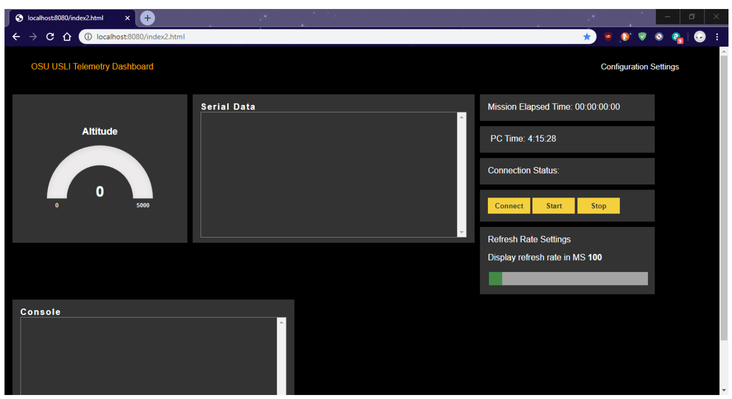

Figure 61: Avionics Ground Station GUI Prototype

3.3.23 Avionics Software Testing

When scaling the firmware over from a test bench GPS sensor, the new GPS sensor appeared to not provide the expected data. Often, this occurs when the GPS module does not acquire a fix with a satellite. Upon further testing, it appeared that the fault was not within hardware, but in the software. Test code that prints the raw National Marine Electronics Association (NMEA) sentences acquired from the GPS indicated that the module was indeed getting a fix. What was not previously accounted for was parsing the multi-Global Navigation Satellite System (GNSS) talker identifier. The ATU firmware was adjusted to include the "GN" identifier, which indicates mixed GPS and Global Navigation Satellite System (GLONASS) data.

The most critical area of software testing concerns the data logs that will be recorded on-board and through the ground station GUI. Each data packet is recorded as a line within the log file, terminating with a newline character. While there are two points in which logs are stored, on-board and on a computer via the avionics ground station GUI, an additional point was added for testing purposes. The avionics ground station microcontroller, being a Teensy 3.6, contains a microSD slot just like how the ATU does. By mirroring firmware code for saving to the microSD card, the GUI's logging capabilities can be compared to what is actually received. The comparison was done through a Python script which compares the logs line by line. Save for the moments the GUI was not running, the contents of the logs matched.

3.3.24 Recovery Integration

3.4 Mission Performance Predictions

3.4.1 Mission Success Criteria

In order for the Launch Vehicle and Payload Demonstration Flight to be successful, all components must fly in the same configuration as they will in Huntsville, Alabama. The launch vehicle must be able to be launched off of a 1515 launch rail, deploy the drogue parachute within 2 seconds of the launch vehicle reaching apogee, and deploy the main parachute before reaching an altitude of 500 ft. The launch vehicle must also land within 90 s of reaching apogee, while maintaining a maximum landing kinetic energy of 75 ft-lbf. The recorded apogee must be able to be recovered from the RRC3 altimeters as well upon landing. After landing, the payload must be able to be ejected from the fore section of the launch vehicle after being moved to an area of the launch site with less sage brush, and must be able to drive. Finally, the payload must also be able to pick up and store at least 10 mL of simulated ice from a collection test bed.

3.4.2 Flight Profile Simulations

Flight profile simulations were done using OpenRocket. Launch day weather conditions and launch site information such as altitude, current air pressure, and wind conditions were input into the simulation in an attempt to prevent or reduce potential error. The simulation predicted the 63.5 lbf launch vehicle would ascend up the rail at an average acceleration of 243 ft/s^2 for 0.29 s before exiting the rail at 70.5 ft/s. It was determined from [6] that OpenRocket time stamps rail exit at full vehicle rod clearance, not the standard designation of foremost rail pin exit. To get the correct rail exit time and velocity, the length between the top of the rail and the fore rail button was used as an effective rail length to replace the rail length in the simulation. The predicted maximum vertical launch acceleration and velocity would occur after 0.91 s at 331.75 ft/s^2, and 2.36 s at 515.02 ft/s respectively. After motor burnout occurs at 2.41 s, the simulation predicted the launch vehicle would achieve an apogee of 4131 ft AGL after 16.6 s. The drogue recovery device would deploy at apogee before descending to approximately 550 ft over 27 s where the main recovery device is deployed, experiencing a maximum recovery acceleration of 3048 ft/s^2 before landing 75 s after launch. The flight profile simulation graph from OpenRocket shown in Figure 62

Figure 62: OpenRocket Flight Profile Simulation

To ensure flight simulations and vehicle dimensions can be tracked accurately, the weight of each piece to be attached to the vehicle was measured and recorded at various stages in the manufacturing process. Careful consideration must be given in the final stages of manufacturing for the launch vehicle as many attachments require a generous amount of epoxy and there is a large amount of surface area to be painted, both of which together added close to a pound of weight to the vehicle.

3.4.3 Computational Fluid Dynamics (CFD) Analysis

CFD analysis of the launch vehicle was utilized using Star-CCM+ to find drag coefficients, both for the vehicle with the airbrakes retained and with the airbrakes extended. This is useful because the algorithm controlling the airbrakes relies on an accurate estimate of drag coefficients to calculate from. While OpenRocket can determine the drag coefficient of the launch vehicle with the blades retracted, it cannot accurately determine the drag coefficient of the launch vehicle with the blades extended.

Unfortunately, the simulations coefficients never matched up within a reasonable error margin with the OpenRocket coefficients, and it was determined that the OpenRocket coefficient of drag was more reliable. The Star-CCM+ drag coefficients were always marginally larger than the OpenRocket coefficient, which is already assumed to be on the large end. The Star-CCM+ drag coefficients ranged between 0.58 - 0.69 depending on the mesh size and physics conditions.

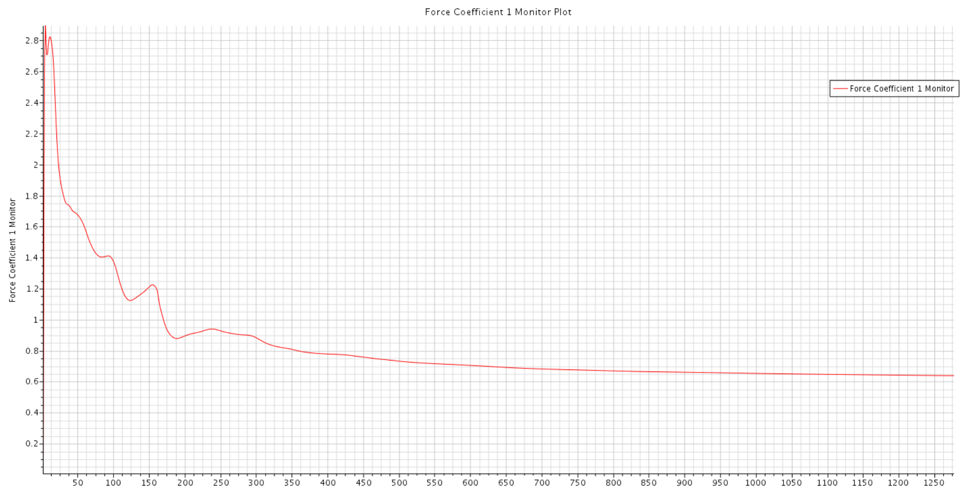

Figure 63: Star-CCM+ Drag Coefficient Plot

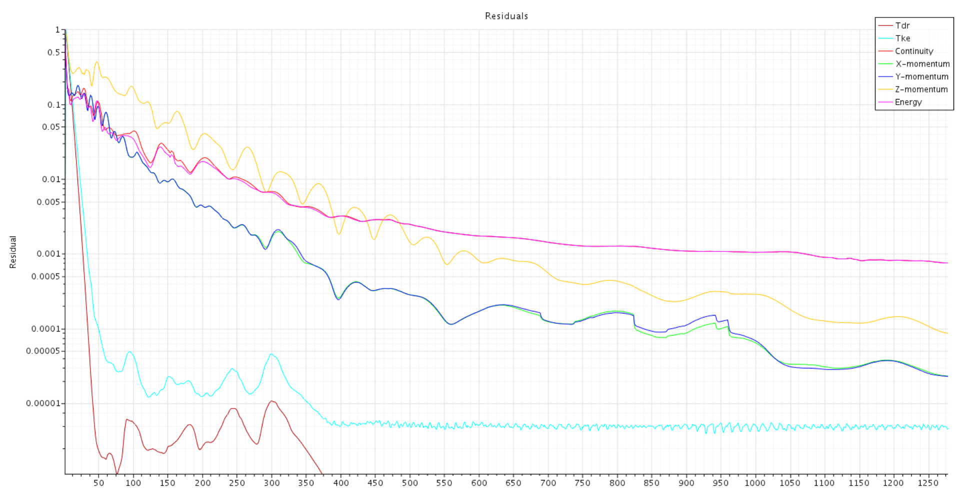

Figure 64: OpenRocket Star-CCM+ Residuals Plot

3.4.4 Stability Margin

The center of gravity and center of pressure were calculated in OpenRocket to be 71.124 in., and calculated to be 88.654 in. from the tip of the nose cone respectively. These measurements yield a static stability margin of 2.73 calibers, well above the 2.00 caliber competition minimum.

3.4.5 Landing Kinetic Energy Estimations

During the Feb 22 2020 launch in Brothers OR. The recovery system was completely successful having a drogue at apogee and a main at 600ft. However we were unable to collect completely accurate flight data s the nose cone fell off 600ft above the ground during main parachute deployment. From the plots and data it can be interpreted that the landing velocity is 15 ft/s. This resulted in 76.3 ft-lbs for the fore section, 19.56 ft-lbs for the coupler, and 74.5 ft-lbs for the aft section. This is slightly off of our data, mostly due to the failure of the nose cone retention and loss of avionics data.

3.4.6 Descent Time Estimations

Using OpenRocket simulation, the descent time was calculated to be 26.8 s from apogee to main parachute deployment, and 32 s from main deployment to landing.This sums to a predicted descent time of 58.8 s. This compares to our simulations fairly closely as it was calculated that the descent would be 64 s for the fullscale launch.

3.4.7 Drift Estimations

OpenRocket was also used as a redundant form of approximation for drift calculations.The simulation predicted that the vehicle would land approximately 110 ft away from the launch pad.

3.5 Launch Vehicle Demonstration Flight

OSRT's Launch Vehicle Demonstration Flight took place on Saturday, February 22nd, 2020 on Oregon Rocketry (OROC)'s property in Brothers, Oregon. The motor burned for 2.32 seconds, and it took the launch vehicle approximately 16.95 s to reach an apogee of approximately 4,456 ft. Upon reaching apogee, the primary drogue charge detonated, but did not manage to deploy the drogue parachute. The backup drogue charge detonated 0.95 s after apogee, and the drogue parachute did deploy, however, it was unable to inflate. The launch vehicle continued to descend, and the primary main charge detonated at 58.3 s into flight, when the altimeter read an altitude of 532.86 ft. The backup charge also detonated at 58.3 s into flight when the altimeter read an altitude of 504.38 ft. The main parachute deployed, and the $1/4$-in. 0-80 shear pins that held the nose cone to the fore section of the airframe sheared, allowing the nose cone to fall approximately 500 ft. The payload, however, was successfully retained, so the nose cone was the only portion of the launch vehicle or payload that fell without a parachute. The launch vehicle landed approximately 87 seconds after launch. The data from the custom avionics was received at a ground station made with a custom PCB, Teensy 3.6 and XBee transceiver.

3.5.1 Launch Day Conditions

When the team arrived at the launch site at approximately 08:00, the weather was clear but cold with a temperature around 35 degrees Fahrenheit, as the sun had just risen at 07:04 Pacific Standard Time (PST). The relative humidity was on its way down from 100% at 06:00, and the ground was completely devoid of snow and was also dry. No watches or warnings were in effect, and the fire danger was rated as low. By the time OSRT was ready to launch at 12:45, the temperature had reached around 54 degrees Fahrenheit, and the humidity had dropped to 59%. Wind was minimal, and the sky was also clear, as seen in Figure 65 sub-figure "A".

Figure 65: Launch Day Conditions as the Launch Vehicle is Placed on the Rail

"A" shows launch day conditions as the launch Vehicle is placed on the Rail; "B" shows first launch of the OSRT launch vehicle

3.5.2 Analysis of Launch Vehicle Demonstration Flight

The flight path of the launch vehicle was as follows: The launch vehicle came off the launch rail, and came off the rail straight, as shown in Figure 65 sub-figure "B", below.

From the simulation OpenRocket, it was predicted the launch vehicle would reach an apogee of 4131 ft. With this data, the coefficient of drag calculated by OpenRocket was an average of 0.469 between motor burnout and apogee.

According to the two Missile Works RRC3 altimeters, as seen in Figures 66 and 67, and the avionics data, which comes from the avionics in the nose cone, as seen in Figure 68, the launch vehicle reached an altitude of approximately 4456 ft. From the primary RRC3, once the launch vehicle reached apogee, the main drogue charge was then detonated. However, it appeared from the ground that the drogue parachute did not deploy immediately at apogee, as seen in Figure 69 sub-figure "A", and that it deployed 0.95 s later when the backup drogue charge detonated, as seen in Figure 69 sub-figure "B". The team originally thought that the drogue parachute did not inflate, however, photographic evidence, as seen in Figure 69 sub-figure "C", shows that the drogue parachute did indeed inflate. It was just so far away at the time, and the drogue parachute was so small as it is, that it looked like the drogue parachute was not having much of an impact on the launch vehicle's descent. The main parachute primary and secondary charges deployed in tandem at 53.8 seconds into flight, which was where both the nose cone became detached, as seen in Figure 69 sub-figure "D", and fell approximately 500 ft.

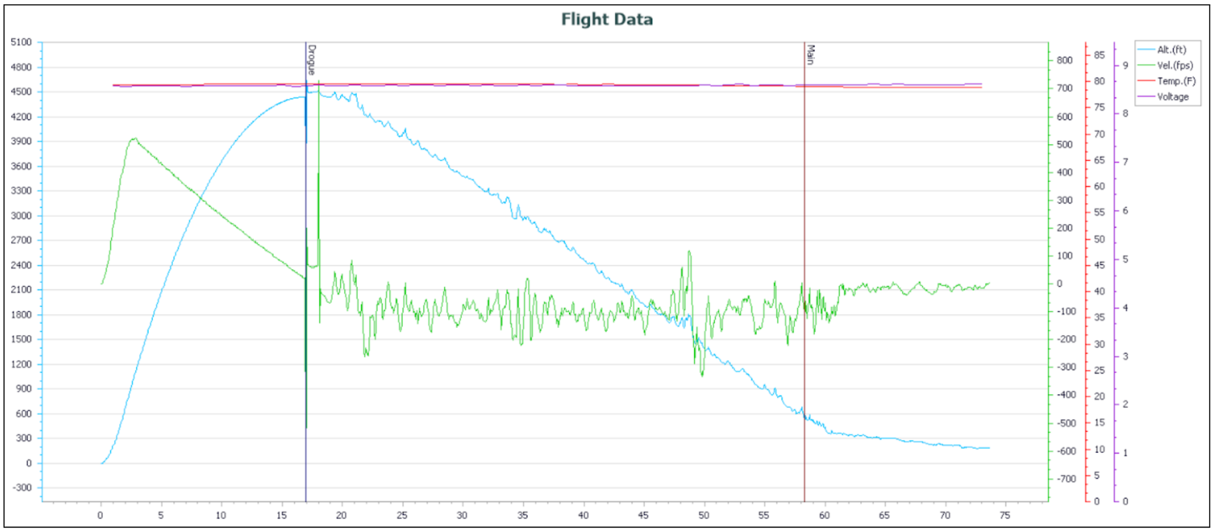

Figure 66: Primary RRC3 Raw Data

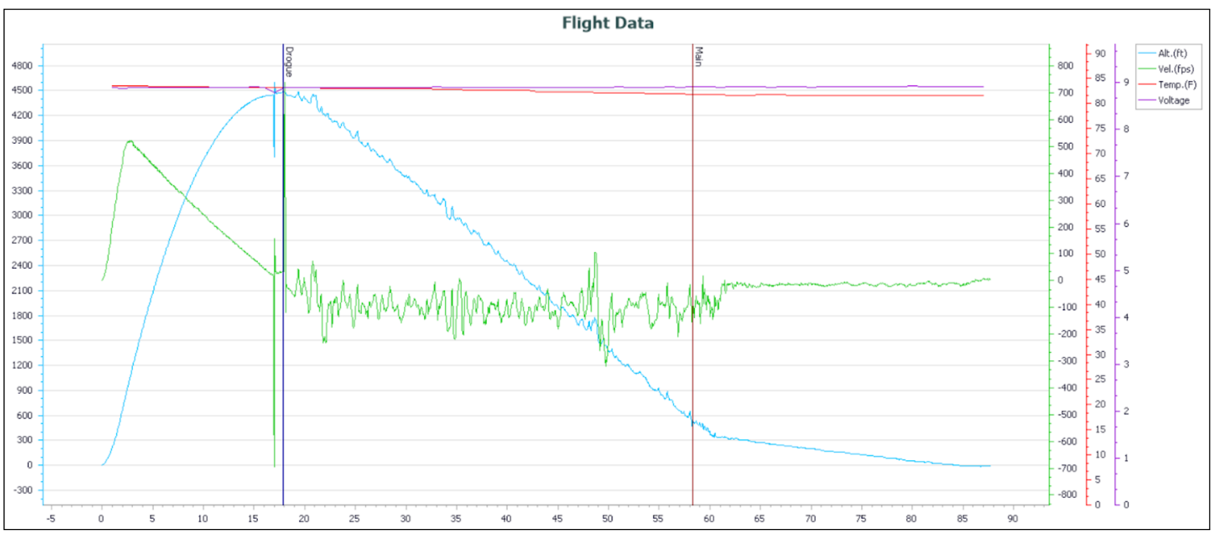

Figure 67: Backup RRC3 Raw Data

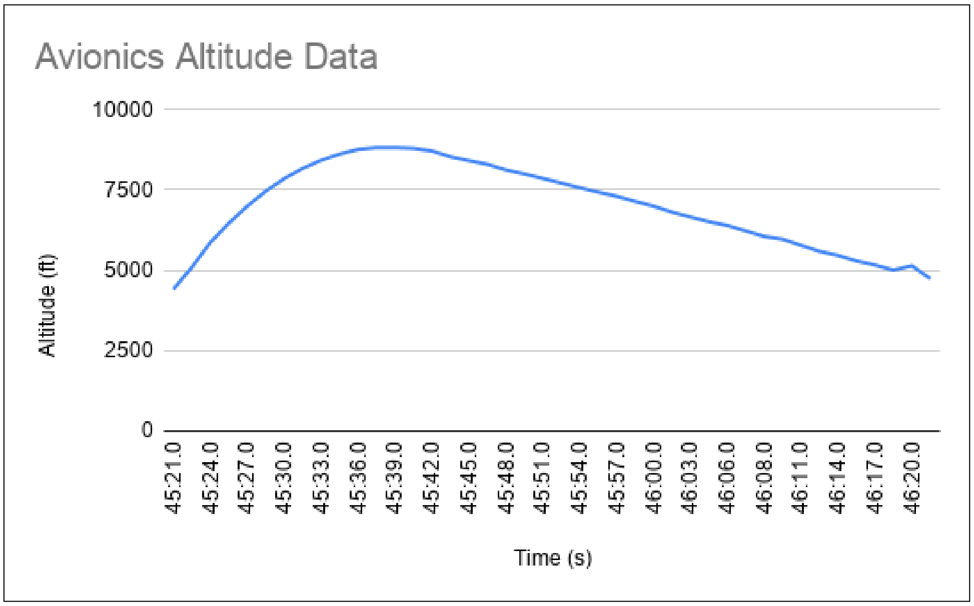

Figure 68: Avionics Raw Altitude Data

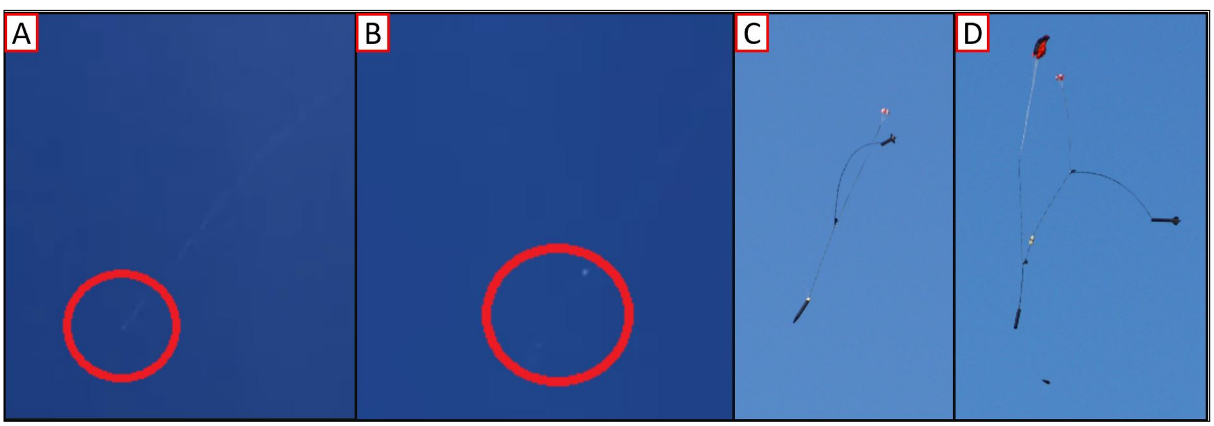

Figure 69: Launch Vehicle Recovery

"A" shows recovery system failing to deploy drogue at apogee; "B" shows drogue parachute deploying with backup charge; "C" shows drogue open during descent; "D" shows main deploying while the Nose Cone has become detached

3.5.2.1 Nose Cone Detachment Inspection, Analysis, and Conclusion

After recovering the nose cone and the rest of the launch vehicle and returning to the team's integration tables, a Post-Flight Assessment was conducted, where the nose cone, nose cone coupler, and the fore section of the airframe were inspected to see what happened that could have caused the nose cone to separate from the rest of the launch vehicle. Originally, it was thought that, since the team was only using 3 1/4-inch long

#0-80 shear pins to hold the nose cone to the rest of the launch vehicle, that the force of the main parachute opening would have sheared the pins. However, after reviewing Figure 69 sub-figure "D", it was clear that the nose cone had become detached well before the main parachute ever opened. Since the parachute had not caused the shear pins to shear, the next thought for the team was that the BP charges must have caused enough force to shear the pins, since the main BP charges went off simultaneously. However, the main parachute is attached between the coupler and the fore section of the launch vehicle, and, therefore, with the BP charges pushing the parachute out of the parachute bay, the charge would have also pushed the fore section of the airframe into the nose cone as opposed to away from it, and therefore, it would not have been able to shear the pins. From that point, since neither the parachute opening nor the BP charges could not have sheared the pins and caused the nose cone to free fall from 500 ft, the team then inspected the shear pin holes. It was then noticed that, when putting in the 1/4-inch long #2-56 shear pins for the other section interfaces in the launch vehicle, the #2-56 shear pins needed to be tapped several times with a mallet in order to be pushed into their respective holes, while the #0-80 shear pins could easily be placed in their respective holes simply with the push of a finger. Therefore, it was established that the holes for the #0-80 shear pins had been drilled to be too large, and therefore, the shear pins had fallen out on descent through launch forces throughout the entire duration of the flight. From this, the team resolved that the current shear pin holes would need to be re-drilled to hold the shear pins better to ensure that they only stop holding when the team wants them to.

3.5.2.2 Nose Cone Damage Sustained

The nose cone free fell from approximately 500 ft in altitude, and impacted the ground on its side, as seen in Figure 70 sub-figure "A". Upon finding it, the team did an on-site inspection of the damage and immediately noticed two things: first, that some rocks and dirt had been embedded into the exterior of the nose cone, and that there were some large fractures in the nose cone's coupler, as seen in Figure 70 sub-figure "C". Upon further inspection, it was discovered that the 2.1 lbs of ballast that had been placed in the nose cone and secured via the threaded through rod had gone through the fiberglass coupler upon impact, as seen in Figure 70 subfigure "D". Once returning the nose cone to the team's integration tables, OSRT was able to disassemble the nose cone to see the extent of the interior damage that had been sustained by the threaded through rod and the avionics bay within the nose cone. The damage turned out to be rather extensive, as the threaded rod was mangled, as seen in Figure 70 "sub-figure "B".

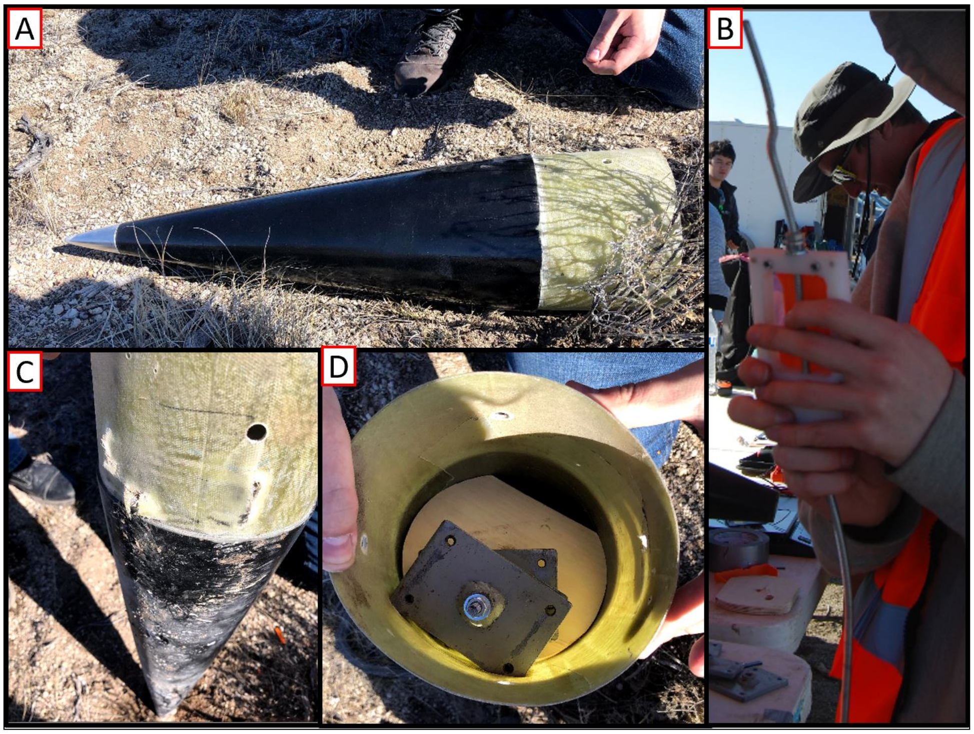

Figure 70: Nose Cone Landing Landing

"A" shows Nose Cone landing orientation; "B" shows the threaded rod condition after flight;"C" shows Nose Cone exterior damage; "D" shows the ballast going through the nose cone coupler.

3.5.2.3 Avionics Electronics Analysis

Following the launch the avionics system was removed from the nose cone. The various elements were tested separately, the result can be seen in Figure 71 sub-figure "A". The data collected was found to be accurate with the altimeters.

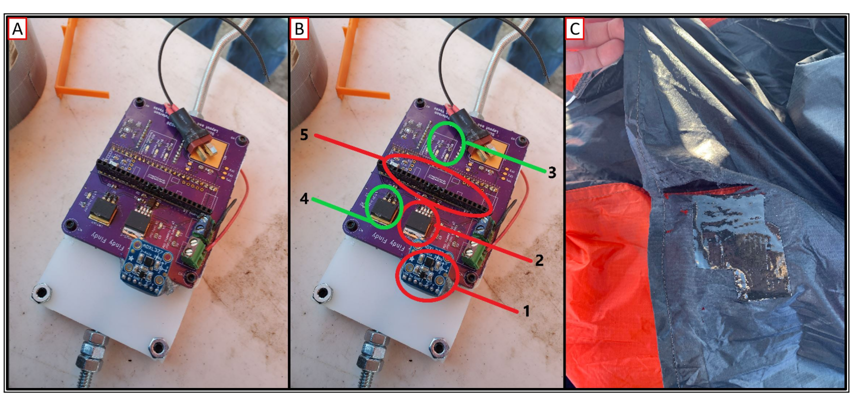

Figure 71: Avionics from Full-scale flight

"A" shows Avionics from Full-scale flight; "B" shows Avionics from full scale with indicators; "C" shows Full Scale 1 Burnt Main Parachute

Each one of these parts were tested individually. The LiPo battery was completely compromised, and was disposed of immediately.This damaged battery is believed to have caused damage to the regulators afterwards. The regulators are in circles 2 and 4 in Figure 71 sub-figure "B". The voltage regulator in circle 2 which received the current directly from the battery and regulated down to 5V, was broken. It was powered separately, and was supplied with 8 V from a DC supply, immediately after receiving power it heated up more than earlier tests indicated, and gave a loud humming noise. The 5 V regulator was isolated from the rest of the system, and the 3.3 V regulator (circle 4) was given 5 V from a lab power supply. It regulated down to 3.29 V, within the specifications of the interface. It is believed the 5 V regulator failed, protecting the 3.3 V regulator from any voltage surge. The GPS was then tested to check its signal reception. It was powered separately from the regulators to ensure that no other damage could occur. It functioned as expected. The antenna was ripped out and had to be replaced. The accelerometer shown in the first circle in Figure 71. It did not function, and gave unreasonable data. It was detached from the board before testing. The XBee transceiver was detached, and was fully functional. The Teensy microcontroller was also tested, and was functional, but requires a new USB plug. No headers were salvageable.

3.5.2.4 Parachutes Condition

Drogue - Upon inspection, the drogue parachute had no thermal damage from the black powder or other physical damages to the chute or shroud lines. Despite this, due to the late ejection charges, the parachute had issues catching air and properly slowing the vehicle. The elliptical parachute is not rated for the forces that the vehicle endured due to the late ejection and therefore OSRT will be moving forward with a cruciform drogue parachute for safety purposes.

Main - The main parachute endured some holes from the black powder charges.

3.5.2.5 Parachutes Repair Plan

The main parachute has a few charred portions due to testing and the full scale launch, shown in Figure 71 sub-figure "C". A parachute repair adhesive/tape has been ordered to properly patch the holes before the next flight. In order to reduce the chances of the main parachute acquiring more damage, the holes in the blankets in which the shock cord is fed through will be tightened to the shock cord via a nylon sleeve.

3.5.2.6 Altimeters and Avionics Comparison and Analysis

After being able to pull the data off of both of the RRC3 altimeters and off of the Avionics, an analysis was conducted as to the accuracy of both the RRC3 data and the avionics data. First, an overlay of the raw altitudes and velocities collected by both of the RRC3 altimeters was made to ensure that the two altimeters agreed with each other data-wise. As seen in Figure 72, the altimeters collected virtually the same data, validating that they were both working properly within the altimeter bay.

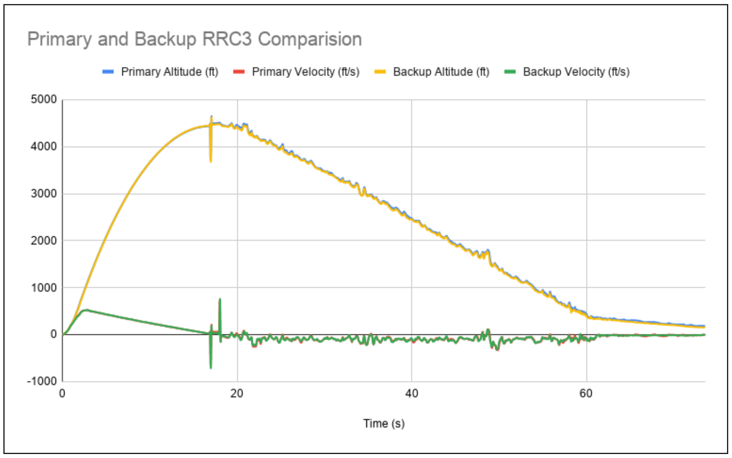

Figure 72: Comparison of the Two RRC3 Altimeters' Data

From there, another overlay was created, this time of the altitudes collected by the two RRC3 altimeters and the avionics to ensure that the systems in the two different sections of the launch vehicle agreed with each other. Since the avionics only collected data every 1-2 seconds, the data from the RRC3s was cut paired down to the same every 1-2 seconds to allow all three data sets to be plotted on the same graph. As seen in Figure 73, the altitude data from the RRC3 altimeters and the avionics are extremely close to each other, and therefore validate the functionality of the static port holes within each of the bays allowing enough access to the atmosphere to equalize the air pressure within the bays to the air pressure outside of the bays.

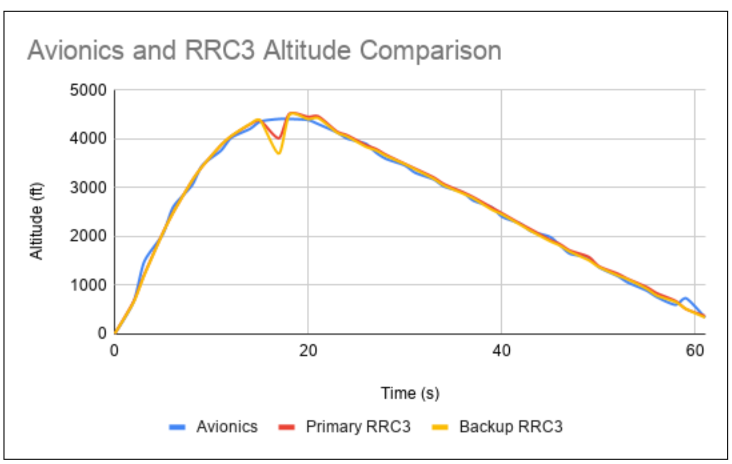

Figure 73: Comparison of the Two RRC3 Altimeters' Data and that of the Avionics

One interesting thing that was noted by the team was that there was a rather large dip in altitude collected by the RRC3 altimeters in the graphs seen in Figures 72 and 73, as well as in the raw data shown in Figures 66 and 67, right during the time of the primary drogue's BP charge detonation. This could possibly explain why the primary drogue charge was unable to deploy the drogue parachute at apogee, as a sudden recorded decrease in apogee suggests that the pressure within the bay increased suddenly, and that could have only been accomplished by having some of the pressure from within the drogue parachute bay leaking into the altimeter bay upon BP detonation. With enough pressure from the charge leaking into the altimeter bay and venting out through the static port holes, the charge would not have been able to deploy the parachute, even though the charge had a safety factor of over 5.

3.5.3 Payload Test Flight 1

The payload's first FRR test flight was on 2/22/2020. For this flight the payload was flown without the rover PCB and camera. Other than the rover electronics the payload was fully assembled with batteries. Shown in Figure 74 are photos from this flight. The payload was integrated in Graf hall at Oregon State University (OSU) the night of 2/21/2020, as per the OSRT checklists. Shown in sub-figure "A" is integration and testing of the ejection system. The payload was integrated into the airframe without the batteries then sent to the launch site. At launch the payload was removed, inspected according to the payload integration checklist, and adding/testing batteries where necessary, as shown in sub-figures "B" and "C". The payload was then weighed at launch, with a recorded weight of 6.42 pounds (sub-figure "D"). This weight was lower than OSRT planned so ballast was added to the nose-cone to balance the launch vehicle. The payload was then inserted and fastened into the payload bay of the fore section of the air frame, followed by the nose cone ("E" and "F"). Prior to installation the ejection system was tested to ensure proper function. Checking direction of motor/leadscrew spin, as well as radio handshake connection. The payload ground-station electronics are shown in sub-figures "G", "H", and "I". The system was then flown within the airframe. After recovery, the fore-section and payload were carried back to the launch site. Initial inspection showed no damage to the payload itself. The ejection system was then actuated. The motor was successfully turned on, however; the leadscrew did not spin. After disassembly it was discovered that the lead screw coupler had slipped from the motor, causing the setscrew to slip on the motor shaft when rotated. The payload after flight is shown in sub-figure "J" and "K". The entire system was intact with no signs of damage to any payload components. During disassembly of the payload it was discovered that one of the two wheels loosened. In conclusion the payload sustained no noticeable damage to any component. The retention system was successful and showed no signs of wear. The ejection system failed, due the motor coupler setscrew loosening. One of the rover wheel couplers also failed. If the rover had been active this would have resulted in the wheel falling off mid-mission.

OSRT payload will be focusing its efforts on reinforcing all payload couplers before the demonstration flight. Large notches will be machined in all motor shafts. This will provide a provide a seat for all set crews. Each coupler will also use 2X set screws per motor shaft, and integration will require the use of lock-tight to protect these fasteners from loosening due to flight forces. Due to the in flight, rapid disassembly of the nose cone, payload team will be investigating additional fastening techniques to better secure the nose cone to the airframe. Specifically attaching the nose cone to the leadscrew using shock cord. This will be further described in the structures section of the report.

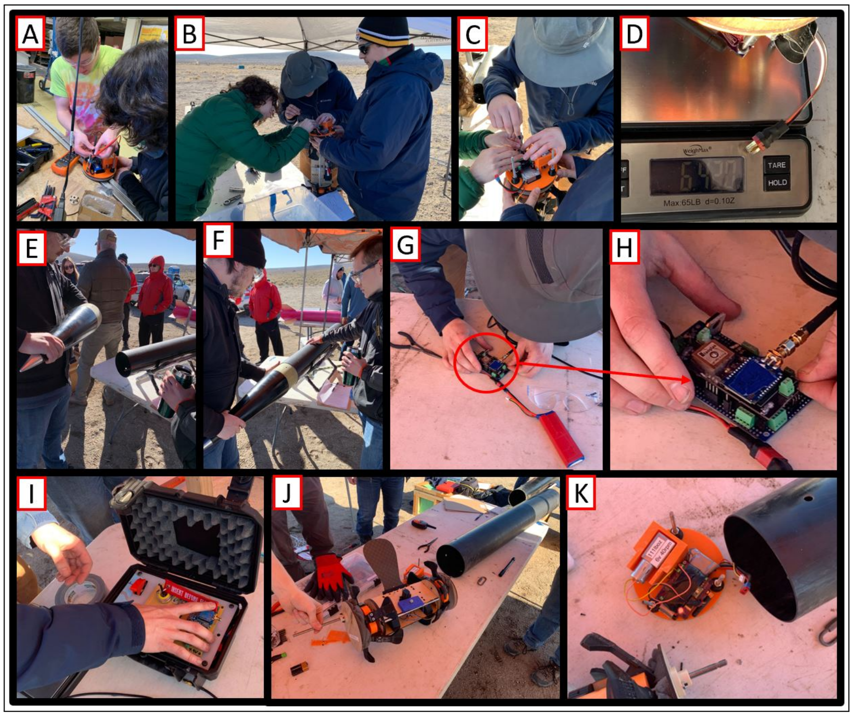

Figure 74: Payload Test Flight 1

"A" shows payload integration at OSU; "B" shows final payload integration at the FRR test launch; "C" shows payload electrical testing; "D" shows payload weight at test launch; "E" and "F" shows the final step of payload integration; "G", "E" and "I" show the ejection system ground control; "J" and "K" show the payload post launch with no noticeable signs of damage.

3.5.4 BEAVS 2.0 Test Flight 1

BEAVS 2.0 was fully integrated into full scale flight 1, although it was not active. This is due to a handful of reasons. The main reason being that the servo arm which the gear sat on was only a straight member and therefore allowed for the gear to tilt when rotated, and this would push the racks off the gears. This was discovered the night before launch and therefore the aluminum rail pushers added to the BEAVS CAD figure 112. The sensors used in the system were not calibrated before the launch so they were unable to record proper flight data. The team will push to get the system active before full scale 2.

3.5.5 Launch Vehicle Landing Kinetic Energy

During the launch on Feb 22 2020, in Brothers, OR there were errors collecting data specifically for landing kinetic energy. The nose cone full of the avionics fell out 600ft above the ground. From the data we did get however it was estimated that the landing speed was around 15ft/s. This resulted in 76ft-lbs for the fore section,

3.5.6 Verification of Coefficient of Drag

After collecting the flight data from the RRC3 altimeters, the coefficient of drag was calculated. Since the two altimeters' altitude and velocity data were so close to each other, the team decided that it would only be necessary to calculate the coefficient of drag from one RRC3 altimeter, and, therefore, the team chose to calculate the coefficient of drag using the data collected from the primary altimeter.

First, the altitude and time data was extracted from the RRC3 and put into an Excel sheet. From there, velocity at each data point was solved for by completing a left-sided finite difference scheme first order equation, shown in Equation 15.

$$^{\delta u}/_{\delta x} = ^{u_i - u_{i-1}}/_{\Delta x} \tag{15}$$

After finding each velocity data point, the total surface area of the launch vehicle was found, since the team decided that it would be best to take the approach that drag is being caused by the friction between the air and the surface of the launch vehicle. The surface area of the nose cone and fins were calculated from their CAD models, but the surface area of the airframe was calculated by Equations 16 and 17.

$$C = \pi * D \tag{16}$$

$$SA = C * h \tag{17}$$

In the equations above, the circumference is the variable C, D is the exterior diameter, and h is the total length of the airframe, all in inches. In order to increase the accuracy of the calculations, the surface area that was taken away from the airframe by the fins was subtracted from the overall surface area of the airframe, and then the surface areas of the four fins, the airframe, and the nose cone were added together to get the total surface area.

Next, the air density of the launch site was derived by first finding the air pressure at 4639 ft above sea level, which is the altitude of the launch site when the temperature was 54 degrees Fahrenheit with Equation 18, where P_b is the pressure at sea level in psi, T_b is the temperature at sea level in kelvin, L_b is the standard temperature lapse rate, which is -0.0065 K/m, h is the height above sea level, h_b is the height at the bottom of the nearest atmospheric layer in meters, R is the universal gas constant, which is 8.31 N*m/mol*K, g_o is the acceleration due to gravity, which is 9.81 m/s/s, and M is the molar mass of Earth's air, which is 0.0289644 kg/mol.

$$P = P_b * [1 + {}^{L_b}/_{T_b} * (h - h_b)]^{(-g_o*M)/(R*L_b)} \tag{18}$$

Then, the air density was calculated via the following series of equations, where T is the air temperature in kelvin, RH is the relative humidity, R_d is the specific gas constant for dry air, which is equal to 287.058 J/kg*K, and R_v is the specific gas constant for water vapor, which is 461.495 J/kg*K, and ρ is the air density in Pa.

$$SaturationVaporPressure(P_1) = 6.1075 * 10^{7.5*T/T+237.3} \tag{19}$$

$$VaporPressure(P_v) = P_1 * RH \tag{20}$$

$$DryAirPressure(P_d) = P - P_v \tag{21}$$

$$\rho = {}^{P_d}/_{(R_d*T} + {}^{P_v}/_{(R_v*T)} \tag{22}$$

Finally, the mass of the launch vehicle was calculated by finding the completely integrated weight of 57.9 lbs., which was then divided by 32.2 ft/s/s. From there, the mass of the fully assembled motor and the empty motor were found through open rocket, the mass of the fully assembled motor was subtracted from the total launch vehicle mass, and the mass of the empty motor was added to the remaining launch vehicle mass.

Finally, the acceleration was found by completing a left-side finite difference scheme first order equation, shown in Equation 23.

$$ {}^{\delta^2 u}/_{\delta x^2} = {}^{(u_i - 2*u_{i-1} + u_{i-2})}/_{(\Delta x^2)} \tag{23}$$

Finally, after solving for all of the variables, Equation 24 was used to solve for the coefficient of drag by finding the coefficient of drag for each of the data points, and then taking the average of all of those data points.

$$C_d = -{}^{(a+g)*2*m}/_{A*\rho*V^2} \tag{24}$$

From all of this, the calculated coefficient of drag is .37.

3.5.7 Conservative Simulations and Drag Coefficient

The actual data from the altimeters and the GPS agreed with each other for the most part. It was determined that the differential between the OpenRocket simulation predicted apogee and the actual flight test apogee data was likely caused by some input error or another factor in the back end calculations OpenRocket performs to simulate data. In order to obtain a more accurate prediction for future simulations, hand calculations of the drag coefficient were conducted. These hand calculations yielded an estimated drag coefficient of 0.37 while OpenRocket had estimated 0.47. This difference would be significant enough for the launch vehicle to reach a higher then expected apogee. With some research into how the simulation uses drag coefficients, it was found that other users had experienced the same relationship between simulation and actual data.

Another simulation was created to compare how the flight data is altered by the two different drag coefficients. Since OpenRocket does not allow the drag coefficient of the launch vehicle to be directly modified, a vehicle modification and a simulation modification were implemented that resulted in pseudo-control of the drag coefficient. The vehicle modification recommended by other users was to assign polish finish to all structure bodies, thereby decreasing the surface drag. This method provided an altered drag coefficient of 0.39, much closer to that of the hand calculations. The simulation modification was to alter the ground level altitude to reduce air density leading to a linear decrease in drag coefficient, although this method was determined to be less accurate. With the polished surfaces method, the simulation now predicted the vehicle would reach apogee after 16.9 s and at 4286 ft. This approximation eliminated the time to apogee differential and reduced the apogee gap from 321 ft to 166 ft, a 3.7% error that can likely be accounted by error in some weight measurements. Based on all versions of flight simulation, the launch vehicle will exceed the target altitude, implying that BEAVS is very likely to deploy during flight in Huntsville.

3.5.8 Differences from Subscale

Full scale launch 1 had some very large differences from the subscale flight that was completed before. There was two systems, BEAVS and payload, that were integrated that had not been present in the subscale launch. This complicated the integration, but was accounted for in preparation and checklists. The launch vehicle itself was a full scale version of final size, with only the BEAVS and payload systems being not completely active. The launch rail used was a full 12 foot 1515 rail. The motor was the final motor of an L2200, with a full 5.5 lbf of ballast in the launch vehicle. The height was also projected to be above 4000 ft, more then double what the subscale flight flew to. The launch vehicle upon landing was visible due to the large size of the parachute and did not require GPS to find. The nose cone after discovered missing was located using the last transmitted coordinates however unlike subscale.

3.6 Reliability and Flight Readiness

OSRT's Launch Vehicle Demonstration Flight was not successful because of how the nose cone was lost at roughly 500 ft AGL, how BEAVS 2.0 was not operating in the same configuration that it will fly in Huntsville, and because of how the deployment for both the drogue and the main parachutes, while acceptable, should be more reliable and should not depend on the backup BP charges in order to deploy either parachute. Therefore, the reliability needs to be improved, and OSRT will need to refly after the FRR due date on Monday, March 2nd, 2020 at 8:00am Central Standard Time (CST). OSRT has notified the coordinators of this program about the necessity of a reflight after FRR is due, and was granted permission for a reflight by Mr. Fred Kepner on Monday, February 24th. The next Launch Vehicle and Payload Demonstration Flight is scheduled for Saturday, March 7th, 2020 in Brothers, Oregon.

4 Payload

4.1 Payload Mission Statement

The payload is capable of withstanding the forces created from being launched from within a high power launch vehicle, land and deploy from the launch vehicle housing, and collect a simulated lunar ice sample from one of several sites on the launch field. In order to successfully withstand the forces produced during the launch and landing of the flight vehicle, there must be a fail-safe retention system which prevents in-flight early deployment. To deploy, there must be a mechanical ejection system. Lastly, the Payload will need to travel the terrain to one of the simulated ice sample locations and collect at least 10 ml of simulated ice sample. To complete the challenge, the payload will have to drive at least ten linear feet away from the collection site with the collected sample to signify a non-existent recovery operation.

4.2 Payload Test Flight

4.2.1 Mission Success Criteria

Payload mission success can be defined as faithfully fulfilling and completing all of the requirements put forward in the Payload Mission Statement. This requires the payload to withstand launch forces, eject successfully, navigate to the collection site, collect the sample, and carry the sample 10 linear ft away from the collection site. In addition to these requirements, there are certain safety related requirements that the payload must follow in pursuit of the mission. The payload must be contained within a fail-safe retention system and the payload must be ejected from the airframe through purely mechanical means without the use of energetics.

4.2.2 Results of Payload Flight

The payload was flow on 2-22-2020 for OSRT's first full scale flight. **This was not the payload demonstration flight** The payload was flown with everything except the rover PCB and camera. Shown in Figure 75 are the events of that day. Beginning with payload integration according to checklists ("A" to "F"). Followed by the launch vehicle flight. The fore section landed as shown in "G". The nose cone unexpectedly ejected in flight. Leaving the payload exposed during recovery. Autonomous ejection of the payload was attempted and failed. The setscrew holding the coupler to the motor came loose and began to slip. The payload was then manually removed ("H"). After inspection of the payload, no damage was found to any of the components. The set screw in one of the wheels came loose, causing one of the wheels to come off, which would have resulted in mission failure.

The payload test flight will happen 3-7-2020. For this launch, the payload will be flown in a launch vehicle. Once landed, the launch vehicle will be carried to the staging area, placed back into its original orientation, then the payload will be remotely ejected. After ejection the payload will be driven around the recovery area. Then once back at OSU the rover will run a simulated collection in a test bed.

Figure 75: Payload Full Scale Launch 1

"A" through "I" shows the payload as launch day events progressed; "A", "B" show the payload being prepared as the team follows the integration checklist; "C" and "D" show the payload being weighed; "E" shows the payload electronics being turned on; "F" shows the payload inside the airframe; "G" shows the payload after launch, "1" shows the open payload bay; "H" shows the payload being removed from the airframe; "I" and "J" show the payload after launch; "K" show the payload as it is packed up after launch.

4.2.3 Retention System Performance Analysis

After flight an in-depth investigation was done on the entire collection system. Shown in Figure 76 are all notable findings from said investigation. To begin, the overall ejection system is shown in sub-figures "A" and "B". The first item of note was signs of wear on the motor shaft. The set screw seat in the d-shaft is clearly shown by a round impression ("C.1") and there is a ring of worn surface on the shaft ("D.1"). The circular impression is evidence that the setscrew was securely fastened, and the wear-ring is evidence that the setscrew came loose and slipped on the shaft itself. This was most likely caused by the impact of the parachute deployment. As predicted, this may have caused the setscrew to slip on the motor, resulting in the coupler pressing against the retaining bulkhead.

Second item of note is the leadscrew itself. Investigation of the leadscrew showed no sign of wear or fatigue in the pin hole shown in sub-figure "E.1". However, since the nose cone will now be connected to the leadscrew, OSRT will be reinforcing this system by using a lead screw with a smaller hole and replacing the pin with a smaller titanium screw. This will increase the strength of the rod while not compromising the strength of the pin.

The third item of note is the ejection electronics. As shown in sub-figures "F", "G", and "H" there was no sign of damage to this system. This also confirmed by the electronics successfully turning the motor on after flight. Regardless, a battery cover will be added to better protect and retain the ejection battery.

The fourth item of note is the retaining bulkhead ("I"). This component retains the coupler, and with it the leadscrew. On the coupler side of the bulkhead ("B.1" and "J.1") it is obvious that the lead screw came in contact with the bulkhead during the mission. There is a discolored ring around the lead screw hole, with small wear lines that were most likely a result of the coupler rotating. On the fore side of this coupler ("K") there are further signs of wear. First there is a circular impression ("K.1"), which is most likely caused by the coupler impacting the bulkhead when the parachute deployed. There are also small signs of delamination on this side of the bulkhead ("K.2"). This system was successful, but this bulkhead will be made from a thicker material for better strength, and a washer will be placed between this system and the coupler to better distribute the force.

The final item of note is the fore mobile bulkhead shown in Figure 76 sub-figure "L". This is the component that pushed against the nose cone. There were no signs of wear on its outer race ("M"), from pushing on the nose cone coupler. There were also no signs of frictionwear on its circumference. As a result of this inspection, OSRT will be strengthening the retention system for an increased factor of safety, although the full scale test has shown the system to function as expected.

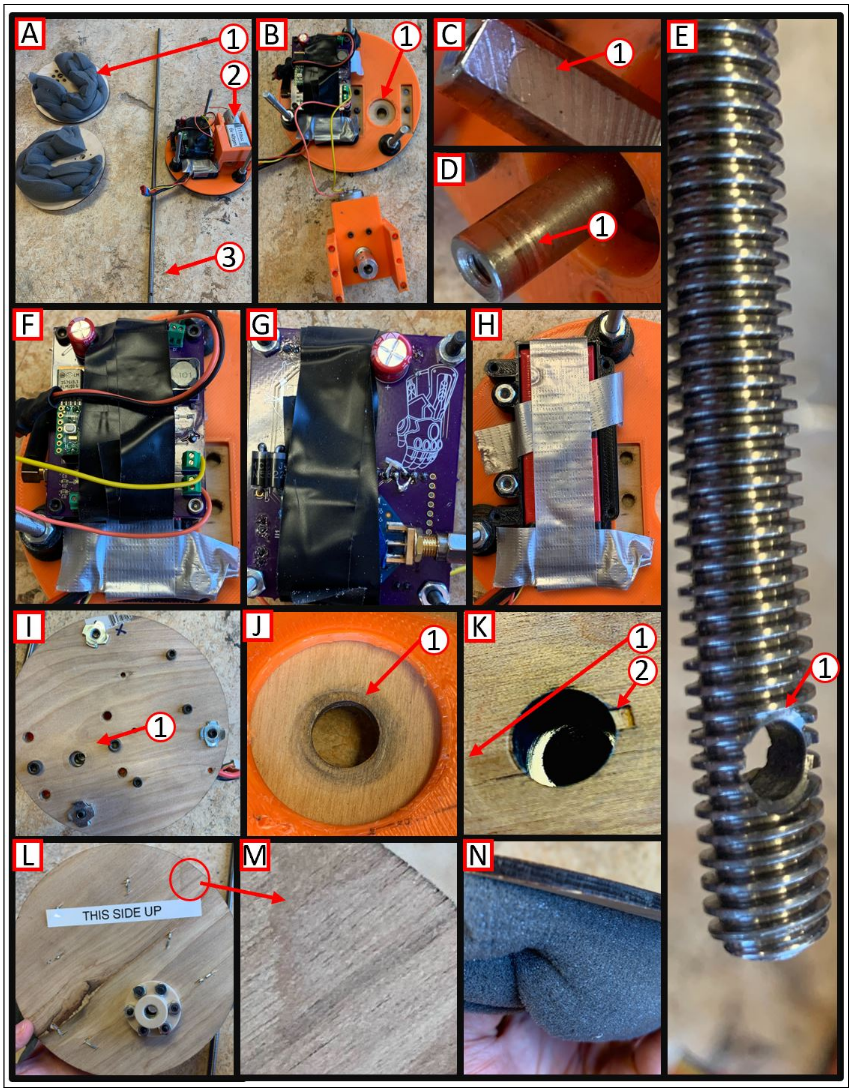

Figure 76: Payload Design Changes

"A" shows the retention system after launch, "A.1" shows the mobile bulkhead, "A.2" shows the Ejection/Retention assembly, "A.3" shows the lead screw; "B" shows the Ejection/Retention assembly, "B.1" shows the coupler wear on the bulkhead; "C" and "D" show the wear on the motor shaft, "C.1" shows an indent were the setscrew was seated, "B.1" shows wear around the shaft from the setscrew slipping off the d-shaft; "E" shows the lead screw and "E.1" shows the pin hole; "F", "G" and "H" show the ejection electronics and battery; "I" shows the retaining bulkhead, "I.1" highlights the wear due to flight; "J" is a detail view of "B.1" where "J.1" shows the where the coupler pressed on the bulkhead; "K" is a detail view of "I.1", showing the damage due to flight, "K.1" shows an indent made in the bulkhead, and K.2" shows slight delamination; "L" and "M" shows the fore mobile bulkhead, and the edges that press on the nose cone; "N" Shows the wear on the edge of the coupler due to friction.

4.3 Changes Made to Payload Since CDR

Few changes have been made to the payload since CDR, these changes are mostly comprised of various mounts and protective cases for payload electronics and batteries. Figure 77 highlights all changes to the payload itself. A mounting plate was added to the ejection system shown in sub-figure "A.1" and also shown in Figure 93 sub-figure "E". This plate provides a mounting location for the ejection PCB and battery. Shown in Figure 77 sub-figure "A.2" is foam that has been added to both of the mobile bulkheads to protect the rover during flight and help to dampen in flight vibrations. A battery case and PCB case have been added to protect the rover electronics ("A.3"). The bracket that holds the rover to the tail ("A.4") has changed from a hinge to a floating bracket that slides onto one of the 1/4 in. aluminum chassis rods. This floating bracket design makes it possible for the tail's angle with respect to the ground to be easily modified using jack screws and is shown in sub-figure "G.2". The chassis itself has been further refined, with slight changes made to both the chassis mounting plates shown in sub-figures "C.1" and "D.1".A groove has been cut into the top mounting plate to make more room for the battery. The bottom mounting plate has new holes for the collection system. A battery case for the rover has also been added ("C.2"). The new design has increased the structural strength of the chassis itself by providing more support than the previous braces as well as allowing the bottom plate to be fastened to the battery case itself which reduces flex in the plate. Before the floating bracket was used, the tail would press against the ground and would press on the bottom plate causing the bottom plate to flex, making the braces pop out of the holes in the bottom plate. To resolve this, two fasteners were added as shown in sub-figure "G.2". A motor mount has also been added to the collection system to protect the motor from dirt and debris ("G.1"). These changes will be discussed in further detail in each respective systems subsection.

A summary of changes per subsystem can be found below.

- Chassis: Changes have been made to cut outs in the wooden components, making room for additional components. A battery case was added to hold and protect the rover battery. An electronics case was added to protect the rover PCB
- Ejection: The groove in the motor shaft was machined to accommodate the set screw to help prevent the screw from slipping. A battery/electronics case was added to securely fasten and protect components, in addition to help align the all-thread rods. The motor has changed from a 110rpm to a 40rpm motor with additional torque, this is because the previous motor failed to shear the nose cone shearpins. Teflon tape will be added to the payload to reduce friction during ejection.
- Retention: The leadscrew pin will now be a 4-40 titanium fastener, and require a smaller hole. The purpose of this is to reduce the size of the hole in the leadscrew to improve the strength of the system. Foam has been added to the mobile bulkheads to better protect the rover.
- Drivetrain: The spokes have been thinned to increase room on the chassis for electronics. Rounded ends have been added to the spokes to make the wheels rounder, decreasing vibration when driving. The

hubs have been modified to make assembly easier.

- Collection: The two supporting rods have been removed to make room for the rover PCB. A motor case has been designed to protect the motor, and motor wires from any obstacles on the ground.

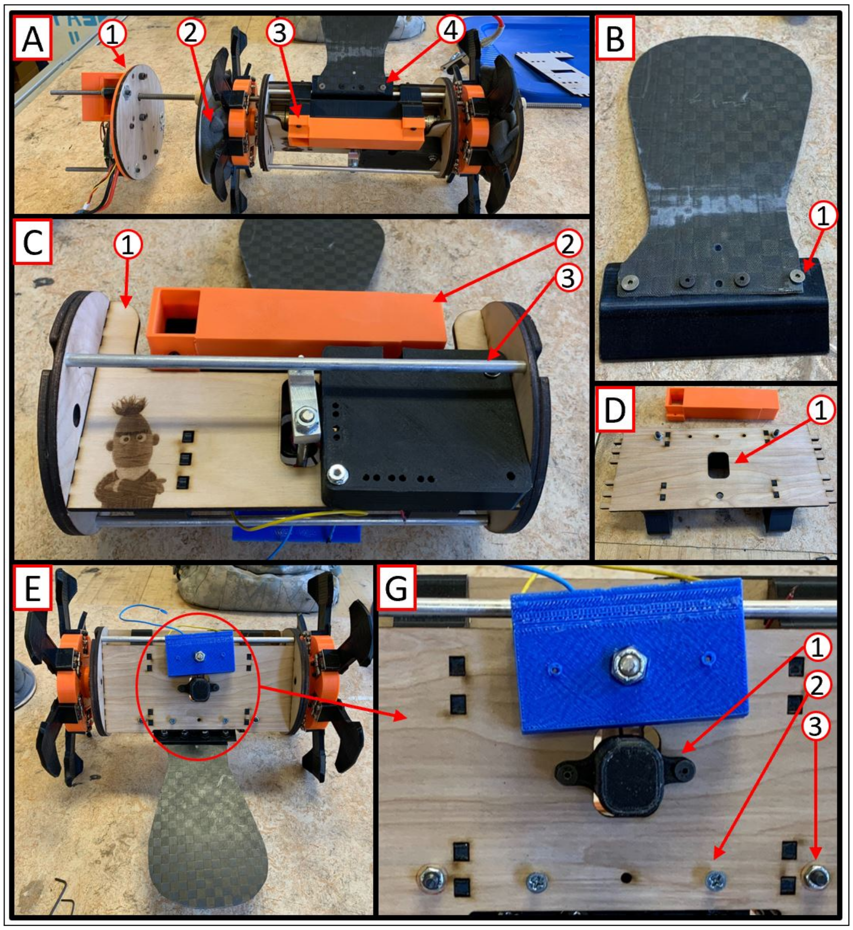

Figure 77: Payload Design Changes

"A" shows the current payload, "1" shows the ejection retention system electronics bracket, "2" shows the mobile bulkhead with shock absorbing foam, "3" shows the rover battery case; and "4" shows the tail bracket; "B.1" shows the new rover tail bracket; "C" shows the chassis changes, "1" shows the new top mounting plate design, "2" shows the battery case, "3" shows the PCB case, "D.1" shows the new bottom mounting plate design; "E" shows the bottom of the assembled rover; "F" is a detailed view of "E", "1" shows the new collection mount, "2" shows the jack screws for the tail, and "3" shows the battery to mounting plate fasteners.

4.4 Payload Mechanical

4.4.1 Payload Overview

The Payload for the OSRT will be a rover with expandable wheels, a beaver tail-shaped stabilizer, and a collection system composed of a device that resembles a scoop. The payload will be ejected from the launch vehicle by means of a lead screw motor with a built-in retention system involving two mobile bulkheads, each with an accompanying threaded pusher for linear motion out of the launch vehicle housing. After ejection, the wheels will expand and the rover will drive to the collection site. Once at the collection site, the scoop will move from a storage position to a lowered collection position. To facilitate sample collection there will be a linear forward motion provided by the wheels to drag the scoop just across the ground and collect the sample material. The sample will then be stored in the scoop as the rover completes the challenge by driving ten linear feet away from the collection site. OSRT designs will be discussed in the following sections along with supporting specifications, justification of concepts, changes since CDR and any relevant analyses.

4.4.2 Payload Measurements

The payload specifications from CDR was a weight of 9lbs, and length of 17 in. long. The payload currently weighs 6.8lbs (neglecting PCB's and cameras) and is 16.5 in. long. These measurements are shown in Figure 78. Shown in sub-figure "A" the payload length is 16.5 in., as measured from the end of the motor mount to the end of the retaining bulkhead. If measured to the end of the lead screw then this length would 25.25 in ("A.2"). The rover was measured to have a length of 12.5 in. ("C.1"). When stowed in the rocket the entire payload has a diameter of 6.25 in., then in the active position the rovers wheels expand to a diameter of 10 in.

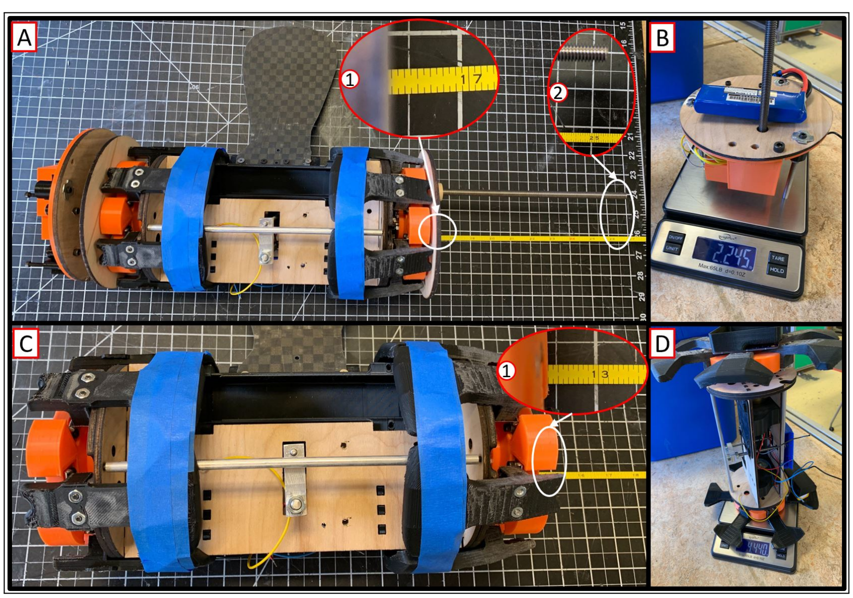

Figure 78: Payload Measurements

"A" shows the length of the payload assembly, "A.1" shows the distance from the end of the coupler retaining bulkhead assembly (point of contact for Fore Bulkhead) to the Fore mobile bulkhead, "A.2" shows the distance to the end of the lead screw; "B" shows the weight of the retention/ejection assembly (with mobile bulkheads); "C" shows the length of the rover assembly, "A.1" shows the length measurement; "D" shows the rover weight, not including PCB's and cameras, but including battery.

4.4.3 Payload Manufacturing

OSRT has multiple printers that are used for manufacturing plastic parts. All printers use 1.75mm Polylactic Acid (PLA), and an infill greater than 20%. Shown in Figure 79 "D" and "C" are two of the said printers. "E", and "D" in Figure 79 show examples of the printer patterns used by OSRT. All printers use Cura software to setup and run the 3D prints. OSRT uses a laser cutter to cut all plywood parts for payload, specifically 3/16 in. laminated plywood. Then the 2024 1/4 in. aluminum rods on the payload are made using OSU's machine shop. The plywood and aluminum materials were chosen for their price and availability. OSRT then uses PLA for 3D printing because it is widely available, strong, and it off-gasses less toxic fumes when compared to other printing materials.

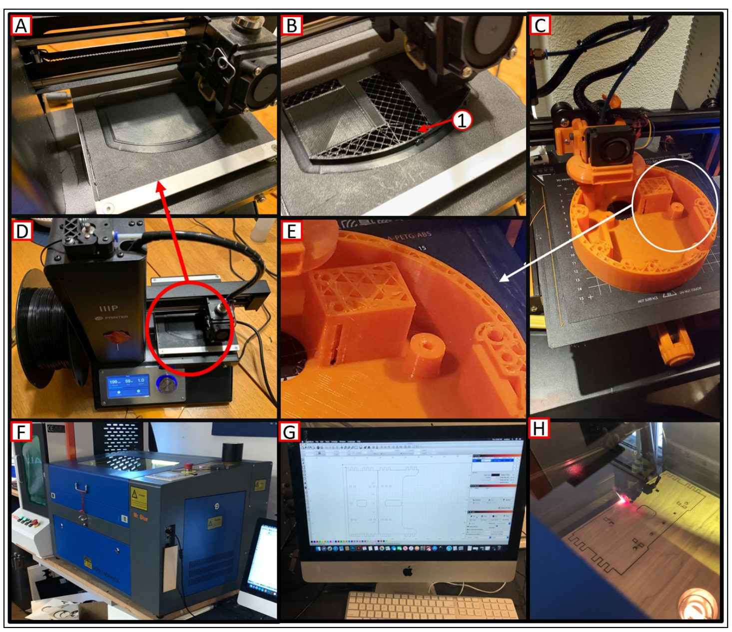

Figure 79: Payload 3D printing

"A", and "B" show a part being printed by one of the OSRT printers, "C.1" shows the print pattern for the part; "C" shows the part being printed on another OSRT printer; "D" shows one of the printers; "E" is a detailed view of the print pattern used by the printer in "C"; "F" shows the laser cutter used for manufacture of the rover; "G" shows the software used to run the laser; "H" shows the laser cutting parts for the rover.

4.4.4 Chassis Design

OSRT considered the chassis to encompass the frame of the rover, the battery case, tail, and the PCB case. Without internal components, the payload chassis weighs 2lbs and is 12.5 in. long. Figure 80 shows the overall design of the chassis. Sub-figures "A" and "B" show the chassis design in Solidworks. "A.1" highlights the location of the PCB. This component is protected by a case and fastened to the chassis using 4, 6-32 screws. "A.2" highlights the battery case. This component consists of 3, 3D printed parts. The assembly press fits into the top and bottom mounting plates, and is fastened to the bottom plate using 2, 6-32 screws. The previous design showcased in CDR did not include this component. The reason for the addition of this component was to increase stability of the rover by moving the battery closer to the ground and towards the tail of the rover. If the battery was placed underneath the bottom plate this could interfere with the wheels when collapsed and reduce ground clearance when the wheels are expanded. This design provides a better mounting location for the battery in addition to increasing the structural strength of the chassis. The larger 3D printed components add more rigidity then the previously laser cut wooden braces showcased in CDR.

The Chassis assembly is shown in real life in Figure 80, sub-figure "C". This picture shows the battery case and PCB case on the chassis. Note that the top part of the battery case will be printed in orange to comply with NASA regulations for the competition that all batteries must be brightly indicated. Another important design change since / glsCDR is the tail. The tail will now be fastened to a 3D printed Tail Mount using 4, 6-32 fasteners, shown in sub-figures "G", "H", and "I". The previous design used a spring hinge, however the ductile nature of the carbon fiber tail negates the need for such a design. The tail is more than capable of springing out from the stowed position within the airframe without the aid of a spring hinge. This change allows OSRT to adjust the angle of the tail using 2 jack-screws, Shown in sub-figures "H" and "I". The jack screws push on the underside of the mount shown by "H.2". This changes the angle of the tail when the rover drives. This allows OSRT to adjust the rover to drive at an angle level with respect to the collection system. For collection to work, the scoop needs to be approximately parallel to the ground.

Figure 81 shows the assembly of the chassis. Following the Sub-figures from "A" to "K" shows the process as the chassis is assembled. OSRT has used 6-32 socket head fasteners wherever possible for consistency. The only exception to this found on the chassis is the motors which use M4 fasteners per the manufacturer.

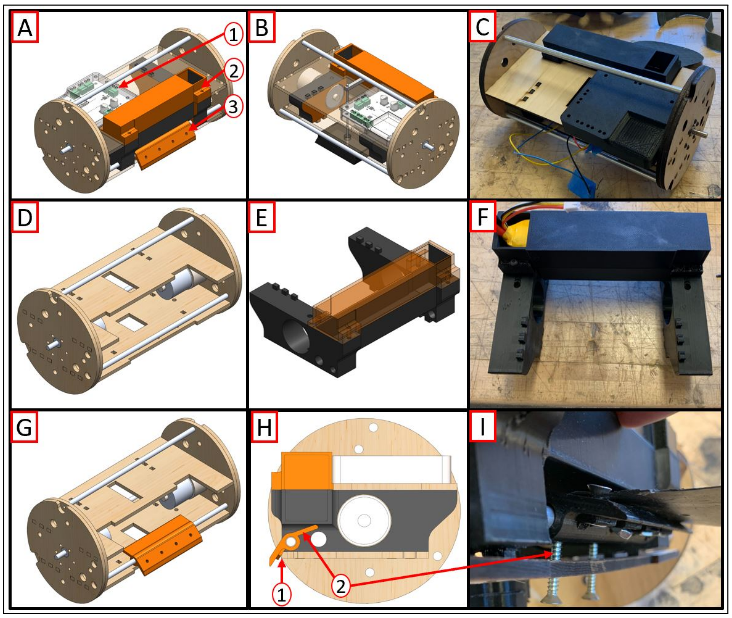

Figure 80: Chassis Design

"A" and "B" show the chassis CAD model, "A.1" shows the PCB, "A.2" shows the Battery Case, and "A.3" shows the Tail Mount; "C" shows the assembled chassis; "D" shows the chassis without the PCB, Battery Case and Tail Mount; "E" and "F" show the Battery Case; "G", "H", and "I" show how the Tail Mount fits to the chassis, "H.1" shows where the Tail Mount contacts the chassis, "H.2" shows where the jack screws contact the tail, giving it an adjustable angle.

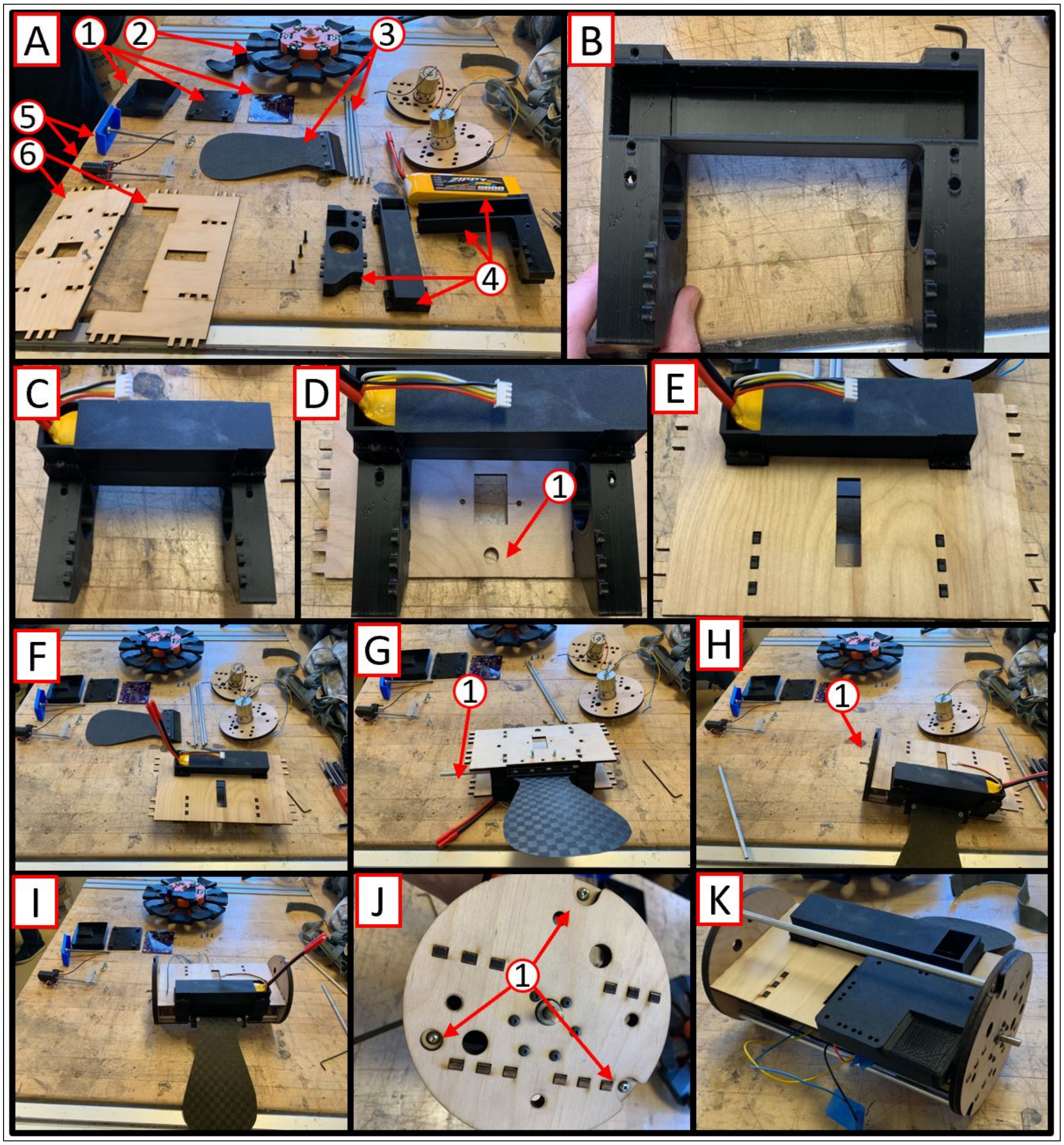

Figure 81: Chassis Assembly

"A" shows the disassembled rover, "A.1" shows the PCB case, "A.2" shows the wheels, "A.3" shows the tail and aluminum rods, "A.4" shows the battery case, "A.5" shows the collection system, and "A.6" shows the mounting plates; "B", "C" show assembly of the battery case; "D" and "E" show mounting of the mounting plates to the case, "D.1" highlights the proper orientation of the bottom plate; "F" shows "A" but missing the components used for initial assembly; "G" shows assembly of tail, "G.1" shows the aluminum rod being inserted through the battery case; "H" and "H.1" show the end plates being mounted to the chassis; "I" shows the chassis with both end plates attached;

"J.1" shows the 3, 6-32 fasteners that connect the end plates to the aluminum rods; "K" shows the assembled chassis.

4.4.5 Chassis Testing

To test the strength of the chassis, a drop test was conducted, as shown in Figure 82. The purpose of this test was to ensure the rigidity of the chassis under in-flight forces and during landing, while being able to identify modes of failure. As shown in Figure 82 "A" the rover chassis was dropped from a height of 20ft onto concrete. The test was conducted three times using the same prototype with no repairs in between drops. The first drop resulted in no visible structural damage. The Second drop also resulted in no visible structural failure. The third drop resulted in a structural failure in the bulkhead. As shown in Figure 82 "K" the aluminum rods punctured through the wooden bulkhead and fell from the chassis.

An investigation into the chassis failure after the third drop is shown in 83. Shown in Figure 83 "A" are the chassis materials that showed signs of wear. The points of failure are highlighted in 83 "C.1", "C.2", "G", and "H". Shown in Figure 83 "B" the end plate is 0.34 in. thick (which is 2 pieces of plywood glued together), meaning that the plywood used for the chassis is 0.17 in. thick. Shown in 83 "D", and "E" is the plywood material that OSRT is using for the chassis. In Figure "F" a detailed view of "E" is shown. Here you can see the laminate ("F.1") and plywood core ("F.2") layers of the plywood. "G" shows signs of wear resulting at the connection point between the second aluminum support and the bulkhead. "H" shows where the aluminum rod punctured the endplate. Figure 83 "K" and "L" show the damage to the mounting plates that are sandwiched between the end plates. There is minimal damage to the teeth on these plates and no sign of wear on any other part of these members. This is evidence that the design protects these parts so long as the aluminum supports stay intact.

OSRT has concluded from this test that the chassis is sufficiently strong enough to withstand any in-flight or landing forces that it may see. The chassis failed after multiple drops due to fatigue. In flight, the chassis may experience some minor impacts or jolts, but is unlikely to see extended fatigue. Expected major stresses are during the initial launch, black powder deployment of parachutes, main parachute deployment, and landing. The expected loads on the chassis during flight is much lower than the 20ft drop test. From this, it can be concluded that the payload chassis should be robust enough to withstand all mission stresses. To further ensure the structural integrity of the rover during the mission an additional aluminum support has been added to the chassis as a precaution.

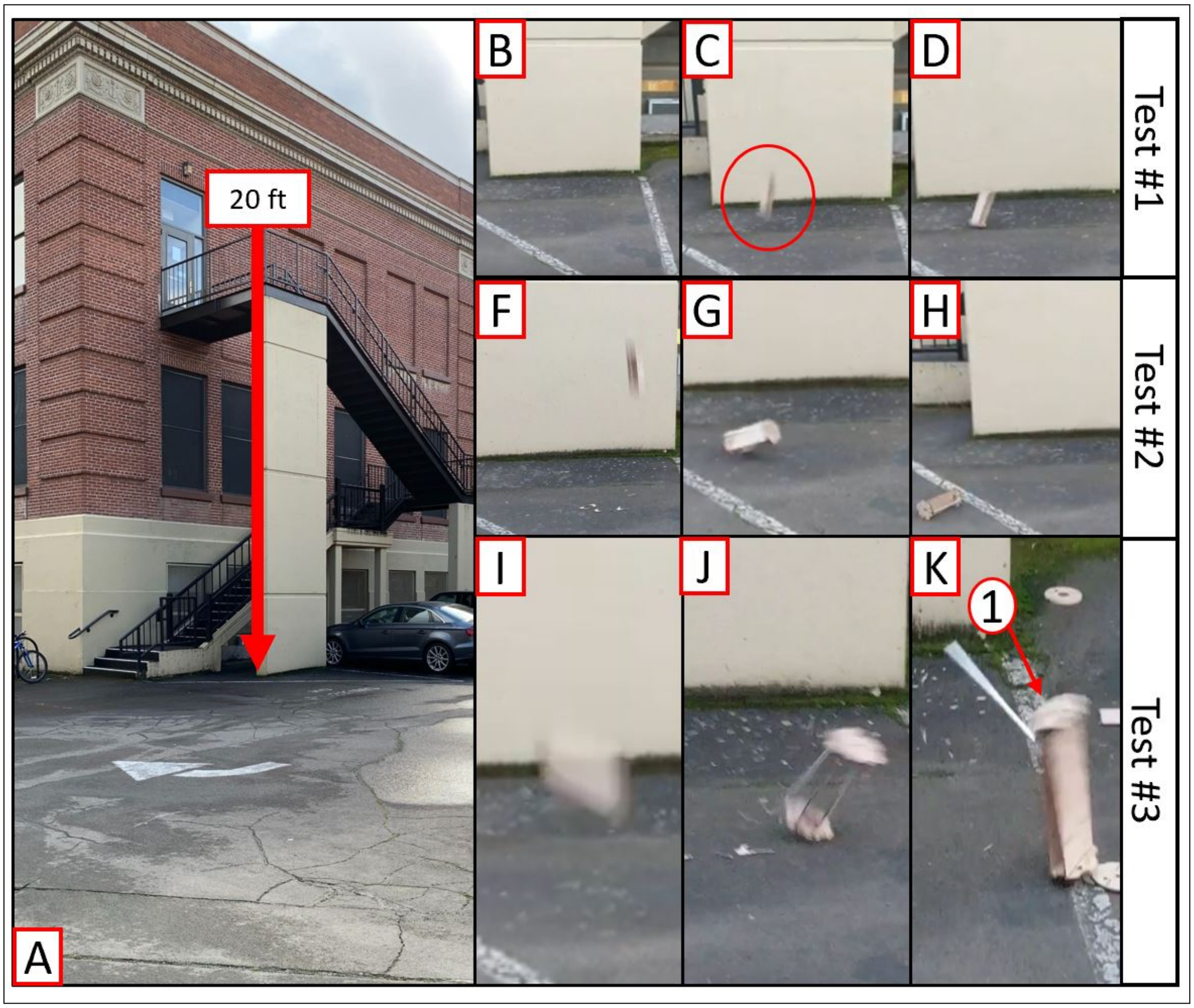

Figure 82: Chassis Drop Test

"A" Shows where the chassis drop testing took place, the chassis was dropped from 20ft onto concrete; "B", "C", and "D" show the first drop test, "B" takes place as the chassis is falling, "C" shows the chassis mid fall, and "D" shows the chassis as it hits the ground; "F", "G", and "H" show the second drop, "F" shows the chassis mid-flight, "G" shows the chassis at impact, and "H" shows the chassis after the fall; "I", "J", and "K" show the results of the 3rd test, "I" shows the chassis as it is falling, "J" shows the chassis at impact, and "K" shows the chassis after a structural failure.

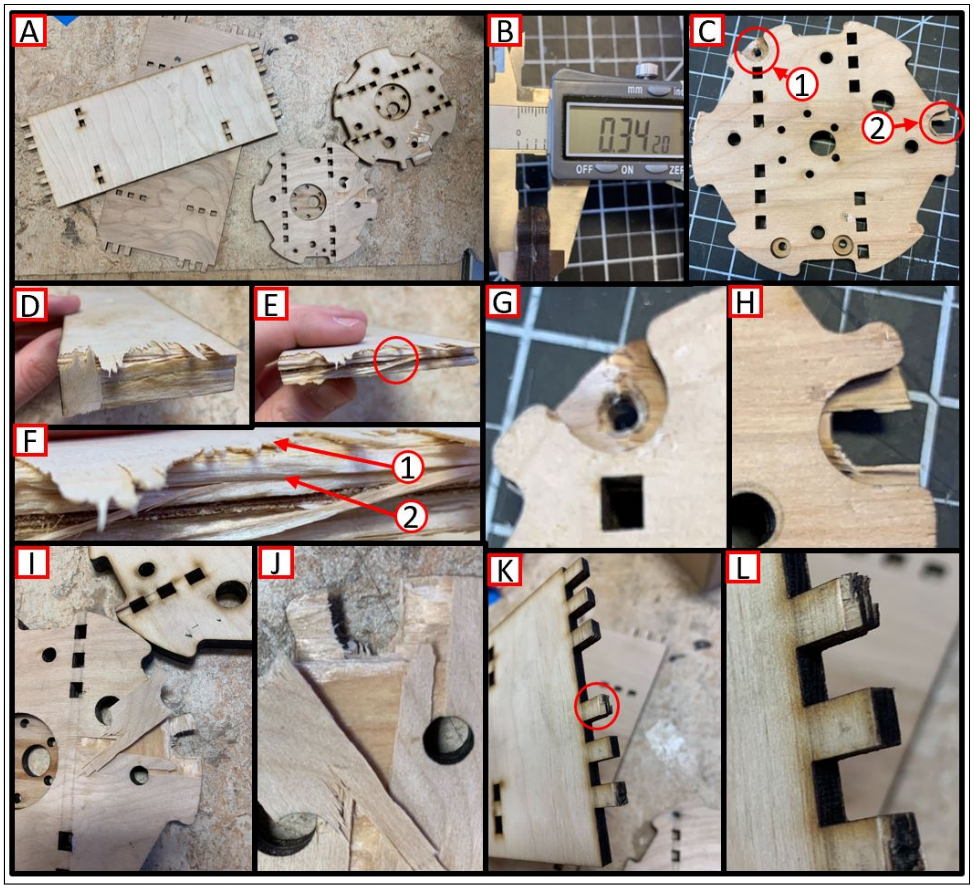

Figure 83: Chassis Drop Test Results

"A" shows the chassis components post testing; "B" shows the width of the chassis end plates; "C" Shows the end plate and "C.1", "C.2" highlight the points of failure; "D" shows the internal composition of the plywood; "E" shows another view of the plywood composition; "F" is a detailed view of the circle highlighted in "E", "E.1" highlights the laminated part of the plywood, and "E.2" highlights the composition of the plywood core; "G" is a detailed view of the failure point "C.1"; "H" is a detailed view of the failure point "C.2"; "I" opposite side of the failed end plate; "J" is a detailed view of the end plate failure, showing the plywood layers; "K"show the post test mounting plate; "L" shows a detailed view of the damage done to the mounting plate.

4.4.6 Drivetrain Design

While the primary concepts and mechanisms for the drivetrain design remain the same, several significant modifications have been made. Several different wheel designs were created, 3D-printed, tested, and then evaluated.

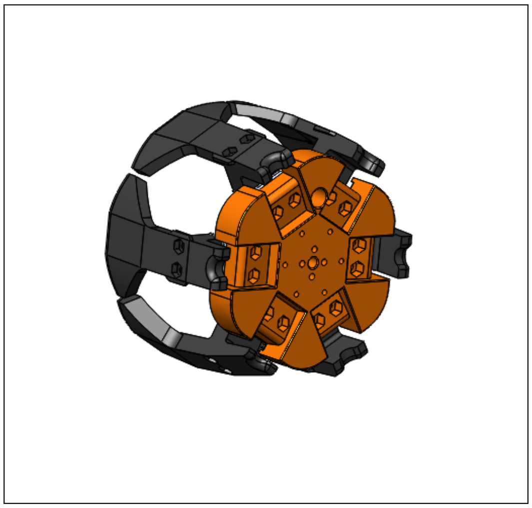

Figure 84: Folding Wheel Collapsed

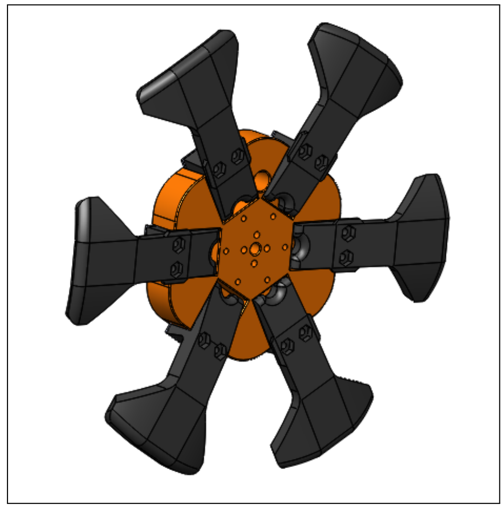

Figure 85: Folding Wheel Expanded

One of the overall changes to the drivetrain design is the modifications accommodating fasteners. First, the 1" butt hinges were measured to anticipate and design for screw hole placement. Second, the dimensions for the hubs and spokes were adjusted to allow the use of standard-length screws without the need for grinding or an excessive number of spacers. Third, nuts were incorporated into the design by adding hexagonal slots for them to sit in. These slots both keep the nuts from protruding off the surface and prevent the nuts from turning.

The wheels' hubs were redesigned to be less intricate than their predecessors, an effort aimed at making the part easier to 3D-print. The dimensions were also refined to sit closer to the payload chassis while still allowing full functionality.

The spokes have also received modifications. The current design includes circular flanges that extend the rolling surface of each spoke, allowing for a much smoother ride. This flange has two diameters: the first is a 10 in. diameter pertaining to the rolling surface, and the second is a 5.25 in. diameter that allows the spokes to fold against the rover's body when within the rocket. The spokes were also made to be thinner, allowing them to fit inside the rocket with room to spare.

A rudimentary power supply was attached to the motors, allowing the team to observe how well the wheels worked. The newer design was able to easily propel the rover forward in a relatively smooth manner as compared to the former design.

When manually holding the spokes down in the "folded" position, the spring hinges easily return the spokes to the "open" position upon release.

The entire payload assembly was integrated into the full-scale launch in Brothers, Oregon. Both wheel assemblies were completely free of damage from the rockets rapid acceleration/deceleration.

The assembly process is demonstrated in 86. The primary components for the wheels were 3D-printed: a total of 2 hubs and 12 spokes. To assemble, all freshly printed components (as shown in "A") are initially sanded and filed to get rid of any rough or warped surfaces ("B"). Each screw hole is also cleared using a drill to ensure no debris or blockage is present("C"). The nuts are first placed over their intended slots and then pressed into place using a soldering iron ("D"). Each nut must melt through a small amount of plastic, allowing each to become accurately fixed in place. Next, the hub, spoke, and hinge are lined up. Screws are then inserted through the thru-hole and fastened into their fixed nuts("E" and "F"). Finally, the four screws for the coupler are inserted into their holes and then forced flush with the hub face using a soldering iron. The coupler is placed on the screws and finally fastened into place with nuts.

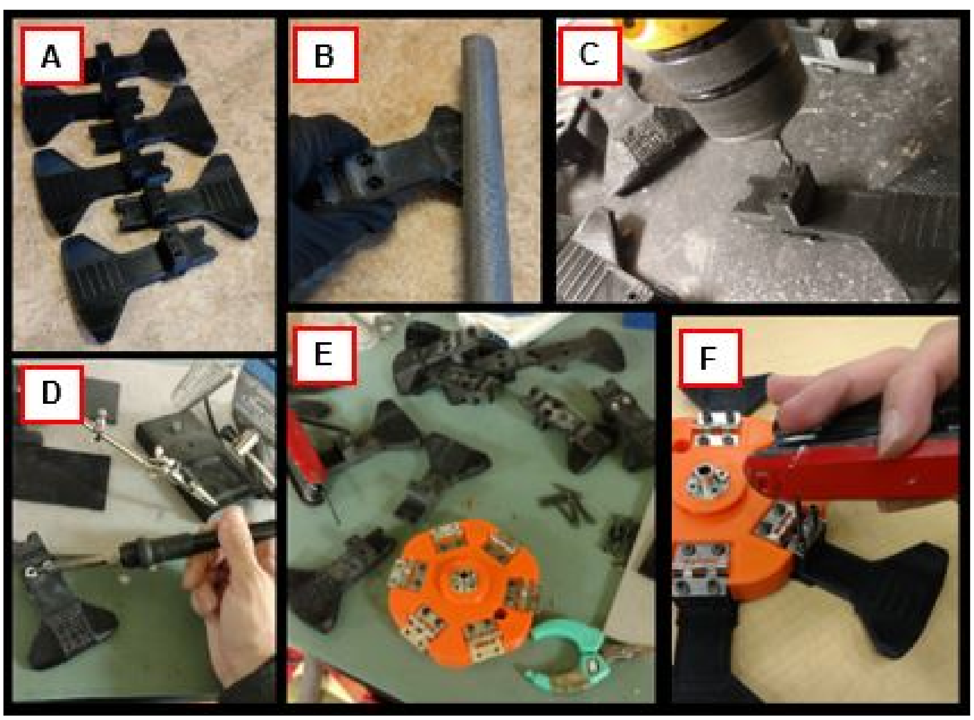

Figure 86: Wheel Assembly

"A" shows 6 spokes as they appear after being printed; "B" shows the rough surfaces being filed smooth; "C" shows the screw holes being cleared; "D" demonstrates the use of a soldering iron to insert the nuts; "E" shows the

assembled hub and the prepared spokes; "F" shows the tightening of screws through the screw holes and into the nuts located on the opposite face.

4.4.7 Drivetrain Testing

One concern OSRT has for the rover drivetrain, is the wheel to motor connection. If the wheels are loose, or if they fall off the motor shaft, then this would result in mission failure. To address this concern, OSRT has conducted a wheel connection test to ensure this connection is rigid, shown in Figure 87. First, to address this issue, notches have been machined into the motor shaft, shown in 87 "A", and "D". A set screw will sit in this notch preventing the wheel from falling off. A second set screw will press against the d-shaft shown in 87 "B". As a result the wheel coupler connects the shaft using two set screws, shown in Figure 87 "C", and "F.1". Finally, to test this connection, the wheel was assembled onto the chassis following OSRT's checklist, then an inspector attempted to tear the wheel from the motor. Specifically the inspector pulled and pressed on the wheel ("G.1"), while also twisting, torquing, and shaking the wheel ("G.2"). As a result of this test the wheel remained securely attached to the chassis.

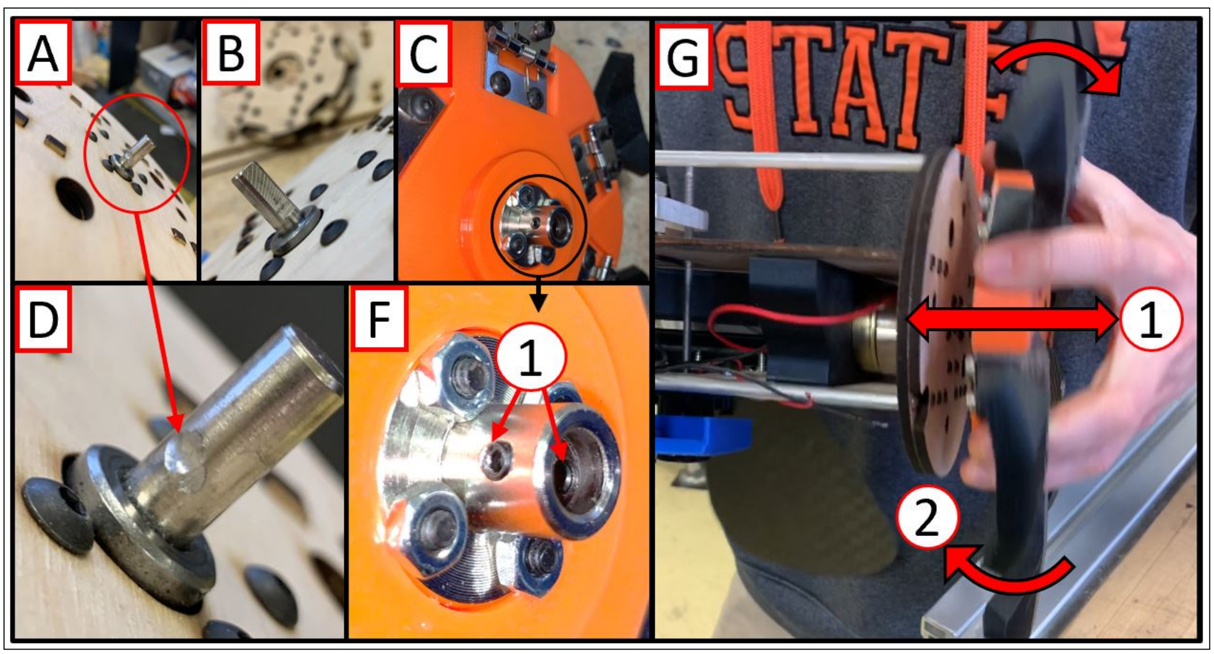

Figure 87: Wheel Mounting Inspection

"A" shows the 12V drivetrain motor on the chassis; "B" shows machined side of the motor shaft, a set screw will sit flush against this side to retain the wheel; "C" shows the coupler mounted on the collapsible wheel; "D" is a detailed view of "A" showing a machined notch in the shaft, a set screw will sit in this notch and add extra support for the wheel; "F" is a detailed view of "C" showing the set screws that will hold the wheel to the motor shaft; "G" shows a visual inspection of the wheel, to ensure that wheel to motor connection was secure, an inspector attempted to remove the wheel by applying tension ("G.1") and torque ("G.2") to the motor shaft/wheel.

4.4.8 Collection System Design

The OSRT payload collection design includes a box-shaped scoop with a ramp facing toward the front of the payload. A single threaded rod is coupled to another threaded rod by means of a bracket. One rod is attached to a lead screw motor and the other to the scoop. This will allow the scoop to move vertically and collect sample material from the ground. Hole patterns for both rods, the bracket, and the motor mount were made in the payload chassis. A few revisions have been made from the design in CDR. These include removing the support rods. This was done to save space on the chassis for electrical components and because the rods were made unnecessary after the OSRT added locking hex nuts to secure the scoop in the proper position. Another minor change is the final material of the scoop. Initially, aluminum was to be used to create the scoop, but 3D printed material on hand proved more than sturdy enough to handle forces seen in collection. Lastly, a motor mount was designed, manufactured, and installed rather than mounting the motor on the chassis directly. This was done to keep the motor safe and because the screws needed to attach the motor were very small and caused the collection device to be hard to assemble.

The OSRT Payload Collection system has proven very reliable. Structurally, it has withstood a full scale rocket launch with no apparent damage and is therefore more than sturdy enough to complete the mission. Functionally, the Collection system has exceeded expectations by driving itself fully into the sample material in testing. With this in mind, the Payload Collection system will likely be able to function without the use of the Payload Drivetrain system.

The scoop of the Payload Collection system was made by a 3D printer with PLA filament. The motor mount was also made in a 3D printer with the same PLA filament. The bracket was made out of aluminum. The threaded rod was purchased and cut to length with a chop saw. The lead screw motor and all fasteners were also purchased and installed. The Payload Collection system and its components can be seen below.

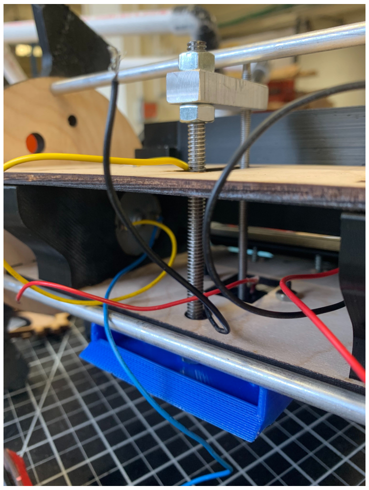

Figure 88: Collection Scoop (front)

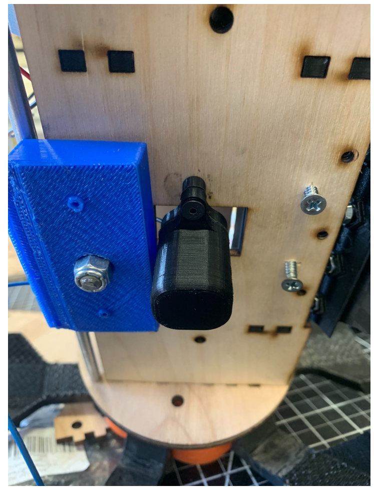

Figure 89: Collection Scoop (bottom)

4.4.9 Ice Collection System Testing

To test the collection system, a static collection test was conducted, as shown in Figure 90. The purpose of this test was to ensure that the collection system was capable of not only collecting enough material, but also retaining it. For this test, the rover and collection system were placed above a container of simulated ice material ("A"). The simulated ice material used is shown in sub-figures "B" and "C", as shown, the ice is simulated using plastic spherical bb's. With a diameter of 0.39 in. (1 cm) this material is comparable in size to the material that will be utilised at competition. However, it differs in geometry and potential weight. Sub-figures "D", "E", and "H" show the scoop as it lowers. Then "H", "I", and "J" show the scoop as it raises back up and flush against the rover. At this point, the rover was lifted up, turned upside-down, and shook, testing the systems ability to retain the ice. This is shown in sub-figure "K". "L" and "M". As shown, the system was able to successfully hold an excess of 10ml of material.

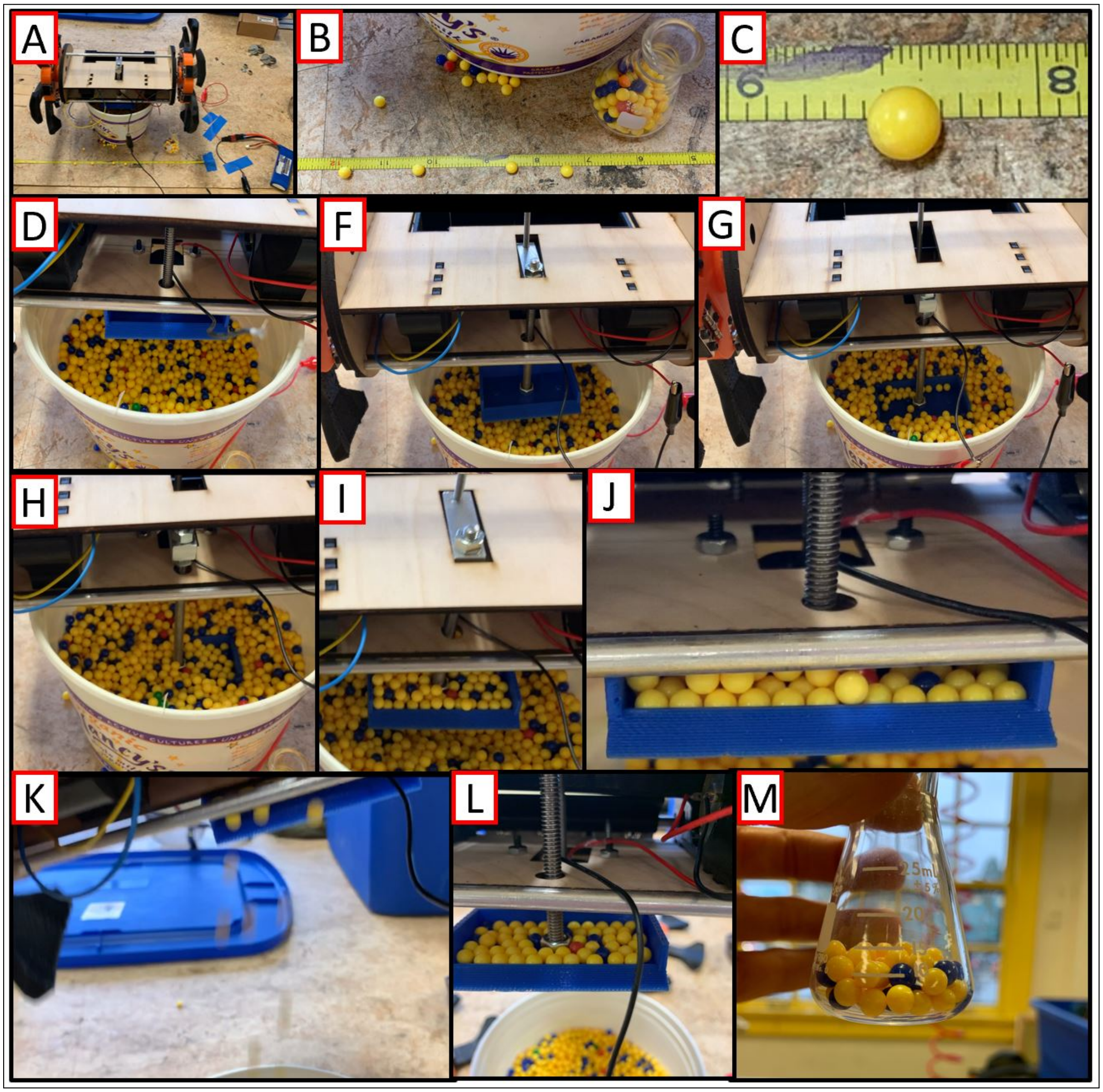

Figure 90: Collection Static Test

"A" shows the test setup, for this test, the rover was placed above a bin of simulated ice, then the collection system was actuated and retracted collecting a measurable amount of material; "B" shows the simulated ice material; "C" is a zoomed-in view of "B" showing the dimensions of the ice sample; "D" shows the scoop in a retracted state; "F", "G", "H", and "I" show the scoop as it is being extended and then retracted; "J" shows the scoop after its been actuated, and returned to its stowed state; "K" shows the simulated ice falling from the scoop as the inspector shook, and flipped the rover over, testing the systems ability to retain the ice sample; "L" shows the ice that was retained within the scoop after retention was tested; "K" shows the measured amount of ice that remained in the scoop after testing, as shown the scoop retained more than 10ml of ice.

4.4.10 Retention and Ejection System Design

As discussed in CDR, payload ejection and retention will be handled by the same system hosted inside of and to the aft of the payload bay. The only change to this assembly since CDR is the addition of the electronics mounting plate. This new part can be seen further down in Figure 93 sub-figure "A.4" and "E". This mount is needed to securely hold the battery and PCB, as well as support the 1/4-20 all threads.

The ejection/retention system encompasses all components used to eject the rover as well as the primary systems retaining the rover. This assembly includes the motor/battery assembly that is held to the retention bulkhead and the ejection lead screw with the mobile bulkheads that it uses to eject the rover. The aft assembly of the ejection/retention system can be seen in the figure below. The pushers, which are not pictured in the below figure, connect to the extending lead screw "6." These pushers will push two accompanying mobile bulkheads on the aft and fore ends of the payload, which will serve the dual purpose of retaining the payload and also being used to deploy it.

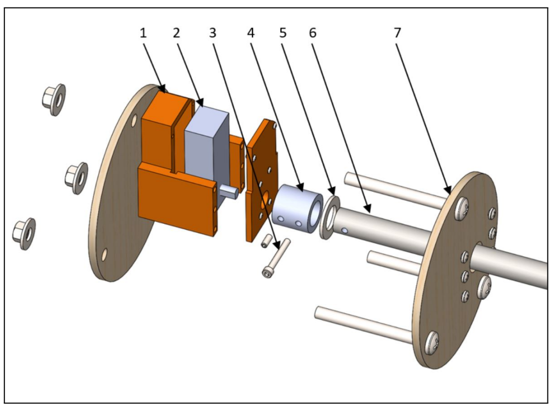

Figure 91: Ejection/Retention System

"1" shows the motor mount; "2" shows the ejection motor; "3" shows the lead screw pin; "4" shows the lead screw coupler; "5"shows a washer that helps distribute any load on the retaining bulkhead ("7"); "6" shows the lead screw; "7" shows the coupler retaining bulkhead.

The lead screw is off center, which reduces the difficulty of having the lead screw pass through the payload rover allowing it to be sent through the edges of the rover, where components can be prepared in such a way as to leave space for a through hole.

The payload is retained by both the leading mobile bulkhead and the nose cone of the rocket to provide an additional level of reliability and reduce the chance of an unexpected early deployment.The leading mobile bulkhead will force the nose cone off the front end of the launch vehicle, allowing the payload to exit behind it. The payload falling from the launch vehicle mid-flight would be an extreme safety hazard, so by having the payload fully contained during all stages of flight, the risk is significantly reduced. Payload ejection will only begin once the launch vehicle is fully landed and can be approached by the team.

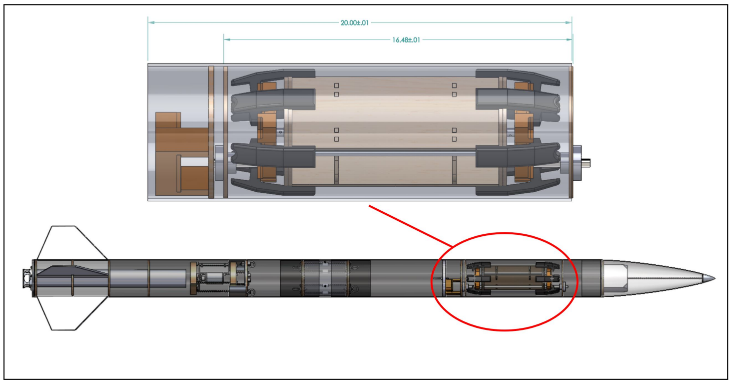

Figure 92: Lead Screw 3D View

When the front pusher and accompanying mobile bulk head reach the end of the lead screw they will unscrew themselves and fall off, allowing the payload to exit the airframe.

The system weighs 2.245 lbs including the battery and is 22 in. long. Shown in Figure 93 is the Ejection Retention system assembly. The fully assembled system is shown in 96 sub-figure "F" where it is undergoing a stress test.

Figure 93 sub-figure "A" shows the fully disassembled system. "B" shows the aft section which holds the motor, logic, and battery. To begin assembling the ejection/retention system, the motor is secured within the 3D printed mount using the assembly shown in sub-figure "F". Next, the motor is fastened to a plastic plate "F.2" using 4 M4 fasteners, as per the manufacturer of the motor. This plate is then slid onto the motor mount "F.1".Then, the coupler is fastened to the shaft using a set screw. This mini-assembly is finally fastened to the retention bulkhead as shown in sub-figure "B". The lead screw is then fastened to the coupler using a pin as shown in "H.1". Now the system is ready to begin being secured to the airframe.

The miniature assembly previously completed is now fastened to the Fore-Bulkhead of the rocket airframe using 3 1/4-20 all thread rods. The 1/4-20 rods are threaded into the insert (shown in "C.1", and "D.2"). A 3D printed mount for electronics is slid onto the retention bulkhead as shown in "B". This 3D printed mount is shown by itself in "E" and has the 3 extruded alignment features shown by "E.1" which is what fastens the mount to the bulkhead. These 3 features are a tight fit around the all thread, and as a result hold the 1/4-20 rods rigidly. To finish securing the mount a hex nut is screwed onto each rod and tightened against the black extrusion ("E.1"). These hex nuts compress the plastic and prevent the 1/4-20 all thread rods from turning. The 1/4-20 rods then slide into holes in the airframe Fore-Bulkhead to firmly attach the retention bulkhead to the airframe. The retention assembly once again secures itself using 3 hex nuts, only now to the airframe fore bulkhead. This full assembly is shown in Figure 96 sub-figures "C.1" and "D.1".

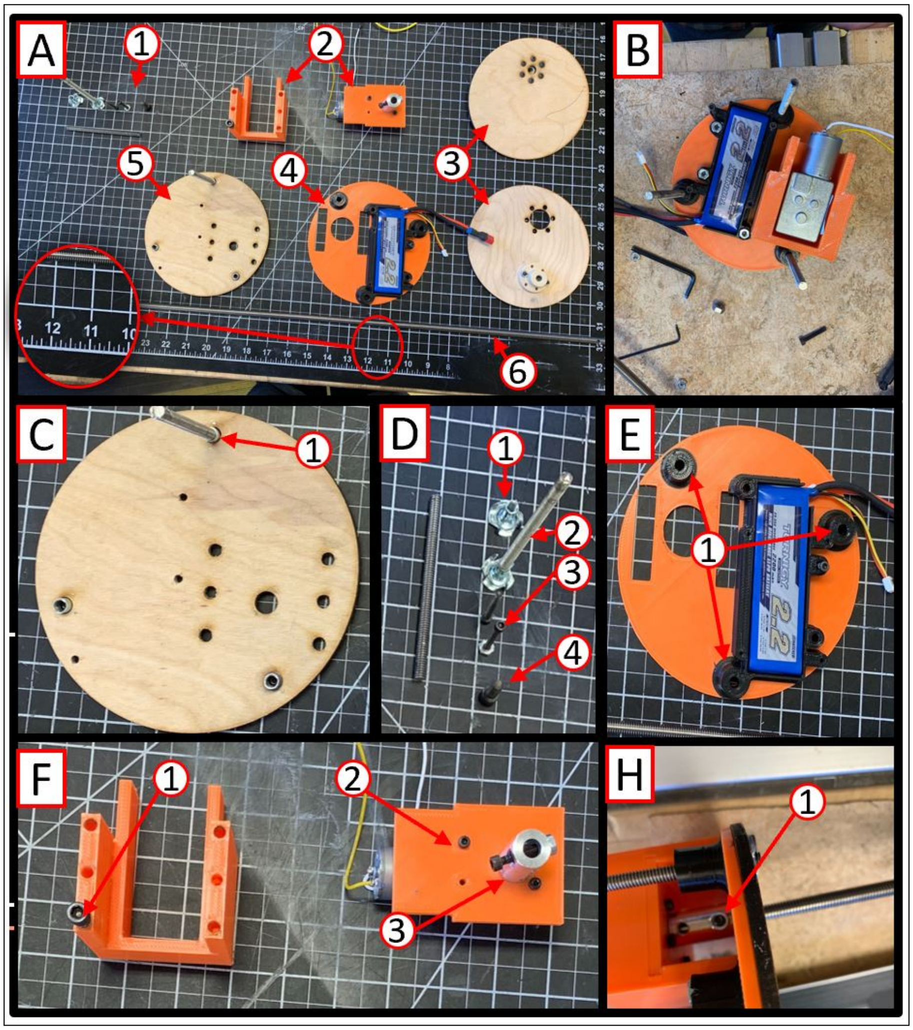

Figure 93: Ejection/Retention Assembly

"A" shows the disassembled ejection/retention system, "A.1" shows the fasteners, "A.2" shows the motor mount, "A.3" shows the mobile bulkheads, "A.4" shows the battery/PCB mount, "A.5" shows the coupler retention bulkhead, "A.6" shows the lead screw; "B" shows the assembled retention bulkhead; "C.1" shows 1/4-20 fastener used to fasten the retention bulkhead to the fore bulkhead; "D" shows the fasteners, "D.1" shows the 1/4-20 wooden insert, "D.2" shows the 1/4-20 wooden insert all thread assembly, "D.3" shows the 6-32 PCB fastener, "D.4" shows the 1/4-20 motor retention fastener; "E.1" shows the battery mount alignment dowels; "F.1" shows the motor retention 1/4-20 fastener, "F.2" shows the motor retention plate, "F.3" shows the coupler with the lead-screw pin; "H.1" shows the lead screw coupled to the motor.

4.4.11 Retention and Ejection System Testing

To ensure that the ejection system will function properly during competition, the system was tested as shown in Figure 94. For this test, the ejection system was assembled along with the payload and inserted into the airframe as it would be at competition, with the exception of the fore-bulkhead. The fore bulkhead end of the airframe was instead left open to allow easy manipulation of the ejection/retention system during testing as shown in "F". The nose cone was inserted into the fore end of the airframe with 3 shear-pins, enclosing the fore of the ejection retention system and accompanying payload within the airframe. During competition, the airframe fore-bulkhead would fully encapsulate the ejection retention system. Shown in Figure 94 "A", and "F" is the test setup. "B" shows the end of the ejection system in the airframe and "D" shows the motor used. To run this test, the motor was connected to a fully charged battery representative of the one that will be used at competition. "B" shows how the motor was controlled. At the time of this test PCB's were still being manufactured, which means that the motor was powered directly using alligator clips. The positive, and negative leads were taped down and separated to prevent short circuiting as seen in "C".

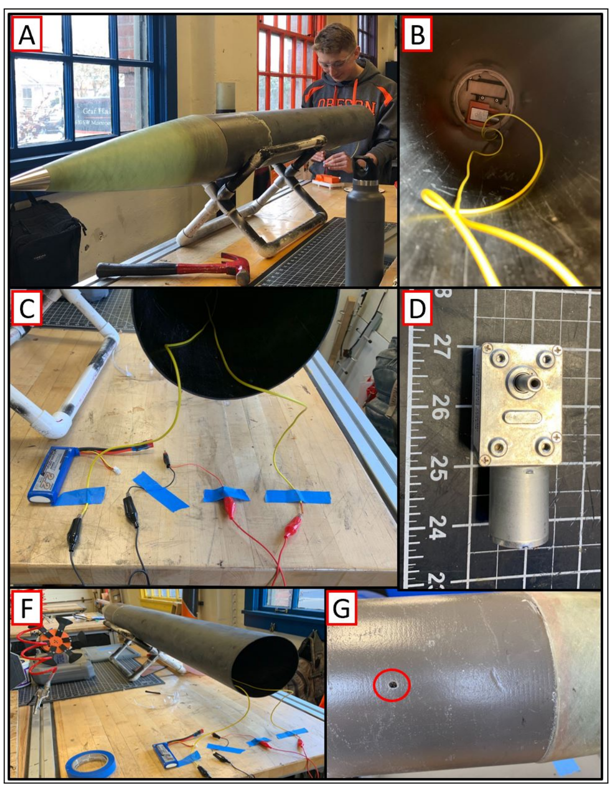

Figure 94: Ejection Testing

"A" show the ejection test setup; the ejection assembly was slid into the air frame followed by the nose cone and shear pins, then the motor was actuated ejecting the nose cone; "B" shows the back of the ejection assembly within the air

frame; "C" shows the electrical setup for testing; a lipo battery was connected to the motor using alligator clips, for safety reasons the clips for all wires were taped to a hard surface to prevent short circuiting the wiring; "D" shows the motor used for testing; "F" shows the rear end of the setup; "G" shows the one of the 3 shear pins fastened to the nose cone.

This test was initially run using a 110rpm 6V motor from RobotShop with 38.89 oz-in. The motor was unable to eject the nose cone under normal conditions. After removing 2 of the 3 shear pins the motor was able to eject the nose cone from the airframe but this is not representative of the competition setting. A geared down version of this motor was purchased in response to this test, specifically one with 40rpm, and 110oz-in. This motor is dimensionaly identical to the previous one and sourced from the same retailer allowing all of the mounts which have already been manufactured to still be used. Additionally OSRT ordered backup shear pins (0-80 1/4 in. LG) with a smaller diameter and required shear force. A second test was conducted with this motor, shown in Figure 95. The motor was unable to shear the original, larger shear pins, but was able to successfully eject the nose cone when the new smaller pins were used. Ejection with the slower motor took 22 minutes to complete. While an ejection time this long is not ideal, OSRT has determined that a reliable ejection with a safely secured nose cone and payload is more important than a rapid payload deployment. This was decided given that the competition allows a max mission time of 1 hour and does not award or penalize points based on a lengthy mission time.

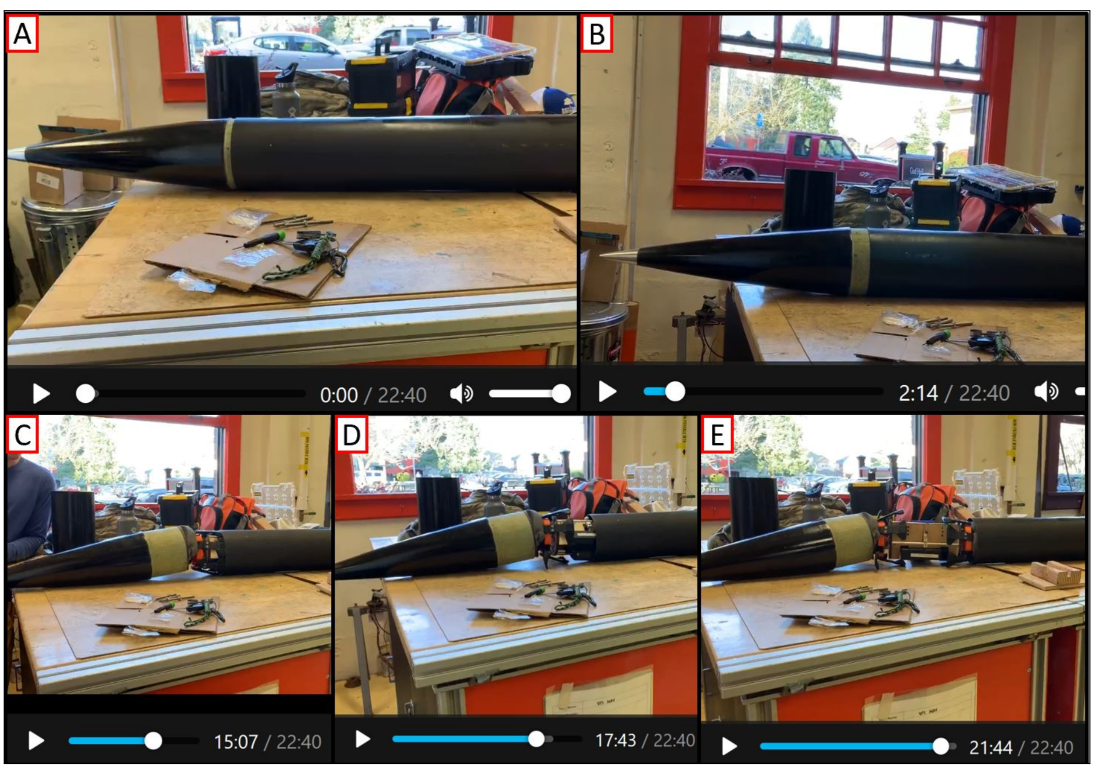

Figure 95: Ejection Testing Attempt 2

"A", "B", "C", "D", and "E" show the nose cone at different times as it is ejected.

In addition to testing the speed of ejection, measuring the strength of the retention system is critical to ensuring the payload does not accidentally deploy mid flight. If during descent, the nose cone was somehow unable to retain the payload, it is important that the ejection/retention system be able to retain the payload with a safety factor of 2. To test the strength of the retention system the fore mobile bulkhead was moved to the extreme end of the lead screw and loaded with weights. After loading a total of 22lbs, well over twice the weight of the payload, the test was determined to be a success and OSRT concluded that the ejection/retention system would not need any adjustments to increase retention strength.

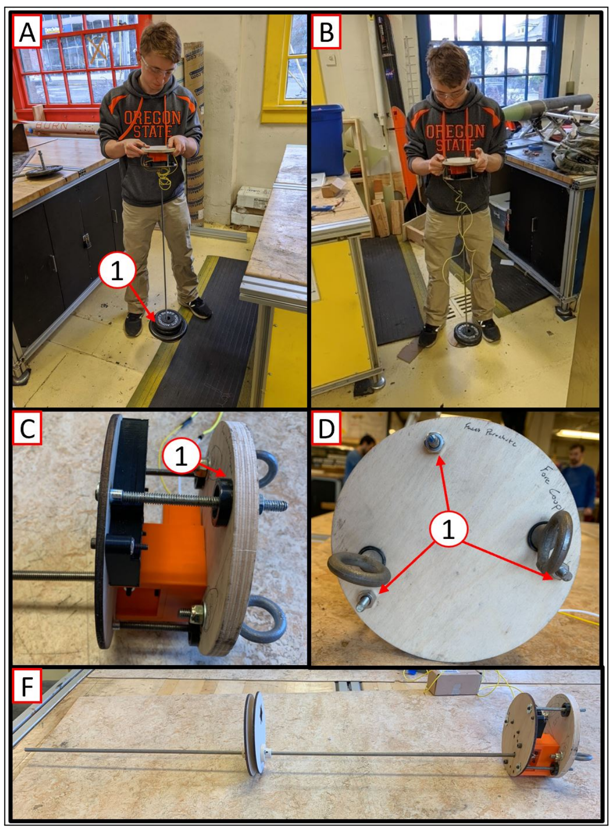

Figure 96: Retention Strength Test

"A", and "B" show the retention strength testing. "A.1" points towards the loaded weights. "C.1" shows the fore bulkhead and a detailed view of the retention system. "D.1" shows the 3 nuts that fasten the retention system to the fore section. "F" shows the retention system before the weight was added.

After loading a total of 22lbs, well over twice the weight of the payload, the test was determined to be a success and OSRT concluded that the ejection/retention system would not need any adjustments to increase retention strength.

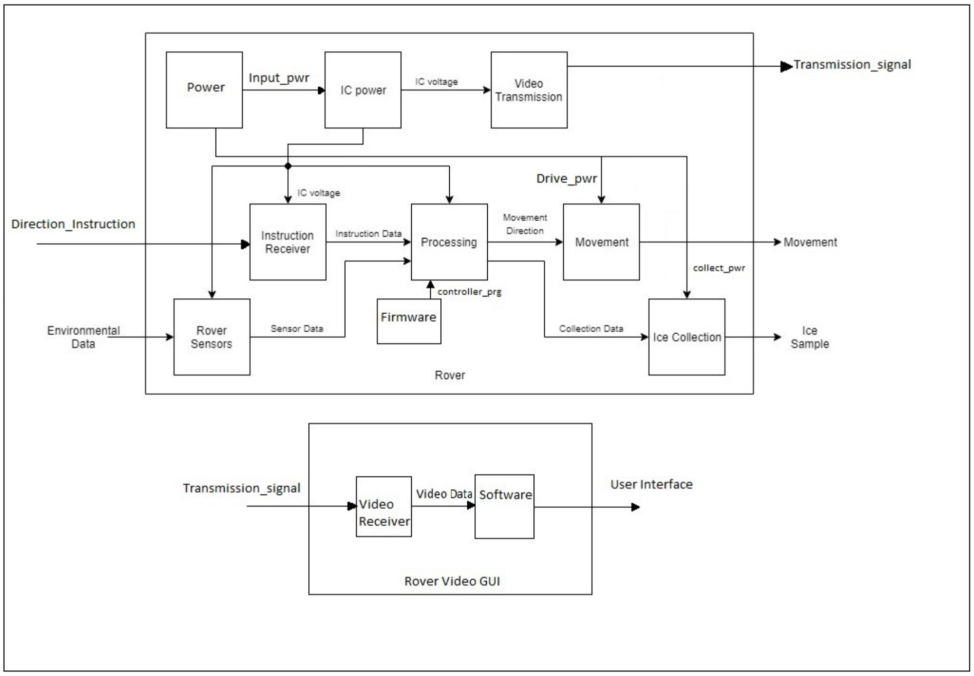

Figure 97: Payload Electronics Block Diagram

4.5 Rover Electrical

The Payload's electronic designs are based off of the block diagram in Figure 97. These blocks were designed to interface with each other.

4.5.1 Electrical Design

In order to meet our design specifications and the interfaces described on the block diagram, appropriate parts were chosen. The schematics can be seen in the Appendix Figures 117, 118, 119, 120, and 121.

4.5.2 Rover Hardware Testing

To ensure that the electronics were assembled correctly, and all parts were functioning as expected, a series of tests were performed. These tests included testing the voltage regulators for the various requirements. The were tested for the maximum current calculated (1 A on 5 V and 100 mA on 3.3 V).

4.5.3 Rover Control System Testing

The Rover is remotely controlled by an Xbox One control console. Processing IDE is used to configure the controller and read in user input from the controller. The directional movement of the rover depends on the left joystick reading of the Xbox controller. The Y coordinates of the joystick reading controls the forward and backward movements of the rover, and the X coordinates of the joystick reading controls the left and right movements of the rover. To ensure that the readings of the joystick are correct and that the correct movement function is called based on the readings, coordinate readings and function calls are printed to the serial monitor when program is running. Figure 98 sub-figures "A", "B", and "C" show the readings of the joystick on remote control and the function call corresponding to the reading.

For sub-figure "A", when the readings of the X and Y positions, Y position corresponds to the forward and backward motion and X position corresponds to the left and right motion, of the joystick are less than 10 in range of 255, the rover should be stopping as the user is not sending any directional command to the rover. For sub-figure "B", when the reading Y position is less than -127, the rover should be going forward as the user is sending a forward command to the rover. For sub-figure "C", when the reading Y position is greater than 127, the rover should be going backward as the user is sending a backward command to the rover.

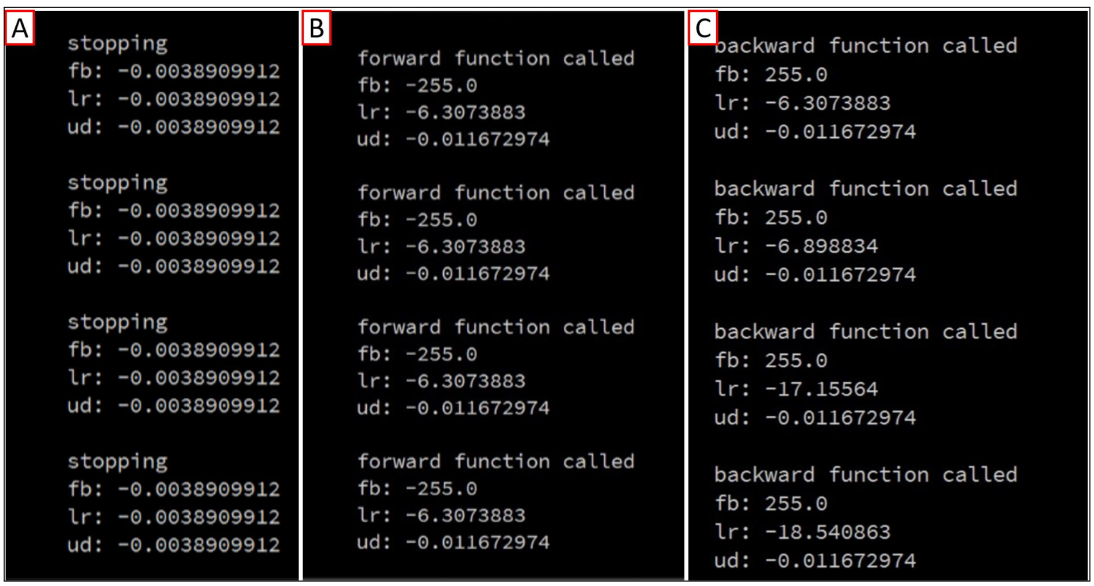

Figure 98: Computer Output

"A" shows stop control testing; "B" shows forward control testing; "C" shows backward control testing

4.5.4 Rover Wireless Transmission Testing

The control signals from the ground station and sensor data from the rover are transmitted wirelessly via XBee Radio Frequency transceivers. To ensure the sensor data are received correctly on the ground station end, a verification function is implemented to ensure the data packets are received correctly and prints a confirmation message to user to acknowledge the transmission.

Important functions for Data Transmission:

```
//Description: Receives User Input Command from Serial Port
void receive_user_input() {
  temp_user = "";
```

```
  while (1) {
    temp_user = Serial.read();
    if (temp_user == "!") {
      break;
    } else {
      received_user = received_user + temp_user;
    }
    delay(2);
  }
  while (Serial.available()) {
    temp_user = Serial.read();
    delay(2);
  }
  temp_user = "";
}
//Description: Verify the checksum of data packets received
bool verify_checksum(String msg, String fields[]) {
  int checksum = 0;
  for (int i = 0; i < msg.length(); i++) {
    if (msg[i] != ',') {
      checksum += msg[i];
    }
  }
  checksum %= 256;
  Serial.println("Calculated " + String(checksum));
  Serial.println("Comparing with " + fields[5]);
  if (checksum == fields[5].toInt()) {
    return true;
  }
  else {
    return false;
  }
}
```

4.5.5 Rover Graphic User Interface Testing

The rover sends data back to the user via the user interface, the user will see a read out of information including coordinates, speed, and video. To test that the user sees the correct data will be compared to the "actual data". Testing for the interface itself will consist of testing the usability in terms of operation. The current GUI uses safeties such as limiting available input, a few ways this is achieved is by the use of drop down menus for features including the selection of the camera, the serial ports, and the refresh rates. Other forms of reduced input are the disabling of buttons when they should not be pressed. An example of this is the connect or disconnect buttons, these buttons try and access a variable that saves the serial port information, if one tries to connect while we are already connected to a port or to disconnect when that variable is empty it can cause the program to work unpredictably and even crash. By reducing the amount of user input we reduce the amount of inputs that can go badly.

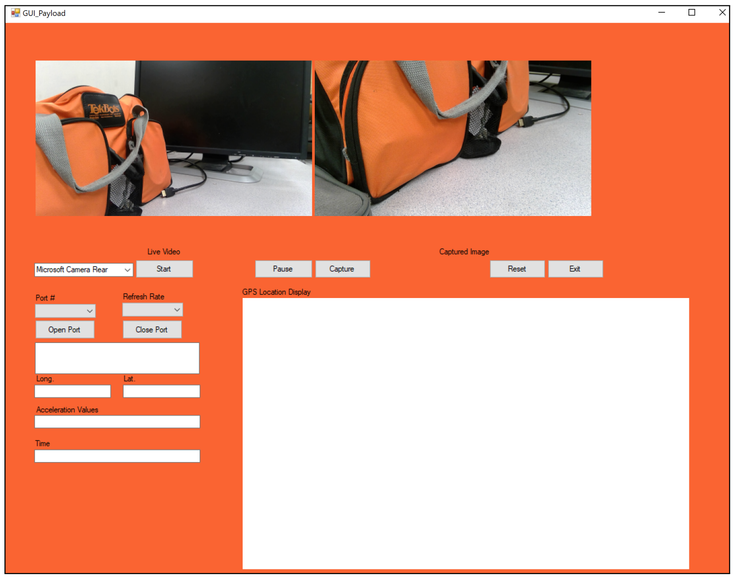

Figure 99: Payload Graphic User Interface Alpha Version

5 Safety and Procedures

5.1 Safety Overview

OSRT has placed additional emphasis on safety in its operations and incident mitigation this year, establishing a team-wide commitment to creating a proactive, adaptive administration and encouraging a culture of self-policing among the team. Though there are specific safety officers overseeing major portions of the project, a core tenet of incident mitigation this year is that all members of OSRT are, in some capacity, part of safety team. By utilizing specialized safety roles during launches, making 'near-miss' hazard reporting readily available for all personnel, and rigorously structuring integration checklists to incorporate safety considerations and officer inspections wherever possible, no significant safety incidents have taken place during the course of the project, and procedures continually improve and iterate in response to changing conditions to ensure safe operation through to the conclusion of the project.

5.1.1 Safety Officers

The Safety subteam lead for 2019-2020 OSRT is Wyatt Hougham, with teammates Nicholas Drachnik, Jessica Peterson, and James Felsher. Nicholas' primary role is on the Aero & Recovery subteam, Jessica's primary role is in Avionics, and James is also a member of the Structures and Propulsion subteam. This selection of officers from multiple OSRT subteams ensures a wide range of expertise and perspectives, broadening the range of hazards that may be addressed with detailed mitigation strategies. Additionally, this team contains multiple members with National Association of Rocketry (NAR) L1 and L2 high-power rocketry certifications, allowing them to handle situations involving high-energy materials like black powder and rocket motors. Safety will also be in charge of organizing and managing a database of checklists pertaining to personnel, environmental, and launch vehicle safety, and implementing any revisions to policy and safety protocol in response to any incidents or identified risks.

5.1.2 Compliance and Legality

Strict adherence to all relevant regulations involved in the construction and operation of high powered rockets is paramount to the success of the team during all stages of development. The safety team is responsible for OSRT member compliance with all OSU, NASA, NAR, Tripoli Rocketry Association, Inc. (TRA), National Fire Protection Agency (NFPA), and Federal Aviation Administration (FAA) safety regulations.

Per Section 5.5 of the handbook, the OSRT will follow FAA regulations regarding visibility, duration, expected altitude, time, and other restrictions of both General Operating Limitations defined in 101.23 as well as Class-2 launch vehicle rules (defined in 14 Code of Federal Regulations (CFR) 101.22), such as advance notification, the involvement of certified Range Safety Officer (RSO) oversight, and launches being conducted in clear spaces, defined as at least a quarter of expected altitude in all directions per the FAA, or 2,500 ft. from launch specified in 3.10 of the USLI 2020 handbook. Additional constraints come from the rigidly defined visibility requirements to minimize danger to the surroundings, including lighting conditions and current cloud coverage. The Certificate of Wavier or Authorization issued by the FAA described in 14 CFR 101.25 must be present, and it is the responsibility of the safety team to verify with the RSO that the flight waiver is valid at each launch.

The team will maintain full compliance with NFPA 1127, as noted in the USLI handbook in Section 1.4. Especially relevant sections of NFPA 1127 are Sections 4.5 through 4.7, which prohibit the use of various materials, prohibit modification of standard motors, enumerate requirements for hazard labeling, and note general expectation of durability and structural integrity with regard to expected aerodynamic forces; Section 4.8, detailing the requirements for stability both in documentation of pressure and mass centers as well as the duties of the RSO in making a final determination of stability before authorization of launch; Section 4.9 detailing the weight and power limitations for the launch vehicle, of which 4.9.1 is the primary concern; 4.10 which places restrictions and requirements on the manner of recovery; and 4.12-4.14 which provides extensive information on the manner of launch, standards for launch ignition sources and the timing or location of ignition installation and system arming/disarming, and legal requirements for the zoning and waivers of a launch site approved for high power rocketry. Other NFPA matters that deal with stages of launch vehicle testing not directly related to design, such as 4.10 recovery procedures, will be addressed in each pre-launch briefing to ensure full compliance from the entire OSRT team.

Handling of all volatile materials such as rocket motors will be performed exclusively by those certified to possess and handle such materials, and their proof of certification will be present at all transaction and relocation of the aforementioned material. Additionally, the team utilizes OSU facilities to store all flammable or reactive materials in fireproof cabinets when not in use, in compliance with NFPA ad NAR regulations regarding storage of high power motors and black powder.

5.2 Safety and Environment

Proper implementation of safety procedures must protect not only the personnel and equipment involved in the project, but also minimize impact on the local environment where test flights, assembly, and other group activities are undertaken. Due to its close connection with the site surveying and post-launch oversight roles, managing these environmental concerns falls within the responsibilities of the safety team. Several strategies are employed to reduce the impact of the project on occupied environments. A key mitigation strategy for loose material is the centralized availability of disposal locations at each launch site, ensuring any debris produced by integration such as lengths of tape, broken shear pins, or plastic packaging will be removed from the site. Other mitigation strategies integrated into launch procedures include using fire-resistant bricks to minimize contact between the motor exhaust and the surrounding soil, and disposing of spent motors in accordance with manufacturer recommendations.

5.2.1 General Mitigation Strategies

Because each of the safety officers possess additional roles elsewhere on the project, it's rare but possible for each safety officer to be occupied in a highly technical task that demands their full attention for upwards of five minutes, especially near the end of the assembly process where multiple teams are interfacing with the launch vehicle; during this time, small details or missteps in mitigating significant hazards could potentially occur, and fail to be noticed. To solve this problem, a minimum of one safety officer must be designated 'on-duty' at all times, signified by wearing a high-visibility safety vest that is easily recognizable at a distance. By ensuring that an on-duty officer is not allowed to perform any assembly tasks and associating a physical object, the vest, with the role, their attention can be completely devoted to spotting and mitigating any developing hazard situations, which should further reduce the chance of an unmitigated, high-severity problem from persisting long enough to damage equipment or harm personnel. Additionally, the high visibility of the on-duty officer provides an excellent channel of communication, should any project personnel need to notify the safety team of a hazard or request clarification on a procedure.

Updated equipment serves as another method for increasing reliability and preventing misuse of safety-critical gear. One instance of this was the acquisition of new face shields, resulting in equipment with a better fit and a reduction in fogging that would sometimes encourage personnel to remove or partially displace the shield for better visibility, even during tasks requiring that level of protection. Another update to the safety team equipment is the 'go-bag', a lightweight assortment of supplies including equipment like gloves, a face shield, and screwdrivers capable of disarming the on board altimeter and EMBERS switches. The go-bag provides all necessary safety supplies to inspect and disarm any stored-energy systems or handle components that may have attained an unsafe temperature once the launch vehicle has come to rest.

By having all needed safety equipment on hand at the site, rather than having to wait for a team to return to the work site for it, the potential for any personnel to expose themselves to armed ejection systems or damaged stored-energy components in the interest of timely retrieval is significantly reduced, and further mitigated by the go-bag stocking burn-focused first aid supplies.

5.2.2 Prevention and Reporting Protocols

Incident reporting for OSRT personnel is conducted primarily through the established channels provided by Oregon State University. In the event that an accident occurs, on-site personnel will record an account and relevant details which may then be transferred up the chain of command within the team to allow for any additional information or corroborating accounts to reach a centralized point of contact with the lead safety officer. Once all relevant detail has been gathered the report is delivered to the team lead, both for cooperation with university reporting processes as well as consultation with mentors about any additional steps or remediation required beyond the safety officer's recommendations.

Existing safety protocol and subteam oversight has been sufficient to prevent any significant safety incidents, and to date no personnel have been seriously injured, nor has any damage to tooling or work spaces resulted from unsafe practices. The desire to continue iterating on safety procedures in a proactive manner, rather than waiting for an incident to spur investigation or policy changes, meant additional scrutiny during work sessions is required. The newly implemented 'Averted Incident Form' serves this purpose by providing a method of reporting events or 'near-miss' situations that don't merit a full investigation or involvement of university oversight, but still provide valuable feedback about the effectiveness of current protocols.

5.2.3 Personnel Hazard Analysis

Any impairment of team members to hazards, either from physical injuries, exposure to toxins, or other incident may impact all other aspects of the project by restricting available skill sets or delaying work, and threatens the reputation of OSRT and associated organizations; therefore, the safety of all personnel involved in every stage of the project must be of utmost importance, and all safety incidents must be deemed unacceptable regardless of severity.

For the Personnel Hazard Analysis in Table 11, each hazard has been assigned a probability and severity, as detailed in Table 10, as well as the mitigation strategies and their forecasted effect on reducing the overall rating of the hazard. Even hazards with a frequency or severity as low as 1 must be monitored, since these risks often have a compounding effect, in which one hazard going unchecked will increase the severity or frequency rating of others, especially in the instance of personnel-related hazard assessment which involve a degree of unpredictability due to human factors.

Table 10: Risk Assessment Chart (RAC)

	Severity				
Probability	**1 - Catastrophic**	**2 - High**	**3 - Moderate**	**4 - Low**	**5 - Negligible**
A - Frequent	1A	2A	3A	4A	5A
B - Probable	1B	2B	3B	4B	5B
C - Occasional	1C	2C	3C	4C	5C
D - Remote	1D	2D	3D	4D	5D
E - Improbable	1E	2E	3E	4E	5E

Table 11: Personnel Hazard Analysis

Hazard	Cause	Effect	RAC Before Controls	Controls	Verification	RAC After Controls
Laceration by Machine	Improper use of machinery	Personnel suffer cutting injuries of varying severity, blood loss	3C	OSU machine shop certification required, additional tooling (ply cutter, etc.) training sessions	All personnel working in shop have completed requisite training class per OSU requirements, no shop entry without badge	3D
	Machine safeguards disabled or malfunctioning			Inspect machines before use	OSU shop inspection and maintenance, manufacturing safety checklist completion	
	Part slips or bucks			Secure parts tightly, machining uses correct feed and speed rates	Physical clamp testing in safety checklists, consult posted feed rate charts for chosen material	
Heat Stroke	Long-term exposure to heat in field work or poorly ventilated workshops	Heavy sweating, nausea, dizziness, permanent brain damage	2C	Hydration, paired/supervised work, education on warning signs	Site setup checklists completed, no symptoms of heatstroke observed in personnel	1D
Hypothermia	Low temperature exposure during field work	Numbness loss of coordination damage to extremities	2C	All personnel will wear clothing appropriate for weather conditions based on forecast data	Clothing and shelter checks during site setup, symptom briefings in pre-departure meeting presentation	1D
	Prolonged exposure in composites freezers			Minimize time retrieving materials, use transfer rolls	Completion of layup schedule calculations	

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Table 11 – continued from previous page

Hazard	Cause	Effect	RAC Before Controls	Controls	Verification	RAC After Controls
Toxic Fumes	Concentrated fumes from binding agents are highly toxic from improper handling of epoxy	Damage to lungs	2C	Ventilated spaces, restrict epoxy use to designated spaces as per Material Safety Data Sheet (MSDS)[4]	Manufacturing checklist completion and safety officer spot-test for concentrated epoxy scent	5D
Detonation	Ignition of airborne combustibles like sawdust or confined epoxy fumes	Internal trauma Severe burns Hearing loss Shrapnel injuries	1C	Keep work spaces clean and ventilated, restrict ignition sources and work with combustibles away from spark-producing machining	Manufacturing checklists and MSDS handling/storage procedures, safety officer spot-checks for ventilation	2D
	Blowout malfunction of fired rocket motor			Follow motor assembly instructions closely, keep personnel at safe distance	Safety checklists minimize number of personnel working on launch vehicle once motor is installed, RSO-designated safe distance sufficient to prevent injury	
Sleep Deprivation	Insufficient rest disorients workers and increases frequency of other hazards	Difficulty concentrating, reduced reaction time, loss of coordination, irritability	4A	Paired/supervised work, self care expectations, detail-oriented checklists	Verbal confirmation from personnel that they are capable of performing their duties	5B
Tripping	Falling over discarded objects or exposed cables	Bruises or other injuries	3C	Keep work spaces clean, walk site before use to note danger regions	Completion of cleanup stage in manufacturing checklists, site setup checklists	3D

Continued on next page

Table 11 – continued from previous page

Hazard	Cause	Effect	RAC Before Controls	Controls	Verification	RAC After Controls
Falling Objects	Dislodged tools or material could strike workers	Severe injury or damaged launch vehicle parts	3C	Secure all materials	Completion of site preparation checklists and manufacturing cleanup checklists, no personnel struck by falling objects	3D
Car Accident	Vehicle collision or terrain impact	Property damage, injury or fatalities	1E	Well-rested drivers, OSRT transportation maintained in good repair with accurate weather forecasts	Vehicle inspections, road condition checked as part of the final launch abort decision	3D
Premature Ignition	Faulty charge wiring; static buildup; failure to disarm launch systems	Accidental firing of launch vehicle motor could strike personnel with high-speed debris or hot exhaust	3C	NFPA storage rules, firing circuit lockouts, no open flames near launch vehicle	Completion of checklists, verification of successful rail final readiness in pre-launch checklist	3D
Pinch Points	Haste or miscommunication during assembly	Bruising Numbness or nerve damage	4B	Consider component from multiple angles before installation, wear gloves	Completion of assembly checklist procedures, especially PPE requirements	5D
	Excess force required to connect components			Move component with incremental motions, use multiple people where needed	PPE requirements for assembly checklists and	
Spray Paint	Inhalation of toxic fumes	Respiratory damage Dizziness	2C	Ventilated spaces and use of masks as per product instructions and MSDS	Safety officer spot-check during use of fume-generating materials, PPE use confirmed in safety checklists	4E

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Table 11 – continued from previous page

Hazard	Cause	Effect	RAC Before Controls	Controls	Verification	RAC After Controls
Ladder Falls	Falling as a result of slips or ladder instability	Uncoordinated and well thought-out physical movements	2C	Limit solo ladder use, follow printed instructions	Prioritization of easy access storage, personnel are not harmed by falling from ladders	3D
Slips	Falling as a result of fluid spills	Injury which could be serious if around dangerous equipment	3C	Announce and clean spills immediately, avoid icy surfaces, and wear proper footwear	Site setup survey and manufacturing area prep checklists, personnel are not harmed by falls or other impacts	4D
Struck by Launch Vehicle	Improper structural integration and flight path analysis. Falling debris or uncontrolled launch vehicles carry significant kinetic energy	Fatality or severe physical trauma	1E	Stay alert, listen to RSO, maintain clear range boundaries	Pre-Flight checklist verifies personnel remain distant, alert, and in designated area until recovery is complete	5E
Electrical Shock	Discharge of firing circuits or other on board electronics	Mild to moderate electrocution of nearby persons	2D	Insulated wiring, disconnection of power sources, inspection of batteries and connections	Devices may be shaken without connections coming loose and devices run without creating visual arcing or audible snapping/sparking/sizzling, personnel are not shocked when handling electrical systems	4E
Mental Health	Consistent high-stress environments can cause attrition of personnel	Depression, anxiety, miscommunication, irritability	3B	Emphasis on team cohesion, work-life balance and self care, individual wellness surveys	One-on-one status checkups with each member of project team during critical periods	4D

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Table 11 – continued from previous page

Hazard	Cause	Effect	RAC Before Controls	Controls	Verification	RAC After Controls
Chemical Burns	Improper education on handling chemicals. Skin contact with solvents and other caustic chemicals	Burning of skin	2D	Consult MSDS sheets, know chemical shower and washing procedures where necessary	Checklist completion for any manufacturing or assembly step, regular inspections of chemical storage containers and wash stations	4C
Sunburn	Ultraviolet (UV) exposure during extended field work	First or Second degree burns	3B	Sunscreen, shaded awnings, and hats	Site setup checklists, verbal confirmation by safety officer of sunscreen usage for field personnel at regular intervals	5D
Splinters	Wood fragments lodged in skin can cause infections	May cause infection	3C	Use gloves and sand down edges of wood	PPE specification in checklists and visual/tactile inspection of all wood components during practice integration	5E
Ergonomic Strain	Back, wrist, and finger strain from awkward angles, lifting, and exerting excessive force on shrouded parts	Back pain, sore muscles and joints, stiffness	3C	High subcomponent accessibility, correct tool for given task, proper lifting and carrying techniques	Accessibility tests in accordance with engineering specifications, personnel do not suffer from soreness or strain after integration of launch vehicle	5E
Uneven Terrain	Holes, ruts, and unstable rubble	Could cause sprained ankles, falls, or twisted joints	3C	Move slowly, wear correct footwear, and use established paths	Completion of site setup checklist, which specifies standards for clear working spaces	4E

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Table 11 – continued from previous page

Hazard	Cause	Effect	RAC Before Controls	Controls	Verification	RAC After Controls
Wildlife Attack	Field work involves regions with wild animals, including possible rabies vectors	Bites, laceration, and possible infection	2D	Avoid deep foliage, wear long pants, walk don't run, keep food off ground, avoid animals	Completion of site setup inspection checklist steps concerning clear ground free of brush or hiding places	4D
High Powered Rocketry (HPR) motor fumes	Airborne fumes are inhaled immediately after launch, contaminated surfaces are contacted	Irritation of skin, lungs, and throat. Liver failure, kidney failure, and cancer	2C	Avoid contact with visible fumes and use proper PPE when handling materials exposed to fumes	Verbal confirmation with RSO that fumes have dissipated, safety officer spot-check of launch site for signs of hazardous materials	2E
Radiation Burns	RF energy is absorbed by the body and converted to heat	Burns on workers skin	3D	Low power transmitters will be used in compliance with Vehicle Requirement 2.22.9, no personnel will stand in direct path of directional antenna	Completion and review of Launch Day Transmitter Data Sheet	3E

5.2.4 Remaining/Pending Hazard Mitigations

Certain hazards present in the project are of special consideration to OSRT, either due to the elevated threat to personnel they represent or due to any uncertainties regarding the effectiveness of current mitigation strategies. For these Priority Hazards, their controls are deserving of more detail and overlapping verifications.

Table 12: Priority Hazard Controls

Remaining Hazard	Proposed Controls	Verification	Justifications
Premature Motor Ignition	Full assembly flowchart modified to install motor as close as possible to final launch setup. Motor handled only by certified personnel. Staged precautions spread through multiple checklists – motor installation, igniter installation, rail setup.	Checklists serve as the primary method for preventing electrical buildup on wires. The on-duty safety officer is responsible for sourcing an ignition-free staging location during site setup. Proof of L1/L2 certification is required before personnel are assigned to post-motor checklist roles.	By reducing the number of personnel to the bare minimum L1 and L2 certified members needed for setup, the number of incidental ignition hazards or chances for mixup/miscommunication drops. Additionally, any incident that may occur will have a lower chance of harming a few, well-protected personnel instead of many moderately-geared people.
Midair Detonation/Fragmentation	All other tasks stop prior to pre-launch countdown. Work spaces are staged at least 500 feet from launch rail.	Pre-launch safety checklist ’go’ confirmation from subteam leads, safety officers present. Confirmation with RSO upon initial site walk that work spaces are sufficiently far away.	Distance from launch vehicle in accordance with NAR High Power Rocketry Code’s minimum distance table is sufficiently outside danger radius of debris from vehicle. Active observation by all personnel ensures that any separation of components from the launch vehicle can be noted, announced, and give sufficient time to move further from the launch site if required.

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Table 12 – continued from previous page

Remaining Hazard	Proposed Controls	Verification	Justifications
Launch Vehicle Drifts Beyond Waiver Area	Rail setup step requires signoff from personnel that performed launch-day simulations of drift distance for a given altitude and best-guess prevailing winds. Rail is angled to account for windage, and any change in conditions that may affect simulated drift distance is grounds for re-simulation during launch final checks.	Preflight checklist completion, RSO verbal confirmation of launch rail orientation and prevailing conditions. Simulation results signoff.	Since rail orientation serves as the only method of counteracting wind-influenced drift, ensuring a rigorous procedure for determining the angle with numeric justification is important. A concrete chain of signoffs regarding where the launch vehicle is projected to land ensures any uncertainty or ambiguity regarding vehicle drift can be retraced to whichever step is in need of improvement.
Recovery of Vehicle With Live Charges	Personnel are not allowed to approach downed launch vehicle until defused. Safety team carries prep bag of disarming, safety, and medical supplies into field. EMBERS system implemented for fail-safe detonation and safe installation.	Black powder checklist completion, pre-launch safety signoffs.	All attempts should be made to control for this occurrence before recovery is completed, since active energetics on the ground violates USLI regulations.

5.2.5 Environmental Hazard Analysis

When operating the launch vehicle it is critical to consider the interactions between the vehicle and its launch environment. This should be considered in both directions: the environment will likely have impacts on the performance and operation of the launch vehicle, but the assembly and use of the launch vehicle could also have adverse effects on its surroundings, especially in the instance of a malfunction or misfire. A Risk Assessment Chart in Table 10 is assigned to each environmental hazard identified by the safety team, indicating its severity and frequency. Additionally, potential mitigation strategies have been devised, with an updated Post-Mitigation Risk Assessment Chart given that predicts the total reduction in hazard rating after these mitigation strategies are successfully employed.

Table 13: Environmental Hazard Analysis

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
Motor catches fire	Direct exposure to extreme sunlight.	Vehicle catches on fire, becomes inoperable, and fails competition.	1E	Store motors and explosives away from any and all heat sources.	There will be a trailer stationed at the launch site. This will contain secure containers for motors and explosives away from heat sources.	1E
Launch vehicle flies past radius of 2,500 ft	High winds past 20 mph at apogee.	The vehicle flies well beyond its calculated drift, It is unrecoverable and unsalvageable.	1D	Launch rail should be adjusted to compensate for wind. Follow all launch procedures and safety checklists prior to ignition as per NAR High Powered Rocket Safety Code (HPRSC) 7 and TRA HPRSC 6-5.	Launch rail will be angled against the wind direction to counteract wind speeds. Pre-flight checklists and rail setup completed.	1E

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Table 13 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
Launch vehicle damage	High winds during descent.	Vehicle drifts into obstacles and/or the ground.	3C	Ensure large area of clearance around launch site as per NAR HPRSC 7 and TRA HPRSC 6-5. Range Safety Officer (SO) cancels flight under high wind conditions as per TRA HPRSC 1-1.2 .	Complete all pre-launch safety checklists, especially RSO communication.	3D
Electrical component failure	High humidity, rain, or lightning as per TRA HPRSC 6-4.	Electronics fail, posing safety hazard and subsequent systems failure	2D	Water-resistant enclosure of each relevant subsystem, cancel flight if needed, seal assembly under sheltered work space	Systems tests and checklists	2E
Loss of visibility	Inclement weather reducing visibility.	Difficulty visually tracking launch vehicle during flight and after touch down. Safety hazard for mid-air systems failure.	2C	Verify weather conditions for launch day as per TRA HPRSC 6-5.	Cross reference FAA, NAR, TRA , and NASA launch safety requirements.	2D
Electrical ignition failure	Rainy or humid conditions	Vehicle does not launch	2C	Use water-resistant enclosed wiring	Ground test in wet conditions, complete continuity testing checklists	2D
Structure and external component malfunction	Exposure to rain or snow.	Material properties or functions are altered and loss of structural integrity.	1E	Build structure with water-resistant materials and test wet conditions of deployment systems.	Pre-flight checklists and data from inclement weather simulation tests.	1E

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Table 13 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
Unexpected or excessive weather-cocking or launch rail failure	High winds, as per TRA HPRSC 6-5.	Trajectory alters toward horizontal, becomes a safety hazard, and recovery/deployment failure	3C	Analysis through calculation and simulation to ensure stable flight. Ensure fins are large enough to counter potential weather-cocking.	Redundant calculations and simulations. Launch only in accordance with safe flight conditions of FAA, NAR, TRA, and NASA	3D
Launch vehicle descends outside of launch range and collection radius	High winds, as per TRA HPRSC 6.5, or early recovery deployment.	Violation of competition rules, loss of line of sight with vehicle, loss of tracking, and a difficult recovery.	2D	Adjust launch rail to preemptively counter the effects of wind during flight.	Current wind measuring prior to launch, and completion of rail setup checklist	2E
Improper motor burn	Humidity, rain, direct sunlight, or other inclement weather, such as what is detailed in TRA HPRSC 6-4.	Motor does not reach projected altitude, and loss of altitude points.	3D	Project altitudes within margin of safety and ensure safe storage of motor out of sunlight and in flame container if possible.	Design motor system to reach higher than projected apogee and allow BEAVS to control final apogee.	3E
Improper apogee variance control	Varying or extreme air density, humidity, disparity in drag calculations used to control BEAVS.	BEAVS does not adjust altitude properly and loss of altitude points.	3D	Use various weather and air conditions to program BEAVS system.	BEAVS setup and activation checklists completed.	3E
Hazardous waste leak	Battery malfunction or broken component leaks chemicals.	Exposing surrounding flora and fauna to hazardous materials.	3D	Inspect and test all batteries prior to use. Enclose batteries if possible.	Completion of required safety checklists. Designated disposal location and proper disposal if necessary	3E

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Table 13 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
Fire started upon motor ignition	Motor ignition flame spreads to surrounding brush.	Brush wildfire presents safety hazard and immediate environmental damage.	2C	Clear flammable brush surrounding launch pad and launch in isolated area clear of all large brush.	Verification of safe launch requirements as set forth by the FAA, NAR, TRA, and NASA. Fire extinguisher kept onsite.	3D
Recovery deployment failure	Failure in deployment system, insufficient deployment forces	Uncontrolled vehicle landing and jettison of parts/debris.	1C	Ground testing of all recovery systems paired with extensive calculations prior to launching.	Consistent successful ground tests and successful prototype launch. Fail safe secondary systems implemented to ensure deployment of recovery system.	1D
Jettison of wadding	Insufficient securing or enclosure of wadding.	Spreading of wadding material into surrounding environment.	4B	Use wadding that is biodegradable and not harmful to environment and collect jettisoned debris.	Line of sight maintained with jettisoned material such that it can be collected.	5B
Vehicle collision with structure on descent	High winds, as detailed in TRA HPRSC 6-5 or early recovery deployment.	Damage to structure and/or surroundings as well as launch vehicle.	2D	Ground test of recovery systems and avionics. Launch out of possible range of any structure. No-Go if winds are too strong.	Pre-launch checklists to ensure system functionality and verification of safe launch requirements as set forth by the FAA, NAR, TRA, and NASA.	2E
Injury or death to animal/wildlife	Animals within launch zone are struck by falling debris.	Injury or death of the animal.	2E	Launch conducted in area most likely away from wildlife, and active monitoring of surroundings at launch site.	Verify clear range prior to launch. Safety subteam issues No-Go if wildlife are in proximity of exposure to risk.	2E

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Table 13 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
Hazardous material in launch debris	Improper motor burn or excessive expelling of shrapnel or fuel leak from the motor. Toxic smoke from motor burn.	Fire hazard for launch and surrounding brush and chemical hazard to wildlife and people. Fume hazard for nearby people and wildlife.	2C	Inspection of motor systems prior to launch, inspection of launch zone after launch, and safe disposal of debris if necessary.	Pre-launch checklists to ensure system integrity. Specific safety considerations addressed before flight so proper PPE can be distributed if necessary	2D
Parachute ejection energetic or motor explosion	Malfunction of energetic system and motor retention failure.	Explosion and expulsion of debris as shrapnel, as well as fire and safety risk.	1C	Extensive ground testing of ejection energetics, all energetics systems checked prior to installation.	Pre-launch checklists, safety verification checklists prior to installation. Disabling switches implemented. Clearing of launch pad and ground station of all flammable brush.	1D
Expulsion of debris mid-flight	Improper fastening of launch vehicle and constituent parts.	Debris littered in area surrounding launch site.	3C	Fastener and hardware securing checklist	Redundant checks and actionable checklist verifications pre-flight.	3D
Launch vehicle breaks into pieces	Zippering or insufficient structural integrity, or other destructive form of material failure	Vehicle breaks apart, dispersing debris at launch site surroundings.	2C	Structural integrity calculations, simulations at event extremes, designed and implemented structural integrity measures.	Redundant calculations, positive taper of airframe by incrementally increased carbon fiber layer depth. Maintaining visual contact with significant pieces of debris to be collected if necessary	2E

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Table 13 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
Improper disposal of waste	Team members not utilising proper garbage disposal procedure at launch site.	Exposes wildlife and landscape to litter and garbage.	4C	Have defined garbage disposal locations/procedures, known by all team members.	Visual inspection of launch site prior to setup and before departure by team leaders.	4E
Destruction of environment due to airframe retrieval	Failure of recovery systems or erroneous flight.	Foliage and ground cleared in effort to retrieve launch vehicle from ground after high speed impact	3A	Ensure nominal flight and recovery by following all checklists, procedures, and applicable rules and laws.	Successful launches due to adherence from checks and safety guidelines, with paperwork available for flight readiness verification.	3D
Fire to surroundings and launch vehicle	Motor fails to fully ignite, and therefore, launch vehicle does not leave launch rail.	Brush fire safety hazard to wildlife, environmental damage, launch vehicle damage.	1D	Have fire extinguishers on-hand in event of fire, checks and verifications during motor build.	Safety checklists and pre-launch verifications.	2D

5.2.6 Failure Mode Effects Analysis (FMEA)

An FMEA was performed on each major subsystem of the vehicle by OSRT. Each failure mode has a severity associated with it, detailing how drastically will it harm the launch vehicle, an occurrence for how often it can or will occur, and detection, which is how easily will it be seen or found prior to launch or during launch. Each of these failure characteristics are rated on a scale from 1 to 10, with a characteristic of 1 being minimal, rare, or easily identified and 10 being catastrophic, constant, or undetectable. Table 14 shows this FMEA table, detailing potential failure points and their controls, as well as the Risk Priority Assessment score indicating which failures are of highest concern. The following are the ten most concering failure modes for the launch vehicle, and their mitigation steps.

- Airframe buckling on impact, caused by the recovery system failing to deploy and having it fall to the ground at 150ft/s. There is no way to fix a broken carbon fiber tube that we have timely access to, so a new one would need to be purchased for the next launch. This can be mitigated by making sure all harnesses, quicklinks, eyebolts, and connection points have a factor of safety that is greater than 2.0 via manufacturer specifications paired with simulation data on recovery forces.
- Premature section separation occurs when the aerodynamic forces experienced by the airframe sections overpower the shear pins joining the sections. Partial or complete loss of the launch vehicle is very likely, a major setback for the project timetable. This can be mitigated by having an adequate number of sheer pins that are installed with the correct procedure, which has been developed through calculations and simulated launch and recovery forces.
- Shear pins failing to break can be caused by insufficient pressure from the black powder charges. This failure causes a complete or partial dysfunction of the recovery system, and therefore will cause structural damage and destroy all electronics inside. This can be mitigated by inspecting all black powder charges and bulkhead seals prior to launch, as well as having a backup charge that is 1.5-2x the primary charge to force an ejection.
- Airframe coupler altimeters are responsible for recovery deployment, and the charges used for ejection may fail to ignite. This is usually caused by the E-match ignition system failing to light and the coupler not separating at apogee to deploy the drogue parachute. This can be controlled by inspecting all E-matches and charges thoroughly before installing.
- Premature extension of BEAVS airbrakes during motor burn will interfere with altitude predictions. It will also destroy BEAVS as it is not meant to open early causing a system failure. This is caused by input data of the wrong numbers or a fault in the electrical system. This can be mitigated by implementing fail safe methods to lock the BEAVS module until motor burnout is completed.
- Battery damage from impact or imparted forces could cause a failure in the avionics systems aboard the vehicle, either as loss of power or even more critically, an onboard battery fire in a compartment adjacent to black powder charges. This can be mitigated by having the battery launch protected from all large impacts, sharp objects, and have it brightly colored to ensure careful handling and care around

sharp tools.

- Failure of the fore payload bulkhead, primarily from slipping off the rod or buckling under applied forces, will result in displacement of the payload into the nose cone. Ultimately at 1200lbs of force due to parachute deployment the rover would be destroyed and non functional for deployment on the ground. This is caused by a high load and moment on the lead screw. This can be mitigated by ensuring the load on the lead screw keeps to a factor of safety of 2 or greater, primarily through material selection and ensuring multiple support points.
- Failure of payload ejection systems will result in an inability for the launch vehicle to complete the payload portion of its mission. This is caused by a motor burnout, explosion, or damage to the inside of the air frame such that the lead screw becomes warped or jammed. This motor needs to be able to break through the shear pins on the nose cone, creating a moment of peak stress on the component. Mitigation consists of a properly sourced motor, well designed electronics, and correct shear pin selection.
- The loss of one or more bulkhead eyebolts may cause premature deployment of the recovery system during ascent. This will tear the parachute if done at ascent, potentially damaging the airframe through zippering or sudden forces. Since this represents a recovery system failure, this will destroy the electronics and the insides of the launch vehicle on ground impact. This is caused by epoxy bond failure, a bulkhead attachment failure, or a defective bolt. This can be mitigated by going through proper curing processes, double checking bolt ratings, and having high safety factors for the bulkheads through redundant connections.
- Delamination of airframe will cause the loss of the entire launch vehicle if not detected before launch. This is caused by storing the airframe and materials in too high or low temperatures, interfering with the composite structure. This can be mitigated with detailed manufacturing procedures and proper material storage in controlled environments to ensure longevity and quality.

Table 14: Structures FMEA

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	Risk Priority Number (RPN)	Mitigation
Nose Cone	Non-Uniform, non-straight nose cone	Unpredictable Flight Path, Increases drag	Damaged nose cone	8	1	8	64	Inspection before and after the use of nose cone as described in checklists required by Requirement 1.2.
	Nose cone detaches during flight.	Flight failure, loss of nose cone, and loss of avionics.	Tip is not properly secured and/or not correctly attached to recovery system.	8	1	5	40	Follow installation checklists methodically. Inspect launch vehicle before sealing using checklists created in compliance with Requirement 1.2.
Airframe	Delamination of airframe materials from temperature.	Launch vehicle is not recoverable or reusable.	Long term storage in unsuitable temperature conditions	9	1	6	54	Choose proper size by calculating thermal stress of materials for long term use in compliance with Requirement 6.1.
	Airframe buckles from high stress.	Launch vehicle is destroyed.	Recovery system fails to deploy.	9	1	8	72	Modify safety factor for adjustments in launch vehicle assembly as described in Requirement 6.1.
	Zippering along the edges from shock cord	Destruction of the launch vehicle	Shock cords pulling across edge of tube	8	2	8	128	Ensure and/or black powder charges are properly sized according to Equations 14.

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Table 14 – continued from previous page

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
Fins	Fins are misaligned.	Unpredictable flight pattern or loss of launch vehicle causing damage to surroundings.	Damage of fins from shipping and handling and/or hard landing. Fins not cured and/or aligned correctly.	7	3	5	105	Inspect fins before and after launches. Handle fins carefully. Use an OSRT designed fin-alignment guide as per Requirement 6.12.
	Fins fall off	Unpredictable flight pattern or loss of launch vehicle causing damage to surroundings.	Insufficient amount of epoxy and/or cured improperly. Forces cause epoxy failure. Insufficient amount of epoxy and/or epoxy cured improperly.	8	3	6	144	Inspect fins before and after launches. Handle fins carefully. Use fin-alignment guide as per Requirement 6.12.
Coupler	Overall Vehicle is bent	Loss of launch vehicle. Unable to use launch vehicle again.	Bending forces from harsh landing or forces experienced from improper integration.	8	4	3	96	Composite layers will be thick in regions that will accommodate higher stresses and achieve a safety factor as per Requirement 6.1.
Bulkhead	Premature ejection	Destruction of airframe.	Shear pins released before ejection	9	4	9	324	Adequate number of shear pins to satisfy Requirement 6.1.

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Table 14 – continued from previous page

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
	Fracture	Internal components damaged and unrecoverable launch vehicle	Internal components damaged and unrecoverable launch vehicle	8	2	2	32	Select plywood from reputable sources, making sure the plywood is thick and has large washers. Bulkheads will be shown to exceed safety factor as per Requirement 6.1.
Threaded Rod	Fracture	Loss of recovery system and launch vehicle	Force is greater than what the strength of the rod is designed for	9	4	5	180	Design the size of threaded rod to a suitable factor of safety as per Requirement 6.1.
Shear Pins	Shear pins fail to break	Loss of vehicle and recovery system does not deploy	Insufficient pressure is created to break shear pins	10	3	5	150	Have black powder ejection charges more powerful than primary ejection charges and test all charges with ejection test.
E-Matches	Poor e-match connection	Loss of coupler detachment	E-match does not light	10	2	6	120	Inspect e-match and wiring thoroughly before integration and launch using checklists as per Requirement 1.2.

Table 15: Recovery FMEA

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
Recovery System								
Parachute	Parachute tears	Parachute rips reducing drag and increasing speeds landing too fast	Parachute tear	8	3	4	96	Check parachutes after every launch using checklists as per Requirement 1.2.
	Parachute breaks off shock cord	Parachute rips off, causing launch vehicle to plummet at terminal velocity	Break in shock or shroud lines	8	3	3	72	Ensure connections between shock cords and parachutes maintain a safety factor in compliance with Requirement 6.1.

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System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
	Parachute tangles	Parachute does not fully deploy, the parachute is tangled drag reduced	Packing bag issue	6	3	3	54	Pack parachutes as defined in checklists per Requirement 1.2.
Quick link	Quick link breaks	Parachute breaks off, drag reduced vehicle hits at high kinetic energy	Quick link ultimate strength issue	7	3	3	63	Calculate impulse prior and select quick links in compliance with Requirement 6.1.
Tender descender	Tender descender fails to release	Main parachute does not deploy. Bag stays in bay vehicle falls at high speeds	Tender descender e-match or failure	9	4	4	144	Check tender descenders and e-matches using checklists as per Requirement 1.2.
E-match avionics	E-match fails to ignite	Main parachute does not deploy. Bag stays in bay vehicle falls at high speeds	Tender descender e-match or failure	9	4	4	144	Check e-matches and avionics using checklists as per Requirement 1.2.
Drogue Parachute	Drogue parachute fails to deploy	Drift becomes exponential speed increases vehicle lands too hard	Ejection charge fails to ignite and/or parachute becomes tangled.	7	4	5	140	Check ejection charges and parachutes using checklists per Requirement 1.2.
	Drogue parachute breaks off	Drift becomes exponential, speed increases, and the vehicle goes ballistic	Shock cord or shroud line failure	7	4	5	140	Ensure shroud lines and shock cords meet safety factor per Requirement 6.1.
Nylon Tether	Nylon tether breaks	Vehicle breaks apart one or both pieces hits the ground with no parachute	Shock cord and tether failure	9	5	2	90	Ensure nylon tether can withstand all impulses with sufficient safety factor as per Requirement 6.1.

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System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
Bulkhead	Bulkhead Eyebolt breaks	One or more of the parachutes separate from the launch vehicle causing catastrophic damage.	Epoxy failure force analysis failure	10	1	2	20	Ensure bulkheads withstand the impulse of recovery in compliance with Requirement 6.1.
Ejection Charges	Ejection charges fail to separate coupler	Vehicle fails to separate and deploy one or both parachutes	Friction between coupler and airframe is greater or ejection charge is less powerful than expected	9	2	2	36	Having backup charges which are larger than the primary charges set to deploy at a delay of no more than 2 seconds after apogee as per Requirement 3.1.2.

Table 16: BEAVS 2.0 FMEA

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
BEAVS 2.0 Mechanical System								
Rack: Airbrake linear actuator	Experiences bending moment	Rack bends or breaks	Exposure to flight forces out of structural tolerance	4	2	5	40	Maximize rod thickness and internal structural support in compliance with Requirement 6.1.

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Table 16 – continued from previous page

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
Linear Guide Sleeve: Guides rack in/out of launch vehicle body	Disconnects from rack	Rack is unable to extend or retract from position, potentially flies out of airframe	Pushed off rack due to flight forces	7	5	1	35	Maximize material strength and fasteners in compliance with Requirement 6.1.
Gear: Translate power from motor to motion in rack	Gets jammed between racks	Rack is unable to extend or retract from position	Gear and rack teeth misaligned	3	2	1	6	Use CNC machine to manufacture parts for tight tolerances. Use checklists to ensure the system is operational before launch as per Requirement 1.2.
Motor shaft: Connects motor and gear	Experiences losses due to friction or play	Rack extends and retracts with reduced speeds	Friction and/or play between motor shaft and gear	2	2	5	20	Use CNC machine to manufacture parts for tight tolerances. Use checklists to ensure the system is operational before launch as per Requirement 1.2.
Bulkhead: Platform for all components to sit on	Splinters	All mechanicals on bulkhead are compromised	Moment from flight forces on the blades when extended	8	4	2	64	Add hard points and reinforcements sufficiently to satisfy Requirement 6.1.
1.3cm								BEAVS 2.0 Electrical System

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Table 16 – continued from previous page

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
Battery: Provides power to mechanical system	Runs out of charge	Entire system fails to receive power and does not operate	Battery is drained from sitting on launch rail too long before flight	8	6	4	168	Choose larger than required battery/have back up battery connected. All batteries will be fully charged prior to each launch in accordance with Requirement 6.14.
Accelerometer: Measures acceleration of launch vehicle	Incorrect measurements relayed to controls system	Data input to control loop produces false values and system acts according to false data	End of product life cycle	5	5	5	125	Accelerometer will be proven to be working via testing prior to launches.
Barometric Pressure Sensor: Measures atmospheric pressure	Incorrect pressure values relayed to controls system	Throws off calculations in control system	collecting noisy data misaligned with venting holes	6	5	5	150	Implement a Kalman filter and PID control loop to ensure clean data is being utilized. Testing will be performed to ensure data is clean and reliable prior to launch.
Motor: Drives the rack and pinion assembly	Disconnects from power source	Entire system fails to work	Battery dies	8	2	2	32	Choose larger than required battery/have back up battery connected. All batteries will be fully charged prior to each launch in accordance with Requirement 6.14.

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System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
PCB: Mechanically supports and electrically connects electrical components	Components disconnect	Entire or portion of system fails to work	Excessive flight forces and not enough electrical potting material	7	4	4	106	Electrical potting material will be used to dampen vibrations as per Requirement 6.15.
BEAVS 2.0 Controls System								
Control System: Controls mechanical system with inputs from electrical system	Blades extend during motor burnout	Structural damages to airframe and BEAVS 2.0 mechanical systems	Input data provides incorrect numbers	10	3	5	150	Implement fail-safe to prevent system activation before motor burnout has been completed.
	Apogee altitude hits over 4,000 ft	Apogee altitude is over shot	Insufficient drag is produced in time to reduce apogee	6	9	9	486	Implement control feature where blades automatically extend once altitude achieves 4,000 ft.
	Apogee altitude does not reach 4,000 ft	Apogee altitude is never reached	Launch day wind conditions, improper ballast, flight angle	7	7	8	392	Do not activate system, but continue to collect data.

Table 17: Payload FMEA

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
Coupler Retention Bulkhead	Fracture	Bulkhead failure	Jolt from parachute ejection	8	2	6	96	Appropriately size component to have a safety factor of at least 2 in accordance with requirement 6.1.
	Bulkhead release	Loss of payload retention	Fastener failure	8	1	1	8	Add additional mounting fasteners to bulkhead to have a safety factor of at least 2 in accordance with requirement 6.1.
	Lead screw coupler shear	Loss of payload retention	Too soft of material	8	3	1	24	Support coupler with washer to ensure a safety factor of at least 2 in accordance with Requirement 6.1.
Lead Screw Nut Bulkhead	Breaks	Lead screw jam	Bolt failure	5	1	3	15	Make bulkhead out of durable material and test ejection system to ensure proper function with a safety factor of at least 2 in accordance with Requirement 6.1.
	Twists	Lead screw jam	Jolt from parachute ejection	2	3	2	12	Use a large lead screw that can withstand the forces of flight and recovery without bending in accordance with Requirement 6.1.
	Spins with lead screw	Ejection failure	Bulkhead pushed out of airframe	6	3	1	18	Lead screw must be shorter than the length of the airframe.
	Twists in airframe	Ejection failure	Thin bulkhead	6	3	1	18	Manufacture to a tight clearance between bulkhead and airframe, and thicken bulkhead to be in compliance with Requirement 6.1.
Lead Screw	Slips off motor shaft	Ejection failure	High loading on lead screw	4	4	2	32	Support lead screw with bulkhead to ensure a safety factor of at least 2 in accordance with Requirement 6.1.

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System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
	Shaft misalignment	Poor lead screw efficiency	Improper Mounting	3	7	3	63	Select a motor with sufficient torque to establish a safety margin of at least 2 as per Requirement 6.1.
	Slips through bulkhead	Loss of payload retention	Improper outer diameter	9	2	1	18	Properly size coupler diameter to have a safety margin of at least 2 as per Requirement 6.1.
	Friction between coupler and bulkhead	Motor stall	Coupler shifted during recovery	6	2	4	48	Modify contact surface to reduce friction and allow for a safety margin of at least 2 as per Requirement 6.1.
Coupler to Lead Screw Pin	Shear	Loss of payload retention	High loading on lead screw	8	1	2	16	Maximize pin shear strength to allow for a safety margin of at least 2 as per Requirement 6.1.
	Pin ejection	Loss of payload retention	Improperly secured	8	1	1	8	Use bolt and nut for pin to allow for a safety margin of at least 2 as per Requirement 6.1.
Lead Screw Nut	Jam/seize	Ejection failure	Poor lubrication	4	1	1	4	Internally lubricated lead screw nuts to ensure a safety margin of at least 2 as per Requirement 6.1.
	Spins with Lead screw	Ejection failure	Improper retention	6	4	3	72	Properly fit bulkheads to launch vehicle to prevent them from spinning during ejection.
	Spins with Lead screw	Ejection failure	Fasteners shear	6	4	3	72	Use rigid fasteners and bulkhead material.
Lead Screw	Lead screw bending	Ejection failure	Side loading on lead screw	7	4	1	28	Appropriately size lead screw, if necessary add supporting structure to ensure a safety margin of at least 2 in accordance with Requirement 6.1.

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Table 17 – continued from previous page

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
Ejection Motor	Stall	Ejection failure	Motor generates insufficient force to push the payload	2	5	2	20	Use motor with enough torque to push the rover from the airframe.
	Overheat	Ejection failure and airframe damage	Motor causes damage to itself and surrounding components	8	1	4	32	Only use motor within voltage specifications found in the datasheet.The motors will be proven to not overheat via testing.
Ejection Electronics	Violent disassembly during flight	Ejection failure	Flight and recovery forces jar electrical components loose	2	6	2	24	Electrical potting material will be used to reinforce the connections between the components and the board as per Requirement 6.15.
	Current damages PCB traces	Ejection failure and PCB damage	PCB traces are improperly sized	4	1	3	12	PCB traces will be appropriately sized for the expected currents going through them to a safety margin of 2 in accordance with Requirement 6.1.
Chassis	Breaks	Parts become misaligned	Stress during flight	6	1	4	24	Testing will be performed to ensure the chassis can withstand forces of launch and recovery to a safety factor of 2 per Requirement 6.1.
	Component fastener failure	Rover failure	Flight and recovery forces	6	3	3	54	Utilize rigid connections between components to ensure a safety factor of 2 per Requirement 6.1.
	High centering	Drivetrain failure	Low ground clearance	6	5	1	30	Expandable wheels will be used to maximize ground clearance in accordance with Requirement 6.5.
Stabilizing tail	Breaks	Speed of payload lowered	Stress during flight	3	2	6	36	Test strength of tail as per Requirement 6.13

Continued on next page

Table 17 – continued from previous page

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
	Excessive Bending	Rover structure spins	To ductile of material	6	3	1	18	Test variable tail thicknesses as per Requirement 6.13
Battery	Fully Discharged	Payload loses function	Payload active for too long	6	4	1	24	Develop power budget to appropriately size battery and fully charge battery before each launch as per a checklist
	Battery is pierced by Foreign Object Debris (FOD)	Battery explodes destroying itself, payload, and launch vehicle if rover is not yet ejected	Improperly protected battery	10	2	4	80	The battery will be protected from impact and brightly colored as per Requirement 2.21
Camera	Signal corruption	Loss of feed	Magnetic Interference	6	3	1	18	Incorporate magnetic protection as per Requirement 6.2
Wheels	Slips off motor	Wheels not powered	Shifting during flight	7	3	7	147	Create a firm padded section for the payload in which it cannot shift as per requirement 4.3.7.1
	Does not unfold and expand	Wheels difficult to turn	Broken/Jammed Hinge	4	4	4	64	Inspect hinges, ensure adequate lubrication in accordance with a checklist as per Requirement 5.1
	Sinks into soft dirt	Rover cannot move	Not enough surface area	5	3	4	60	Increase surface area in contact with the ground as per Requirement 6.5
Drive motors	Breaks	Wheels not powered	Damaged in flight	7	1	7	49	Have motors attached firmly, make sure rover is securely fixed in launch vehicle and well padded as per Requirement 6.1
Scoop	Fails to collect	No sample collected	Not enough power	7	4	4	112	Make sure the motor has ample strength as per Requirement 6.6
	Sample falls out of scoop	No sample collected	Improper scoop angle, lip too shallow	7	5	6	210	Design sample retention system as per Requirements 4.3.4 and 6.6

Continued on next page

Table 17 – continued from previous page

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
	Failure to penetrate soil	No sample collected	Not enough weight behind rover	7	6	3	126	Ensure rover scoop deployment has sufficient power.
Scoop Motor	Jam	No sample collected	Misaligned Parts	7	4	6	168	Ensure proper assembly as per a checklist and repeated tests on scoop deployment as per Requirement 6.13

5.3 Launch Operations Procedures

5.3.1 Initial Inspection

General Safety Operations Checklist

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Watch for trip hazards while walking site.
		- Heed all RSO instructions, especially for potential falling hazards.
		- Note all major hazards and conditions.
		- Verbally verify that on-duty officer is selected and chain of responsibility is clear.
		- Prioritize approval of staging and assembly area so other teams can work.
		Prerequisite lists: N/A
	_____	**Tools Needed:** Burn Bucket, Go-Bag, Safety Vest
	_____	**Components Needed:** N/A
		Site Setup
1	_____	Weather conditions permit operation of launch vehicle.
2	_____	All site personnel are adequately dressed for conditions.
3	_____	Site personnel are made aware of locations for burn bucket and other hazardous material disposal.
4	_____	Sufficient water available for anticipated stay.
5	_____	Work area clear of holes, bramble, other tripping/abrasion hazards.
6	_____	No ignition sources or armed electrical components within 25 feet of motors or black powder not in sealed storage.
7	_____	Volatile component storage is out of direct sunlight or other heat sources.
		Meet with Range Safety Officer
8	_____	One member of each subteam must be present when meeting with RSO to answer any questions regarding vehicle payload, proposed altitude, motor impulse, and other specifications required for launch.
		Payload Initials: ________________
		Structures/Propulsion Initials: ________________
		Aerodynamics/Recovery Initials: ________________
		Avionics Initials: ________________
9	_____	Confirm that the proposed altitude of launch is valid for the FAA waiver.
		Before Launch
10	_____	Confirm each subteam checklist is completed:
		Payload Initials: ________________
		Structures/Propulsion Initials: ________________
		Aerodynamics/Recovery Initials: ________________
		Avionics Initials: ________________
11	_____	No greater than 5 team members transporting vehicle to launch site.
12	_____	Confirm that Safety Go-Bag is packed.
		Face Shield ________________
		Safety Gloves ________________
		Disarming Tools ________________
		First Aid ________________

Continued on next page

Table 18 – continued from previous page

#	Inspector Initials	Step Instructions
13	______	On-Duty Safety Officer is carrying go-bag and dressed for field recovery.
14	______	Confirm that the Structures subteam representatives sent to the range have completed their launch preparations. Structures/Propulsion Initials: ______________
15	______	Rail correctly angled away from populated areas for prevailing conditions.
16	______	All personnel clear from range.
		Launch and Recovery
17	______	Complete 'Launch Checklist' up to step 10 before proceeding.
18	______	Verify deployment of recovery systems at apogee. Until safety officer or RSO gives all clear, all safety officers must stop work and watch for falling hazards.
19	______	Track descent of launch vehicle. Notify work teams if they are to seek shelter. Confirm landing and the full discharge of all onboard energetics.
20	______	Ensure group in charge of recovering launch vehicle is correctly dressed for a potential long walk through brush and uneven terrain.
21	______	Thank the RSO for their time.

5.3.2 *Launch Vehicle Assembly*

Full Assembly Checklist

Assembler Signature:______________ **Safety Officer Signature:** ______________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Personnel wearing appropriate safety gear - All shear pins present and flush with frame - Fully assembled launch vehicle is pointed towards range **Prerequisite lists:** - All subsystem assembly checklists completed **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Hex keys, screwdriver
	______	**Components Needed:** Assembled airframe, BEAVS system, avionics electronics for coupler bay and nose cone bay, payload system, ejection system for fore and aft sections, Parachutes (Drogue and main)
S	______	**Safety consideration: The launch vehicle contains active energetics. Minimize number of personnel near launch vehicle, and strictly control sources of sparks/heat/flame.**
S	______	**Safety consideration: Rough handling or water damage to board may short electrical systems and ruin the entire PCB.**
1	______	Attach nose cone to fore airframe section.
2	______	Rotate nose cone to align shear pin holes with corresponding holes in airframe. Install shear pins.
3	______	Visually inspect launch vehicle for defect, missing shear pins, misaligned rail guides, missing components.

5.3.3 *Aft Assembly*

Motor Installation Assembly Checklist		
Assembler Signature:________		Safety Officer Signature: ________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Keep area clear of ignition, heat, and spark sources - Motor is being handled by certified personnel only - Launch vehicle must ALWAYS be pointed towards range during and after installation - All bolts present and tight - Check motor plate is level **Prerequisite lists:** - All main body assembly checklists – motor should be the VERY LAST thing installed! **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	____	**Tools Needed:** Gloves, Face Shield
	____	**Components Needed:** Aft Body Section, L2200G Motor, L2200G Motor Casing, Motor Plate, Motor Plate Bolts (3x), Fuse
S	____	**Safety consideration: Failure to secure Motor Plate Bolts could result in the motor dropping out and sustaining damage, or result in misalignment.**
S	____	**Safety consideration: Minimize number of personnel around the launch vehicle once the motor is installed. Active personnel MUST have at minimum a NAR L1 certification or equivalent.**
S	____	**Safety consideration: Motor contains highly explosive propellant, ensure proper PPE is in use, handle with care. Misuse or failure to follow procedure may result in injury.**
1	____	Unscrew motor casing cap.
2	____	Insert motor into casing.
3	____	Insert casing into alignment tube in aft section.
4	____	Install motor plate flush and level with motor alignment tube using bolts.

BEAVS 2.0 Checklist		
Assembler Signature:________		Safety Officer Signature: ________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - All electronics are securely attached to BEAVS 2.0 - Ensure exposed metal on all boards have been coasted in an insulating material to avoid shorting between components - Verify system is powered on - Verify blades are fully retracted - Verify motor is at it's "0" position **Prerequisite lists:** - Prefield Inspection - Preflight Inspection - Aft Airframe
		Continued on next page

Table 19 – continued from previous page

#	Inspector Initials	Step Instructions
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** $\frac{1}{8}$ in. hex key, flat-head screwdriver, micro flat-head screwdriver, digital multimeter, allen wrench set.
	______	**Components Needed:** Aft airframe, 4x radial bolts, 4x 8 in aluminum threaded rods, 24x $\frac{1}{4}$-20 hex nuts, BEAVS mechanical system, 3x bulkheads, BEAVS PCB, 12v battery, servo motor.
S	______	**Safety Consideration: - Failure to follow these steps in sequential order can 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 before power supply is turned on.
3	______	Secure screws into terminal.
S	______	**Safety Consideration: Failure to ensure blades are fully retracted may cause encoder to lose positional accuracy on blades**
4	______	Plug in battery.
5	______	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**
6	______	Ensure nominal voltage output from battery with multimeter is 12 volts.
S	______	**Safety Consideration: - Do not touch both terminals of the battery to any electronics or body parts.**
7	______	Ensure radial bolts are removed from bulkhead.
8	______	Slide mechanism into aft section of the airframe, on top of the aft ballast.
9	______	Once positioned properly in airframe, ensure blades are lined up with slits and radial holes in bulkhead are aligned with airframe radial holes.
S	______	**Safety Consideration: - Failure to properly secure components and radial bolts may cause damage to internal components due to loose pieces.**
10	______	Secure radial bolts into bulkhead with 1/8 in. hex key.

5.3.4 Main Coupler Assembly

Altimeter Checklist

Assembler Signature:______________ **Safety Officer Signature:** ______________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Ensure that the two altimeters are securely fastened to the altimeter bay. - Ensure that the e-match wires are securely attached to the altimeters. - Ensure that the correct black powder charge is plugged into the correct port. - Ensure that the 9V battery has adequate charge (8.0V or more). **Prerequisite lists:** N/A

Continued on next page

Table 20 – continued from previous page

#	Inspector Initials	Step Instructions
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Digital Multimeter, tiny flat-head screwdriver, tiny Phillips screwdriver, sharpie
	______	**Components Needed:** 2 Missileworks RRC3 Altimeters (1 "P1" Altimeter, 1 "B1" Altimeter), 4 e-matches, 2 9V batteries.
S	______	**Safety Consideration: - All steps must be carried out by HPR level 1 certified team member due to the presence of black powder.**
S	______	**Safety Consideration: - Process includes the use of black powder. Follow black powder handling guidelines.**
S	______	**Safety Consideration: - Ensure all team members in close proximity to the black powder are wearing safety glasses to avoid black powder contacting the eyes.**
S	______	**Safety Consideration: - Ensure altimeters are powered down while installing black powder charges.**
S	______	**Safety Consideration: - Ensure the e-matches are installed in the correct port. Failure to correctly install the e-matches will lead to premature/late detonation, or failure to detonate.**
S	______	**Safety Consideration: - Ensure the multimeter is turned to volts. Having the multimeter turned to another setting can damage the multimeter or battery.**
1	______	Measure 9V battery voltage with a multimeter.
2	______	Verify each battery has at least 8V worth of power.
S	______	**Safety Consideration: - Batteries with a charge below 8V may not activate the altimeters, particularly if they have to sit and wait a while on the launchpad.**
3	______	Record battery name and voltage: ________ / ________ ________ / ________
4	______	Install batteries into the battery holders on the altimeter bay.
5	______	Install battery wires into the altimeter.
S	______	**Safety Consideration: - Installing the leads backwards into the altimeter will destroy the altimeter. Black goes to negative, red goes to positive.**
		P1 Altimeter
6	______	Ensure that DIP switch 4 is in the OFF position on the P1 Altimeter. This switch is located next to the program button.
7	______	Turn P1 altimeter on via the switch.
8	______	During the 5 second beep, press the program button.
9	______	Ensure that the arming altitude is set to 200 feet by listening to the beeps. There should be two short beeps, followed by a long beep, and then a very low frequency beep.
10	______	If the arming altitude is **not** set to 200 feet, set it to 200 feet by pressing the program button 20 times after the very low frequency beep.
11	______	Ensure setting is kept by listening for the double beep after inputting the new setting.
S	______	**Safety Consideration: - If the arming altitude is not set correctly, the ejection system may experience issues.**
12	______	Flip the switches so that the first switch is ON, and the other three are OFF.
13	______	Ensure that the main deployment altitude is at 600 feet for the primary altimeter. There should be 6 beeps.
14	______	If the main deployment altitude is **not** set to 600 feet, press the program button 6 times after the very low frequency beep.

Continued on next page

Table 20 – continued from previous page

#	Inspector Initials	Step Instructions
15	______	Ensure the setting is kept by listening for the double beep after inputting the new setting.
S	______	**Safety Consideration: If the main parachute deployment altitude is not set correctly, this may result in premature or late ejection, resulting in loss of launch vehicle.**
16	______	Flip the switches so that the first switch is OFF, the second switch is ON, the third switch is OFF, and the fourth switch is OFF.
17	______	Ensure that the Deployment Mode setting is on number 1 for primary (Drogue at Apogee and Main at Altitude).
18	______	If the Deployment Mode setting is not set to 1 for the primary, press the program button 1 time after the very low frequency beep.
19	______	Ensure the setting is kept by listening for the double beep after inputting the new setting.
S	______	**Safety Consideration: If the Deployment Mode is not set correctly, the main parachute may not eject at apogee, resulting in loss of launch vehicle.**
20	______	Return all DIP switches to the OFF position.
21	______	Turn off the P1 Altimeter.
		B1 Altimeter
22	______	Ensure that DIP switch 4 is in the OFF position on the B1 Altimeter. This switch is located next to the program button.
23	______	Turn B1 altimeter on via the switch.
24	______	During the 5 second beep, press the program button.
25	______	Ensure that the arming altitude is set to 200 feet by listening to the beeps. There should be two short beeps, followed by a long beep, and then a very low frequency beep.
26	______	If the arming altitude is **not** set to 200 feet, set it to 200 feet by pressing the program button 20 times after the very low frequency beep.
27	______	Ensure setting is kept by listening for the double beep after inputting the new setting.
S	______	**Safety Consideration: - If the arming altitude is not set correctly, the ejection system may experience issues.**
28	______	Flip the switches so that the first switch is ON, and the other three are OFF.
29	______	Ensure that the back-up main deployment altitude 500 feet by listening to the beeps. There should be 5 beeps.
30	______	If the main deployment altitude is **not** set to 500 feet for the back up, press the program button 5 times for the back up after the very low frequency beep.
31	______	Ensure the setting is kept by listening for the double beep after inputting the new setting.
S	______	**Safety Consideration: If the main parachute deployment altitude is not set correctly, this may result in premature or late ejection, resulting in loss of launch vehicle.**
32	______	Flip the switches so that the first switch is OFF, the second switch is ON, the third switch is OFF, and the fourth switch is OFF.
33	______	Ensure that the Deployment Mode setting is on number 2 for back up (Drogue at apogee + delay and Main at Altitude).
34	______	If the Deployment Mode setting is not set to 2 for the back up, press the program button 2 times for the back up after the very low frequency beep.
35	______	Ensure the setting is kept by listening for the double beep after inputting the new setting.
S	______	**Safety Consideration: If the Deployment Mode is not set correctly, the main parachute may eject at apogee, resulting in loss of launch vehicle.**

Continued on next page

Table 20 – continued from previous page

#	Inspector Initials	Step Instructions
36	______	For B1, flip the switches so that the first, second, and third switches are ON and the fourth switch is OFF.
37	______	If the Drogue Delay is **not** set to 1 second, press the program button 1 time after the very low frequency beep.
38	______	Ensure the setting is kept by listening for the double beep after inputting the new setting.
S	______	**Safety Consideration: If the Drogue Delay is not set correctly, the drogue parachute may eject later than the allowed time frame after apogee, or the parachute bay may over pressurize, resulting in loss of launch vehicle.**
39	______	Return all DIP switches to the OFF position.
40	______	Turn off the B1 altimeter.
S	______	**Safety Consideration: Not turning off the altimeters may lead to premature detonation of black powder charges.**
41	______	Install the 4.8 g and 1.9 g black powder charges into the primary altimeter in the Main and Drogue ports, respectively, by feeding the wire end of the e-matches through the bulkhead via the non-centered hole and into the correct port, routing the wire under the board if need be.
S	______	**Safety Consideration: Installing a charge in the wrong port will lead to the failure of the recovery system.**
42	______	Install the 6.0 g and 2.4 g black powder charges and respective EMBERS into the back up altimeter in the Main and Drogue ports, respectively, by feeding the wire end of the EMBERS through the bulkhead and into the correct ports.
43	______	Install EMBERS into the appropriate parachute bay.
44	______	Plug EMBERS into the BP charge.
45	______	Adhere the EMBERS wire to the inside of the coupler, once the altimeter bay is installed, via duct tape.
S	______	**Safety Consideration: If the wire is not firmly adhered to the inside of the coupler, it may be pulled out by the parachute ejection process and damage either the altimeter or EMBERS.**
46	______	Run the ejection charge down the length of the parachute bay, and hold the charge to the bulkhead at the other end by using a small piece of duct tape.

Drogue Parachute Packing Checklist

Assembler Signature:______________________ **Safety Officer Signature:** ______________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Ensure one 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 sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** One 36 in. elliptic-form drogue parachute, One swivel, masking tape, and one red REMOVE BEFORE FLIGHT tag, kevlar blanket.

Continued on next page

Table 21 – continued from previous page

#	Inspector Initials	Step Instructions
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.**
1	______	Get the 36 in. elliptic-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).

EMBERS Checklist

Assembler Signature:____________________ **Safety Officer Signature:** ____________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Ensure the 9V battery is firmly secured in the systems. - Ensure that there is a voltage across the leads connected to the 9V battery in each of the systems. - Ensure that the 9V battery has adequate charge (8.0V or more). - Ensure that the pull tabs are all the way into the slider chambers. - Ensure that the altimeter leads are connected securely to the black powder leads in the slider chamber. - Ensure that the altimeter wire is knotted in front of the pull tab in each system. **Prerequisite lists:** Black Powder Checklist must be completed. **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.

Continued on next page

Table 22 – continued from previous page

#	Inspector Initials	Step Instructions
	______	**Tools Needed:** Digital Multimeter, two small screwdrivers
	______	**Components Needed:** 2 black powder charges, 2 EMBERS, a roll of electrical tape, 2 9V batteries.
S	______	**Safety Consideration: - All steps must be carried out by HPR level 1 certified team member due to the presence of black powder.**
S	______	**Safety Consideration: - Process includes the use of black powder. Follow black powder handling guidelines.**
S	______	**Safety Consideration: - Ensure all team members in close proximity to the black powder are wearing safety glasses to avoid black powder contacting the eyes.**
S	______	**Safety Consideration: - Ensure all 9V batteries are at least 3 ft away from the leads of the live black powder charge at all times.**
S	______	**Safety Consideration: - Ensure that there is a voltage across the 9V battery leads in the slider chambers. No voltage will cause recovery failure.**
S	______	**Safety Consideration: - Ensure the multimeter is turned to volts. Having the multimeter turned to another setting can damage the multimeter or battery.**
1	______	Measure 9V battery voltage with a multimeter.
2	______	Verify each battery has at least 8V worth of power.
S	______	**Safety Consideration: - Batteries with a charge below 8V may not detonate the black powder charge, particularly if they have to sit and wait a while on the launchpad.**
3	______	Record battery name and voltage: ________ / ________ ________ / ________
4	______	Install one 9V battery into the 9V battery connector within the first EMBERS.
5	______	Turn the switch to the ON position.
6	______	Measure the voltage across the leads connected to the battery in the slide chamber.
S	______	**Safety Consideration: - Leads with a charge below 8V may not detonate the black powder charge, particularly if they have to sit and wait a while on the launchpad.**
7	______	Measure the voltage across the leads that will be connected to the BP charge while in the actuated position.
S	______	**Safety Consideration: - Leads with a charge below 8V may not detonate the black powder charge, particularly if they have to sit and wait a while on the launchpad.**
8	______	Using 2 of the larger screwdrivers in the set of small screwdrivers, slide the slider back by placing one screwdriver on each end of the slider and pulling backwards toward the spring.
S	______	**Safety Consideration: - Pinching can occur if the compressed system is released suddenly.**
S	______	**Safety Consideration: - Not being careful while sliding the slider back could result in the detachment of leads or even the spring.**
9	______	Insert the plastic divider in between the two leads to ensure that they do not touch each other before they are supposed to.
S	______	**Safety Consideration: - Not ensuring that the divider is completely installed by pressing down and trying to wiggle it around could result in loss of limbs, life, and launch vehicle.**
10	______	Measure the voltage across the leads for the BP in the slide chamber.
S	______	**Safety Consideration: - If any voltage is read across the leads for the BP at this point, DO NOT PROCEED WITH INSTALLATION OF CHARGES. This will result in instantaneous detonation of the charges.**
11	______	Turn the switch to the OFF position.
		Continued on next page

Table 22 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: - Not turning the switch to the OFF position can lead to the premature detonation of the BP charge.**
12	______	Connect the BP charge to the BP leads on the EMBERS.
13	______	Wrap the leads in electrical tape so that they are no longer exposed.
14	______	Install EMBERS into the airframe by screwing it into the airframe.
15	______	Secure the BP charge on the bulkhead by placing a piece of duct tape over the e-match line and sticking it to the bulkhead.
16	______	Install altimeter wire into altimeter.
S	______	**Safety Consideration: - Plugging the wire into the wrong port will cause failure of the recovery system.**

Black Powder Ejection Charge Checklist

Assembler Signature:_______________________ **Safety Officer Signature:** _______________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Ensure there are 4 charges marked properly. - Back up charges need to be explicitly labeled with a sharpie. - All cable ties need to be sufficiently tight. - Ensure all charges are packed tightly. Each charge should be squeezed and have minimum give. - Inspect all e-matches - they should be twisted so that the striping looks like a candy cane. - All checklists pertaining to Black Powder Ejection Charges must be completed and verified by an inspector for the Safety Officer to be able to sign off. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Digital Multimeter, black powder scale, measuring cup for scale, batteries for scale, pliers, a heavy-duty cutting tool like tin snips, two differently colored sharpies (one of them RED), Electrostatic Discharge (ESD) bracelet.
	______	**Components Needed:** Surgical Tubing, Rubber Stopper Material, cable ties, 4F black powder, e-match
S	______	**Safety Consideration: - All steps must be carried out by HPR level 1 certified team member.**
S	______	**Safety Consideration: - Process includes the use of black powder. Follow black powder handling guidelines.**
S	______	**Safety Consideration: - Ensure all team members in close proximity to the black powder are wearing safety glasses to avoid black powder contacting the eyes**
S	______	**Safety Consideration: - Ensure all ignition sources have been removed from the area within 5 linear feet of the black powder staging area**
S	______	**Safety Consideration: - Make sure that the multimeter is set to measure Ohms before checking the charges. Failure to do so will result in premature detonation of the charge.**
S	______	**Safety Consideration: - Failure to load correct charges into airframe can result in the failure of the recovery system.**

Continued on next page

Table 23 – continued from previous page

#	Inspector Initials	Step Instructions
1	______	Test four (4) e-match resistances with multimeter.
2	______	Verify e-match resistance is between 1.3 and 1.8 Ohms.
S	______	**Safety Consideration: - E-matches without a resistance between 1.3 and 1.8 Ohms are duds and will not ignite.**
3	______	Record e-match name and resistance: __________ / ______ __________ / ______ __________ / ______ __________ / ______
4	______	Label each e-match with their name.
5	______	Cut eight 1/2 in.-long pieces of the rubber stopper material with the tin snips.
6	______	Cut one 3-inch piece, one 2-inch piece, and two 1.5-inch pieces of surgical tubing.
		Primary Main (4.8 g) Charge
7	______	Insert one rubber stopper into one end of the 2-inch long surgical tubing so that it is completely housed within the tubing.
8	______	Firmly tighten a cable tie around the outside of the surgical tubing and rubber stopper.
S	______	**Safety Consideration: - Allowing the cable ties to be loose around the surgical tubing may result in failed ejection.**
9	______	Ensure that the scale is measuring in grams.
S	______	**Safety Consideration: - Failure to measure in grams will result in the wrong size of BP charges.**
10	______	Zero the scale to include the measuring cup.
S	______	**Safety Consideration: - Failure to properly zero the scale will result in the wrong size of BP charges.**
11	______	Measure 4.8 g of black powder for the main parachute primary charge.
12	______	Record mass: ________________
13	______	Insert tip of measuring cup into the open end of the surgical tubing.
14	______	Pour half of the black powder into the surgical tubing. Set the rest aside for later.
15	______	Unwrap the e-match.
16	______	Clip copper leads at the fold with a wire cutter.
17	______	Twist the e-match so that it looks like blue and white candy cane striping.
18	______	Remove the red cover from the live end of the e-match, and slide it six inches down the e-match to ensure that it stays on the outside of the charge.
19	______	Bury the live end of the e-match into the black powder that is currently in the surgical tubing.
20	______	Insert tip of measuring cup into the open end of the surgical tubing.
21	______	Pour the remaining black powder into the surgical tubing, further covering the e-match.
22	______	Set aside measuring cup.
23	______	Insert rubber stopper in the open end, and push with a capped Sharpie until the rubber stopper cannot go in any further.
S	______	**Safety Consideration: - Allowing extra room in black powder charges will result in failed ejection.**
24	______	Firmly tighten a cable tie around the outside of the surgical tubing and the newly installed rubber stopper.
25	______	Ensure both cable ties are secured as tightly as possible around the surgical tubing and rubber stopper by tightening them with pliers.
S	______	**Safety Consideration: - Failure to check cable tie tightness may result in failed ejection.**

Continued on next page

Table 23 – continued from previous page

#	Inspector Initials	Step Instructions
26	______	Remove cable tie tails with tin snips.
27	______	Write the charge name and size on the surgical tubing in sharpie.
28	______	Remove label tag on the e-match and set aside charge.
		Primary Drogue (1.9 g) Charge
29	______	Insert another rubber stopper into the end of one 1.5-inch piece of surgical tubing so that it is completely housed within the tubing.
30	______	Firmly tighten a cable tie around the outside of the surgical tubing and rubber stopper.
S	______	**Safety Consideration: - Allowing the cable ties to be loose around the surgical tubing may result in failed ejection.**
31	______	Ensure that the scale is measuring in grams.
S	______	**Safety Consideration: - Failure to measure in grams will result in the wrong size of BP charges.**
32	______	Zero the scale to include the measuring cup.
S	______	**Safety Consideration: - Failure to properly zero the scale will result in the wrong size of BP charges.**
33	______	Measure 1.9 g of black powder for the primary drogue charge.
34	______	Record mass: ______________
35	______	Insert tip of measuring cup into the open end of the surgical tubing.
36	______	Pour half of the black powder into the surgical tubing. Set the rest aside for later.
37	______	Unwrap the e-match.
38	______	Clip copper leads at the fold with a wire cutter.
39	______	Twist the e-match so that it looks like blue and white candy cane striping.
40	______	Remove the red cover from the live end of the e-match, and slide it six inches down the e-match to ensure that it stays on the outside of the charge.
41	______	Bury the live end of the e-match into the black powder that is currently in the surgical tubing.
42	______	Insert tip of measuring cup into the open end of the surgical tubing.
43	______	Pour the remaining black powder into the surgical tubing, further covering the e-match.
44	______	Set aside measuring cup.
45	______	Insert rubber stopper in the open end, and push with a capped Sharpie until the rubber stopper cannot go in any further.
S	______	**Safety Consideration: - Allowing extra room in black powder charges will result in failed ejection.**
46	______	Firmly tighten a cable tie around the outside of the surgical tubing and the newly installed rubber stopper.
47	______	Ensure both cable ties are secured as tightly as possible around the surgical tubing and rubber stopper by tightening them with pliers.
S	______	**Safety Consideration: - Failure to check cable tie tightness may result in failed ejection.**
48	______	Remove cable tie tails with tin snips.
49	______	Write the charge name and size on the surgical tubing in sharpie.
50	______	Remove label tag on the e-match and set aside charge.
		Back-up Main (6.0 g) Charge
51	______	Insert another rubber stopper into the 3-inch piece surgical tubing so that it is completely housed within the tubing.

Continued on next page

Table 23 – continued from previous page

#	Inspector Initials	Step Instructions
52	______	Firmly tighten a cable tie around the outside of the surgical tubing and rubber stopper.
S	______	**Safety Consideration: - Allowing the cable ties to be loose around the surgical tubing may result in failed ejection.**
53	______	Ensure that the scale is measuring in grams.
S	______	**Safety Consideration: - Failure to measure in grams will result in the wrong size of BP charges.**
54	______	Zero the scale to include the measuring cup.
S	______	**Safety Consideration: - Failure to properly zero the scale will result in the wrong size of BP charges.**
55	______	Measure 6.0 g of black powder for the main parachute back-up charge.
56	______	Record mass: ________________
57	______	Insert tip of measuring cup into the open end of the surgical tubing.
58	______	Pour half of the black powder into the surgical tubing. Set the rest aside for later.
59	______	Unwrap the e-match.
60	______	Clip copper leads at the fold with a wire cutter.
61	______	Twist the e-match so that it looks like blue and white candy cane striping.
62	______	Remove the red cover from the live end of the e-match, and slide it six inches down the e-match to ensure that it stays on the outside of the charge.
63	______	Bury the live end of the e-match into the black powder that is currently in the surgical tubing.
64	______	Insert tip of measuring cup into the open end of the surgical tubing.
65	______	Pour the remaining black powder into the surgical tubing, further covering the e-match.
66	______	Set aside measuring cup.
67	______	Insert rubber stopper in the open end, and push with a capped Sharpie until the rubber stopper cannot go in any further.
S	______	**Safety Consideration: - Allowing extra room in black powder charges will result in failed ejection.**
68	______	Firmly tighten a cable tie around the outside of the surgical tubing and the newly installed rubber stopper.
69	______	Ensure both cable ties are secured as tightly as possible around the surgical tubing and rubber stopper by tightening them with pliers.
S	______	**Safety Consideration: - Failure to check cable tie tightness may result in failed ejection.**
70	______	Remove cable tie tails with tin snips.
71	______	Write the charge name and size on the surgical tubing in sharpie.
72	______	Stripe the e-match wire with red sharpie.
73	______	Remove label tag on the e-match and set aside charge.
		Back-up Drogue (2.4 g) Charge
74	______	Insert another rubber stopper into another 1.5-inch piece surgical tubing so that it is completely housed within the tubing.
75	______	Firmly tighten a cable tie around the outside of the surgical tubing and rubber stopper.
S	______	**Safety Consideration: - Allowing the cable ties to be loose around the surgical tubing may result in failed ejection.**
76	______	Ensure that the scale is measuring in grams.

Continued on next page

Table 23 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: - Failure to measure in grams will result in the wrong size of BP charges.**
77	______	Zero the scale to include the measuring cup.
S	______	**Safety Consideration: - Failure to properly zero the scale will result in the wrong size of BP charges.**
78	______	Measure 2.4 g of black powder for the drogue parachute's back-up charge.
79	______	Record mass: ________________
80	______	Insert tip of measuring cup into the open end of the surgical tubing.
81	______	Pour half of the black powder into the surgical tubing. Set the rest aside for later.
82	______	Unwrap the e-match.
83	______	Clip copper leads at the fold with a wire cutter.
84	______	Twist the e-match so that it looks like blue and white candy cane striping.
85	______	Remove the red cover from the live end of the e-match, and slide it six inches down the e-match to ensure that it stays on the outside of the charge.
86	______	Bury the live end of the e-match into the black powder that is currently in the surgical tubing.
87	______	Insert tip of measuring cup into the open end of the surgical tubing.
88	______	Pour the remaining black powder into the surgical tubing, further covering the e-match.
89	______	Set aside measuring cup.
90	______	Insert rubber stopper in the open end, and push with a capped Sharpie until the rubber stopper cannot go in any further.
S	______	**Safety Consideration: - Allowing extra room in black powder charges will result in failed ejection.**
91	______	Firmly tighten a cable tie around the outside of the surgical tubing and the newly installed rubber stopper.
92	______	Ensure both cable ties are secured as tightly as possible around the surgical tubing and rubber stopper by tightening them with pliers.
S	______	**Safety Consideration: - Failure to check cable tie tightness may result in failed ejection.**
93	______	Remove cable tie tails with tin snips.
94	______	Write the charge name and size on the surgical tubing in sharpie.
95	______	Stripe the e-match wire with red sharpie.
96	______	Remove label tag on the e-match and set aside charge.

Coupler Altimeter Bay Checklist

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Personnel are using proper gloves and other safety equipment. - Work in dry, well-lit area to avoid electronics damage. - Avoid touching electrical components directly; grasp board from edges. - Keep battery contacts from brushing or resting on conductive surfaces, including circuit board. **Prerequisite lists:**

Continued on next page

continued from previous page

#	Inspector Initials	Step Instructions
		- N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Hex key set, coupler socket tool, rubber mallet.
	______	**Components Needed:** coupler, altimeter bay, altimeter batteries (2X), altimeters (2X).
S	______	**Safety consideration: Rough handling or water damage to board may short electrical systems and ruin the entire PCB.**
S	______	**Safety consideration: Tightening the set screws too far could warp or damage the board.**
S	______	**Safety consideration: Batteries represent a stored energy hazard. Handle with care, and do not try to force it into the battery enclosure if there is a fitting issue. Slightly loosen bolts along the top of the cage if extra room is required.**
S	______	**Safety consideration: Black powder is an explosive energetic; ensure no phones, radios, or other transmitting/receiving electronics are in the vicinity. Use safety eyeglasses and face masks.**
S	______	**Safety consideration: Ensure all ignition sources have been removed from the area.**
1	______	Check that both of the altimeters are secured by at least three screws to the altimeter bay mounting plate. Check the screws to make sure none are loose.
2	______	Ensure battery enclosures are secured to the altimeter bay mounting plate securely. Remove both covers and batteries and ensure screws in bottom of enclosures are secure. Reinstall batteries when complete; leave covers removed for voltage checks.
3	______	Ensure arming switches can be switched without moving the arming switch itself. (Use tape for more secure fit if switch moves.) Ensure altimeter activation when arming switches are turned. (220 off, 110 on)
4	______	Remove both e-match wire hole covers and ensure battery wiring is secure in such a way that e-match wires can be installed.
5	______	Avionics functionality and black powder installation. Initials: _______
6	______	Thread wiring corresponding to the fore section of the launch vehicle through the coupler itself. Fore section wiring should be labeled and should be associated with the side of coupler housing mounting points for set screws and arming switches.
7	______	Slide altimeter bay into coupler assembly, aligning the fore and aft sections of the bay with the fore and aft of the coupler. Ensure the markings on the aft of the coupler and bay are aligned as this will assist with hole alignment. Visually inspect the two set screw holes and two switch holes for alignment.
8	______	Thread and tighten the two set screws into the set screw holes.
9	______	Using the coupler bay socketed tool, tighten down the bulkheads on either end of the altimeter bay to compress the sealing gasket.
S	______	**Safety consideration: Insufficiently tight sealing gaskets could result in partial ejection failure or damage to electronics by recovery system emissions.**
10	______	Parachute installation initials: _______
		This may require some force and multiple people holding down launch vehicle.
11	______	Align the star patterns on the fore and aft sections of the launch vehicle to align with the coupler. Visually inspect holes for alignment. Install four shear pins each into for and aft section of launch vehicle. This may require mallet to force into shear pin holes.

5.3.5 Fore Assembly

Nose cone Avionics Electronics Checklist

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - All electronics are securely attached to the PCB - Power LEDs are on (5V and 3.3V). - Fly back LED is not on. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	_____	**Tools Needed:** Digital Multimeter.
	_____	**Components Needed:** ATU unit, ATU LiPo, battery voltage checker, electrical tape, microSD card, Teensy 3.6, and XBee
S	_____	**Safety Consideration: - Ensure that battery is at maximum capacity before insertion into launch vehicle; Acceptable range: >7.7 V**
12	_____	Avionics LiPo Battery Voltage _____
S	_____	**Safety Consideration: - Any breakout board that is incorrectly installed could result shorts, and broken parts. All boards should be installed prior to assembly**
13	_____	Teensy should be installed into the larger pin slot with the USB connector oriented off of the board.
14	_____	The XBee should be installed on the back of the board such that the antenna is lying across the back.
S	_____	**Safety Consideration: - When plugging the battery in make sure the connections go all the way into the correct slots. Insecure connections can result in electrical shock and shorting.**
15	_____	At least 30 minutes before launch, plug the battery into the power connection. The light on the GPS should start flashing immediately.
16	_____	Check lights: GPS should be flashing. After half an hour, ensure that the GPS is only flashing infrequently indicating a location lock.
S	_____	**Safety Consideration: - Do not unplug any sensors, XBee, or Teensy while the system is powered. This could result in pin shorting and breaking of parts.**
S	_____	**Safety Consideration: - Ensure that the Teensy VIN and USB power pads on the bottom are not connected. If they are and it is plugged into a computer it could result in destruction of the USB port or the computer.**

Nose Cone Avionics Installation Checklist

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Assembly location is dry and free of conductive debris - Keep battery contacts from brushing or resting on conductive surfaces, including circuit board - Ensure all fasteners on Avionics Bay and threaded rod are tightened fully - Nose cone bulkhead must be flush and level - Confirm all bolts are present and tight enough that they cannot be unfastened by hand

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#	Inspector Initials	Step Instructions
		Prerequisite lists:
		- N/A
		ALL steps below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Hex Key Set
	______	**Components Needed:** Nose Avionics Frame, Frame Battery Cover,Nose cone Bulkhead, ¼" nut (2x), Avionics board, LiPO battery, PCB set screws (4x, 4-40 1/2"), PCB set nuts (4x, size 4-40)
S		**Safety consideration: Rough handling or water damage to board may short electrical systems and ruin the entire PCB.**
S		**Safety consideration: Tightening the set screws too far could warp or damage the board and other mounting components.**
1	______	Align PCB with the four fastener holes on the side of the avionics frame **not** occupied by the battery mount.
2	______	Secure fasteners through PCB into raised plastic standoff holes, tightening until flush. Not all four screws may seat or tighten fully, depending on warping of the frame. Prioritize the two lower holes, but ensure at least one fastener on each end of the PCB.
3	______	Tighten four nuts onto the protruding bolts on the opposite side of the frame.
4	______	Insert the LiPo battery into the battery cage, positioned so the wire leads sit in the vertical slot cut at the top right corner of the battery cage.
S		**Safety consideration: LiPo batteries represent a stored energy hazard. Handle with care, and do not try to force it into the battery cage if there is a fitting issue. Slightly loosen bolts along the top of the cage if extra room is required.**
5	______	Place the battery casing lid on the battery cage, oriented so the lid sits flush against the casing and the fastener holes are aligned.
6	______	Insert the two battery lid fasteners and tighten fully.
S		**Safety consideration: An improperly tightened bolt may shake loose during launch vibrations and allow the LiPo battery to fall free, damaging components.**
S		**Safety consideration: Overtorquing the 3D printed plastic parts could cause failure or warping.**
7	______	On-site personnel responsible for avionics will now connect the LiPo battery to the avionics board and confirm functionality.
		Avionics Functionality Initials: _______
8	______	Thread a ¼ in. nut onto the threaded rod in the nose cone and turn it until the nut is located approximately 8 in. into the nose cone.
9	______	Slide the nose cone-threaded rod through the hole through the center of the avionics frame. Ensure the end closest to the battery wires is facing upward.
S		**Safety consideration: Installing the avionics bay too far forward may cause direct contact between the electronics of the board and the nose cone, directly imparting launch vibrations onto delicate components.**
S		**Safety consideration: Installing the avionics bay too far forward into the nose cone may alter the center of gravity of the launch vehicle and affect stability.**
S		**Safety consideration: Installing the avionics frame too far back in the nose cone may affect the fit of other components, or the seal between the Nose Cone and the fore section.**
S		**Safety consideration: Installing this module upside-down may impart launch forces onto wires in an unanticipated manner.**

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#	Inspector Initials	Step Instructions
		Safety consideration: Installing the avionics bay upside-down will negatively impact the ability for onboard accelerometers to gather accurate data.
10	______	Move the full avionics frame up against the previously placed nut.
11	______	Press nose cone bulkhead up against the bottom of the avionics frame and tighten the bulkhead fasteners. The bulkhead should be flush against the curvature of the nose cone such that the majority of the tension is taken by the structure of the nose cone and not the avionics frame.

Main Parachute Packing Checklist

Assembler Signature:______________ **Safety Officer Signature:** ______________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Ensure one REMOVE BEFORE FLIGHT tag is placed under the tape holding the bag closed and one tag is holding the shroud lines together. There should be at least one tag. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** One 144 in. Standard Iris Parachutes, 22.5x22.5 Kevlar nomex blanket, masking tape, and one red REMOVE BEFORE FLIGHT tag.
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.**
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.

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Table 25 – 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 outer edge of the gore on the right side of the parachute making sure to flatten after each fold. Repeat this process for one side of the canopy until all the gores are folded and there are half of the gores on either side of the center (7 each). 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	______	Ensure the resulting gores left are opposite colors.
16	______	Flatten the folded canopy as much as possible by pushing out all the air make sure there is a seam down the middle with wtih a gore on either side.
17	______	Lay the shock cords into a reverse loop in the middle section of the parachute and fold the canopy in half over the shock cords, similar to folding a hotdog. Once the shrouds and shock cords are layed down Z-Fold the parachute upon itsself starting from the top.
18	______	Ensure the canopy is folded into a Z, similar to an accordion. Then fold the parachute how you like, roll it or fold it further (at this point it will always deploy)
19	______	Pack the folded canopy in and on the nomex blanket, hold the parachute closed with a small piece of masking tape.
20	______	Make sure the nomex/kevlar blanket is threaded through the shock cord.
21	______	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 nomex blanket.
22	______	Ensure all masking tape has a REMOVE BEFORE FLIGHT tag attached directly to it.

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 two remove before flight tags are on the assembly. **Prerequisite lists:** - Drogue Parachute Packing Checklist. **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** One packed 18 in. X-form drogue assembly, masking tape, One Kevlar blast protector, sharpie, One 44 ft nylon shock cord, 3 1600lbf yield quick links, 4 Standard Quick Links, 1 3 ft Kevlar sleeves, Kevlar cord, One 16ft Nylon cord (tethered to bulkheads.)

Continued on next page

Table 26 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: Check the drogue packing looks correct, and that a REMOVE BEFORE FLIGHT tag is placed under the tape holding it closed.**
1	______	Get One 16 ft Nylon shock cord riser.
2	______	Inspect the riser for any tearing or excessive scorching; inspect the butterfly loops (if still tied) for any stressed areas.
3	______	Make sure on each bulkhead in the fore section and coupler that there is a 3 piece quick link layout, one quick link on each eye bolt and a third quick link connecting the two.
4	______	Attach 16ft Nylon cord to the 3rd quick link, on fore section and to the coupler side with a butterfly loop referred to as loop 1.
5	______	Get One 44 ft Nylon shock cord riser.
6	______	Inspect the rider for any tearing or excessive scorching; inspect the butterfly loops (if still tied) for any stressed areas.
7	______	Tie/ensure a single butterfly loop is located 2/3 of the way from the main body bulkhead 5ft from couplet. This loop is for the drogue and will be referred to as loop 2.
8	______	Ensure a short Kevlar sleeve is located after loop 1. It should be secured just next to loop.
9	______	Place the drogue swivel on a standard quick link, make a new loop at the top of the shock cord above loop 2 and attach this quick link is tightened all the way down.
10	______	Tape an artificial zipper along the Nylon cord between loops 2 and 3. The artificial zipper should be 6 thicknesses of the riser.
11	______	Tape a second artificial zipper between loops 1 and 2, making sure to get at least 3-4 thickness of riser.
12	______	Pack the nylon shock cord until loop 2, then pack the second cord and the packed drogue parachute into the parachute bay. After that is placed to finish packing the cord from the coupler into the bay, making sure all charges and blast lines are ready.

5.3.6 Payload Assembly

Payload Airframe Integration

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

#	Inspector Initials	Step Instructions
	______	**Safety Officer Checklist:** - Safety glasses must be worn during assembly of any components. - Ensure that no black powder or other energetics are present in the Fore section of the airframe. Payload is to be integrated before the Fore Parachute. - Ensure that the lead screw is fully installed by pulling on the lead screw. **Prerequisite lists:** - Rover Assembly Checklist - Payload Ejection/Retention Checklist **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off. **Tools Needed:** Standard Allen Wrench Set, 7/16" socket, 7/16" 8 wrench, Nathan's really long wrench

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#	Inspector Initials	Step Instructions
	______	**Components Needed:** Rover Assembly, Ejection/Retention Assembly, Ejection/Retention Mobile Bulkheads w/ lead screw nuts (2X), 1/4-20 X 6 in. lg all thread (3X), 1/4-20 hex head nuts (3X), Ejection System Controller, Fore Section of the Airframe, 12 volt lipo battery.
1	______	Gather all necessary components (the fore section of the Airframe is only needed for the last steps of this checklists)
2	______	Inspect the rover to ensure it is working properly. Check that the wheels are secured, the electronics function, and that the remote is able to connect to the system.
3	______	Inspect the ejection system. Apply tension to lead screw ensuring that the coupler connection is secure.
4	______	Inspect the electronics, ensuring all components are securely fastened and that the remote can actuate the ejection system.
5	______	Check motor is spinning in the correct direction (CCW).
6	______	Yellow wire to 23 and red wire to 24.
7	______	Spin one mobile bulkhead to the bottom of the lead screw against the coupler retaining bulkhead.
8	______	Thread the second mobile bulkhead down the leadscrew such that the foam side of the mobile bulkhead is facing the rover. Work the bulkhead down, squishing the rover between both bulkheads.
S	______	**Safety Consideration: If the bulkheads are loose this could result in the rover shifting during flight, it can also prevent the nose cone from securely fitting onto the Airframe**
9	______	The payload is now assembled, now carefully slide it into the fore section of the airframe into the payload bay. Do this by collapsing the rover wheels and wrapping the tail as you slide the payload in. Rotate the payload until the threaded rods slide into the fore bulkhead.
10	______	Using Nathan's really long wrench, a 7/16" socket, and 1/4-20 hex head nuts fasten the rods down clamping it against the fore bulkhead. The nuts are placed on the aft side of the Fore bulkhead.
11	______	Pull on the lead screw to ensure that the payload is securely fastened.
S	______	**If you are still able to pull the leadscrew out of the airframe then a mistake was made. If the lead screw is not secure then the payload could move within the Airframe. Changing the launch vehicle stability, and potentially resulting in an in-air ejection of the payload.**

5.3.7 Preflight Procedures

Setup on Launcher Checklist for Full Scale #1 (2/22/2020)

Assembler Signature:______________________ **Safety Officer Signature:** ______________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Ensure that 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 sign-off.
	______	**Tools Needed:** Digital Multimeter, tiny flat-head screwdriver, pen, notebook, sharpie

Continued on next page

Table 27 – continued from previous page

#	Inspector Initials	Step Instructions
	______	**Components Needed:** Assembled Launch Vehicle, Launch rail fixtures
S	______	**Safety Consideration: - Inspect the launch area for any flammable material and remove if necessary.**
1	______	5 members (Amy, Nathan, Wyatt, Gerardo, and Jessica) bring launch vehicle to launch pad.
S	______	**Safety Consideration: - Launch vehicle is both heavy and long, so it must be supported by three people at all times.**
2	______	Bring launch rail into a horizontal position, adjusting the feet as needed.
3	______	Use shop towel and acetone 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 it in place.**
5	______	Bring launch rail to specified angle as per RSO instructions and verify launch rail bolts are tight.
6	______	All but two members (Nathan and Amy) step back from the pad for arming of EMBERS and the altimeters.
S	______	**Safety Consideration: - Only two team members shall be present for the arming of EMBERS and the altimeters to ensure no distractions during the process.**
7	______	Turn the switches for EMBERS to the ON position.
S	______	**Safety Consideration: - Not turning on EMBERS could result in a major safety hazard upon launch vehicle landing.**
		Back-up Altimeter
8	______	Turn on the first RRC3 (P2) (This is the backup RRC3).
9	______	5 second long start up beep.
10	______	10 second initiation pause.
11	______	Series of beeps to read the voltage of the battery (At least 8.0V) (Read as X.X).
12	______	5 Beeps (Main deploys at 500 feet).
13	______	2 Beeps (Setting for Drogue at Apogee + Delay, Main at Altitude).
14	______	3 Beeps to demonstrate a successful continuity check with the drogue and main chutes.
		Primary Altimeter
15	______	Turn on the second RRC3 (B1) (This is the primary RRC3).
16	______	5 second long start up beep.
17	______	10 second initiation pause.
18	______	Series of beeps to read the voltage of the battery (At least 8.0V) (Read as X.X).
19	______	6 Beeps (Main deploys at 600 feet).
20	______	1 Beep (Setting for Drogue at Apogee and Main at Altitude).
21	______	3 Beeps to demonstrate a successful continuity check with the drogue and main chutes.

Ignition Installation and Launch Vehicle Placement Checklist

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Keep area clear of ignition, heat, and spark sources

Continued on next page

continued from previous page

#	Inspector Initials	Step Instructions
		- Ensure motor is being handled by certified personnel only
		Prerequisite lists:
		- Final Assembly checklist
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Wire strippers, multimeter
	______	**Components Needed:** Aft body section, motor, motor casing, motor plate, motor plate bolts (3x), fuse
S	______	**Safety consideration: Insufficiently stripped wires may not achieve connectivity with launch pad contacts and fail to launch .**
S	______	**Safety consideration: If the fuse does not make contact with the motor, ignition may fail.**
S	______	**Safety consideration: Failing to short fuse wires may result in premature ignition of the fuse and motor.**
S	______	**Safety consideration: The launcher cables activate the ignition, which activates the motor; this is a safety hazard and face shields and safety glasses must be worn along with safety gloves.**
1	______	Strip wires on fuse back half an inch.
2	______	Short stripped ends together and twist together to ensure contact.
S	______	**Failure to short contacts could result in premature ignition of motor due to static discharge.**
3	______	two to three team members carry rocket with some assistance with rail placement.
4	______	Lower launch rail to horizontal position and slide launch vehicle onto launch rail
S	______	**Safety consideration: Launch vehicle must sit on rail without twisting or misalignment of guide rollers, in order to launch properly.**
5	______	Raise launch rail to vertical position and set angle according to RSO instructions. This may include moving sand and dirt under launch rail to get a vertical position, set angle into wind with threaded rod and nut on the launch rail.
S	______	**Safety consideration: Failure to align rail with respect to current conditions could result in the launch vehicle drifting on recovery or exceeding the safe launch radius.**
6	______	Insert fuse into motor tube until it is touching the combustible segment (until resistance is felt).
7	______	Secure fuse at depth with plastic motor cap (if applicable).
8	______	Ensure all bystanders are beyond the launch area boundary, install wireless launcher cables to igniter, wrapping wires around launcher attachment points. Retreat beyond launch area boundary after complete.

Final Launch Checklist for Full Scale (2/22/2020)

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
	______	**Tools Needed:** N/A
	______	**Components Needed:** Remote launch system

Continued on next page

Table 28 – continued from previous page

#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: - Arming launch system before clearance is granted by the Range Safety Officer can lead to premature ignition.**
1	______	Confirm with Safety Officer that all Remove Before Flight Tags have been removed.
2	______	Move all personnel to safe area designated by the Range Safety Officer.
3	______	Wait for launch clearance from the Range Safety Officer.
4	______	Receive GO/NO-GO from Aero/Recovery.
5	______	Receive GO/NO-GO from Avionics.
6	______	Receive GO/NO-GO from Payload.
7	______	Receive GO/NO-GO from Structures/Propulsion.
8	______	Receive GO/NO-GO from Safety.
9	______	Arm the remote launch system.
10	______	Wait for the countdown from the Range Safety Officer.
S	______	**Safety Consideration: - Countdown must be loud enough so everyone in the vicinity is aware of launch. Do not press launch button if people are unaware of launch.**
11	______	Press the launch button on the remote launch system.

Ground Station Checklist

Assembler Signature:______________________ **Safety Officer Signature:** ______________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - All electronics are securely attached to the PCB - Power LED is on. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Digital Multimeter.
	______	**Components Needed:** PCB for Ground station, XBee, microSD card, large Yagi antenna, and Yagi cable adaptor.
S	______	**Safety Consideration: - Any breakout board that is incorrectly installed could result shorts, and broken parts. All boards should be installed prior to installing battery.**
S	______	**Safety Consideration: - Ensure that the Teensy VIN and USB power pads on the bottom are connected.**
1	______	Teensy should be installed into the larger pin slot with the USB connector oriented off of the board, facing the 4-pin green screw terminal. The microSD card should be installed into the Teensy's mciroSD card slot.
2	______	The XBee should be installed into the bottom of the board with the antenna lying across the pins.
3	______	Screw the smaller end of the antenna adaptor onto the antenna jack of the XBee.
4	______	Screw the larger end of the adaptor onto the large Yagi antenna.
S	______	**Safety Consideration: - Do not unplug any sensors, XBee, or Teensy while the system is powered. This could result in pin shorting and breaking of parts.**

Continued on next page

Table 29 – continued from previous page

#	Inspector Initials	Step Instructions
5	______	Insert a micro USB cable into the computer and plug the micro USB end into the Teensy 3.6.
6	______	Check lights. The light on the GPS should start flashing immediately.
7	______	Open a serial port, and ensure that input is being received.

5.3.8 Post-Flight Inspections

Post-Flight Launch Vehicle Checklist for Full Scale (2/22/2020)

Assembler Signature:______________________ **Safety Officer Signature:** ______________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Ensure there are no burn hazards before inspection.
		- Note any sharp edges on broken parts prior to inspection.
		- Ensure all energetic charges have been disabled.
		Prerequisite lists: N/A
	______	**Tools Needed:** Acetone, Paper Towels, 6 Gloves, Safety Glasses
	______	**Components Needed:** Recovered launch vehicle
S	______	**Safety Consideration: - Ensure all burn hazards have been extinguished or allowed time to cool. Follow proper energetic disarming procedures if any are not disabled.**
S	______	**Safety Consideration: - Failure to notify team of damage to launch vehicle could result in unstable flight or full mission failure.**
1	______	Inspect airframe for any damage.
2	______	Inspect fins for any damage and ensure secured position.
3	______	Inspect nose cone for any damage, such as cracks, scratches, and chips.
4	______	Inspect airframe and couplers for dirt, clean with acetone and paper towels if necessary.
5	______	Inspect airframe for zippering and delamination.
6	______	Inspect motor retainer for damage, such as bends and cracks.
7	______	Inspect epoxy fillets for damage such as air bubbles, cracks, and holes.
8	______	Inspect all couplers for damage.
9	______	Inspect shear pins, and remove/replace if necessary.
10	______	Inspect launch lugs, and ensure that they are securely fastened and aligned with the launch vehicle.
11	______	Inspect all venting ports to ensure functionality, clean with acetone and paper towels if necessary.
12	______	Inspect all parachutes to ensure functionality.
13	______	Inspect all shock cords and Nomex blankets/coverings to ensure functionality and effectiveness.
14	______	Inspect all EMBER Systems for cracks, chips, and/or melting.
15	______	Inspect payload for cracks, breaks, chips, bends, disconnected wires, and/or damaged electronics.
16	______	Record any and all damage below and report to appropriate subteam lead.

5.3.9 Troubleshooting

Disarming Unexploded Recovery Charges Checklist		
Assembler Signature:________		Safety Officer Signature: ________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist:
		- Ensure that all nonessential personnel maintains a 15-ft distance from any live charges in a launch vehicle while they are being dismantled.
		- Ensure that proper PPE is being worn at all times.
		- Ensure that all charges have been removed from the launch vehicle before allowing any personnel to return it to base camp.
		- Ensure that all charges have been dismantled before returning to base camp.
		Prerequisite lists: Launch vehicle must have flown and had an unsuccessful recovery event. **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	____	**Tools Needed:** small screwdriver set, wire cutters, tin snips
	____	**Components Needed:** black powder container
S	____	**Safety Consideration: - All steps must be carried out by HPR level 1 certified team member due to the presence of black powder.**
S	____	**Safety Consideration: - Process includes the use of black powder. Follow black powder handling guidelines.**
S	____	**Safety Consideration: - Ensure all team members in close proximity to the black powder are wearing safety glasses to avoid black powder contacting the eyes.**
1	____	Identify which charges need to be dismantled.
S	____	**Safety Consideration: - If a back-up charge has yet to detonate, that takes priority, as EMBERS tries to connect the charges to a battery, making it extremely easy for the charge to go off while on the ground.**
		Back-up Charges
2	____	Identify which back-up charge(s) is/are live, and list it/them here: ____ ____
S	____	**Safety Consideration: - If the back-up charge for the main parachute did not go off, dismantle it first, as is poses the largest safety threat.**
3	____	Using the larger of the small flathead screwdrivers, turn off the EMBERS from the exterior of the launch vehicle.
4	____	Using the wire cutters, separate the live charge(s) from the EMBER System(s) by cutting the e-match wire within 3 inches of the EMBER System(s).
5	____	Remove the charge(s) from the airframe.
6	____	Using the tin snips, make an approximately 1 inch-long incision width-wise across the middle of the surgical tubing until the black powder is exposed.
7	____	Empty the black powder into a designated black powder container.
8	____	If another charge needs to be dismantled, using the tin snips, make a 1 inch-long incision width-wise across the middle of the surgical tubing until the black powder is exposed.
9	____	If another charge needs to be dismantled, empty the black powder into a designated black powder container.
10	____	Seal black powder container and return to base camp.
		Primary Charges
11	____	Identify which primary charge(s) is/are live, and list it/them here: ____ ____

Continued on next page

Table 31 – continued from previous page

#	Inspector Initials	Step Instructions
12	______	Using the wire cutters, separate the live charge(s) from the altimeter bay by cutting the e-match wire within 3 inches of the altimeter bay.
13	______	Using the tin snips, make an approximately 1 inch-long incision width-wise across the middle of the surgical tubing until the black powder is exposed.
14	______	Empty the black powder into a designated black powder container.
15	______	If another charge needs to be dismantled, using the tin snips, make an approximately 1 inch-long incision width-wise across the middle of the surgical tubing until the black powder is exposed.
16	______	If another charge needs to be dismantled, empty the black powder into a designated black powder container.
17	______	Seal black powder container and return to base camp.

Launch Misfire Diagnostic Checklist

Assembler Signature:______________________ **Safety Officer Signature:** ______________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Personnel approaching a misfired launch vehicle MUST wear face shields and gloves
		- Visually confirm disconnection of ignition power source or removal of ignition key
		Prerequisite lists:
		- N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Digital multimeter, Wire strippers, Safety Goggles, Walkie-Talkies
	______	**Components Needed:** Armed launch vehicle
S		**Safety consideration: Misfired launch vehicle contains high-energy components in an unknown state. Handle with extreme care and use all reasonable precautions and equipment.**
1	______	If launch vehicle does not launch when button/key is used for the electrical launch system, remove the launcher's safety interlock and/or disconnect its battery, and wait 60 seconds after the last launch attempt before allowing anyone to approach the launch vehicle (per NAR/Tripoli regulations).
2	______	Wait for approval from launch desk/RSO to enter range.
3	______	Check for power to the launch remote.
4	______	Inspect ignition system for damage, tape, dust.
5	______	Confirm signal to remote launch controller.
6	______	Confirm continuity through ignition cables.
7	______	Make sure ignition charge is properly installed.
8	______	Check lights: power to ignition should be flashing.
S		**Safety consideration: All personnel must return to safety before attempting a re-fire of launch systems. Refer to .**

Disarming Full Launch Vehicle Checklist		
Assembler Signature:__________		Safety Officer Signature: __________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Ensure that all nonessential personnel maintains a 15-ft distance from any live charges or motors in a launch vehicle while they are being dismantled. - Ensure that proper PPE is being worn at all times. - Ensure that all explosives have been removed from the launch vehicle before allowing any personnel to return it to base camp. - Ensure that all charges have been dismantled before returning to base camp. **Prerequisite lists:** Launch vehicle must have tried to fly and have failed to get off the rail or the launch waiver passed, and therefore, the launch vehicle needs to be dismantled. **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** small screwdriver set, wire cutters, tin snips, pliers
	______	**Components Needed:** black powder container
S	______	**Safety Consideration: - All steps must be carried out by HPR level 1 certified team member due to the presence of black powder and a live motor.**
S	______	**Safety Consideration: - Process includes the use of black powder. Follow black powder handling guidelines.**
S	______	**Safety Consideration: - Ensure all team members in close proximity to the black powder are wearing safety glasses to avoid black powder contacting the eyes.**
1	______	Identify which charges need to be dismantled.
S	______	**Safety Consideration: Prioritize disarming routine in the order of most to least dangerous. Therefore, the motor needs to be taken care of first, then the EMBER Systems, then the primary black powder charges.**
2	______	Remove igniter from the back end of the motor and, if constructed from an e-match and Pyrodex pellets, return to assemblers (Wyatt and Gerardo) for deconstruction.
3	______	Bring the launch rail down to horizontal.
4	______	Switch off both altimeters and EMBER Systems with the larger of the small flathead screwdrivers.
5	______	Remove launch vehicle from the launch rail and place on the ground away from trip hazards.
6	______	Remove motor from the launch vehicle, and return it to the assembler.
7	______	Remove the shear pins from the main and drogue parachute bays.
8	______	Separate the altimeter bay from the main and drogue parachute bays.
S	______	**Safety Consideration: Do NOT move the altimeter bay more than 1 foot from the main and drogue parachute bays due to the presence of the EMBER Systems.**
9	______	Remove the parachutes from their respective bays without disconnecting them from their attachment points, due to the presence of black powder.
10	______	Follow the Disarming Unexploded Recovery Charges Checklist.
11	______	Return all objects back to base camp after all explosives have been disarmed and appropriately destructed.

To improve safety, organization, and efficiency during launch day integration, an integration operations flow chart was created. The Safe Integration Flow Chart (SIFC), shown below in Figure 100 was designed to outline the integration process with a specific structure built around the completion of integration checklists. The SIFC process was developed around prevalent safety considerations present at launch integration and lean manufacturing principles. The goal of this process is to establish a Standard Order of Events Standard Order of Events (SOE) for launch vehicle integration that maintains a safe environment for all personnel and vehicle equipment and systems, while also ensuring that all subteams are working simultaneously in parallel to reduce time spent integrating the launch vehicle, thereby reducing exposure to integration safety hazards such as primed energetics. Shown below in figure the chart is organized with arrival at the site at the top of the chart, and descending through the processes before being flight ready at the bottom of the chart. Each subteam has their checklists for completion at launch day integration listed in the respective columns. Events highlighted in red reflect events involving significant safety risk. Sub teams in charge of checklists which can be done in parallel by two groups of two members, are delineated by the orange or black arrows representing separate work paths. The motivation for the creation of this flowchart was to organize high risk events to be grouped toward the end of the process so less time is spent in a high risk scenario.

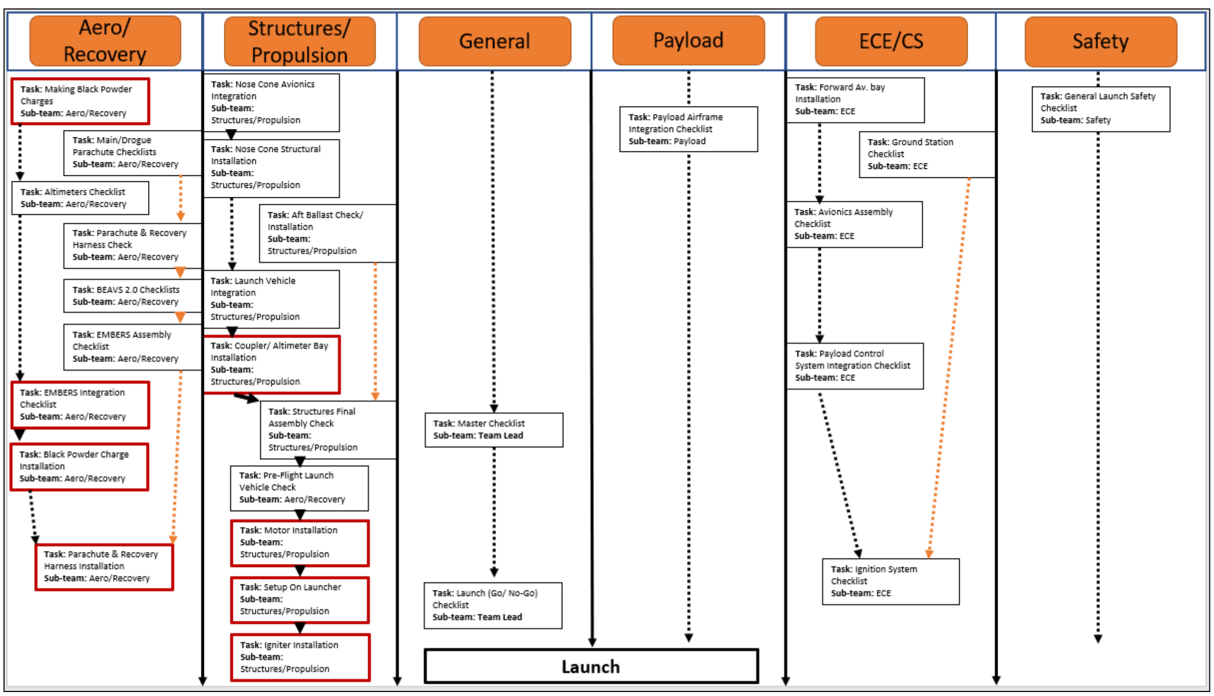

Figure 100: Safe Integration Flow Chart

6 Project Plan

6.1 Verification Procedures

6.1.1 Launch Vehicle Verification Procedures

1.1 Coupler Shoulder Length Test	
Status:	Completed – Successful
Meets Requirement(s):	2.5.1; 1.3, 6.3.8
Verification Method:	Inspection
Objective:	To ensure coupler shoulder is sufficient for stability.
Success Criteria:	The coupler length will equal or exceed one airframe caliber.
Discussed in:	FRR Section 3.2.3

Description: Determine the total length of coupler shoulder is sufficient for stability.

Safety and Equipment Requirements: See Coupler Manufacturing Checklist in Launch Vehicle Appendix.

Procedure: See Coupler Shoulder Inspection Checklist in Launch Vehicle Appendix.

Results: The coupler shoulder length measured more than 1 airframe caliber in length.

Lessons Learned:

Differences between Predicted and Actual Results:

1.2 Ensure component accessibility	
Status:	Completed – Successful
Meets Requirement(s):	2.5.1; 1.3
Verification Method:	Inspection
Objective:	To ensure ease access to necessary components.
Success Criteria:	All components designated easy-access must be no more than 8″ deep from the nearest airframe access point.
Discussed in:	FRR Section 3.2.3

Description: All components designated easy-access must be no more than 8″ deep from the nearest airframe access point.

Safety and Equipment Requirements: See Accessibility checklist in Launch Vehicle Appendix.

Procedure: See Accessibility Checklist in Launch Vehicle Appendix.

Results: All necessary bays are accessible within 8 in.

Lessons Learned: Easy access to all bays in the launch vehicle is necessary.

Differences between Predicted and Actual Results: Only some bays are easily accessible, however all bays are accessible.

1.3 Ensure All Structures Survive Launch Forces	
Status:	Completed – Successful
Meets Requirement(s):	
Verification Method:	Analysis
Objective:	All structural components of vehicle must survive launch forces with a safety factor of 2 or greater.
Success Criteria:	The results of the CAD simulation must show all factors of safety equal to or greater than 2.
Discussed in:	FRR Section 3.2.3, 3.2.8

Description: The structural analysis of the full-scale launch vehicle will be completed using CAD simulation tools.

Safety and Equipment Requirements: See Structural Integrity checklist in Launch Vehicle Appendix.

Procedure: See Structural Integrity Checklist in Launch Vehicle Appendix.

Results: All analyses meet or exceed minimum factor of safety.

Lessons Learned: Most structural components not likely to fail.

Differences between Predicted and Actual Results: Components had larger factors of safety than necessary.

1.4 Bulkhead Integrity During Pressurization	
Status:	Completed – Successful
Meets Requirement(s):	6.3.4, 6.3.6
Verification Method:	Analysis
Objective:	Bulkheads will withstand the forces due to pressurization during parachute deployment with a safety factor of 2 or greater.
Success Criteria:	the bulkhead simulation must return a safety factor for static failure equal to or greater than 2. The verification test must show there is minimal air leakage from airframe and ensure there is no failure of the bulkhead.
Discussed in:	FRR Section 3.2.11, 3.2.12

Description: Bulkheads will withstand the forces due to pressurization.

Safety and Equipment Requirements: See Bulkhead Pressurization checklist in Launch Vehicle Appendix.

Procedure: See Bulkhead Pressurization Checklist in Launch Vehicle Appendix.

Results: All analyses meet or exceed minimum factor of safety.

Lessons Learned: Most structural components not likely to fail.

Differences between Predicted and Actual Results: Components had larger factors of safety than necessary.

1.4 Eyebolt Retention During Recovery Forces	
Status:	Completed – Successful
Meets Requirement(s):	
Verification Method:	Analysis
Objective:	Eyebolts and securing points will withstand all forces experienced during parachute deployment with a safety factor of 2 or greater. factor of 2 or greater.
Success Criteria:	All tests on both the bays must not show any structural failure at loads below a safety factor of 2.0. Full scale launch vehicle must show no signs of failure or splintering in bulkhead that eyebolt is mounted too.
Discussed in:	FRR Section 3.2.4, 3.2.10

Description: The structural analysis of the eyebolt assembly will be completed using CAD simulation tools.

Safety and Equipment Requirements: See Eyebolt Retention Checklist in Launch Vehicle Appendix.

Procedure: See Eyebolt Retention Checklist in Launch Vehicle Appendix.

Results: All analyses meet or exceed minimum factor of safety.

Lessons Learned: Most structural components not likely to fail.

Differences between Predicted and Actual Results: Components had larger factors of safety than necessary.

1.6 Airframe RF Transparency	
Status:	Completed – Successful
Meets Requirement(s):	2.22.9, 2.22.10
Verification Method:	Inspection
Objective:	The airframe will block 0 of the required RF signals required to pass through it.
Success Criteria:	all connections must be maintained at the three testing distances. The connection must also be maintained during full scale test launch unless proven to be due to another system failure unrelated to the airframe.
Discussed in:	FRR Section 3.2.3

Description: Check that all receivers and transmitters are communicating correctly. Ensure viable connection at 5ft, 25ft, and 50ft.

Safety and Equipment Requirements: See RF Transparency Checklist in Launch Vehicle Appendix.

Procedure: See RF Transparency Checklist in Launch Vehicle Appendix.

Results: All signals confirmed connections.

Lessons Learned: Full fiberglass prevents any risk of RF blocking.

Differences between Predicted and Actual Results: None.

1.6 Airframe Exterior Holes	
Status:	Completed – Successful
Meets Requirement(s):	6.3.5, 6.3.7
Verification Method:	Inspection
Objective:	There will be 0 holes more than the required venting, arming holes, and subsystem holes in the airframe.
Success Criteria:	all holes in airframe are validated with venting or subsystem purpose, and that all venting holes are verified to be an acceptable size based off of venting requirements.
Discussed in:	FRR Section 3.2.3, 3.2.13

Description: ensure airframe holes will be large enough to maintain correct internal pressures for airframe. This along with number of required arming and securing holes for launch vehicle subsystems

Safety and Equipment Requirements: See Airframe Holes Checklist in Launch Vehicle Appendix.

Procedure: See Airframe Holes Checklist in Launch Vehicle Appendix.

Results: Only necessary holes are present. Holes are in the correct location and of the correct dimensions.

Lessons Learned: Hole location and size is crucial.

Differences between Predicted and Actual Results: None.

1.8 Fin Impact Durability	
Status:	Completed – Successful
Meets Requirement(s):	6.3.1
Verification Method:	Inspection
Objective:	Fins will withstand maximum force of a landing to a factor of safety of 2.
Success Criteria:	fins are verified through CAD simulations to survive the maximum 75lbf impact force with a factor of safety greater than 2 in accordance with the team requirements. It will also need to survive impact during the full scale testing of the launch vehicle, and be able to launch again without any repair to the fins.
Discussed in:	FRR Section 3.2.6

Description: Primary testing of fins will be done through CAD simulations, using a maximum impact energy of 75 lbf in accordance with NASA regulations.Perform Instron testing on composite coupons of the same material as the fin to confirm properties.

Safety and Equipment Requirements: See Fins Impact Test Checklist in Launch Vehicle Appendix.

Procedure: See Fins Impact Test Checklist in Launch Vehicle Appendix.

Results: Fins can withstand landing impact forces with excessive factors of safety.

Lessons Learned: Composite sandwich method is extremely strong.

Differences between Predicted and Actual Results: Stronger than expected.

1.2 BEAVS FEA Test	
Status:	Completed – Successful
Meets Requirement(s):	2.1
Verification Method:	Analysis
Objective:	Ensure the blades and BEAVS assembly can withstand max pressure experienced during coast phase.
Success Criteria:	Minimum safety factor of 2 on all BEAVS components;Bending moment is within acceptable range.
Discussed in:	FRR Section 3.2.19

Description: Utilize Solidworks FEA to simulate expected flight forces.

Safety and Equipment Requirements: See BEAVS FEA Test Checklist in Launch Vehicle Appendix.

Procedure: See BEAVS FEA Test Procedures

Results: Successful - components will be able to withstand flight forces.

Lessons Learned: FEA simulations must be set up correctly to collect accurate results.

Differences Between Predicted and Actual Results: N/A

1.2 BEAVS Controls Test	
Status:	Incomplete
Meets Requirement(s):	2.1
Verification Method:	Test
Objective:	Ensure the controls can predict the expected altitude with simulated data to test if the controls will tell the blades to extend or stay retained.
Success Criteria:	Blades are extended when desired predicted apogee altitude < actual predicted apogee altitude; Blades are not extended when desired predicted apogee altitude > actual predicted apogee altitude; Flight data is constantly recorded through simulated flight
Discussed in:	FRR Section 3.2.24

Description: Test all of the BEAVS components together as a system to ensure no bugs.

Safety and Equipment Requirements: N/A

Procedure: See BEAVS Controls Test Procedures in the Appendix

Results: Has not been tested yet.

Lessons Learned: N/A

Differences Between Predicted and Actual Results: N/A

6.1.2 Recovery Verification Procedures

NOTE: See appendix B for full Aerodynamics and Recovery Testing procedures

2.1 Ejection Charge Sizing Test	
Status:	Completed – Successful
Meets Requirement(s):	3.2; 6.1.2; 6.1.3
Verification Method:	Test
Objective:	To make sure the main and drogue parachute will both be able to be deployed.
Success Criteria:	Both the main and drogue parachutes are pushed entirely out of their respective chambers.
Discussed in:	FRR Section 3.3.20

Description: BP charges are built as per the Black Powder Ejection Charge Checklist and then are integrated into the launch vehicle or into the BP Ejection Charge Test Stand as if preparing for flight. However, instead of connecting the charges to EMBERS or the RRC3 altimeters, the charges are connected to 10 ft of wire which is routed to the side of the launch vehicle so that the individual who is running the test is not directly behind or in front of the launch vehicle when the BP charge is detonated. The free end of the wire is then connected to a 9 V battery when the individuals testing are ready to detonate the BP charge.

Safety and Equipment Requirements: See Ejection Charge Test Checklist on next page.

Procedure: See Ejection Charge Test Checklist on next page.

Results: For Full Scale ejection testing, both the drogue and main primary sizes were tested, as, if the smaller-sized charges could deploy the parachutes, then the larger backup sizes would have no problem doing the same. Since it was raining on and off during the testing, the airframe of the launch vehicle became damp before conducting the test. Also, since the BEAVS 2.0 sealing bulkhead had just been installed, it had not been tested for an accurate seal yet. The primary drogue parachute size charge of 1.9 g was unable to completely deploy the drogue parachute, as seen in Figure 101, but the primary main parachute size charge of 4.8 g was able to completely deploy the main parachute, as seen in Figure 102. Later testing of the 1.9 g primary drogue parachute charge resulted

Figure 101: Drogue Parachute Primary Charge Size Testing

Figure 102: Main Parachute Primary Charge Size Testing

Lessons Learned: If the airframe is damp due to rain or other sources of moisture, it can become more difficult to deploy the parachutes. Therefore, if it is raining during integration, or the launch frame becomes wet for any other reason, the launch frame needs to be dried before completing integration and launching. Also, the BEAVS 2.0 bulkhead had significant pressure leaking issues that needed to be resolved before flight that caused a good amount of the pressure to be able to escape.

Differences between Predicted and Actual Results: The primary drogue parachute charge should have been able to deploy the drogue parachute without issue, however, it only managed to break the shear pins and push the coupler out of the airframe about half way.

Altimeter Functionality Testing	
Status:	Completed – Successful
Meets Requirement(s):	3.1, 3.1.1, 3.1.2
Verification Method:	Test
Objective:	To make sure the altimeters will detonate the correct e-matches when appropriate.
Success Criteria:	The drogue primary e-match pops at simulated apogee, the drogue backup pops at one second past that, the main primary pops at 600 ft, and the main back up pops at 500 ft.
Discussed in:	FRR Section 3.3.17

Description: The altimeter bay will be assembled in the same way as if it were being prepared for launch, including placing the bay in the coupler and sealing it in. However, instead of putting in fully assembled BP charges in the altimeters, only ematches will be placed in the ports to be detonated in the vacuum chamber, which will be used to simulate the pressure change during a launch. The setup in the vacuum chamber is shown in Figure 103.

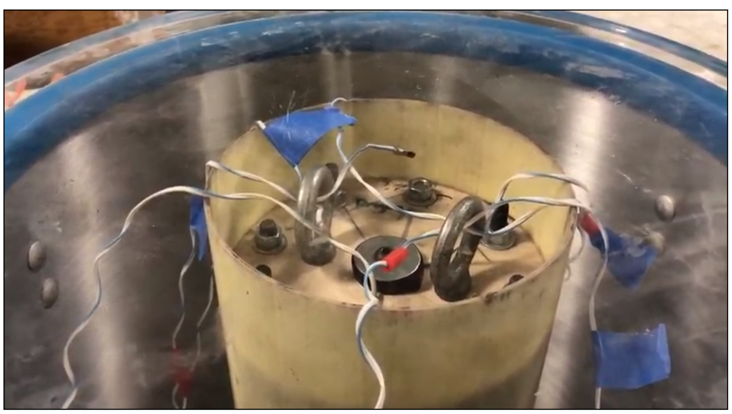

Figure 103: Altimeter Testing Vacuum Chamber Setup

Safety and Equipment Requirements: See Altimeter Testing Checklist below.

Procedure: See Altimeter Testing Checklist below.

Results: Both of the altimeters acted as expected, with the primary drogue e-match going off at the simulated apogee, the backup drogue e-match going off at one second past apogee, and the primary and back up main charges going off at 600 and 500 ft respectively.

Lessons Learned: A far as pressure chamber testing goes, these altimeters are fully functional and are ready to fly in the launch vehicle.

Differences between Predicted and Actual Results: There were no differences between the predicted and actual results.

EMBERS Testing	
Status:	Completed – Successful
Meets Requirement(s):	6.1.17
Verification Method:	Test
Objective:	To ensure that the EMBERS can be actuated while in the airframe and keep pressure within the airframe.
Success Criteria:	The wire to the separation piece can be pulled out of EMBERS easily and little to no venting happens around the holes in the airframe allowing access to the EMBERS switch.
Discussed in:	FRR Section 3.3.15 and 3.3.16

Description: In order to test the functionality of EMBERS, the entire system will be created as if it were going to be launched, however, it will be integrated into the BP test stand where the holes for EMBERS integration have been drilled. This testing will also show whether or not the system can withstand the pressure and heat involved with having a BP charge detonate right next to the system.

Safety and Equipment Requirements: See EMBERS Testing Checklist on next page.

Procedure: See EMBERS Testing Checklist on next page.

Results: The tab was able to be pulled out of the EMBERS with minimal force as the parachutes were pushed out of the system, and the EMBERS survived detonation, as seen in Figures 104 and 105.

Lessons Learned:

Differences between Predicted and Actual Results:

Figure 104: EMBERS Testing Setup Before Pull

Figure 105: EMBERS Testing Setup After Pull

2.2 Pre-Launch OpenRocket Simulation	
Status:	Complete- Successful
Meets Requirement(s):	2.14, 2.16, 2.22.8, 3.3, 3.10, 3.11
Verification Method:	Analysis
Objective:	Test flight parameters before launch to collect simulated data such as apogee altitude, max velocity, landing energy, center of gravity, center of pressure, motor burnout time, drift, etc.
Success Criteria:	Landing energy < 75 ft-lbs; Descent time < 90s; Drift < 2500 ft; Stability is between 2-4 calibers
Discussed in:	FRR Section

Description: Determine launch parameters such as drift radius, descent time, landing energy, and stability margin and adjust parameters as needed to satisfy competition rules.

Safety and Equipment Requirements: N/A

Procedure: See Pre-Launch OpenRocket Test Procedures

Results: The OpenRocket simulation for subscale was accurate within 20 ft of altitude. This is considered successful by OSRT because the margin of error was less than 1%. The OpenRocket simulation for fullscale was around 250 ft off at 4,150 ft, or 6.5%. It is assumed that the cd calculated was on the high range of values and the model was later corrected and modeled a 4430 ft apogee altitude.

Lessons Learned: Bring scale out to launch site to measure launch vehicle weight once it is all assembled to ensure accurate weights. Set surface finishes to lowest cd on OpenRocket

Differences Between Predicted and Actual Results: The subscale altitude predicted was 1805 ft while the actual apogee altitude was 1785 ft. (<1% difference). The fullscale apogee altitude

2.2 Pre-Launch Matlab Simulation	
Status:	Complete- Successful
Meets Requirement(s):	2.14, 2.16, 2.22.8, 3.3, 3.10, 3.11
Verification Method:	Analysis
Objective:	Test flight parameters before launch to collect simulated data such as apogee altitude, max velocity, landing energy, drift, etc.
Success Criteria:	Numbers for landing energy, descent time and drift match with OpenRocket within a 10% margin of error.
Discussed in:	FRR Section

Description: Determine launch parameters such as drift radius, descent time, landing energy, and stability margin and adjust parameters as needed to satisfy competition rules.

Safety and Equipment Requirements: N/A

Procedure: See Pre-Launch Matlab Test Procedures

Results: See section 3.3.10

Lessons Learned: Landing energy limit must be below 3*75 ft-lbf because each tethered section can land at 75 ft-lbf. Matlab will produce incorrect numbers if it thinks the whole launch vehicle has to land under 75ft-lbf.

Differences Between Predicted and Actual Results: See section 3.3.10

6.1.3 Avionics Verification Procedures

Avionics Sensor Test	
Status:	Completed – Successful
Verification Method:	Test
Objective:	To make sure all sensors were installed correctly, and give good data.
Success Criteria:	GPS sensor, barometric pressure, and accelerometer all output reasonable data

Description: The sensors should print reasonable raw data to the screen, and the indicator lights should light up.

Procedure: See Avionics test, next page.

Results: The sensors worked as expected.

6.1.4 Payload Verification Procedures

3.1 Payload Drop Test	
Status:	Completed – Successful
Meets Requirement(s):	12.1; 13.25.2
Verification Method:	Test
Objective:	To make sure the payload is able to withstand in-flight and landing forces expected during competition.
Success Criteria:	The payload does not receive any debilitating damage.
Discussed in:	FRR Section 4.4.5

Description: Payload chassis is dropped from a high height until the damage sustained is too large for the chassis to maintain integrity.

Safety and Equipment Requirements: See Payload Drop Test Checklist in Payload Test Appendix.

Procedure: See Payload Drop Test Checklist in Payload Test Appendix.

Results: The payload was able to withstand 2 drops onto concrete from a height of approximately 20 feet. The third drop resulted in the chassis breaking. Payload chassis was deemed sufficiently strong to withstand forces expected during the competition.

Lessons Learned: The payload chassis is sufficiently strong.

Differences between Predicted and Actual Results: The payload chassis ended up being stronger than expected. Initially, we believed that the drop test would only require a single drop to cause the chassis to fail, but it ended up fully surviving 2 drops and only breaking on the third.

3.2 Payload Collection Test	
Status:	Completed – Successful
Meets Requirement(s):	6.2.2; 6.2.4
Verification Method:	Test
Objective:	To ensure payload collection system is able to successfully collect and hold at least 10 ml of sample material in a competition like setting.
Success Criteria:	The payload is able to collect and hold at least 10 ml of sample.
Discussed in:	FRR Section 4.4.9

Description: Ensure payload is able to collect the sample material.

Safety and Equipment Requirements: See Collection Test Checklist in Payload Test Appendix.

Procedure: See Collection Test Checklist in Payload Test Appendix.

Results: The payload is able to successfully collect and hold 10 ml of sample material. Test was successful.

Lessons Learned: The payload collection system is able to collect material easily. The collection system will likely not require driving forward in order to collect the sample and in our testing was able to collect material while stationary.

Differences between Predicted and Actual Results: OSRT had expected to need the payload to drive forward in order to collect the sample, but during testing the payload was able to collect while stationary. This shows that the collection system is more reliable than previously thought.

3.3 Payload Drivetrain Testing	
Status:	Completed – Successful
Meets Requirement(s):	4.2; 4.3.4
Verification Method:	Test
Objective:	To test the capabilities of the payload rover drivetrain.
Success Criteria:	The payload is able to drive and turn.
Discussed in:	FRR Section 4.4.7

Description: The payload drivetrain was assembled, each wheel being secured with two set screws. Each wheel was then subjected to force that attempted to remove the wheel from the motor shaft. In both cases, the wheels did not perceptibly move along the motor shaft.

Safety and Equipment Requirements: See Payload Drive Test Checklist in Payload Test Appendix.

Procedure: See Payload Drive Test Checklist in Payload Test Appendix.

Results: Wheels remained securely attached.

Lessons Learned: Using divots as attachment points for set screws is quite effective.

Differences between Predicted and Actual Results: System performed as predicted.

3.4 Payload Ejection Testing	
Status:	Completed – Successful
Meets Requirement(s):	2.18.2.3; 4.3.7; 4.3.7.1; 4.3.7.2; 6.2.7; 6.2.8;
Verification Method:	Test
Objective:	The payload ejection/retention system must be capable of successfully ejecting the payload.
Success Criteria:	The payload is ejected.
Discussed in:	FRR Section 4.4.11

Description: The payload is placed inside the ejection/retention system and then ejected from the airframe.

Safety and Equipment Requirements: See Payload Ejection Test Checklist in Payload Test Appendix.

Procedure: See Payload Ejection Test Checklist in Payload Test Appendix.

Results: The payload was successfully ejected in 22 minutes after changing to smaller shear pins and a more geared motor. This means that we have failed the team derived requirement 6.2.7 to eject the payload in 2 minutes. Using a faster, less geared motor would force OSRT to use fewer shear pins than the team would like and could be unsafe. Since the payload has 1 hour to complete the mission OSRT has determined that this long ejection time is acceptable.

Lessons Learned: The ejection system requires a long time to eject the payload.

Differences between Predicted and Actual Results: We expected an ejection time of 1-5 minutes. The full ejection taking 22 minutes was unexpected but ultimately deemed unimportant. OSRT decided that given the long mission time the payload has, even with an ejection time of 22 minutes the payload would still complete the mission.

3.5 Payload Retention Testing	
Status:	Completed – Successful
Meets Requirement(s):	2.18.2.3; 4.3.7; 4.3.7.1; 4.3.7.2; 6.2.8;
Verification Method:	Test
Objective:	The payload ejection/retention system must be strong enough to retain the payload and withstand any in-flight shocks and jolts.
Success Criteria:	The ejection/retention system is able to hold 20 lbs.
Discussed in:	FRR Section 4.4.11

Description: The retention system is loaded with weights to see the strength of the retention system.

Safety and Equipment Requirements: See Payload Retention Test Checklist in Payload Test Appendix.

Procedure: See Payload Retention Test Checklist in Payload Test Appendix.

Results: The retention system was able to hold 22 lbf while showing no damage or wear. The team did not continue loading all the way until 25 lbf as the payload weighs less than 10 lbf, so being able to hold 22 lbf still allows for a greater than 2 times safety factor.

Lessons Learned: The retention system is sufficiently strong and reliable.

Differences between Predicted and Actual Results: The retention system performed as expected showing little difficulty even with more than 20 lbf loaded, much more than the actual weight of the payload.

Test/System	Number/Type	Status	Results	Notes
Ground Ejection Test - BP for Subscale	1	Complete	Successful	Burnt Main Chute- look into larger blankets or deployment bags
	2	Complete	Successful	Expand aft section to allow more room for drogue shock cords
Primary and Backup Altimeter Testing for Deploy Drogue and Main Parachutes	1	Complete	Successful	Could only get the RRC3s to work, still need to wrestle with the Stratologgers.
BEAVS 2.0 - Mechanical Testing	FEA Airframe Buckling Tests	Complete	Successful	The blade width is NOT constrained due to airframe buckling, rather it is constrained due to space within airframe. Structural damage is not a concern.
BEAVS 2.0 - Simulation Testing	MATLAB Simulations	In Progress	N/A	
	Star-CCM+ Simulations	In Progress	N/A	
Subscale Launches	1	Complete	Successful	Recovery system worked great!
	2	Incomplete	N/A	Cancelled due to weather
Payload Testing	CES Chassis Material Analysis	Complete	Successful	
	Chassis FEA	Complete	Successful	
	Chassis Prototyping	Complete	Successful	
	Wheel Prototyping	Complete	Successful	
	Collection Prototype Testing	Complete	Successful	
	Drop Testing	Complete	Successful	
	Drive Testing	In Progress	N/A	
	Battery Life Testing	In Progress	N/A	
	Ejection System Testing	Complete	Successful	
	Retention Strength Testing	Complete	Successful	
	Retention Robustness Testing	Complete	Successful	
Structure Testing	Radial Bolt	In Progress	N/A	
	Fin Impact Testing	Complete	Successful	Fins show minimal wear and abrasions after landing and getting drug several feet through rock and dirt.
	Vehicle Thrust Plate	Complete	Successful	Simulations verified by test flight, showing no buckling or damage to thrust plate.
	Pressure Testing of Parachute Bays	Complete	Successful	Ejection testing with sealing bulkheads proved to be successful after adjustments
	Pressure Testing of Coupler Altimeter Bay	Complete	Successful	Venting calculations proved to be correct as vacuum chamber testing showed drogue deployment at simulated apogee.
Altimeter Testing	1	Complete	Successful	
	2	Complete	Successful	
	3	Complete	Successful	

6.2 Requirement Compliance

Below is a detailed description of all NASA-derived and Team-derived requirements, why they are important, how they are verified, the status of each one, and where they are located with FRR. For the Verification Method (VM) column, the letter "A" denotes that the verification will be done via analysis, "D" will be done via demonstration, "I" will be done via inspection, and "T" will be done via testing.

6.2.1 NASA Requirements

6.2.1.1 General Requirements

Table 33: General Requirement Verification Matrix

Requirement	Validation	VM	Verification Plan	Status	Report Location
1.1.1 Students on the team will do all of the work on the project, except when it comes to assembling motors and handling black powder or any other kind of ejection charge.	This is a Student Launch Initiative, meant to teach students about the NASA design process, so having mentors and other individuals do the work would negate the point of the project, with the exception of where safety concerns come into play, such as with motor assembly. At that point, whoever has the proper certifications needs to be the one to handle those systems.	I	Individuals who are not students on the team will be prohibited from doing work on the project at any point in time, unless it is for motor assembly or ejection charge purposes, and only team members will be granted access to the team's shared drive and LaTeX documents.	In progress - This will be a daily practice starting from the time the handbook is released to when the Post-Launch Assessment Review is submitted and included in the timeline, as everything in the timeline is student work.	N/A
1.1.2 The team will submit new work.	Since learning about the NASA design process and working to complete a challenging project is the point of the competition, submitting old work would negate the purpose of joining the competition	I	The team will not copy and paste large sections of material from previous documents into new documents without significantly modifying that which is copied.	In progress - This will be completed at each deliverable submission and is included in the timeline with ample time to write, compile, and edit all deliverables before submission.	N/A

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Table 33 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
1.2 The team will provide and maintain a project plan, including project milestones, budget and community support, checklists, personnel assignments, Science, Technology, Engineering and Mathematics (STEM) Engagement events, and risks and mitigations.	Maintaining a project plan allows for the team to be much more organized, which enhances the overall safety and efficiency of the team.	I	The Team Lead will maintain the project plan, monitor the work of the team done by project milestones, and keep track of personnel assignments, while Budget and Finance keeps the budget up to date and works to maintain community support. STEM Engagement will keep track of all STEM Engagement activities and record and report the outcome of each activity to NASA via the STEM Engagement Activity Report, and Safety will be responsible for keeping risks and mitigations up to date. All aforementioned subteams will update these respective pieces of information in each deliverable submitted to RSO	In progress - A project plan with the milestones, budget and community support, checklists, personnel assignments, STEM Engagement events, and risks and mitigations will be repeatedly updated and submitted to NASA personnel up to and including to when the Post-Launch Assessment Review is submitted. This is included in the timeline in the compiling and editing phase of each deliverable.	
1.3 Foreign National team members must be identified by the Preliminary Design Review.	The project coordinators need time to file the appropriate paperwork in order to get the proper permissions for Foreign Nationals to enter Redstone Arsenal and Marshall Space Flight Center	I	Team members will be required to report to the Team Lead that they are a Foreign National before the Preliminary Design Review submission deadline.	Complete - OSRT does not have any Foreign National (FN)s to report to NASA, and that has been reported to NASA	N/A .
1.4 The team must identify all team members attending launch week activities by the Critical Design Review.	The project coordinators need time to be able to organize the event for the correct number of people who will be attending the launch week events.	I	The Team Lead will collect a list of members and one mentor who will be attending launch week activities and submit it by the Critical Design Review submission deadline.	Complete - The list of the team members and mentor has been submitted to Jon Greenfield.	N/A
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Table 33 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
1.5 The team will engage a minimum of 200 participants in educational, hands-on activities, as defined by the STEM Engagement activity report between project acceptance and FRR.	While the members of the team will go on to do incredible things, the generation behind them will be able to do even more incredible things with what this team does, and therefore, it is incredibly important to encourage younger students to pursue STEM careers	D	The team will keep a tally of how many students participate in each educational activity, and will submit this number, along with the STEM Engagement Activity Report, within two weeks of the STEM Engagement activity to RSO.	Complete - The OSRT has engaged over 200 participants in hands-on STEM Engagement activities, and has plans to continue to do so up to and after FRR	
1.6 The team will establish a social media presence to inform the public about team activities.	In many ways, social media is the best way to educate the public about topics, and the therefore, a significant part of outreach lies in having active social media accounts.	D	The team will create a Snapchat and Instagram account, and will post on these platforms regularly to keep followers up to date on team activities.	Complete - Snapchat, Instagram, Facebook, and Twitter accounts have been created.	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 either by e-mailing the file directly, or, if the file is too big, by including a link to download the file.	It is easiest for the project coordinators to receive the deliverables via email.	D	The team will send all deliverables to the NASA project management team, and then will screenshot the sent e-mail with a timestamp and keep the screenshots in a file on the team's shared drive.	In progress - This will be completed at each deliverable submission and is accounted for in the timeline on the day of deliverable deadlines.	N/A

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Table 33 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
1.8 All deliverables must be in PDF format.	Putting all files in PDF format streamlines and simplifies the documentation review process, and eliminates the possibility of something happening during the review process that will jumble or destroy the document.	I	All deliverables submitted to NASA will be saved in PDF format, and one copy of each deliverable will be saved to the team's shared drive.	In progress - This will be completed at each deliverable submission and is accounted for in the timeline on the day of the deliverable deadlines.	
1.9 In every report, the team will provide a table of contents with major sections and their respective subsections.	This streamlines and enhances the efficiency of the review process, as it makes items easier to find in the document	I	A table of contents will be submitted within each deliverable that details the deliverables sections and subsections.	In progress - This will be completed at each deliverable submission and is accounted for in the timeline in the compiling and editing schedule of each deliverable.	Pages 1 - 12
1.10 In every report, the team will include a page number at the bottom of each page.	This helps streamline and enhance the efficiency of the review process, as well as making it much easier to reference sections of the document, should they need to be referenced.	I	A page number will be included at the bottom of each page in every deliverable.	In progress - This will be completed at each deliverable submission and is accounted for in the timeline in the compiling and editing schedule of each deliverable.	Each page has been numbered, starting with the table of contents.
1.11 The team will provide any computer equipment necessary to perform a video teleconference with the review panel.	Each team needs to perform a video teleconference, and asking each team to provide their own equipment will streamline the process for the project coordinators, as well as the teams.	I	The team will reserve a conference room on the Oregon State University campus for the duration of the video teleconference that has a speaker and projector system. The team members will provide a camera, a microphone, and a telephone.	Complete - The team has acquired all computer equipment necessary to perform a video teleconference with the review panel for each teleconference.	N/A

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Table 33 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
1.12 The team will use a launch pad provided by Student Launch's launch services provider.	This will streamline and enhance the efficiency of the launch schedule.	I	The team will only use Student Launch's launch services provider's launch pad, and will design the launch vehicle so that it is compatible with either 8-foot 1010 or 12-foot 1515 rails.	Complete - The launch vehicle is designed to launch on a 1515 launch rail.	
1.13 The team will identify a "mentor".	Particularly since this is a Student Launch Initiative, and is geared toward students, having a mentor to guide them is crucial for the success of their project.	I	The team will identify their mentor and report their mentor to the NASA project management team by the time the Proposal is submitted.	Completed - The team's mentor is Joe Bevier and the team's advisor is Dr. Nancy Squires.	Section 1.1

6.2.1.2 Vehicle Requirements

Table 34: Vehicle Requirement Verification Matrix

Requirement	Validation	VM	Verification Plan	Status	Report Location
2.1 The launch vehicle will deliver the payload to an apogee between 3,500 ft and 5,000 ft AGL.	For any lunar mission, the launch vehicle will need to deliver the payload to an exact orbit and an exact site.	D	The Aerodynamics/Recovery and Structures/Propulsion Teams will maintain altitude simulations as the launch vehicle is constructed in order to accurately select a motor that will deliver the launch vehicle into the given altitude window. Aerodynamics/Recovery will also develop an altitude control system to hone in on our declared altitude during flight.	Complete - The team was able to deliver the payload to an apogee of 4,456 ft in its first Launch Vehicle and Payload Demonstration Flight.	Section 3.5.1

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Table 34 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
2.2 Teams shall identify their target altitude goal at the Preliminary Design Review milestone.	In order to be able to define a motor, the target altitude needs to be defined, and the earlier it is defined, the earlier the motor can be selected and the launch vehicle can be designed to house it.	I	The team will report our target altitude on our submission for the Preliminary Design Review.	Complete - The target altitude goal of OSRT is 4,000 ft AGL.	Section 3.1.1
2.3 The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner.	A commercially available barometric altimeter must be flown because it is a reliable component that will not give any advantages to a team.	I	The team will select a commercially available barometric altimeter for implementation into the recovery system by the Preliminary Design Review submission deadline.	Completed - OSRT has chosen to use the Missile Works RRC3 Sport altimeters to initiate the deployment of the parachutes from within the launch vehicle, which will also record and report the apogee of the flight at competition.	Section 3.3.16
2.4 The launch vehicle will be designed to be recoverable and reusable.	Reusable launch vehicles are more cost efficient and eco-friendly.	D	The launch vehicle will be designed so that it has a recovery system that allows it to land softly, and an interchangeable motor and ejection charges that allow for the launch vehicle to relaunch within a reasonable time frame.	In progress - The full scale launch vehicle was recovered after the first attempt of the Launch Vehicle and Payload Demonstration flights, however, it was not immediately reusable due to nose cone damage. This will be completed once the Launch Vehicle and Payload Demonstration flights have been completed, and has been accounted for withing the project plan.	

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Table 34 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
2.5 The launch vehicle will have a maximum of four (4) independent sections.	More than four independent sections add unnecessary complexity to the recovery system, and unnecessary weight to the launch vehicle for this challenge.	I	The launch vehicle will be designed to have three (3) independent sections.	Complete - The launch vehicle will have three (3) independent sections, the nose cone, the fore body section, and the aft body section.	Section 3.1
2.5.1 Coupler/airframe shoulders, which are located at in-flight separation points, will be at least one body diameter in length.	It is important that the coupler is long enough to prevent any accidental separations, and also have enough space to have the necessary amount of shear pins.	I	The team will design the airframe shoulders to be at least 6.25 in. in length.	Complete - The airframe shoulders are designed to be 6.5 in. in length on both the fore and the aft breaks of the launch vehicle.	Section 3.2.13
2.5.2 Nose cone shoulders, which are located at in-flight separation points, will be at least 1⁄2 body diameter in length.	Much like for the coupler shoulders, it is important that the nose cone shoulders are long enough to prevent any accidental separations and also have enough space to have the necessary amount of shear pins.	I	The team will design the airframe nose cone shoulders to be at least 3.125 in. long.	Complete - The nose cone shoulders are designed to be 4 in. long.	Section 3.2.14
2.6 The launch vehicle will be capable of being prepared for flight at the launch site within two hours of the time the Federal Aviation Administration flight waiver opens.	It is important to be able to integrate within a reasonable time frame, as the launch site will open at 6:00am, and the first round of volleys will begin at 8:00am	D	The team will arrive to the launch site at least two hours before the flight waiver opens, and will practice integration of all of the systems into the launch vehicle no later than one day in advance of the launch day in order to ensure that the assembly of the launch vehicle takes no longer than two hours.	In Progress - OSRT was able to completely assemble the subscale launch vehicle in one hour and thirty minutes. This will be completed when the full scale launch vehicle is built, flown in two test flights, and is assembled at competition.	Section 3.5

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.7 The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of two hours without losing the functionality of any critical on-board components.	Unexpected issues could cause the launch to be delayed for an unknown length of time after setting the launch vehicle up on the launch rail, and, in order to prevent further schedule delays, the launch vehicle needs to be able to sit on the launch pad for this length of time.	T, D	The team will design all on-board electronics to last a minimum of 10 hours, and the payload to last a minimum of 18 hours on the Launch Pad.	In progress - The design for the avionics, altimeters, and the payload and its respective electronics system have all been finalized. New or freshly charged batteries will be used in the altimeter or avionics system to ensure that the systems can last 10 hours. This requirement will be completed when the payload is built and tested for electronic longevity, and is accounted for in the timeline in launch vehicle and payload build schedule.	Section 3.3 and 4.5.1
2.8 The launch vehicle will be capable of being launched by a standard 12 V direct current firing system.	Not needing any special launch systems will streamline and simplify the timeline for launch day activities	D	The team will use a standard, commercially available motor and will ensure that it will be able to be ignited with a standard 12 V direct current firing system by launching it at least once with a 12 V direct current firing system.	Complete, the launch vehicel has been launched successfully using a slandered 12 V direct current firing system.	Section 3.5
2.9 The launch vehicle will require no extraneous external circuitry or special Ground Support Equipment (GSE) to initiate launch.	Not requiring any special GSE will streamline and simplify the timeline for launch day activities	I	The team will use a standard, commercially-available motor, will not make any modifications to it, and will ensure that the motor can be launched without extraneous external circuitry by launching an identical motor at least once.	Complete - No extraneous external circuitry or special GSE is required to launch the launch vehicle.	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.10 The launch vehicle will use a commercially available solid motor propulsion system using Ammonium Perchlorate Composite Propellant (APCP), which is approved and certified by the NAR, TRA, and/or the Canadian Association of Rocketry (CAR).	Using a commercially available solid motor both enhances the safety of the team members, as they do not need to mix and build their own custom motors, and enhances the safety of the spectators as it decreases the liklihood of mid-flight launch vehicle explosions	I	The team will only select a motor that uses APCP that is approved and certified by NAR, and will have the team mentor approve of the purchase as a representative of NAR before purchase of the motor.	Completed - A commercially available motor has been selected and has been purchased after approval of a NAR mentor.	Section 3.2.9
2.10.1 Final motor choices will be declared by the CDR milestone.	Finalizing the motor selection at this stage allows time for the launch vehicle to be designed to be able to hold a motor of a particular size.	I	The team will include a declaration of a final motor by the team's CDR deliverable submission.	Completed - The OSRT's final motor choice for the full scale competition flight is AeroTech L2200G.	Section 3.2.9
2.10.2 Any motor change after CDR must be approved by the NASA RSO.	A motor change at a later stage of the project could be indicative of poor planning or hasty decisions, and therefore, needs to be approved to ensure that the decision was made with all safety protocol in mind.	I	The team will not change their motor after their CDR deliverable submission unless it is absolutely necessary, in which case, the team will seek approval from the NASA RSO before finalizing any motor changes.	Completed - The motor selection will not change after CDR.	Section 3.2.9
2.11 The launch vehicle will be limited to a single stage.	Limiting the launch vehicle to a single stage greatly increases the safety and simplicity of the launch vehicle and integration process.	I	The launch vehicle will be designed to only hold one motor in the aft section of the launch vehicle.	Completed - The launch vehicle has been designed so that it has one stage.	3.2

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.12 The total impulse provided by a college or university launch vehicle will not exceed 5,120 N-sec (L-class).	Limiting the motor size will limit the weight of the launch vehicle, and therefore, will help keep teams safe from potential issues around being able to lift a fully assembled launch vehicle, and limit the damage done should any portion of the launch vehicle become ballistic during descent.	I	The team will not select a motor larger than an L-class for implementation into the launch vehicle, and will keep the launch vehicle and rover weight low enough that an L-class motor or smaller can carry the launch vehicle to the predetermined altitude.	Complete - The team has selected a AeroTech L2200 with a total impulse of 5104 N-sec.	3.2.9
2.13 Pressure vessels on the vehicle will be approved by the RSO.	Pressure vessels will increase the number of safety hazards present within the launch vehicle, and could increase the chance of a premature explosion during integration, therefore, they must be completely necessary and deemed safe before being allowed to fly.	I	The team will have all checklists that involve pressure vessels require a signature from the RSO after the RSO approves the vessel in order for the checklist to be complete.	Complete - There are no pressure vessels featured on this launch vehicle.	N/A
2.13.1 The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.	A factor of safety of less than 4:1 will increase the potential of a safety incident occurring and threaten the safety of the team assembling the launch vehicle and inspectors.	I	The team will ensure that all pressure vessels have a minimum factor of safety of 4:1, and will supply updated calculations in each deliverable to demonstrate that the factor of safety remains at least 4:1.	Complete - There are no pressure vessels featured on this launch vehicle.	N/A

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.13.2 Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	In the event of a pressure vessel malfunction or failure, the compressed gas needs to be able to be vented safely.	I, A, T	The team will incorporate a pressure relief valve into all pressure vessels, and test it to ensure that the valve can withstand the maximum pressure and flow rate of the vessel.	Complete - Since there are no pressure vessels on this launch vehicle, a valve is not necessary.	N/A
2.13.3 The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/de-pressurization, and the name of the person or entity administering each pressure event.	The older and more used the pressure tanks are, the more likely they are to have a failure and threaten the safety of their operators.	I	The team will keep a log explicitly for each tank used, and will record the number of pressure cycles and the dates of pressurization/depressurization, along with requiring the signature of the individual who administered each pressure event. This documentation, along with the description of the application for which the tank was designed, will be included in all deliverables.	Complete - There are no pressure vessels or tanks on this launch vehicle.	N/A
2.14 The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit.	Too low of a stability will cause the launch vehicle to fly erratically, threatening the safety of all of those on the ground during launch.	A	The team will ensure that the static stability margin of the launch vehicle will at least be 2.0, and the updated calculations will be included in each deliverable submitted.	Complete - The static stability margin is 2.78	3.4.4

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.15 Any structural protuberance on the launch vehicle will be located aft of the burnout center of gravity.	Structural protuberances on the launch vehicle will alter the stability margin considerably if located fore of the center of gravity	3.2.17	The burnout center of gravity will be calculated twice: first, prior to finishing the design of the launch vehicle to ensure that all protuberances are designed to be aft of the burnout center of gravity, and second, after finishing the design of the launch vehicle to ensure that the protuberances are still aft of the burnout center of gravity after their addition.	Completed - The launch vehicle has been designed so that the only structural protuberance is the BEAVS system, which is located aft of the burnout center of gravity.	3.2.17
2.16 The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	The launch vehicle must achieve a minimum velocity before it clears the stabilizing rail in order to rely on fins for continued stability.	A,D	Simulations will be conducted in OpenRocket throughout the development of the launch vehicle, recovery system, and payload to ensure that the launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit. If it cannot, either the motor will be increased, or the weight of the overall launch vehicle will be decreased.	Completed - Simulations and tests have both confirmed an exit velocity above 52 fps.	Section 3.4.2
2.17 All teams will successfully launch and recover a subscale model of their launch vehicle prior to CDR.	The subscale launch vehicle is supposed to be a smaller version of the full scale launch vehicle, and, therefore, a successful launch and recovery of the launch vehicle will demonstrate that the foundational work completed by the team is accurate.	D	The team had one subscale launch to test the launch vehicle and recovery system designs, which was photographed and signed off by two members in every checklist leading up to the launch, on Saturday, November 16th.	Completed - The team successfully launched and recovered a subscale model of the launch vehicle on November 16th, 2019.	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.17.1 The subscale model should resemble and perform as similarly as possible to the full scale model.	If the subscale launch vehicle is similar to the full scale model, a successful subscale flight will demonstrate how the foundational work for the full scale launch vehicle is accurate.		The subscale model will be designed to be tow-thirds scale replica of the full scale launch vehicle.	Completed - The subscale launch vehicle was a 2/3rds replica that flew a similar but smaller flight path than the larger full scale launch vehicle is expected to do. The designs for the full scale launch vehicle have been detailed in this report and are scaled appropriately.	
2.17.2 The subscale model will carry an altimeter capable of recording the model's apogee altitude.	Since the subscale launch vehicle is similar to the full scale model, the altimeter is carried on the subscale model to be able to test the altimeter that is being used before it is carried on the full scale model to ensure it works. Additionally, this allows us to confirm the validity of our subscale simulations.	I	The subscale model will use the same altimeters as the full scale model.	Completed - The subscale launch vehicle carried two Missile Works RRC3 Sport altimeters, which recorded the apogee altitude each flight.	
2.17.3 The subscale launch vehicle must be a newly constructed launch vehicle, designed and built specifically for this year's project.	Building from scratch ensures that students are participating in the spirit of the competition, and also reduces the chance of structural failure from repeatedly stressed materials.	I	The launch vehicle and recovery system will be constructed from all-new materials, ensuring that these systems are built specifically for this year's project.	Completed - The subscale launch vehicle was designed specifically for this year's project, and was built out of all new materials.	Section 3.2

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.17.4 Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.	Proof of a successful flight is necessary to demonstrate that the vehicle design is functional. It also demonstrates that the recovery system can operate with less risk to spectators	T,D	Altimeter data and photos of the launch day, including of the launch and of the recovery, will be provided as proof of a successful flight.	Completed - A successful flight was flown on November 16th, 2019, as detailed in the Subscale Flight Results section.	
2.18.1.1 All teams will successfully launch and recover their full scale launch vehicle prior to FRR in its final flight configuration.	The launch vehicle should be demonstrated to function without injuring. It also serves as a validation of the vehicle designs.	D	The team has scheduled two launch days to do a successful launch and recovery of the launch vehicle and recovery system, which will all be photographed and signed off by two members in every checklist leading up to the launch, one on Saturday, February 1st and another on Saturday, February 22nd.	Not completed - This will be completed upon successfully launching and recovering the launch vehicle and recovery system in February, which is accounted for in the timeline with scheduled full scale launches.	
2.18.1.2 The launch vehicle flown must be the same launch vehicle to be flown on launch day.	The launch must be the same as the vehicle flown on launch day as the launch vehicle will have demonstrated a safe flight that avoids any problems.	I	The team will not change the launch vehicle or recovery system between its final flight before FRR and its flight on launch day, and will use the same checklists as will be used on launch day to ensure this.	Not completed - This will be completed between the final launch before the Flight Readiness Review and launch day, where no technical modifications will be made to the launch vehicle or recovery system between the two flights, and has been accounted for in the timeline with a scheduled launch vehicle repair time, but not a launch vehicle modification time.	
2.18.1.3 The vehicle and recovery system will have functioned as designed.	The recovery system must work as designed with no modifications to ensure the recovery system at competition will be reliable.	T,D	The vehicle will meet all speed and energy requirements, will separate at the correct times, and the recovery system will deploy and inflate its parachutes at the correct times to ensure that the vehicle lands under the energy requirements as well.	Completed - This was completed at the full scale launch.	Section 3.5.3

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.18.1.4 The full scale launch vehicle must be a newly constructed launch vehicle, designed and built specifically for this year's project.	This is necessary since it better demonstrates the design abilities of the participants. It also ensures that the launch vehicle will meet all of this years expect	I,D	The launch vehicle and recovery system will be constructed from all-new materials, ensuring that these systems are built specifically for this year's project.	Not completed - This will be completed when the full scale launch vehicle and recovery system are built and is accounted for in the timeline both in material and components purchasing for the launch vehicle and recovery system, and in both of their manufacturing schedules as well.	
2.18.1.5 If the payload is not flown, mass simulators will be used to simulate the payload mass, and will be located in approximately the same location as where the payload would be.		D	If the Payload Team is not ready to fly the payload, they will manufacture a mass that is the same size and basic shape of the payload, and can be retained by the same retention and ejection system in the launch vehicle.	Not complete - This will be completed when the Payload Team manufactures a mass representative of the payload that is flown in a full scale flight, which is accounted for in the timeline in the manufacturing schedule of a full scale payload.	
2.18.1.6 If the payload changes the external surfaces of the launch vehicle (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full scale Vehicle Demonstration Flight.		D	The team will activate all payload features that change the external surface of the launch vehicle and/or manage the total energy of the vehicle, and will have two team members sign off on the checklist for this system, along with photos taken of the system, to verify its actuation later.	Completed - The payload will not change the external surface of the launch vehicle, nor will it manage the total energy of the vehicle.	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.18.1.7 Teams shall fly the launch day motor for the Vehicle Demonstration Flight.	The motor is crucial to understand and predict the final outcome. This will be validated by only selecting one motor for full scale. The final motor choice will be used in the vehicle demonstration.	D	The team will fly the launch day motor at both full scale launches and will have two people sign off on its checklist for this feature, along with photos taken of this system, to be able to verify this later if need be.	Not completed - This will not be completed until both full scale launches are completed and is accounted for in the timeline in the ordering schedule for launch vehicle components, the integration schedule the day before launch, and the February launch days' schedules.	
2.18.1.8 The vehicle must be flown in its fully ballasted configuration during the full scale test flight.	Full ballast is required to ensure the recovery system can handle the extra weight and still recover within competition guidelines.	I,T	The team will fly the vehicle in its fully ballasted configuration, and will have two people sign off on its checklist for this feature, along with photos taken of this system, to be able to verify this later if need be, and if it is necessary to change the ballasted configuration after the second full scale flight, a third full scale flight will be conducted to ensure that the final ballasted configuration is flown before the Flight Readiness Review.	Completed - Full scale 1 flew with a full 10% weight in ballast, 5.9 lbf	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.18.1.9 After successfully completing the full scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA RSO.	This will ensure that the final launch has the highest chance of success. It is necessary for safety to make sure that the behavior can be predicted. In the event that a change is necessary it should be approved to minimize risk.	I	The team will not modify any portion of the launch vehicle and its components without a signature or written consent of the NASA RSO.	Not completed - If necessary, this will be completed when the NASA RSO either sends a letter of approval in the form of an e-mail or letter, or signs a form stating their approval, and has been accounted for in the timeline in the modify/repair schedules between the two February launches should the first launch be successful, or in the repair schedules should the second launch be successful.	
2.18.1.10 Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement.	Full scale flight success must be portrayed through physical evidence and altimeter data for proof.	D,A	Altimeter data and photos of the launch day, including of the launch and of the recovery, will be provided as proof of a successful flight.	Completed - A successful flight has been completed and the photos and analysis are included in this report	Section 3.5.3
2.18.1.11 Vehicle demonstration flights must be completed by the FRR submission deadline.	Flight data is analyzed to be sure that the launch vehicle is competition ready	D	The team will have two full scale vehicle demonstration flights that will be photographed and signed off by two members in every checklist leading up to the launch, the first on Saturday, February 22nd and the second on Saturday, March 7th.	In progress - This will be completed when both launches are completed before the FRR submission deadline, which is accounted for in the timeline in the two scheduled February/March launch days and their respective integration days.	Section 3.5.3

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.18.2.1 All teams will successfully launch and recover their full scale launch vehicle containing the completed payload prior to the Payload Demonstration Flight deadline.	This will demonstrate that the system can function. There will be several scheduled launch dates in case a design change is necessary or conditions prevent launch.		The team will launch and recover the full scale launch vehicle with the payload twice while the launch vehicle and recovery system meet all requirements, and will photograph the payload's flight during launch, after landing before payload deployment, after payload deployment, and after payload actuation.	Not completed - This will be completed when the payload is flown and documented in February, and is accounted for in the timeline in the two scheduled February launch days and their respective integration days.	
2.18.2.2 The launch vehicle flown must be the same launch vehicle to be flown on launch day.	The launch vehicle flown on launch day cannot be altered from that which was flown at a previous flight to ensure safety and reliability	D	The team will not change the launch vehicle or recovery system between its final flight before FRR and its flight on launch day, and will use the same checklists as will be used on launch day to ensure this.	In progress - This will be completed between the final launch before the Flight Readiness Review and launch day, where no technical modifications will be made to the launch vehicle or recovery system between the two flights, and has been accounted for in the timeline with a scheduled launch vehicle repair time, but not a launch vehicle modification time.	
2.18.2.3 The payload must be fully retained until the intended point of deployment, all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.	There will be a launch with progressive design changes until the payload is retained. This will prevent the payload or the retention system from malfunctioning unpredictably.	T,D	The team will design and test the retention system before flying it in the launch vehicle to ensure the robustness of this system.	In progress - The payload team finished designing a payload retention and ejection system, which is demonstrated in the ejection system subsection of the payload section. This requirement will be completed once the payload team has manufactured and tested their retention system, all of which has been accounted for in the timeline in the designing, ordering, manufacturing, and testing schedules for the payload.	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.18.2.4 The payload flown must be the final, active version.	The payload will not be changed after the successful flight. It will help prevent risk.	I,D	The team will fly the payload in its final, active state, with photographs being taken, along with two people signing off on all of the payload checklist, leading up to the flight to be able to ensure that the payload was flown in its final and active state.	Not completed - This will be completed between the final launch before the Flight Readiness Review and launch day, where no technical modifications will be made to the payload between the two flights, and has been accounted for in the timeline with a scheduled payload repair and testing time, but not a payload modification time.	
2.18.2.5 Payload Demonstration Flights must be completed by the FRR Addendum deadline.	The payload demonstration flight will have several scheduled dates to ensure that unforeseen circumstances will not prevent the launch from occurring.	D	The team will complete two Payload Demonstration Flights that will be photographed and signed off by two members in every checklist leading up to the launch, the first on Saturday, February 1st and the second on Saturday, February 22nd.	Not completed - This will be completed when both launches are completed before the FRR Submission deadline and therefore, will also be completed before the FRR Addendum deadline, which is accounted for in the timeline in the two scheduled February launch days and their respective integration days.	
2.19 An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA-required Vehicle Demonstration Re-flight after the submission of the FRR Report.	The project coordinators must ensure that the launch vehicle and payload have both had successful flights to ensure the safety of the spectators during launch day.	D	If an FRR Addendum is necessary to submit to NASA project management, the team will complete the addendum and submit it by the due date of March 23rd, 2020.	Not completed - This will be completed when it the FRR Addendum is submitted to NASA project management, and time has been allotted to ensure that the FRR Addendum is completed by the time it is due.	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.19.1 Teams who complete a Payload Demonstration Flight that is not fully successful may petition the NASA RSO for permission to fly the payload at launch week.	The team will attempt several launches, and analyse what caused a failure if necessary. NASA will be petitioned to fly the payload.	I	If it is necessary to petition the NASA RSO for permission to fly the payload, the team will petition the NASA RSO no later than March 25th, 2020 with a letter from the team and a detailed report of what caused the Payload Demonstration Flight failure, and what the team has done to fix those causes.	Not completed - This will be completed when the team sends the letter and report to the NASA RSO, and time will be allotted, if necessary, to ensure that the letter and report are sent to the NASA RSO no later than March 25th, 2020.	
2.20 The team's name and launch day contact information shall 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. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	Team name and contact information is added on the launch vehicle airframe to be able to get the vehicle back to the team to ensure the vehicle ends up back in our possession in the event that the vehicle goes missing.	I	The team will place a label detailing the team's name and the launch day contact information of the team lead to the outside of the fore and aft sections of the launch vehicle, and on the underside of the payload in an area that is clearly visible.	Not completed - This will be completed when the launch vehicle and payload are built, and has been accounted for in the timeline in the launch vehicle manufacturing schedule.	
2.21 All LiPo batteries will be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	All LiPo batteries will be labeled in bright colors with clearly labeled. This will make them easy to identify upon recovery.	I	The team will develop a uniform method of brightly coloring and clearly labeling all LiPo batteries so that they are easily distinguished from other electronics components and payload hardware. This method will be turned into a checklist, which, once completed, will need to be signed by the person in charge of the system, the team SO, and the Team Lead.	Not completed - This will be completed when a uniform method of clearly marking the LiPo batteries is developed and properly executed, and is accounted for in the design, order, and manufacturing of the launch vehicle.	

Table 35: Vehicle Prohibition Verification Matrix

Requirement	**Validation**	**VM**	**Verification Plan**	**Status**	**Report Location**
2.22.1 The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the launch vehicle's stability.	There will not be any forward canards on the body. They will not be included in the designs.	I,D	The launch vehicle will be designed without the need for forward canards, excluding camera housings.	In progress - Completed in current designs, all future design iterations will not include forward canards. This requirement will be completed when manufacturing of the full scale launch vehicle is complete.	
2.22.2 The launch vehicle will not utilize forward firing motors.	The designs will not include any forward firing motors. The designs will rely on drag to slow the vehicle.	I	The launch vehicle will be designed without the need for forward firing motors, using drag characteristics to slow down instead.	In progress - Completed in current design, all future design iterations will not include forward firing motors. This requirement will be completed when manufacturing of the full scale launch vehicle is complete.	
2.22.3 The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, Metal- Storm, etc.)	The motors that expel titanium sponges will be considered or used in the design.	I	The launch vehicle will be designed without utilizing motors that expel titanium sponges.	In progress - Completed in current design, all future design iterations will not include motors that expel titanium sponges. This requirement will be completed at CDR, when the final competition motor is selected.	
2.22.4 The launch vehicle will not utilize hybrid motors.		I	The launch vehicle will be designed without the need for hybrid motors.	In progress - Completed in current design, all future design iterations will not include hybrid motors. This requirement will be completed upon manufacturing of the full scale launch vehicle.	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.22.5 The launch vehicle will not utilize a cluster of motors.	The launch vehicle will not use designs that allow for more than one motor. The launch vehicle should only have one motor.	I	The launch vehicle will be designed without the need for a cluster of motors.	In progress - Completed in current design, all future design iterations will not include clusters of motors. This requirement will be completed upon manufacturing of the full scale launch vehicle.	
2.22.6 The launch vehicle will not utilize friction fitting for motors.	The launch vehicle will secure the motor without friction fitting. Friction fitting will not be incorporated into the designs.	I	The launch vehicle will be designed without using friction fitting for motor retention.	In progress - Completed in current design, all future design iterations will not utilize friction fitting for motors. This requirement will be completed upon manufacturing of the full scale launch vehicle.	
2.22.7 The launch vehicle will not exceed Mach 1 at any point during flight.	At launch, the measured acceleration and noise, as well as altitude data will be used to verify that the speed never exceeded Mach 1.	D,A	The launch vehicle will use a motor with a long enough burn time and low enough thrust to stay below Mach 1 but reach apogee.	In progress - OpenRocket simulations verify the vehicle will not exceed Mach 1 at any point during flight. Flight data from the Vehicle Demonstration Flight will be used to ensure the vehicle does not exceed Mach 1.	
2.22.8 Vehicle ballast will not exceed 10 percent of the total unballasted weight of the launch vehicle as it would sit on the pad (e.g., a launch vehicle with an unballasted weight of 40 lbf on the pad may contain a maximum of 4 lbf of ballast).	Ballast will not make up more than 10% of the total vehicle weight because it is inefficient and puts strain on the recovery system	I,A	The launch vehicle will have its fully fueled weight measured prior to flight to determine the max ballast available to use.	In progress - Completed in current design, less than 10 percent ballast is required for all planned launch conditions. Full scale 1 had the max ballast amount. All future design iterations will utilize less than 10 percent ballast for all flight conditions.	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
2.22.9 Transmissions from onboard transmitters will not exceed 250 mW of power (per transmitter).		I,A	The launch vehicle will be designed without transmitters that use more than 250 mW of power.	In progress - Completed in current design, the transmitters selected do not transmit more than 250 mW of power. Any future changes to the transmitters will require no more than 250 mW of power.	
2.22.10 Transmitters will not create excessive interference. Teams will utilize unique frequencies, hand-shake/passcode systems, or other means to mitigate interference caused to or received from other teams.	The frequency used will be different compared to any other team to ensure that the controller and vehicle used on launch day will allow communication only between the two.	I,D	The launch vehicles transmitters will not create excessive interference and will use frequency unique to OSRT.	In progress - Completed in current design, OSRT tracking systems have implemented this previously; similar methods will be utilized this year. Any changes to the systems will have means to mitigate interference.	
2.22.11 Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of light- weight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	The launch vehicle will be primarily composed of nonmetal materials. Very few items will be made from metal, but only if necessary.	I	The launch vehicle will be designed mainly using composites, wood, plastics. Use of metals will be minimized to critical components which cannot be manufactured from other materials.	In progress - Completed in current design, all future designs will be made with the intent to minimize metal usage.	

6.2.1.3 Recovery System Requirements

Table 36: Recovery System Requirement Verification Matrix

Requirement	Validation	VM	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.	A drogue parachute must be deployed at apogee to begin the descent phase, the main parachute must be deployed at an altitude which complies with descent time and landing energy parameters.	D	The team has designed the recovery system to deploy its drogue parachute at apogee and its main parachutes at 500 ft. in altitude, which will be completed by checklists that will be signed by the team member in charge of this system, the Team SO, and the Recovery Team Lead. Video from the ground will be taken for verification that the parachutes ejected at the appropriate time and altitude.	Completed - The recovery system design as been finalized and was tested successfully in the full scale launch.	Section 3.5.3
3.1.1 The main parachute shall be deployed no lower than 500 feet.	Deploying the main parachute below 500 ft poses too much of a safety risk and doesn't leave enough time for back up charges	D	The team has decided to deploy the parachute at 500 ft., and that is what the RRC3 altimeters will be set to while it is being assembled via the Altimeter checklist, which will be signed by the team member in charge of this system, the Team SO, and initialled by a third witness.	Completed - The full scale main parachute will deploy at 600 ft for its primary charge with a back up charge at 500 ft	Section 3.3.2
3.1.2 The apogee event may contain a delay of no more than 2 s.	A delay longer than 2 seconds will allow the vehicle to gain too much momentum and will exert too much force if an event occurred later	D	The team will set the apogee events to be as such: drogue primary at apogee, drogue back up at 1 second past apogee.	Completed - This was demonstrated at full scale launch 1.	3.3.13

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Requirement	Validation	VM	Verification Plan	Status	Report Location
3.1.3 Motor ejection is not a permissible form of primary or secondary deployment.	Motor ejection poses a threat to safety	I	The team will design the motor retention system to ensure that the motor will not fall out during or directly after launch, and will test their system at the first subscale launch for verification that it securely holds the motor in place.	Complete - a motor retainer has been designed and utilized and proven successful as a retention method.	Section 3.2.7
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.	Ground ejection tests allow the system to be tested and flaws to be caught before integrated and launched	D	The team will conduct at least five ground ejection tests for both the drogue and the main parachutes in order to ensure that both the parachute and ejection system work, and that the operators receive enough practice to minimize the chance of making an error that could cause the recovery system to fail during a launch. These tests will be photographed, and a summary of will be written no later than three days after the testing took place.	Completed - This will be completed when the parachutes and their ejection system's designs are finalized, and are constructed to the point that they can be tested.	Section 6.1.3
3.3 Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	A max landing energy ensures safety to those at the launch site	A,D	The team will run simulations in OpenRocket in order to determine the correct size and shape of the parachutes, as well as when they need to deploy, to determine how to land with a maximum kinetic energy equal to or less than 75 ft-lbf.	Complete - For the full scale launch, the drogue will open at apogee, and the main will open at 600 ft, reducing the kinetic energy of of landing to below 75 ft-lbf.	3.3.11

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Requirement	Validation	VM	Verification Plan	Status	Report Location
3.4 The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	Commercially available altimeters are reliable and are the most precise way to track apogee altitude	I	The team will purchase and install at least four different altimeters, one for each ejection charge and one for each back up ejection charge.	Completed - Missileworks RRC3's are used as primary and backup altimeters	Section 3.3.17
3.5 Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.	In the event of a dead battery or disconnection, there will be a back up altimeter and power source for that altimeter.	I	The team will ensure that each altimeter has its own battery, and will select a battery that can be purchased either online or from local hobby stores.	Completed - Each altimeter has its own commercially available 9v battery	Section 3.3.18
3.6 Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the launch vehicle airframe when the launch vehicle is in the launch configuration on the launch pad.	The altimeters must be able to be activated and deactivated from outside the launch vehicle so that the battery can maintain its charge for the optimal amount of time	I	The team will design each avionics bay so that the mechanical arming switch is easily accessible from the exterior of the launch vehicle and the altimeters can be armed within 10 seconds.	Complete - The arming switches are easy to find and turn on.	Section 3.2.15
3.7 Each arming switch will be capable of being locked in the On position for launch (i.e, cannot be disarmed due to flight forces).	Arming switches must be accessible for activation yet resilient to flight forces	I	The team will ground test the arming switches to ensure that they cannot be disarmed by flight forces.	Completed - This was tested and verified at full scale launch 1	Section 3.2.15

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Requirement	Validation	VM	Verification Plan	Status	Report Location
3.8 The recovery system electrical circuits will be completely independent of any payload electrical circuits.	There will be no interference between payload and recovery electronics	I	The team will design the payload and recovery system electrical circuits will be independently designed and built by separate member on the team as to not depend on each other electrically in any way.	Completed - Recovery system electronics are completely independent of payload electronics.	Section 3.3.20
3.9 Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Removable shear pins will provide enough fastening to keep the compartments together for ascent but will shear under enough pressure from black powder charges	D	The team will use 2-56 1/4-in. nylon shear pins to fix the nose cone to the fore section of the launch vehicle, and the fore section of the vehicle to the aft section of the vehicle.	Completed - Shear pins have been purchased, tested, and installed in the launch vehicle. This has been tested during full scale launch 1.	Section 3.3.14
3.10 The recovery area will be limited to a 2,500 ft. radius from the launch pads.	Due to launch location, over 2500 ft radius from launch pad will be trespassing property which must be avoided.	A,D	The team will deploy the main parachutes as low as possible in order to minimize the mount of drift while still keeping the landing kinetic energy less than or equal to 52 fps.	Completed - The recovery system components were assembled and main was deployed at 600 ft during full scale 1.	Section 3.5.3
3.11 Descent time will be limited to 90 seconds (apogee to touch down).	Descent time under 90 seconds ensures the drift radius will be minimized and the launch window time for each team will be minimized as well.	A,D	The team will deploy the main parachutes as low as possible in order to minimize the amount of time it takes the launch vehicle to go from apogee to landing while still keeping the landing kinetic energy less than or equal to 52 fps.	Complete - Full scale 1 descended in less than 90 seconds.	3.3.10

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Requirement	Validation	VM	Verification Plan	Status	Report Location
3.12 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.	The launch vehicle must be tracked at all times for post processing and for locating during launch.	I	The team will install an active electronic tracking device in the aft section of the airframe, and another in the fore section of the airframe or in the nose cone. They will have a life of at least 18 hours to ensure that the active tracking is still functional even if the launch vehicle waits for several hours on the launch pad.	Completed - Subscale and full scale launches have been successfully tracked during launch and data was analyzed post launch.	
3.12.1 Any section or payload component, that lands untethered to the launch vehicle, will contain an active electronic tracking device.	All components must be tracked in the event that those components detach or recover in separate areas	I	The team will install an active electronic tracking device in the aft section of the airframe, and either in the fore section of the airframe or in the nose cone, and will have a life of at least 18 hours to ensure that the active tracking is still functional by the time it is launched, even if the launch vehicle waits for several hours on the launch pad.	Completed - The launch vehicle is designed to recover under one parachute, the payload also has a tracking device.	3.3.19
3.12.2 The electronic tracking device(s) will be fully functional during the official flight on launch day.	The launch vehicle and payload must be tracked for the duration of the flight and after the vehicle and payload have been recovered.	D	The team will test extensively electronic tracking devices before launch day and will record what tests were conducted and the results of those tests within three days after conducting the tests.	Complete - the electronic tracking device has already been determined through initial recovery system designs, however, and has been purchased and installed. The tracking systems have been tested through subscale and full scale flights.	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
3.13 The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The recovery electronics must not suffer from interference to ensure the recovery system will not be compromised.	I	The team will design a shield that can be easily placed and secured around the recovery system electronics to prevent them from being adversely affected by other on-board electronic devices during flight.	Not completed - This requirement will be complete when the shielding system is designed, finalized, manufactured, and tested. This is accounted for in the timeline in the recovery system design, ordering, manufacturing, and testing schedules.	
3.13.1 The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	No transmitters will be in the same compartment of the launch vehicle as the altimeters. The launch vehicle designs will have the avionics and other transmitters in other compartments.	I	The team will design the sections of the launch vehicle to allow space to for the recovery system altimeters to be separated from other radio frequency transmitting devices.	In progress - The initial designs of the recovery system and launch vehicle have been completed, but, the requirement will be complete when the avionics and parachute bay's designs are finalized. This is accounted for in the timeline in both recovery and launch vehicle design.	
3.13.2 The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The transmitter will be placed in separate compartments. They will be surrounded by a ground plane. The altimeters will be tested with their operation.	I	The team will design a shield that can be easily placed and secured around the recovery system electronics to prevent the early excitation of the recovery system due to transmitting devices.	Not completed - This requirement will be complete when the shielding system is designed, finalized, manufactured, and tested. This is accounted for in the timeline in the recovery system design, ordering, manufacturing, and testing schedules.	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
3.13.3 The recovery system electronics will be shielded from all onboard devices that may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	There will be a shield to prevent electromagnetic interference from causing premature detonation or inaccurate readings.	I	The team will design a shield that can be easily placed and secured around the recovery system electronics to prevent There will be a shield to prevent electromagnetic interference from causing premature detonation or inaccurate readings.t the early excitation of the recovery system due to magnetic waves.	Not completed - This requirement will be complete when the shielding system is designed, finalized, manufactured, and tested. This is accounted for in the timeline in the recovery system design, ordering, manufacturing, and testing schedules.	
3.13.4 The recovery system electronics will be shielded from any other onboard devices that may adversely affect the proper operation of the recovery system electronics.	The recovery system electronics will be isolated from the rest of the rocket by being in another compartment.	I	The team will design a shield that can be easily placed and secured around the recovery system electronics to prevent the early excitation of the recovery system due to all other sources other than transmitting devices and magnetic waves.	Not completed - This requirement will be complete when the shielding system is designed, finalized, manufactured, and tested. This is accounted for in the timeline in the recovery system design, ordering, manufacturing, and testing schedules.	

6.2.1.4 Payload Requirements

Table 37: Payload Experiment Requirement Verification Matrix

Requirement	Validation	VM	Verification Plan	Status	Report Location
4.2 Teams will design a system capable of being launched in a high power launch vehicle, landing safely, and recover simulated lunar ice from one of several locations on the surface of the launch field.	Required for mission success	D	The team will design, build, and test a payload that can fit within the airframe of the launch vehicle, sustaining launch forces. Once the launch vehicle has landed, it will be able to be deployed and navigate to one of the predetermined locations to retrieve a lunar ice sample and carry the sample away from the location from which it was taken.	In progress - The payload can survive launch and recovery but the lunar ice mission has not yet been tested	Section 4.2.2, Figure 74
4.3.1 The launch vehicle will be launched from the NASA-designated launch area using the provided launch pad. All hardware utilized at the recovery site must launch on or within the launch vehicle.	This is required for the payload mission	D	The launch vehicle will entirely contain the payload within the airframe and the payload will be able to deploy from the launch vehicle once it has landed. It will be able to navigate to one of the predetermined collection areas to collect a lunar ice sample without any exterior hardware.	In progress - The current payload design is finalized, however a collection test mission is waiting on electronics, this will be done for the payload test flight	NA
4.3.2 Five recovery areas will be located on the surface of the launch field. Teams may recover a sample from any of the recovery areas. Each recovery site will be at least 3 ft in diameter and contain sample material extending from ground level to at least 2 in. below the surface.	This ensures the payload can collect the simulated ice material	D	The team will design, build, and test a payload that can navigate to the recovery site and dig down 1 in. below the surface in order to access an ice sample.	In progress - All payload systems have been tested except remote control, this will be tested at the payload demonstration flight	Section 4.2

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Requirement	**Validation**	VM	**Verification Plan**	**Status**	**Report Location**
4.3.4 Once the sample is recovered, it must be stored and transported at least 10 linear feet from the recovery area.	This is required for mission success	D	The team will design the payload to have a storage system that will securely hold the ice sample and have the capability to drive at least 20 linear feet from the recovery area.	Complete - The design has been manufactured and tested	Section 4.4.9, 90
4.3.5 Teams must abide by all FAA and NAR rules and regulations.	Required by NASA rules and regulations	I	The team will familiarize itself with FAA and NAR rules and regulations and design a system that does not violate any rules or regulations from the FAA and NAR.	Complete - The payload has been reviewed by OSRT, NAR. and NASA officials	NA
4.3.6 Black powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Any ground deployments must utilize mechanical systems.	Required by NASA rules and regulations	I	The team will design, build, and test a mechanical payload deployment system that uses a motor to turn a threaded rod that will contact a metal cylinder that pushes the payload out of the airframe.	Complete - The finalized design contains no energetic	Section 4
4.3.7 Any part of the payload or vehicle that is designed to be deployed, whether on the ground or in the air, must be fully retained until it is deployed as designed.	Failure to do this could result in damage to payload, or pre-mature ejection of payload	I	The team will design, build, and test a payload retention system that will retain the payload until it is intended to be deployed.	Complete - The payload has been tested, and shown to survive full scale flight	Section 4.2
4.3.7.1 A mechanical retention system will be designed to prohibit premature deployment.	An in air payload ejection presents a considerable safety risk	I	The team will design and build a mechanical retention system that will prohibit the payload from prematurely deploying both in flight, during recovery, and on the ground until it is supposed to do so.	Complete - The retention system has been tested and shown to fully retain the payload during flight	Section 4.2

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Requirement	Validation	VM	Verification Plan	Status	Report Location
4.3.7.2 The retention system will be robust enough to successfully endure flight forces experienced during both typical and atypical flights.	Retention system failure could result in an pre-mature ejection of the payload	I	Once the retention system is designed, the team will put it through rigorous testing to ensure that it can withstand anything from launch forces to ballistic impact forces.	Complete - The retention was tested for strength and durability before test flight	Section 4.4.11
4.3.7.3 The designed retention system will be fail-safe.	A backup means of payload retention reduces likelihood of a pre-mature ejection of the payload.	I	The team will design the retention system so that if the system loses power before the launch vehicle lands, the rover will still be secured inside the airframe and not pose a safety threat to spectators.	Complete - The leadscrew system is capable of retaining the payload in the event of power failure	Section 4.4.10

6.2.1.5 Safety Requirements

Table 38: Safety Requirement Verification Matrix

Requirement	Validation	VM	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.	Launch and safety checklists are vital not only for the safety of project personnel, other teams, and bystanders but also the smooth operation of the OSRT launch vehicle by allowing for detail-oriented, verified assembly and use.	I	The team will develop a launch and safety checklist for each system that is designed and implemented into the launch vehicle, the recovery system, and the payload.	Checklists have been developed by the safety team and iterated several times to account for new information or changing systems. All major test launches have been accompanied by checklists for all subsystem installations and major launch steps.	Section 5.3.7

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Requirement	Validation	VM	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.	This NASA-required role ensures a single point of coordination for safety matters, and is vital for consistent, responsive implementation of safety plans or response to incidents.	I	The team will identify a student SO by September 14th, 2019.	Completed - The team student SO is Wyatt Hougham.	Section 5.3.1
5.3 The role and responsibilities of the SO will include, but are not limited to: Monitor team activities with an emphasis on safety during: design of vehicle and payload, construction of vehicle and payload components, assembly of vehicle and payload, ground testing of vehicle and payload, subscale launch test(s), full scale launch test(s), launch day, recovery activities, and STEM engagement activities.	Safety oversight of the project is critical at all stages, to identify and prevent hazards as early as possible. By working closely with each subteam as they design aspects of the launch vehicle, the SO will have a better understanding of the risks and challenges associated with each piece of the overall vehicle.	I	The SO will approve final designs before orders are placed. The SO and their safety team will help subteams draft safety documents for the construction process of their respective system, and either the SO, or a member of the team appointed and trained by the SO, will be present at all construction and assemblies of systems, as well as at all ground tests, launches, recovery activities, and STEM Engagement activities.	Complete - The SO has established a team of safety officers from the various subteams to ensure a wide range of project knowledge and applicable skills when creating the necessary documentation and procedures. Each team's designs have been inspected at each major iteration for compliance with all relevant rules and regulations.	Section 5.3.1

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Requirement	Validation	VM	Verification Plan	Status	Report Location
5.3.2 Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	Close cooperation with subteams ensures that created plans are not developed in a vacuum, but iterative and living documents that reflect the unique challenges of each team. A document developed by a team rather than imposed by another group is more likely to be accepted and followed.	I	The safety team will work alongside the subteams to develop procedures that are both safe and effective for construction, assembly, launch, and recovery activities.	Completed - Teams have coordinated with their team-specific safety liaison to develop and implement plans for manufacturing, assembly, and final integration that fulfill requirements for personnel safety while ensuring high quality of work.	Section 5.3
5.3.3 Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	Centralized, documented records of hazards and their controls ensures that policy is clear and concise, but also allows personnel to seek more detailed information whenever they require it. A single, unified roster of procedures and checklists prevents overlap or the use of outdated materials.	I	The safety team will maintain a binder that will be stored in OSRT's main work space in an easily accessible area. This binder will hold all of the team's current hazard analyses, failure modes and analyses, procedures, and MSDS/chemical inventory data, and will be updated weekly.	Complete - The team safety binder contains information regarding hazard analyses, failure modes, and updated policies. The SO maintains database containing all subteam checklists for assembly and integration of their components.	Section 5.3
5.3.4 Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	These formal analyses of the launch vehicle serves as the basis for any claims regarding its reliability, safety, and performance. Their accuracy is critical to developing verifiable benchmarks and approving designs.	I	The safety team will assist the subteams with writing and developing their hazard analyses, failure modes and analyses, and procedures throughout the duration of the project.	Complete - Analyses for personnel and environmental hazards are complete with multiple iteration passes for updated conditions and new information, and FMEA has been performed on each vehicle subsystem.	Section 5.2.6

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Requirement	Validation	VM	Verification Plan	Status	Report Location
5.4 During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those 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.	Coordination with local rocketry clubs and cooperation with their standards and procedures serves as a reflection of OSRT and the professionalism of its members. Experienced high power rocketry enthusiasts serve as an essential resource for developing designs and procedures that are safe and effective.	I	The SO and Team Lead will work together to contact the local club's president or prefect and RSO at least a week before attending any NAR or TRA launch.	Complete - All relevant activities have been coordinated with other rocketry teams and the OSU American Institute of Aeronautics and Astronautics (AIAA) chapter.	N/A
5.5 Teams will abide by all rules set forth by the RSO.	The RSO serves as the final say on the launch of any vehicle by OSRT, and their experience with high power rocketry serves as a valuable resource for ensuring a successful project.	I	The SO and safety team will familiarize themselves with the FAA rules regarding rocketry, and help the rest of the team familiarize themselves with the FAA rules. The safety team will be responsible for holding the entire team to the FAA rules.	Complete - The safety team has thoroughly researched FAA and NAR regulations as they pertain to the RSO flight permission and the project as a whole, and implemented several of these policies in checklists and design review.	Section 5.1.2

6.2.2 Team Derived Requirements

Table 39: Team Derived Requirement Verification Matrix

Requirement	Validation	VM	Verification Plan	Status	Report Location
6.1.1 All batteries used for a flight will be charged (if rechargeable) or never before used (if single use) prior to each flight.	Batteries must have full charge because launch vehicle may be active on the rail for hours at a time	I	Rechargeable batteries will be marked with the date of charging once charged prior to launch. Single use batteries will be removed from manufacturer packaging during integration on the day of launch. This will be verified via checklists per Requirement 1.2.	In progress - This is accounted for in the checklists while preparing for launch. However, it will not be fully completed until after the end of the competition flight.	Section 3.3.13, Section 4.5
6.1.2 All back-up BP charges will be twice the size of the calculated and tested primary BP charge.	In the event that a main charge does not eject the parachutes, OSRT does not want to risk the recovery system failing	I	The appropriate primary BP charge size will be calculated using the math found in the BP portion of the Recovery section, and then this size will be tested via OSRT's BP test stand to ensure that it can appropriately deploy the parachutes. From there, the size for the back-up BP charge will be double that of the primary charge, and will be recorded in the BP charge assembly checklist. This checklist will be signed by the assembler and SO, as well as initialed by a third witness.	Completed - As per NASA's recommendation, the back up charges will be 1.25x the size of the primary because the primary charges were already large and 2x could pose a safety threat.	Section 3.3.14
6.1.3 All BP charges will be able to deploy the parachute within their respective bay.	The recovery system must be reliable.	I	The smaller charges of BP will be ground tested to ensure that they eject the parachutes. Once their ability to eject the parachutes has been tested and documented.	Completed - The sized BP charges were able to deploy both the drogue and main parachutes in ground tests and in the test flights.	Section 6.1.3

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Requirement	Validation	VM	Verification Plan	Status	Report Location
6.1.4 The BP charges must remain in the airframe at all times during launch.	Loose BP charges pose a threat to the recovery hardware such as parachutes and bystanders in the event that the charges detonate.	T,I	Quick release connectors will be attached to the end of the e-match and also to wires that come out of the altimeters so that, when the bay is opened, the wires can come disconnected and all charges, blown and not, remain within the airframe at all times.	In progress - Quick releases have been selected and tested. This will be competed when the quick release connectors are flown on a test flight.	Section 3.3.13
6.1.5 The Carbon Dioxide (CO2) ejection system must be able to be affixed to the launch vehicle and not hinder airframe section separation.	Each system should be secure in the airframe and be able to withstand separation forces.	I	The team will design the CO2 ejection system so that it can be bolted to the permanently attached bulkheads in the fore and aft sections, and a quick release connector will be installed onto the motor wires and the wires connected to the altimeters so that the force of separation can pull the wires apart. The quick release connectors will also be incorporated into the the BP charges so that the charges will remain inside the airframe at all times after they are created.	INCOMPLETE - The CO2 ejection system has been discontinued	N/A

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Requirement	Validation	VM	Verification Plan	Status	Report Location
6.1.6 All BP must be stored in its original container or a commercially bought container away from any heat sources and/or moisture, and stored in a flame cabinet whenever possible to prevent safety incidents from occurring.	BP is extremely easy to ignite due to static discharge.	I	All BP will be stored in its original container and in a separate plastic box that will further protect the BP from heat sources that could potentially ignite it. The BP will be stored in its original container the plastic box in OSU's AIAA lab in the explosives flame cabinet at all times unless it is being transported to a test or launch site, or being used for testing or launch, or being used in events out of the state, such as at competition. In the event that the BP cannot be stored in the flame cabinet, it will be kept sealed in its original container within the designated plastic box unless it is explicitly being used.	In progress - This verification plan has been followed thus far, but will not be complete until the end of the competition season when using BP is not longer necessary.	Section 5.1.2
6.1.7 All live BP charges must be kept away from all sources of electricity, including static electricity.	BP is extremely easy to ignite due to static discharge.	I	BP charges will be built in an area away from any avionics, batteries, walkie-talkies, or other electronics that could potentially provide a small electric charge to the e-match in a live BP charge. To reduce electricity introduced to the charge via human interaction, the individual building the charge shall wear ESD bracelets to cut down on the amount of static electricity.	In progress - ESD bracelets have been purchased, and BP charges are always made away from all sources of electricity. This will be complete after the competition launch.	Section 5.1.2

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Requirement	Validation	VM	Verification Plan	Status	Report Location
6.1.8 The internal batteries must be able to power the avionics system for at least 5 hours continuously.	The launch vehicle must be able to remain active on the pad for multiple hours.	T	The avionics system is powered on and allowed to run with full functionality. The transmission rate is set to 5 Hz. The GPS is set to constantly send data, and the sensors are being read constantly. Additionally the microcontroller should be processing all of this data, storing it to the microSD card and transmitting the information. Timestamps from the microSD card data and the transmitted data can be used to verify consistent transmission. It will then be run for five hours. Every 15 minutes, the transmission and the output voltages will be checked. The voltages must be within the allowed ranges. This should be consistent over 5 hours.	Completed - The avionics system design is finalized with power efficiency in mind. This will be tested for after the avionics components are assembled.	
6.1.9 The launch vehicle must accurately report its location within 10-feet range of its real location.	Accurate GPS recording is important to finding the launch vehicle and post processing.	A	The tracking device implemented in the launch vehicle sends location data to a computer on the ground. The offset will be calculated using National Oceanic and Atmospheric (NOAA)'s National Geodetic Survey markers with exact GPS coordinates. The GPS will be used to find the location of the GPS coordinates of the marker. The distance between the marker and the GPS unit can then be measured. This will give us an absolute error. Digits of precision and antennas will be adjusted to give the desired accuracy.	In progress - Two GPS units were tested in an empty field. Without an antenna accuracy was not as accurate, but more than one location will be tested.	

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Requirement	**Validation**	**VM**	**Verification Plan**	**Status**	**Report Location**
6.1.10 The avionics system must transmit and receive data at a range of at least 1 mile.	The launch vehicle may recover over a mile away or may reach an altitude of up to 4500 ft, in which event the tracking system must be able to transmit and receive data.	T,D	Send data from all rocket sections that will be detached from the launch vehicle to the receiver. The avionics system and the ground station will be taken to a open location near the OSU campus. The two devices will be separated while the ATU is transmitting. The ATU will be moved further away until the ground station no longer receives information. This distance will be measured and must be greater than 1 mile.	Completed - Subscale designs successfully transmitted and received data at least 1 mile away, this is also true for full scale avionics.	
6.1.11 The avionics system must survive forces of at least 10 Gs.	The launch vehicle may experience forces up to 10 G's and all systems must be able to handle these forces	T,D	The system will be sent up in a rocket. The accelerometer will record the accelerations during flight and parachute deployment. The acceleration reached should be greater 10 Gs. This should result in high accelerations. The system should remain fully functional for all of the accelerations until landing.	In progress - Final designs include an Inertial Measurement Unit (IMU) to record acceleration. The current design survived launch forces, but more than one launch is desired to prove it.	

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Requirement	Validation	VM	Verification Plan	Status	Report Location
6.1.12 The avionics system must accurately transmit data at 32 degrees Fahrenheit.		D	The avionics system is powered on in a freezing environment, such as a large freezer, and transmits data to the ground station. If data is consistently read while held at this temperature for an hour, and if the data remains accurate, then this requirement is met. Additionally the avionics system will be placed in a vacuum chamber to change the barometric pressure and test correct altitude readings. If it maintains full operation during both these environmental stimuli then it meets the requirement.	Not completed - The Device is designed to survive low temperatures, but has not been placed below freezing.	
6.1.13 There must be programmed GUI to display altitude, location, and acceleration data.		D	Multiple members from the team/class should be easily able identity data set within the GUI with no previous experience with the interface. If 9 out of 10 members of OSRT are able to use the GUI and identify the data then it meets this requirement.	In progress - Several members have used the current GUI with no issues.	

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Table 39 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
6.1.14 Data packets sent must be accurate at least 90% of the time as compared to data received onboard.		A	Following a flight or during the range test mentioned previously. Data will be collected and stored on the microSD card. It will also be transmitted to the ground station, and the data will be stored in a CSV file. A script will compare the the ATU log and ground station log for accuracy by reporting the percentage of matching information between both logs. This must be greater than 90% to pass.	In progress- Two data sets have been collected without error.	
6.1.15 Data packets sent from transmitter must be received at least 80% of the time by the receiver.		T,D,A	Following a flight or during the range test mentioned previously. Data will be collected and stored on the microSD card. It will also be transmitted to the ground station, and the data will be stored in a CSV file. A script will compare the the ground station log and onboard log for accuracy. At least 80% of the data on the launch vehicle must also be received at the ground station to pass.	In Progress - Due to an microSD card issue only one data set has been used to test.	

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Table 39 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
6.1.16 The flight data collected must be transmitted through wireless communication and stored internally on the launch vehicle at least 5 times a second.		T,D,A	Once the launch vehicle lands, we will recover the storage device for the flight data and analyze it for redundancy. The flight data collected should be broadcast over RF, and stored internally on the launch vehicle. The data should be stored 5 times a second. This can be checked by validating that there are five timestamps per second by checking flight records on the ATU log and the ground station log.	Not completed - the code has not been optimized for reading sensors this often yet.	
6.1.17 All extra safety components for the parachute ejection system must be ground tested before flight.	All components, particularly those integrated with a system as mission critical as recovery, must be tested before flight to ensure the safety of the spectators during launch and the success of the recovery systems.	T	The EMBERS will be ground tested in the BP test stand for pull ability and BP charge detonation survival ability	Completed - Testing has been completed and was successful.	Section 3.3.16
6.2.1. Team can deploy and operate rover from up to 1/2 mile away.	This required to ensure the payload can work remotely	T,D	Test rover and ejection systems at appropriate distance.	In progress - Electrical systems are currently being manufactured.	N/A
6.2.2 Rover collection system must be capable of digging into sample material.	This is required for the payload mission	T,D	Scoop will be tested on a test bed to measure force required to push down into material and results will be compared with motor capability.	Complete - Scoop system is being designed with motor that is capable of pushing down into the sample material.	4.4.9
6.2.3 Rover wheels must be able to expand to increase ground clearance.	This will help protect the rover from high centering on obstacles	T	Rover will be observed being ejected from the airframe to confirm that the wheels expand.	Complete - Wheels have been manufactured and tested	4.4.7

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Table 39 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
6.2.4 Rover Collection system must be designed to securely retain at least 10 mL of sample material.	Failure to retain material could result in mission failure	T	System will be tested to ensure sample material is securely stored during transport.	Complete - The system has been tested and shown to securely retain a sufficient amount of material	4.4.9
6.2.5 Payload system must consistently use standard fasteners.	This is required to decrease assembly time	I	The team will assemble the payload using only Imperial tools.	Failed - Purchased parts like motors, and couplers use some metric fasteners	N/A
6.2.6 Payload team must be able to manufacture the chassis within 1 day. An easy assembly will greatly simplify integration and testing.	A easy to manufacture payload makes it possible to quickly modify and adjust the design as needed	I	Payload assembly will be timed during full scale launch integration prep.	Complete - All manufactured components can be made and assembled in less than 1 day.	N/A
6.2.7 Payload ejection must be completed within 2 minutes of activation.	The faster the payload ejects the more time the payload has for the ground mission	A,I	The team will test payload ejection for success as well as completion time. Successful ejection will still be the most important aspect.	Failed - Due to testing failures the payload a geared down motor must be used, resulting in slower ejection.	4.4.10
6.2.8 Payload retention system must retain the payload even if the system is unpowered, incorrectly installed, and/or missing components. The system must be as robust as possible.	For safety reasons the payload must not eject if power is lost	I,T	When testing the retention system different possible situations will be tested to identify possible safety concerns.	Complete - The leadscrew system requires power to eject the payload	4.4.10
6.2.9 Payload drivetrain wheels must be able to fit inside the rocket body.	This is required for mission succes	I	The team will test the payload assembly to ensure it can fit within the 6.25 in. diameter rocket.	Complete - The fully assembled payload has been flown in the launch vehicle	4.4.7
6.2.10 Payload drivetrain wheel assemblies must be light weight.	Payload weight is a concern for rocket stability	I	The team will test this requirement by weighing the finalized wheel assembly.	Complete - The final payload and wheels weigh less than expected	4.4.7

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Table 39 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
6.2.11 Payload drivetrain wheels must be easy to construct.	Easy to manufacture components allows the team to make back up parts	T	The wheels must be manufacturable according to the team member's skills and resources.	Completed - Most parts are 3D-printed. The other parts are standard ordered parts.	4.4.7
6.3.1 Both full scale and subscale launch vehicles will be checked post flight for defects or wear.	It is important to immediately identify any damages or defects and identify if there are any immediate threats such as shrapnel or live charges	I	A checklist will be created for post flight analysis of launch vehicles, with areas of interest to check for wear, or excessive stresses on the airframe and subsystems. Any defects or issues with subsystems will be reported and fixed before the next flight.	In progress - Will be completed after each test launch	Section 3.5.2
6.3.2 OpenRocket simulations will be performed prior to each launch to hit a predetermined altitude.	Using a flight simulation software will help determine flight statistics and parameters before actually launching, to help predict launch outcomes	T,A	OpenRocket will be used to verify apogee and the weight adjusted accordingly before every flight using the measured weight of the launch vehicle.	In progress - Will be completed before each launch, before arriving to and on the launch site.	Section 3.5.2
6.3.3 Two step verification of checklists prior to flight will be completed for both full scale and subscale launches.	Multiple sign-offs ensures that a checklist is being completed to a high standard of detail and with each discrete step in mind, even in situations involving impaired focus or a distracting environment.	I	Checklists will be completed and signed by two team members to ensure all steps are completed properly, and any mistakes are identified. Two signatures will be required on each checklist prior to each launch.	Complete - All safety checklists used during subscale and full scale flights require the signature of an assembler, the initials of the 'inspector' role co-assembler, and a final sign-off by a safety officer after confirming completion.	Section 5.3
6.3.4 The altimeter bay will have sealing bulkheads on either side that are able to seal completely against the inner airframe in order to ensure deployment of recovery systems.	Failure to properly seal ejection bay may result in failed ejection system	T,I	The seal will be pressure checked after manufacture using a custom built cap affixed to the end of the coupler, affixed with a pressure gauge and a standard one way valve.	Completed - Testing has ensured a properly sealed bay for ejection	Section 3.2.11

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Table 39 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
6.3.5 The coupler must have adequate venting to the exterior of the launch vehicle airframe in order to ensure accurate readings of the barometric pressure sensor for deployment.	Failure to adequately vent the pressure sensors bay will result in inaccurate readings	I	Calculations will be done to determine the required hole size, and then will be tested in a vacuum chamber to ensure drogue deployment at a simulated apogee.	Completed - The required hole sizes and number have been calculated and drilled	Section 3.2.13
6.3.6 The coupler and altimeter bay subsystem must have e-match access but be able to seal against pressurization of the parachute bays after integration.	Failure to pressurize parachute bays may result in failed ejection system	I,T	The seal will be pressure checked after manufacture using a custom built cap affixed to the end of the coupler, affixed with a pressure gauge and a standard one way valve.	Completed- The parachute bays seal properly	Section 3.2.13
6.3.7 The altimeter arming switches must be accessible from the exterior of the airframe while the launch vehicle is on the launch rail. This should be accomplished with as few exterior holes in the airframe as possible.	Switches must be able to be armed from the launch pad.	I	The launch vehicle will be designed with this in mind, and be ensured through a full scale integration test where the switches are able to be armed from outside the launch vehicle.	Completed - arming switches are accessible from the launch vehicle exterior	Section 3.2.13
6.3.8 The coupler must be manufactured symmetrically in order to preserve a balanced subsystem of the launch vehicle so that the launch vehicle Center of Gravity (CG) will not shift from the center axis.	A shift in the center of gravity will result in a lowered stability margin.	I	The coupler will be designed to be symmetrical, and then its CG will be determined after manufacture to ensure it is centered along the axis.	Completed - The coupler has been manufactured and is symmetrical	3.2.13

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Table 39 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
6.4.1 Maintain a minimum safety factor of 2 on all systems.	This minimum factor of safety accounts for uncertainty in procedures or quality of parts/manufacturing, ensuring consistent performance of vehicle systems.	A,I	Calculations and simulations of designs and will be conducted ensuring a minimum factor of safety of all components and systems on the launch vehicle.	In progress - All current designs determined to have minimum factor of safety of 2. This will be continually checked and updated for every deliverable, change in design, or new design.	Section 3.2
6.4.2 All screws and threaded rods will be analyzed for stress to ensure proper structural integration.	Failure in proper structural integration may result in system failures that could have been prevented	A	Analysis will be conducted on all threaded rods and screws prior to design integration to ensure they will hold the loads and stresses required of them.	In progress - All screws and threaded rods currently in design are calculated to withstand their required stresses to a factor of safety. Will be updated as parts are added or taken away.	Section 3.2
6.4.3 All materials to be used for the manufacturing process will have credible analyzed properties.	No unknown materials will be used to ensure proper analyses can be conducted	I	All materials used will required data sheet either from the manufacturing company or verified through testing.	In progress - All current materials used adhere to these requirements, and all future materials will be verified before integration.	Section 3.2
6.4.4 The safety officer will verify and check all pre-flight checklists prior to launch.	Final verification of all systems aboard the vehicle is critical for a successful flight. By centralizing this duty through safety, a clear count from each subteam is easier to maintain.	I	Checklists will require the signature of a safety officer before launch of launch vehicle.	Complete - Pre-flight checklists have been created and utilized at each test launch	Section 5.3.7
6.4.5 When no existing tool will allow for manufacturing within desired specifications, OSRT will manufacture such a tool.	Tight tolerances are often required by systems to be reliable.	I	Analysis will be performed on existing manufacturing options and, if none are sufficient, proprietary means will be pursued.	In progress - Tools will be manufactured as need arises.	Section 3.2

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Table 39 – continued from previous page

Requirement	Validation	VM	Verification Plan	Status	Report Location
6.4.6 Testing will be conducted with the goal and expectation of developing meaningful data and information in order to improve a part, system, or method.	All systems will go through a series of tests, and the data after each test will be made available on the team drive.	T	All test data will be accessible to team members for use and verification.	In progress - Testing data is made available via team storage drives as testes are conducted.	See respective subteams testing sections
6.5.1 All PCBs used in the launch vehicle will use electrical potting material to cover components.	The electronics will be covered with an insulating protective material on launch day.	I	Electrical potting material will be confirmed to be present on all PCBs during launch vehicle integration via checklists.	In progress - Potting will be done once PCBs have arrived and are assembled.	Section 3.2
6.6.1 All capstone team members will have attended at least one USLI STEM Engagement event or helped the STEM Engagement Coordinator procure supplies/ lesson plan.	It is important that all team members have a holistic view of the USLI experience, as the next generation will improve upon what we have already done and are important to create a better future.	I	A spreadsheet log has been kept of who has been to each STEM Engagement event or whether someone helped with supplies or lesson planning.	Complete	Section 6.4

6.3 Budgeting and Timeline

6.3.1 Budget

Table 41 shows itemized lists of components and materials necessary to realize this design. This table represents a breakdown of components and raw materials which OSRT plans to use in the manufacture and launching of the launch vehicle and payload. OSRT's funding sources can be found in Table 40.

Table 40: Funding Source

Funding Source	Amount
Oregon Space Grant Consortium (OSGC) Grant	$12,000
Innovative Composite Engineering	$5,000
NW Consulting Inc.	$2,000
Student Expenditure	$6,624
Total	**$25,624**

Table 41: Budget

Quantity	Object	Cost per Unit	Vendor	Total Cost
Aerodynamics and Recovery				
2	8 ft Main Parachute	$348.15	Fruity Chutes	$696.30
1	Drogue Parachute	$55.97	Fruity Chutes	$55.97
10	Shock Cord (per yard)	$23.13	Fruity Chutes	$231.30
6	Shear Pins	$5.50	Home Depot	$33.00
4 3	Small Nylon Shear Pins	$3.22	Apogee Rockets	$9.66
4 4	Nomex Fire Proof Blankets	$27.00	Fruity Chutes	$108.00
15	Quick Release Hooks	$4.10	Apogee components	$61.50
2	6 ft Chute	$225.75	Fruity Chutes	$451.50
2	5 ft Chute	$193.50	Fruity Chutes	$387.00
1	8 ft Deployment Bag	$74.18	Fruity Chutes	$74.18
1	7 ft Deployment Bag	$46.23	Fruity Chutes	$46.23
1	6 ft Deployment Bag	$46.23	Fruity Chutes	$46.23
1	5 ft Deployment Bag	$46.23	Fruity Chutes	$46.23
1	Iris Ultra 72 in. Compact Chute	$299.88	Fruity Chutes	$299.88
2	RRC3 SPORT Altimeter	$69.95	Missle Works	$139.90
1	MJG Firewire Initiator (Box of 3ft: 80 pieces)	$74.20	Electric Match	$74.20
1	Avionics Electronic Parts	$58.32	DigiKey	$58.32

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Quantity	Object	Cost per unit	Vendor	Total Cost
1	Avionics Parts	$8.49	DigiKey	$8.49
3	Kevlar 18x18 Fabric	$15.88	Amazon	$47.66
1	Heavy Duty Needles	$2.89	Amazon	$2.89
1	Kevlar Thread	$26.15	Amazon	$26.15
1	Dino Chutes 36" X-Form Parachute	$23.99	Apogee Rockets	$23.99
1	1500 lb Rosco Swivel, set of 3	$12.00	Apogee Rockets	$12.00
1	RTx/RRC3 Bluetooth Master Module	$14.95	Apogee Rockets	$14.95
6	Weather and Chemical Resistant Santoprene Rubber Rod	$2.54	Apogee Rockets	$15.24
1	12 Ft Toroidal Parachute	$667.66	Fruity Chutes	$667.66
1	18 in. elliptical parachute	$64.50	Fruity Chutes	$64.50
1	3/8 in. Stainless Steel Quick Link	$10.50	Fruity Chutes	$10.50
1	60 in. Nomex Fire Blanket Material	$20.30	Pegasus	$20.30
2	5 ft. of 1/2 in. ID surgical Tubing	$8.90	McMaster	$17.80
1	80 3 ft. Long Firewire Ignitors	$60.00	Pegasus	$17.80
3	1 ft. of 1/2 in. OD Silicone Rubber Rod	$7.45	Pegasus	$22.35
3	Rectangular Gear Rack, 24 Pitch 18 in. Length	$141.07	Pegasus	$141.07
100	Molex 19023-0005 Male Quick Disconnect	$0.09	Waytekwire	$9.00
100	Scotchlok Female Quick Disconnect	$0.13	Waytekwire	$12.50
1	Avionics Assembly Electronics	$72.04	digikey	$72.04
1	Brown Clipboard	$4.98	Office Depot	$4.98
1	Ballpoint Pens	$13.99	Office Depot	$13.99
BEAVS				
1	MS5802-14AB Barometric Pressure Sensor	$4.87	Mouser	$4.87
1	MMA8452Q Accelerometer	$34.95	Sparkfun	$34.95
1	Turnigy 12v LiPo	$10.99	HobbyKing	$10.99
1	OSRT Designed PCB	$0.00	OSRT	$0.00
1	FIT0441 Brushless Direct Current (DC) Motor	$19.90	DFRobot	$19.90
1	Teensy 3.6 Microcontroller	$29.25	Sparkfun	$29.25
3	Teensy 4 Microcontroller	$23.15	Sparkfun	$69.44

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Quantity	Object	Cost per unit	Vendor	Total Cost
12	5/16th Stainless Steel Quick Link	$8.00	Fruity Chutes	$96.00
2	Small Nylon Shear Pins - 20 Pack	$3.22	Fruity Chutes	$6.44
1	Brother P-touch, PTD210 One Touch Keys	$24.99	Fruity Chutes	$24.99
1	PTD210 Touch Label Tape	$18.99	Fruity Chutes	$18.99
1	AC Adapter for Brother P-Touch PT	$9.99	Fruity Chutes	$9.99
2	1/8 in. Aluminum Plate (2 in. x 24 in. bar)	$11.08	McMaster	$11.08
4	1/4-20 Fasteners	$0.00	OSRT	$0.00
4	8-32 Threaded Rod	$1.67	McMaster	$6.68
3	1/2 in. Aerospace Grade Plywood Bulkhead	$1.53	Wicks	$4.59
1	PLA 3D Printer Filament (1 kg)	$19.99	Amazon	$19.99
100	M2 Fasteners	$0.00	OSRT Machine Shop	$0.00
2	7mm Linear Guide Block	$41.33	McMaster	$82.66
2	7mm Linear Rail (24 mm)	$21.06	McMaster	$42.12
10	GA Steel Plate	$2.37	JCI	$23.70
1	Gear	$34.69	McMaster	$34.69
Parachute Ejection				
1	Yakamoz 14pcs 0.5-3mm Small Electric Drill Bit	$8.99	Amazon	$8.99
3	Turnigy D1104-4000 kv 5.5g Brushless Motor	$7.09	HobbyKing	$21.27
1	Hobbywing Quicrun 60 A 2S-3S Waterproof Brushed ESC for 1/10	$20.99	HobbyKing	$20.99
2	Turnigy 1700 mAh 2S 20C LiPo Pack (Suits 1/16th Monster Beatle, SCT & Buggy)	$8.82	HobbyKing	$17.64
1	Turnigy 12 v 2-3S Basic Balance Charger	$5.10	HobbyKing	$5.10
1	Turnigy TGY-i6 AFHDS Transmitter and 6CH Receiver (Mode 1)	$57.80	HobbyKing	$57.80
1	2 in. x 2 in. x 3 ft Aluminum Stock	$78.72	McMaster	$78.72
1	INTOO Mini Drill Bit Set 60 Pcs+12 Pcs	$11.99	Amazon	$11.99
10	12gm CO_2 Cartridge (each)	$4.50	Tinder Rocketry	$45.00
1	NYLON SHEAR PINS - 20 PACK	$3.22	Apogee Components	$3.22
1	Fantasycart Fiberglass Cloth Plain Weave 4.12 Oz 39 in. wide in 16.6 yards long	$36.99	Amazon	$36.99

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Quantity	Object	Cost per unit	Vendor	Total Cost
1	3M 20124 All Purpose Fiberglass Resin, 1 Gallon	$57.40	Amazon	$57.40
6	1 ft of 1/2 in. ID Surgical Tubing	$1.78	McMaster	$10.68
2	Pack of 24 E-Matches	$15.60	MJG Technologies	$31.20
4	1 ft of 1/2 in. Outer Diameter (OD) Silicone Rubber Rod	$7.45	McMaster	$29.80
1	1 lb of GOEX FFFFg Black Powder	$17.95	Powder Valley Inc.	$17.95
1	1 lb of GOEX Powder 1LB 4F (Primming) 25/CS	$29.94	Powder Valley Inc.	$29.94
1	8 in. Black Cable Ties 100 Pk.	$1.99	Harbor Freight	$1.99
1	Hornady G2-1500 Digital Powder Scale 1500 Grain Capacity	$39.49	Midway USA	$39.49
1	5 ft of 1/2 in. ID Surgical Tubing	$8.90	McMaster	$8.90
1	80 3 ft Long Firewire Ignitors	$60.00	Aircraft Spruce Co	$60.00
1	1 ft of 1/2 in. OD Silicone Rubber Rod	$7.45	McMaster	$7.45
1	8 in. Black Cable Ties 100 Pk.	$1.99	Harbor Freight	$1.99
2	1/4 in. X 6ft LG Aluminum Rod	$8.23	Harbor Freight	$16.46
1	1 in. 10 yd Nylon Shock cord	$30.13	Fruity Chutes	$30.13
3	1 in. 5 yd Nylon Shock cord	$23.13	Fruity Chutes	$69.93
			Recovery Total:	$5,317.70
Payload				
Rover Parts				
5	Driver Motors	$80.00	RobotShop	$80.00
1	Battery Charger	$35.00	Hobby King	$35.00
2	Battery	$100.00	Hobby King	$160.00
1	RC Remote/Reciever	$150	Hobby King	$150
1	12V 100 RPM Brushed DC Motor	$13.00	Robot Shop	$13.00
1	Couplers	$8.99	Robot Shop	$8.99
1	High Speed DC 6V 90 RPM Reversible Motor	$28.88	Amazon	$28.88
1	Hatchbox 3D Printer Filament Orange	$19.99	Amazon	$19.99
1	Hatchbox 3D Printer Filament Black	$19.99	Amazon	$19.99
1	DC 6/12V N20 Metal Speed Reduction Motor With Long Shaft	$12.49	Amazon	$12.49
1	Payload Assembly	$104.95	Digikey	$104.95

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Quantity	Object	Cost per unit	Vendor	Total Cost
1	Payload Ejection	$23.58	Digikey	$23.58
2	Spring Loaded Hinges	$6.99	Amazon	$ 13.98
2	7mm Sleeve Bearing Carriage	$41.33	McMaster	$ 82.66
1	6mm Couplers	$8.99	McMaster	$ 8.99
1	3D Printing Material (Orange)	$19.99	McMaster	$19.99
4	Electronics Rotary Switch	$10.33	Apogee Rockets	$41.32
4	9V Battery Connector	$1.36	Apogee Rockets	$5.44
4	110 RPM 12V Worm Gear Motor	$34.99	Apogee Rockets	$34.99
2	DC 6/12V N20 Metal Speed Reduction Motor Micro Motor	$12.49	Amazon	$12.49
2	Satin Finish Carbon Fiber Veneer	$25.99	ProTech Composites	$25.99
#	Structural Material	$100.00	Self Machined	$100.00
1	Camera/Receiver	$50.00	RobotShop	$50.00
#	Wire/Assorted Bits	$30.00	Home Depot	$30.00
1	3/4 in. Drill Bit	$17.00	Home Depot	$17.00
1	PBC Pipe	$2.00	Home Depot	$2.00
1	Collection Assembly	$20.00	Self Machined	$20.00
1	Lead Screw Motor	$15.00	Amazon	$15.00
1	6VDC 160RPM, 38.89oz-in Worm Gear Motor	$33.11	Robot Shop	$33.11
2	12V 100RPM 583 oz-in Brushed DC Motor	$22.97	Robot Shop	$22.97
1	Trapezoidal Lead Screw Right-Hand Thread	$19.06	Igus	$19.06
2	Trapezoidal Lead Screw C15	$33.82	Robot Shop	$67.64
1	FPV Camera	$17.99	Amazon	$17.99
1	FPV Receiver	$29.99	Amazon	$29.99
1	Remote Controller	$39.99	Amazon	$39.99
2	Igniters	$18.52	Apogee Rockets	$18.52
2	Open Frame Actuator	$5.99	Amazon	$11.98
2	Push Pull Type Open Frame Solenoid	$5.99	Amazon	$11.98
2	4Port USB 3.0 Hub	$7.99	Amazon	$15.98
5	Inertial Measurement Unit	$7.10	Apogee Rockets	$35.48

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Quantity	Object	Cost per unit	Vendor	Total Cost
4	Radio Transceiver	$13.57	Apogee Rockets	$54.28
1	3.75 in. Aluminum 6061-T6511 Round Stock 24 in.	$118.76	Apogee Rockets	$118.76
Testing Accessories				
1	Terrain Bed Material	$30.00	Self Built	$30.00
Rocket Ejection				
1	Ejection Motor	$40.00	RobotShop	$40.00
1	Ejector	$20.00	Self Machined	$20.00
#	Composite Ejection Material	$60.00	Self Machined	$60.00
1	Payload Housing	$50.00	Self Machined	$50.00
1	1 Meter Long Drylin Trapezoidal Lead Screw	$19.06	Igus	$19.06
1	Ultra Low Friction Tape	$43.65	McMaster	$43.65
1	6V Worm Gear Motor	$19.99	Robot Shop	$19.99
1	RRC3 Sport Altimeter	$69.95	Missle Works	$69.95
1	Trapezoidal Lead Screw Right Hand Thread	$	Igus	$19.06
1	Screw-Locking Tee Nut Inserts	$10.19	McMaster	$10.19
2	Spring Hinges	$6.99	Amazon	$13.98
2	1/4"-20 Thread Size, 10" Long	$9.15	McMaster	$18.30
2	ZIPPY Compact 5000mAh	$38.17	HobbyKing	$38.17
1	DC 6V Gear Motor With Long M355MM Lead	$8.29	McMaster	$8.29
			Payload Total:	$2,095.09
Structures/Propulsion				
Structure				
3	Tubes (fore, aft, motor)	$1666.67	Innovative Composite Engineering	$5000
1	Epoxy	$81	ApogeeRockets	$81
1	Epoxy Resin	$59	Fiberglass Supply Depot	$59.00
1	4 ft X 8 ft Carbon Sheet	$395.00	Tim McAmis Performance Parts	$395.00
4	Fiberglass sheets	$6.50	Fiberglass Supply Depot	$26.00
1	Plywood	$43.50	Aircraft Spruce Co	$43.50

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Quantity	Object	Cost per unit	Vendor	Total Cost
1	Colloidal Sillica Filler	$12.48	Aircraft Spruce Co	$12.48
1	Titanium Socket Head Screw 4-40 Thread Size 1 in. Long	$12.48	Aircraft Spruce Co	$12.48
1	1/2 in. Drive Micrometer Torque Wrench	$23.56	Aircraft Spruce Co	$23.56
1	3/8 in. Square Drive Socket Extension, 17-3/16 in. Long	$17.12	Home Depot	$17.12
1	Nose Cone	$169.95	Madcowrocketry	$169.95
2	Aluminum "Pipe" Stock 4 in. OD, 1 ft thick, 3 in. long	$16.05	McMaster	$32.10
2	Threaded Rod	$5.97	McMaster	$11.94
8	Eye Bolt 1/4-28	$4.83	McMaster	$38.64
1	Coupler	$32.00	Madcowrocketry	$32.00
1	Bulkhead	$0	OSRT	$0
1	Switch Band	$5.00	Madcowrocketry	$5.00
5	60 in. Nomex Fire Blanket Material - Black	$20.30	Pegasus	$101.50
1	Digital Scale	$21.99	Amazon	$21.99
1	Elmer's E9415 All Purpose Glue- All Max	$9.08	Amazon	$9.08
1	Airfoiled Rail Buttons	$7.83	ApogeeRockets	$7.83
1	Aluminum Bar	$28.84	ApogeeRockets	$28.84
1	Aluminum "Pipe" Stock	$7.22	McMaster	$7.22
1	Motor Tube (22 in. long)	$27.00	McMaster	$27.00
1	G5000 Rocket Epoxy 2 Quart	$81.25	ApogeeRockets	$81.25
1	3" G12 Airframe (30")	$50.00	Apogee Rockets	$50.00
1	Multipurpose 6061 Aluminum	$38.72	Apogee Rockets	$38.72
1	10 ft O-ring Material	$12.50	Apogee Rockets	$12.50
1	Loctite Superglue	$3.99	Apogee Rockets	$3.99
1	Prepreg 7781 E-Glass (5yard roll)	$13.35	Harbor Freight	$13.35
Propulsion				
3	AeroTech L2200G-P	$279.99	AeroTech	$839.97
1	RMS-75/5120 Casing W/Forward Seal Disk	$459.03	Apogee	$459.03
Devices				
4	Altimeter	$69.95	MissileWorks	$279.80

Continued on next page

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Quantity	Object	Cost per unit	Vendor	Total Cost
			Structure/Propulsion Total:	$7,710.56
Testing Accessories				
1	Terrain Bed Material	$30.00	Self Built	$30.00
Educational Outreach				
#	Office Supplies, Stickers, PPE, High Vis. Clothing/Material	#	As Needed	$500.00
			Outreach Total:	$500.00
Budget/Finance				
#	Office Supplies, Shipping and Handling	#	As Needed	$320.00
			Finance Total:	$320.00
Administrative				
#	Office Supplies	#	As Needed	$100.00
			Administrative Total:	$100.00
Safety				
#	Office Supplies, Stickers, PPE, High Vis. Clothing/Material	#	As Needed	$200.00
2	Face Masks	$7.25	Amazon	$14.50
6	Gloves	$11.95	Amazon	$71.70
2	Fire Resistant Gloves	$15.99	Amazon	$31.98
1	Burn Bucket	$41.99	Amazon	$41.99
			Safety Total:	$359.97
Traveling Expenses				
25	Plane Tickets	$400.00	United Airlines	$10,000.00
25	Lodging	$1,200.00	Hilton Hotels	$6,300.00
			Traveling Total:	$16,300.00

Budget allocation is seen in Figure 106 and the updated budgeted amount of the amount spent in each of the categories is seen in Figure 107.

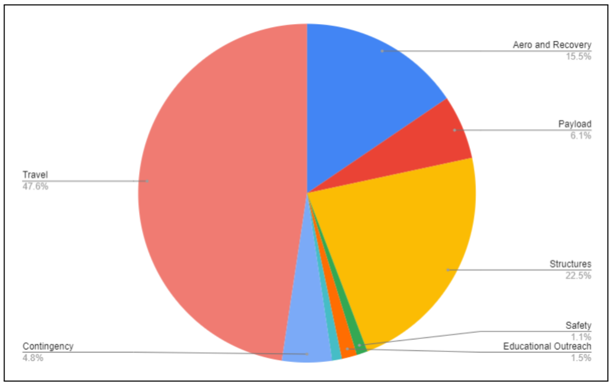


Figure 106: Budget Allocation

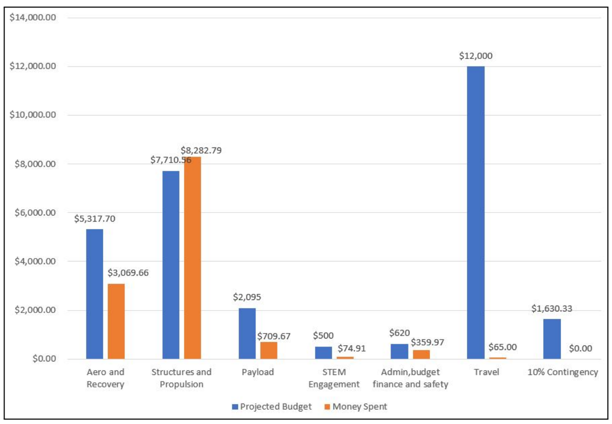
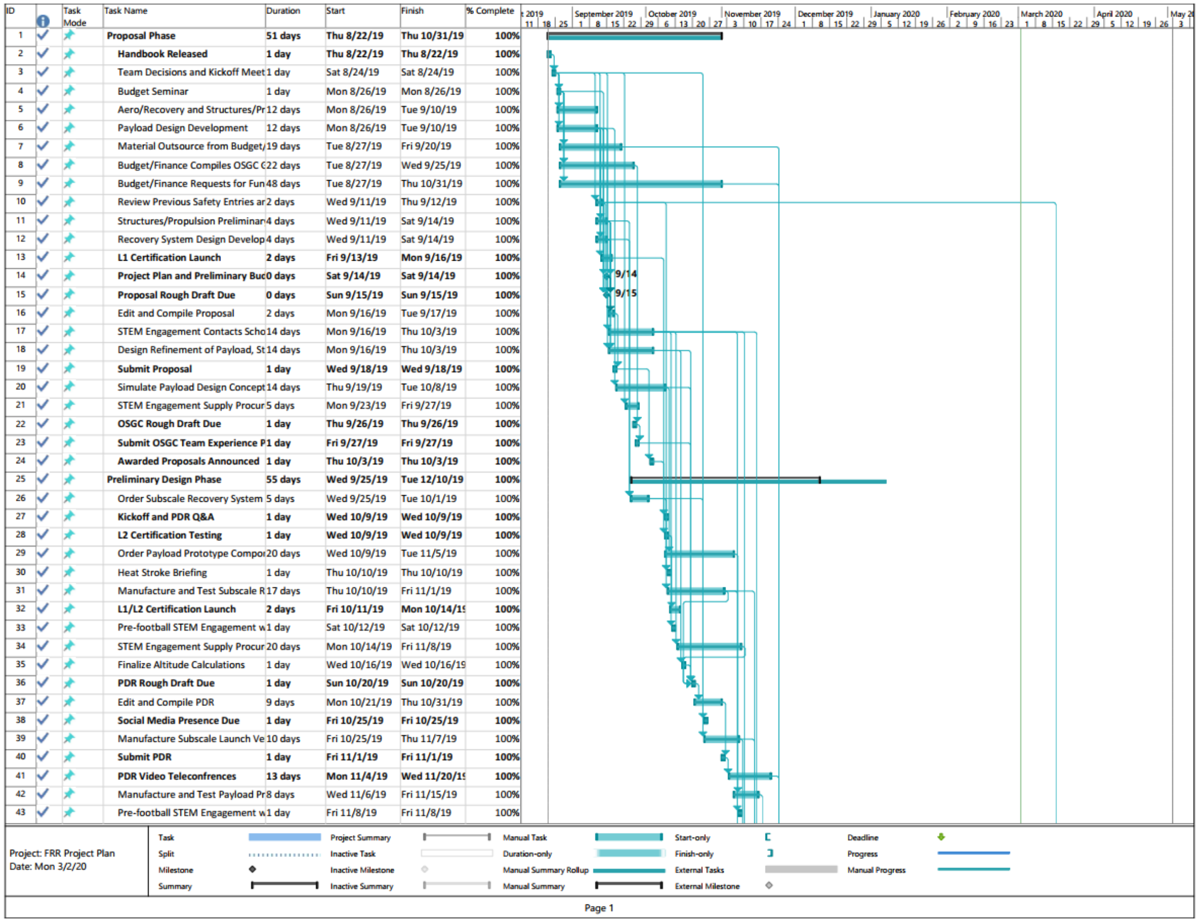


Figure 107: Projected Budget and Money Spent

6.3.2 Finance Plan

The OSRT is supported in part through NASA/OSGC, grant NNX15AJ14H. OSGC is sponsoring the OSRT with $12,000 through the OSGC Undergraduate Team Experience Award at a 1.5:1 matching rate. This means that, for every $1 that OSGC provides the OSRT, the team must supply $1.50, a total of $18,000 of matching funds. This sponsorship makes up the majority of the funding for the team. The remaining cost share that must be matched will be done through sponsorships, discounts, and materials donations from other companies and resources. The OSU chapter of AIAA, OSGC, and ICE represent the primary funding sources for OSRT.

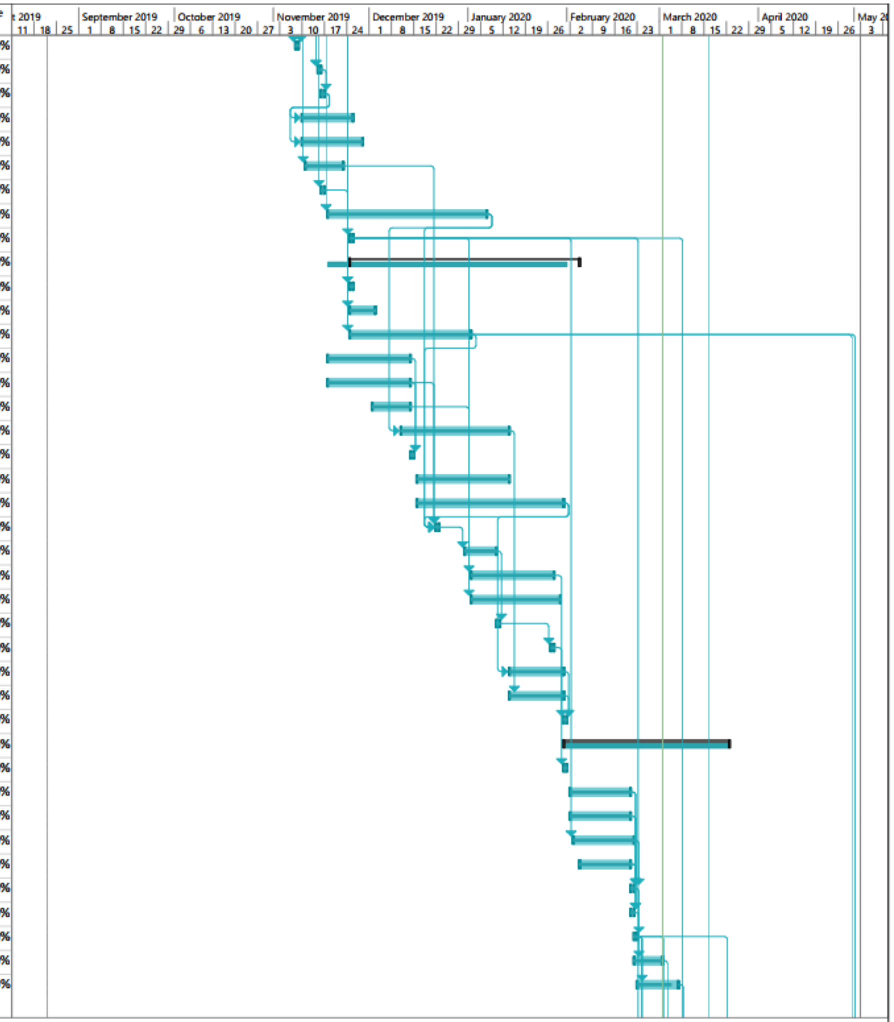
6.3.3 Timeline



ID	Task Mode	Task Name	Duration	Start	Finish	% Complete
1		**Proposal Phase**	**51 days**	**Thu 8/22/19**	**Thu 10/31/19**	**100%**
2		**Handbook Released**	**1 day**	**Thu 8/22/19**	**Thu 8/22/19**	**100%**
3		Team Decisions and Kickoff Meet	1 day	Sat 8/24/19	Sat 8/24/19	100%
4		Budget Seminar	1 day	Mon 8/26/19	Mon 8/26/19	100%
5		Aero/Recovery and Structures/Pr	12 days	Mon 8/26/19	Tue 9/10/19	100%
6		Payload Design Development	12 days	Mon 8/26/19	Tue 9/10/19	100%
7		Material Outsource from Budget/	19 days	Tue 8/27/19	Fri 9/20/19	100%
8		Budget/Finance Compiles OSGC (	22 days	Tue 8/27/19	Wed 9/25/19	100%
9		Budget/Finance Requests for Fun	48 days	Tue 8/27/19	Thu 10/31/19	100%
10		Review Previous Safety Entries ar	2 days	Wed 9/11/19	Thu 9/12/19	100%
11		Structures/Propulsion Preliminar	4 days	Wed 9/11/19	Sat 9/14/19	100%
12		Recovery System Design Develop	4 days	Wed 9/11/19	Sat 9/14/19	100%
13		**L1 Certification Launch**	**2 days**	**Fri 9/13/19**	**Mon 9/16/19**	**100%**
14		**Project Plan and Preliminary Buc**	**0 days**	**Sat 9/14/19**	**Sat 9/14/19**	**100%**
15		**Proposal Rough Draft Due**	**0 days**	**Sun 9/15/19**	**Sun 9/15/19**	**100%**
16		Edit and Compile Proposal	2 days	Mon 9/16/19	Tue 9/17/19	100%
17		STEM Engagement Contacts Scho	14 days	Mon 9/16/19	Thu 10/3/19	100%
18		Design Refinement of Payload, St	14 days	Mon 9/16/19	Thu 10/3/19	100%
19		**Submit Proposal**	**1 day**	**Wed 9/18/19**	**Wed 9/18/19**	**100%**
20		Simulate Payload Design Concept	14 days	Thu 9/19/19	Tue 10/8/19	100%
21		STEM Engagement Supply Procur	5 days	Mon 9/23/19	Fri 9/27/19	100%
22		**OSGC Rough Draft Due**	**1 day**	**Thu 9/26/19**	**Thu 9/26/19**	**100%**
23		**Submit OSGC Team Experience P**	**1 day**	**Fri 9/27/19**	**Fri 9/27/19**	**100%**
24		**Awarded Proposals Announced**	**1 day**	**Thu 10/3/19**	**Thu 10/3/19**	**100%**
25		**Preliminary Design Phase**	**55 days**	**Wed 9/25/19**	**Tue 12/10/19**	**100%**
26		Order Subscale Recovery System	5 days	Wed 9/25/19	Tue 10/1/19	100%
27		**Kickoff and PDR Q&A**	**1 day**	**Wed 10/9/19**	**Wed 10/9/19**	**100%**
28		**L2 Certification Testing**	**1 day**	**Wed 10/9/19**	**Wed 10/9/19**	**100%**
29		Order Payload Prototype Compo	20 days	Wed 10/9/19	Tue 11/5/19	100%
30		Heat Stroke Briefing	1 day	Thu 10/10/19	Thu 10/10/19	100%
31		Manufacture and Test Subscale R	17 days	Thu 10/10/19	Fri 11/1/19	100%
32		**L1/L2 Certification Launch**	**2 days**	**Fri 10/11/19**	**Mon 10/14/1**	**100%**
33		Pre-football STEM Engagement w	1 day	Sat 10/12/19	Sat 10/12/19	100%
34		STEM Engagement Supply Procur	20 days	Mon 10/14/19	Fri 11/8/19	100%
35		Finalize Altitude Calculations	1 day	Wed 10/16/19	Wed 10/16/1	100%
36		**PDR Rough Draft Due**	**1 day**	**Sun 10/20/19**	**Sun 10/20/19**	**100%**
37		Edit and Compile PDR	9 days	Mon 10/21/19	Thu 10/31/19	100%
38		**Social Media Presence Due**	**1 day**	**Fri 10/25/19**	**Fri 10/25/19**	**100%**
39		Manufacture Subscale Launch Ve	10 days	Fri 10/25/19	Thu 11/7/19	100%
40		**Submit PDR**	**1 day**	**Fri 11/1/19**	**Fri 11/1/19**	**100%**
41		**PDR Video Teleconfrences**	**13 days**	**Mon 11/4/19**	**Wed 11/20/1**	**100%**
42		Manufacture and Test Payload Pr	8 days	Wed 11/6/19	Fri 11/15/19	100%
43		Pre-football STEM Engagement w	1 day	Fri 11/8/19	Fri 11/8/19	100%

Figure 108: OSRT Project Plan 1/3

ID	Task Name	Duration	Start	Finish	% Complete
44	Distribute PTPs and Full-Team Sat	1 day	Fri 11/8/19	Fri 11/8/19	100%
45	Subscale Integration	1 day	Fri 11/15/19	Fri 11/15/19	100%
46	**Subscale Launch #1**	**1 day**	**Sat 11/16/19**	**Sat 11/16/19**	**100%**
47	Modify/Repair Subscale Launch V	12 days	Sun 11/10/19	Mon 11/25/19	100%
48	Modify/Repair Subscale Recovery	15 days	Sun 11/10/19	Thu 11/28/19	100%
49	STEM Engagement Supply Procur	10 days	Mon 11/11/19	Fri 11/22/19	100%
50	Pre-football STEM Engagement w	1 day	Sat 11/16/19	Sat 11/16/19	100%
51	Modify Payload Prototype and De	36 days	Mon 11/18/19	Mon 1/6/20	100%
52	STEM Engagement Evaluation	1 day	Mon 11/25/19	Mon 11/25/19	100%
53	**Critical Design Phase**	**52 days**	**Mon 11/25/19**	**Tue 2/4/20**	**100%**
54	**CDR Q&A**	**1 day**	**Mon 11/25/19**	**Mon 11/25/19**	**100%**
55	Determine Manufacturing Compa	6 days	Mon 11/25/19	Mon 12/2/19	100%
56	Budget/Finance Cold Calls and Fo	28 days	Mon 11/25/19	Wed 1/1/20	100%
57	Modify/Repair Subscale Recovery	20 days	Mon 11/18/19	Fri 12/13/19	100%
58	Modify/Repair Subscale Launch V	20 days	Mon 11/18/19	Fri 12/13/19	100%
59	Order Full Scale Launch Vehicle C	10 days	Mon 12/2/19	Fri 12/13/19	100%
60	Order Full Scale Payload Compon	24 days	Wed 12/11/19	Mon 1/13/20	100%
61	Subscale Integration	1 day	Sat 12/14/19	Sat 12/14/19	100%
62	Order Full Scale Recovery System	21 days	Mon 12/16/19	Mon 1/13/20	100%
63	Manufacture and Test Recovery S	34 days	Mon 12/16/19	Thu 1/30/20	100%
64	**CDR Rough Draft Due**	**1 day**	**Sun 12/22/19**	**Sun 12/22/19**	**100%**
65	Edit and Compile CDR	8 days	Tue 12/31/19	Thu 1/9/20	100%
66	Maunfacture Full Scale Launch Ve	18 days	Thu 1/2/20	Mon 1/27/20	100%
67	STEM Engagement Supply Procur	20 days	Thu 1/2/20	Wed 1/29/20	100%
68	**Submit CDR**	**1 day**	**Fri 1/10/20**	**Fri 1/10/20**	**100%**
69	**CDR Video Teleconfrence**	**1 day**	**Mon 1/27/20**	**Mon 1/27/20**	**100%**
70	Modify and Test Full Scale Recov	13 days	Tue 1/14/20	Thu 1/30/20	100%
71	Manufacture Full Scale Payload	13 days	Tue 1/14/20	Thu 1/30/20	100%
72	Full Scale Integration	1 day	Fri 1/31/20	Fri 1/31/20	100%
73	**Final Readiness Phase**	**37 days?**	**Fri 1/31/20**	**Sun 3/22/20**	**64%**
74	**FRR Q&A**	**1 day**	**Fri 1/31/20**	**Fri 1/31/20**	**100%**
75	Modify Full Scale Recovery Syster	15 days	Sun 2/2/20	Thu 2/20/20	100%
76	Modify Full Scale Launch Vehicle	15 days	Sun 2/2/20	Thu 2/20/20	100%
77	STEM Engagement Supply Procur	15 days	Mon 2/3/20	Fri 2/21/20	100%
78	Modify Full Scale Payload and De	12 days	Wed 2/5/20	Thu 2/20/20	100%
79	**FRR Rough Draft Due**	**1 day**	**Fri 2/21/20**	**Fri 2/21/20**	**100%**
80	Full Scale Integration	1 day	Fri 2/21/20	Fri 2/21/20	100%
81	**Full Scale Launch #1**	**1 day**	**Sat 2/22/20**	**Sat 2/22/20**	**100%**
82	Edit and Compile FRR	7 days	Sat 2/22/20	Sun 3/1/20	100%
83	Modify/Repair Full Scale Payload and Design	11 days	Sun 2/23/20	Fri 3/6/20	80%



Project: FRR Project Plan
Date: Mon 3/2/20

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

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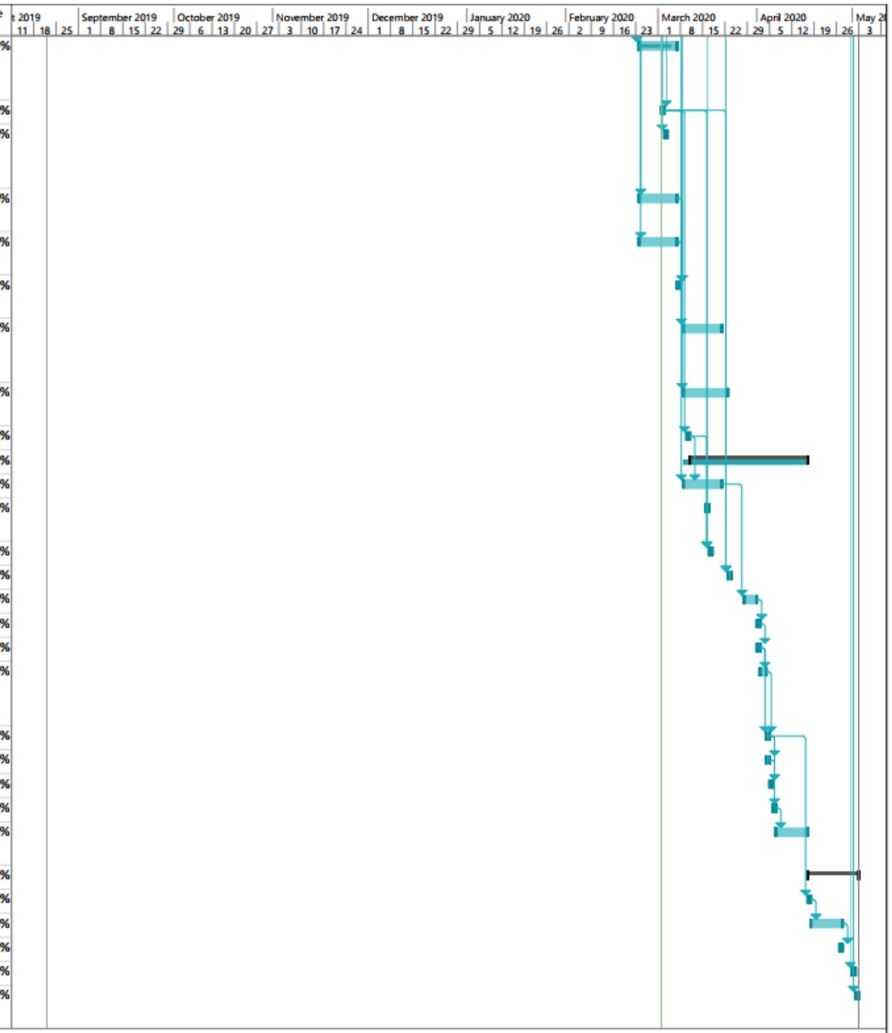
Figure 109: OSRT Project Plan 2/3

ID	Task Mode	Task Name	Duration	Start	Finish	% Complete
84		STEM Engagement Supply Procurement and Lesson Plans #17 and 18 Development	10 days	Mon 2/24/20	Fri 3/6/20	80%
85		**Submit FRR**	**1 day**	**Mon 3/2/20**	**Mon 3/2/20**	**100%**
86		Purchase Unexpected Replacements for All Subteams	1 day	Tue 3/3/20	Tue 3/3/20	0%
87		Repair Full Scale Launch Vehicle	10 days	Mon 2/24/20	Fri 3/6/20	0%
88		Repair Full Scale Recovery System	10 days	Mon 2/24/20	Fri 3/6/20	0%
89		**Launch Vehicle and Payload Demonstration Reflight**	**1 day**	**Sat 3/7/20**	**Sat 3/7/20**	**0%**
90		STEM Engagement Supply Procurement and Lesson Plans #19 and 20 Development	10 days	Mon 3/9/20	Fri 3/20/20	0%
91		Final Modification and Testing of Full Scale Payload	11 days	Mon 3/9/20	Sun 3/22/20	0%
92		**FRR Video Teleconference**	**1 day**	**Tue 3/10/20**	**Tue 3/10/20**	**0%**
93		**Competition Phase**	**27 days**	**Wed 3/11/20**	**Thu 4/16/20**	**0%**
94		Pack for Competition	10 days	Mon 3/9/20	Fri 3/20/20	0%
95		FRR Addendum Rough Draft Due	1 day	Mon 3/16/20	Mon 3/16/20	0%
96		Huntsville Safety Brief	1 day	Tue 3/17/20	Tue 3/17/20	0%
97		**FRR Addendum Due**	**1 day**	**Mon 3/23/20**	**Mon 3/23/20**	**0%**
98		Drive to Huntsville	3 days	Sat 3/28/20	Tue 3/31/20	0%
99		Arrive in Huntsville	1 day	Wed 4/1/20	Wed 4/1/20	0%
100		**LRR**	**1 day**	**Wed 4/1/20**	**Wed 4/1/20**	**0%**
101		Meet with RSO/Launch Safety Preparation and Oversight Implementation	2 days	Thu 4/2/20	Fri 4/3/20	0%
102		**Launch Day**	**1 day**	**Sat 4/4/20**	**Sat 4/4/20**	**0%**
103		Award Ceremony	1 day	Sat 4/4/20	Sat 4/4/20	0%
104		**Backup Launch Day**	**1 day**	**Sun 4/5/20**	**Sun 4/5/20**	**0%**
105		Leave Hunsville	1 day	Mon 4/6/20	Mon 4/6/20	0%
106		Clean Up/Move Out of Shop Area	8 days	Tue 4/7/20	Thu 4/16/20	0%
107		**Post Launch Phase**	**11 days**	**Fri 4/17/20**	**Sat 5/2/20**	**0%**
108		**PLAR Rough Draft Due**	**1 day**	**Fri 4/17/20**	**Fri 4/17/20**	**0%**
109		Edit and Compile PLAR	7 days	Sat 4/18/20	Mon 4/27/20	0%
110		**Submit PLAR**	**1 day**	**Mon 4/27/20**	**Mon 4/27/20**	**0%**
111		Thank you Letters to Donors	1 day	Fri 5/1/20	Fri 5/1/20	0%
112		Catalogue Materials for Future Teams	1 day	Sat 5/2/20	Sat 5/2/20	0%



Project: FRR Project Plan
Date: Mon 3/2/20

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

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Figure 110: OSRT Project Plan 3/3

6.4 STEM Engagement

During the competition time period, OSRT has completed many STEM Engagement events throughout the Oregon community and even into California. OSRT was able to reach 1,643 community members. These events hosted by OSRT reached age ranches from toddlers to adults in the community. The majority of people reached were within the elementary to high-school age range. We gave presentations that informed viewers of the work of OSRT, helped students make straw rockets, and complete lesson plans. The teams favorite activity was anytime our lesson plan involved helping the students launch rockets, whether that was straw rockets with all age levels, bottle rockets with middle-schoolers at Franklin K-8, or model rockets with students at Crescent Valley High School. It was so rewarding to see the amazed looks on the faces of everyone as they watched their straw rocket launch 50 or so feet in the air at Evergreen Air and Space Museum; we love being able to share our passion of rockets with others in the community. The one change that STEM Engagement made was adding a team requirement that everyone senior team member attend at least one STEM Engagement event or help the STEM Engagement coordinator procure supplies or lesson plan as we were having trouble with STEM Engagement participation and we wanted each team member to have the holistic USLI experience and discover all the bright potential for our future as young people are so important for creating a better future.

Figure 111: A USLI Team Member helping high school students launch a model rocket.

OSRT has also planned events for after the competition deadline. The team will be participating in Bring Your Children to Campus Day, an event that involves increasing STEM Engagement for girls, another Discovery Days event and a currently undefined event. Discovery Days is an Event put on by the college of engineering at Oregon State University that draws the elementary students from all of the surrounding towns and engages them in science activities. Having been one of the groups present for the fall discovery days, OSRT is looking forward to the second opportunity to engage so many students in our community.

7 APPENDIX A: DRAWINGS AND SCHEMATICS

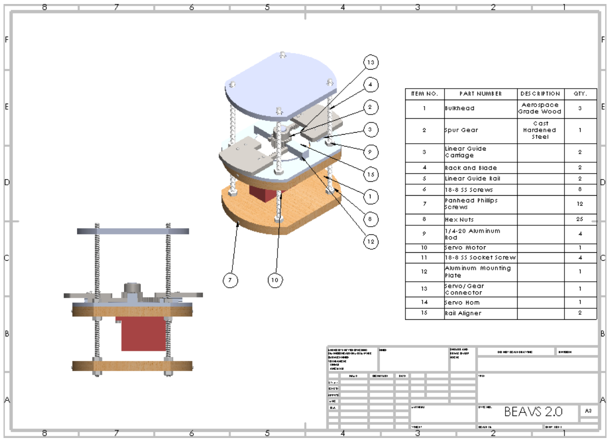

Figure 112: BEAVS 2.0 Assembly Sketch

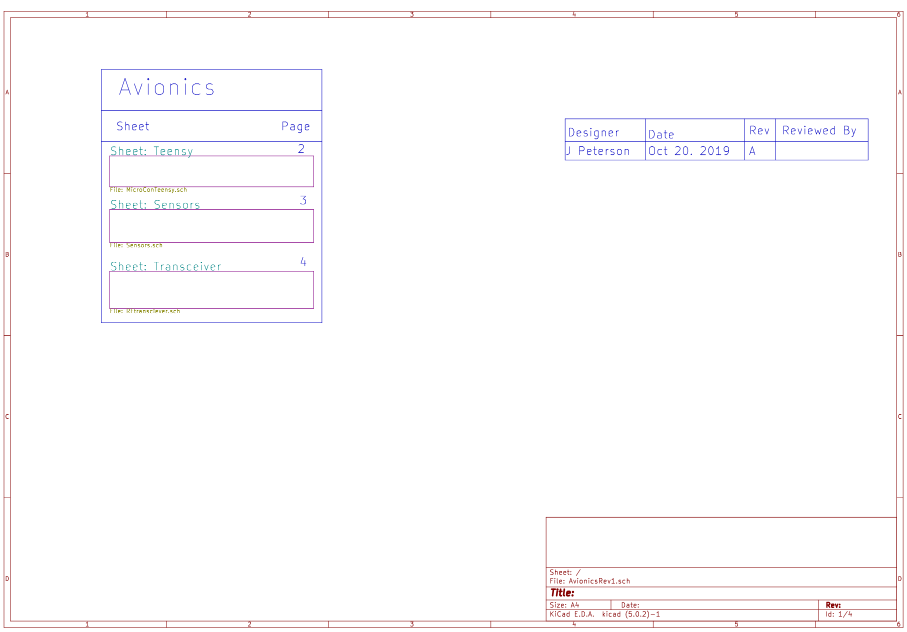

Figure 113: Avionics Schematics Microcontroller and Power Supply Page

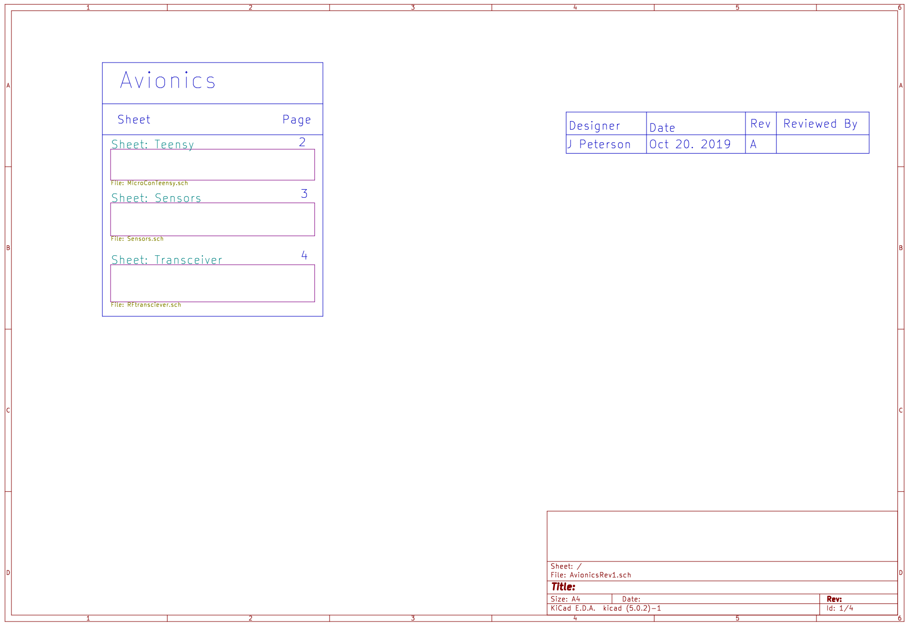

Figure 114: Avionics Schematics Sensors Page

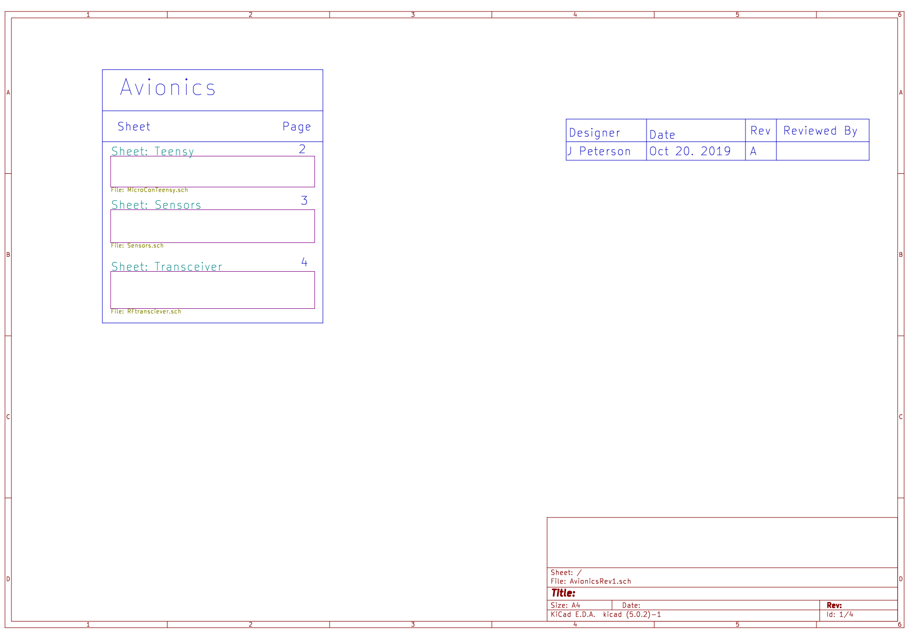

Figure 115: Avionics Schematics Transmitter Page

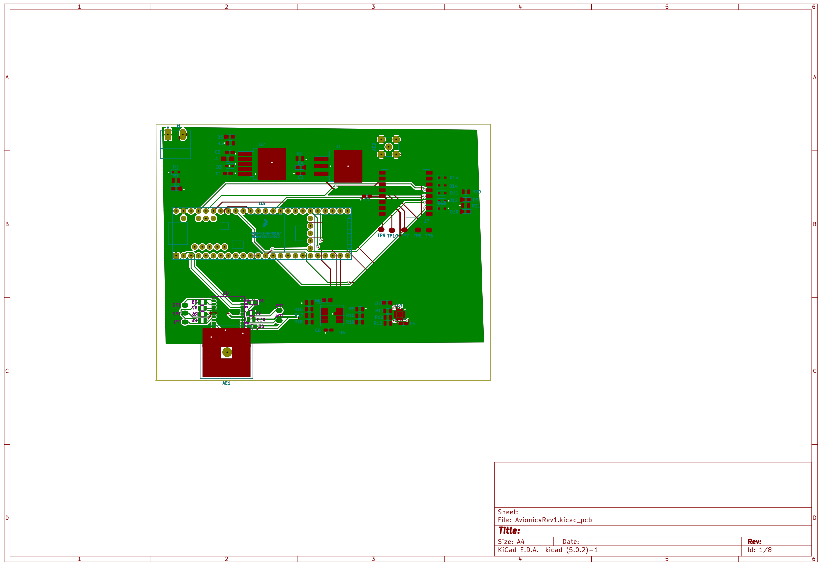

Figure 116: Avionics PCB Layout

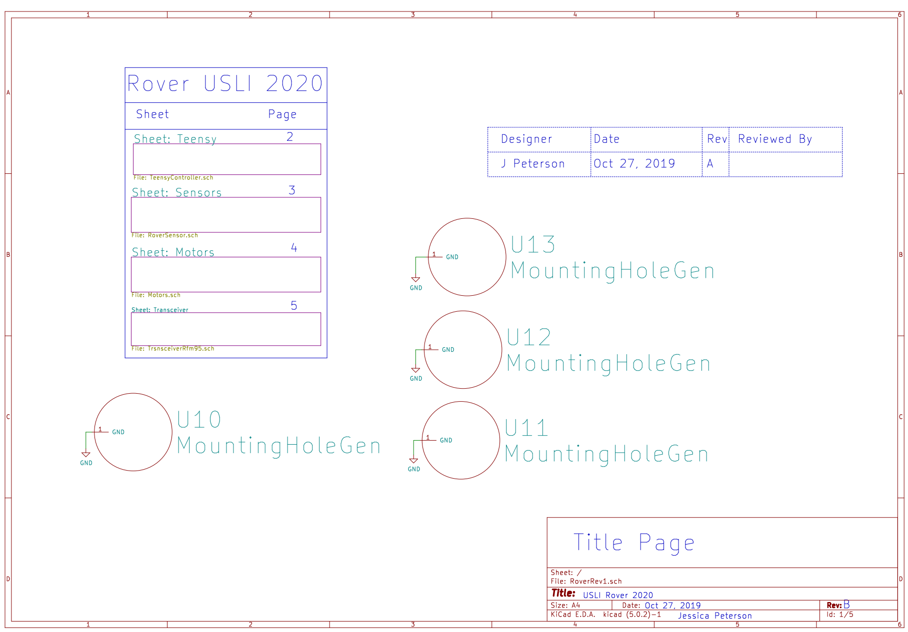

Figure 117: Payload Schematics Title Page

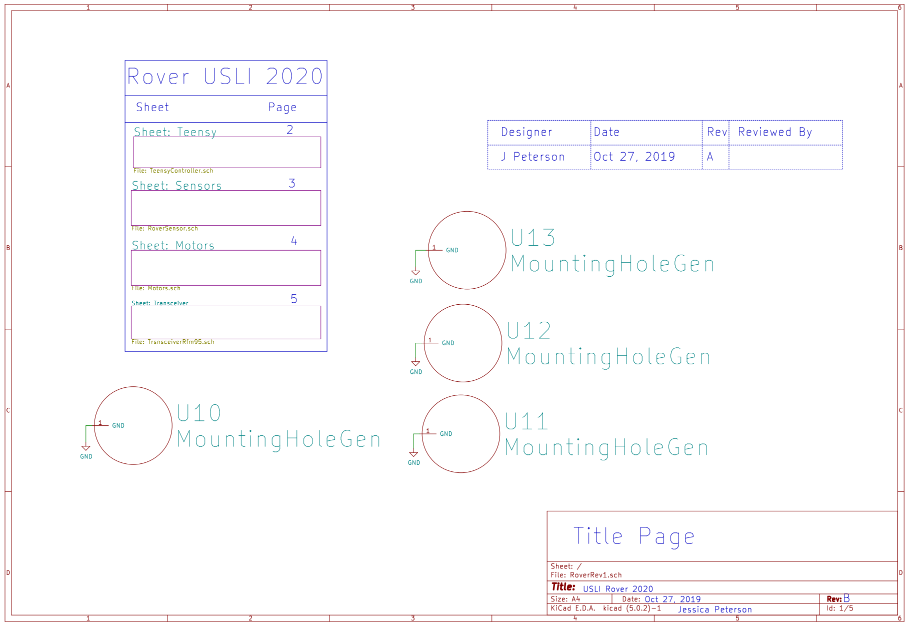

Figure 118: Payload Schematics Microcontroller Page

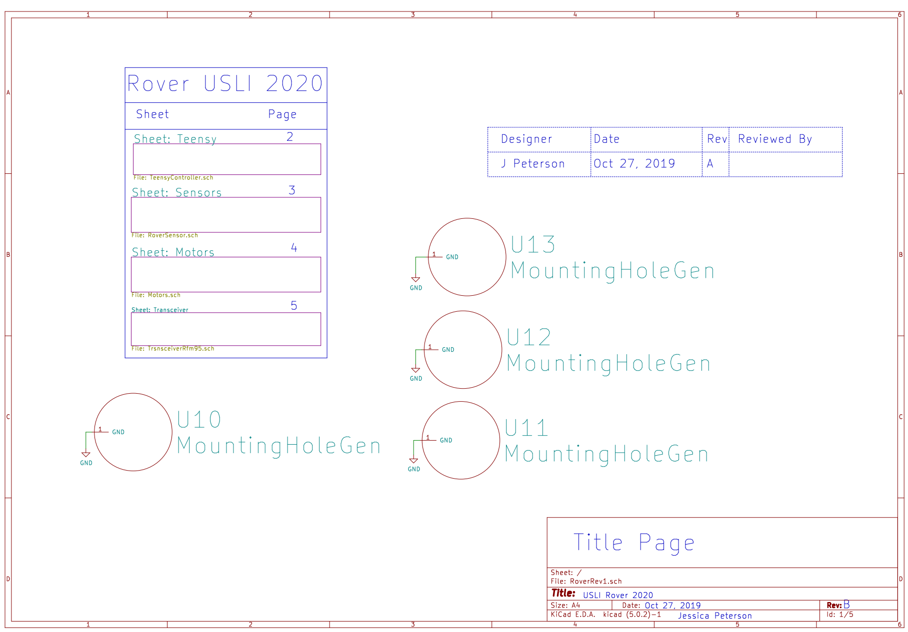

Figure 119: Payload Schematics Sensor Page

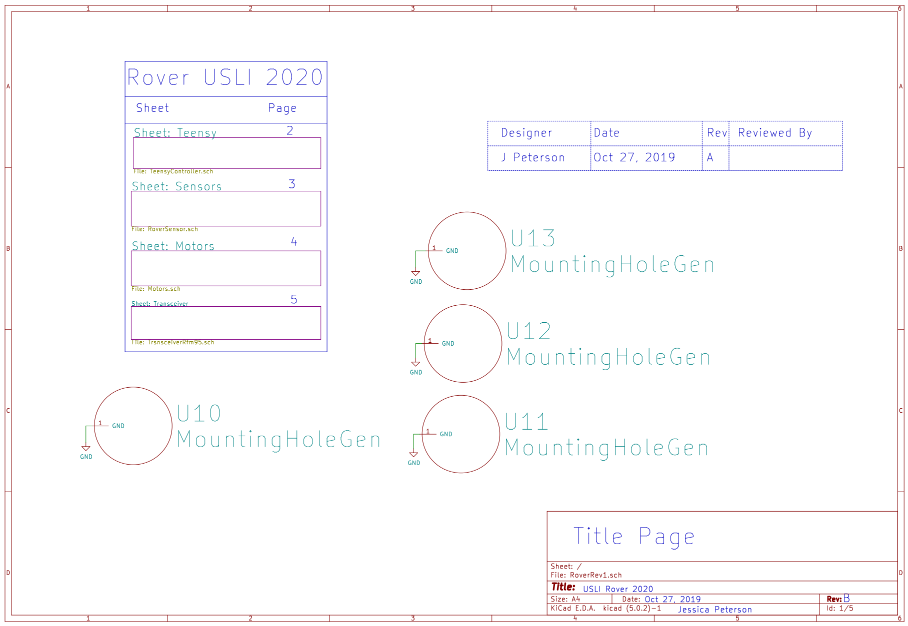

Figure 120: Payload Schematics Motor Driving Page

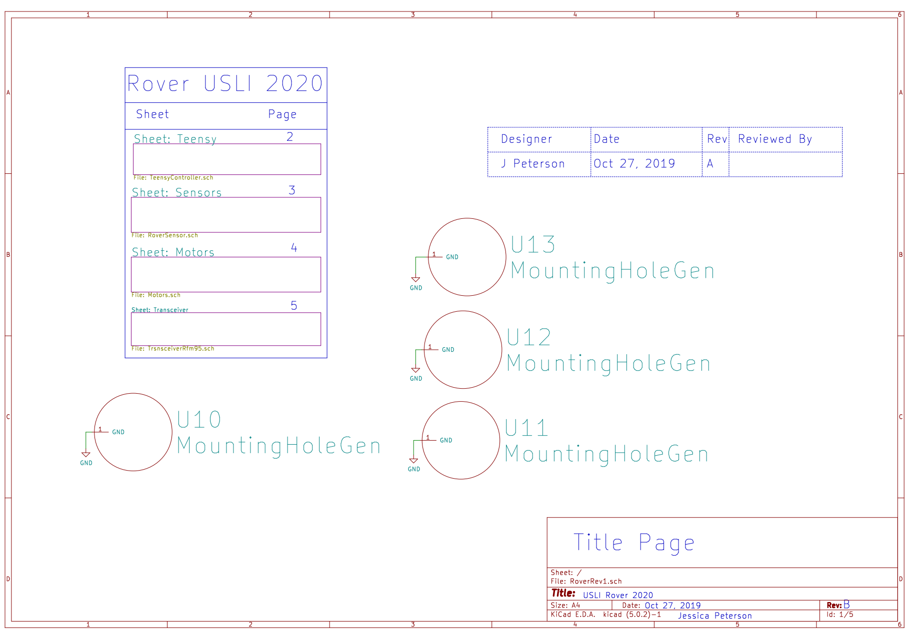

Figure 121: Payload Schematics Transmitter Page

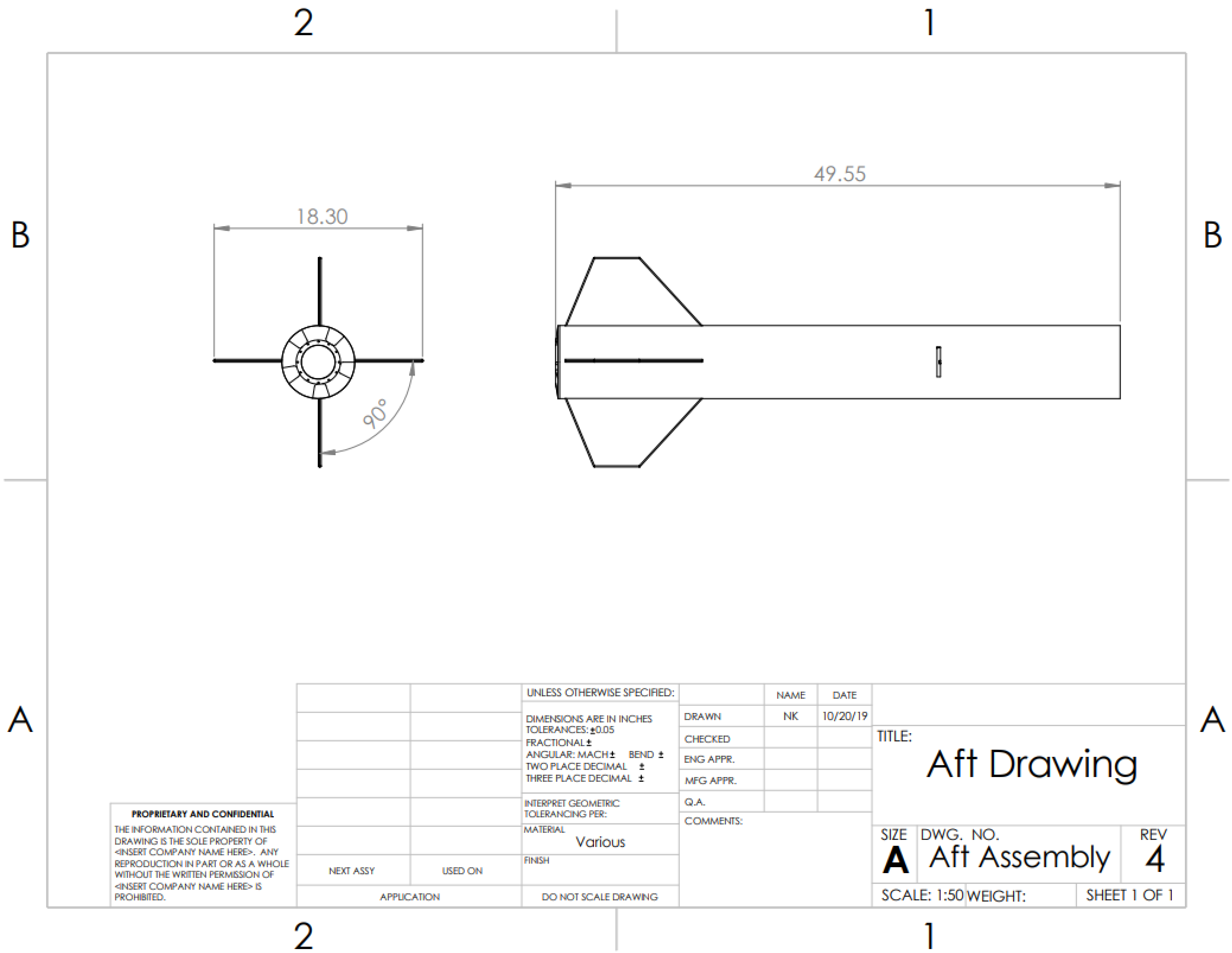

Figure 122: Aft Assembly

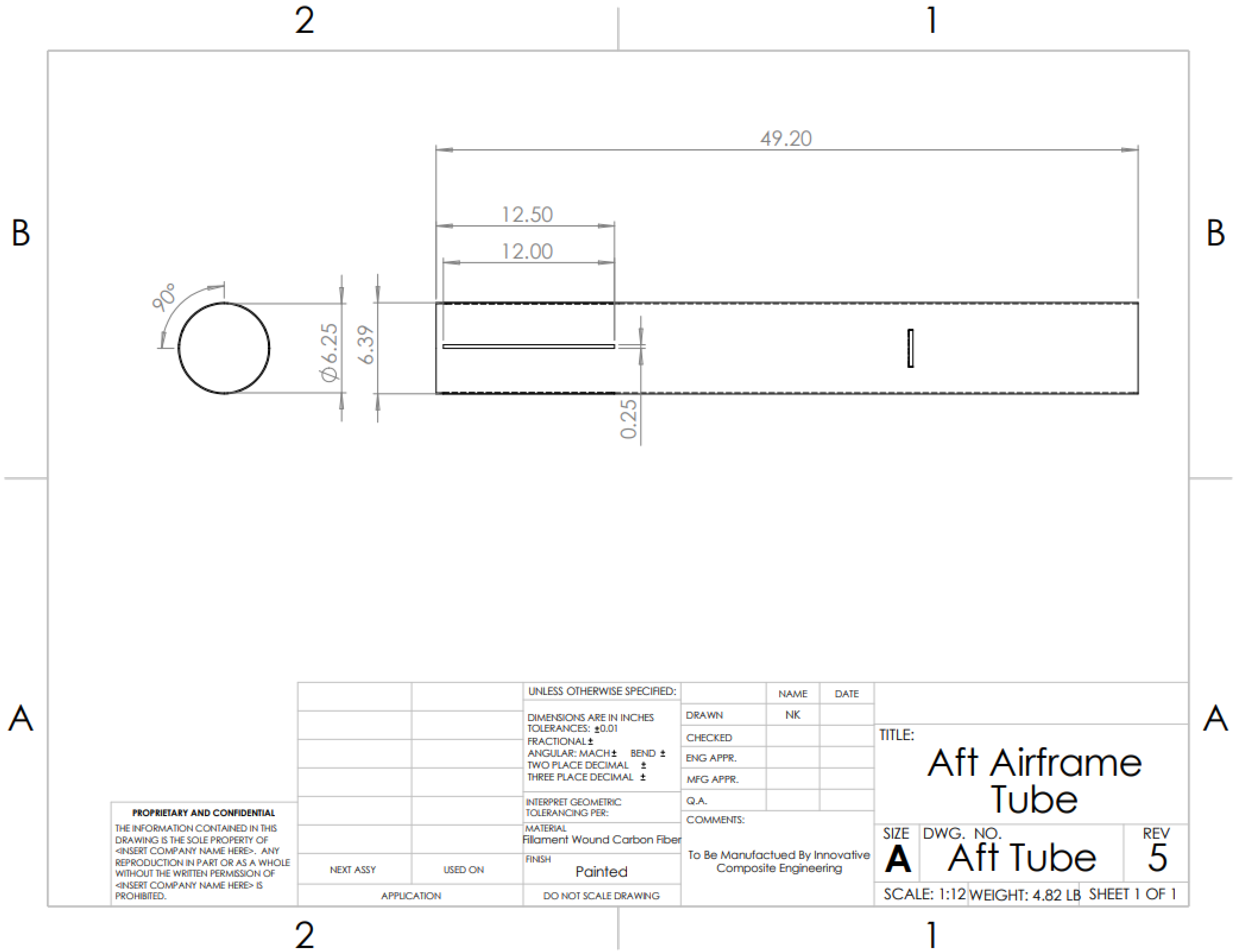

Figure 123: Aft Tube

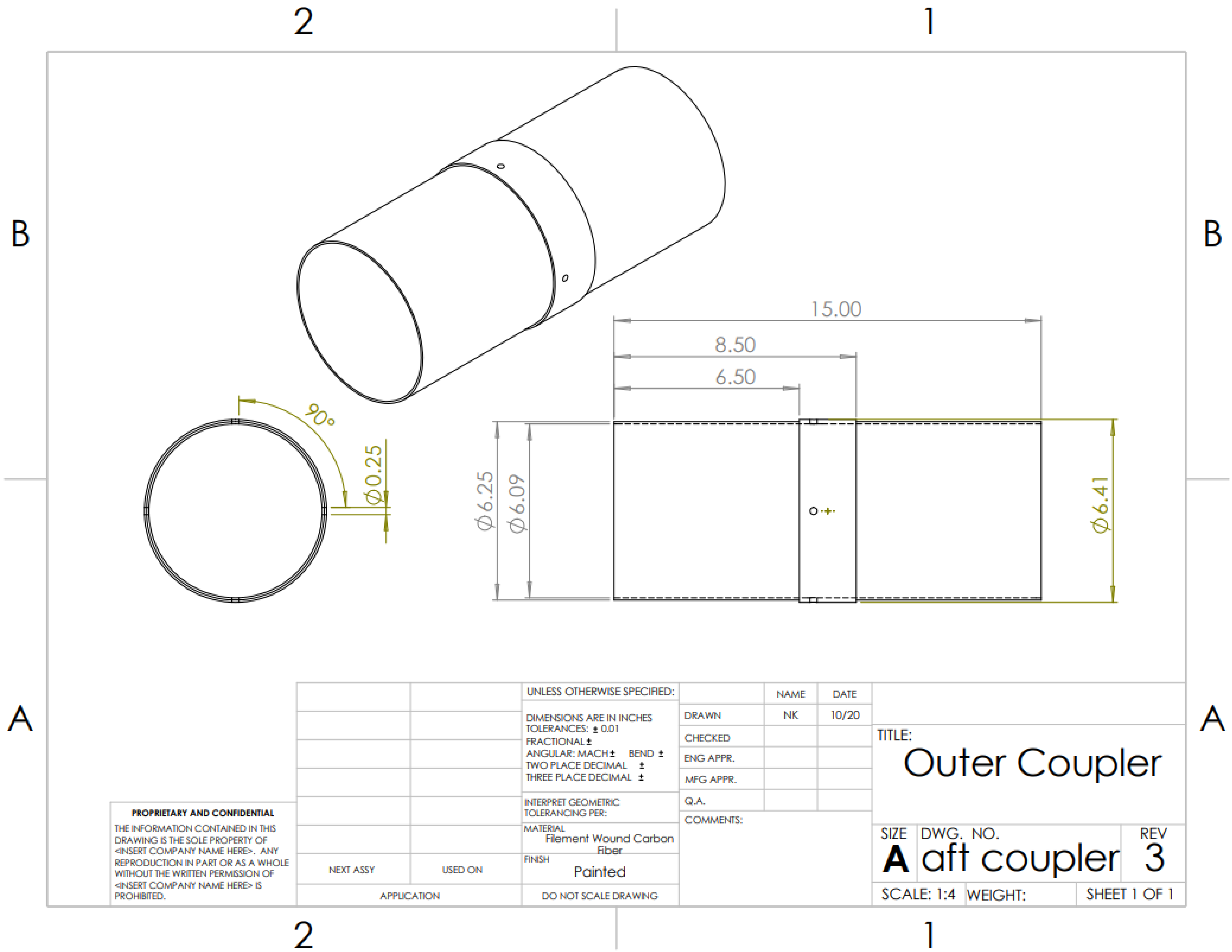

Figure 124: Coupler

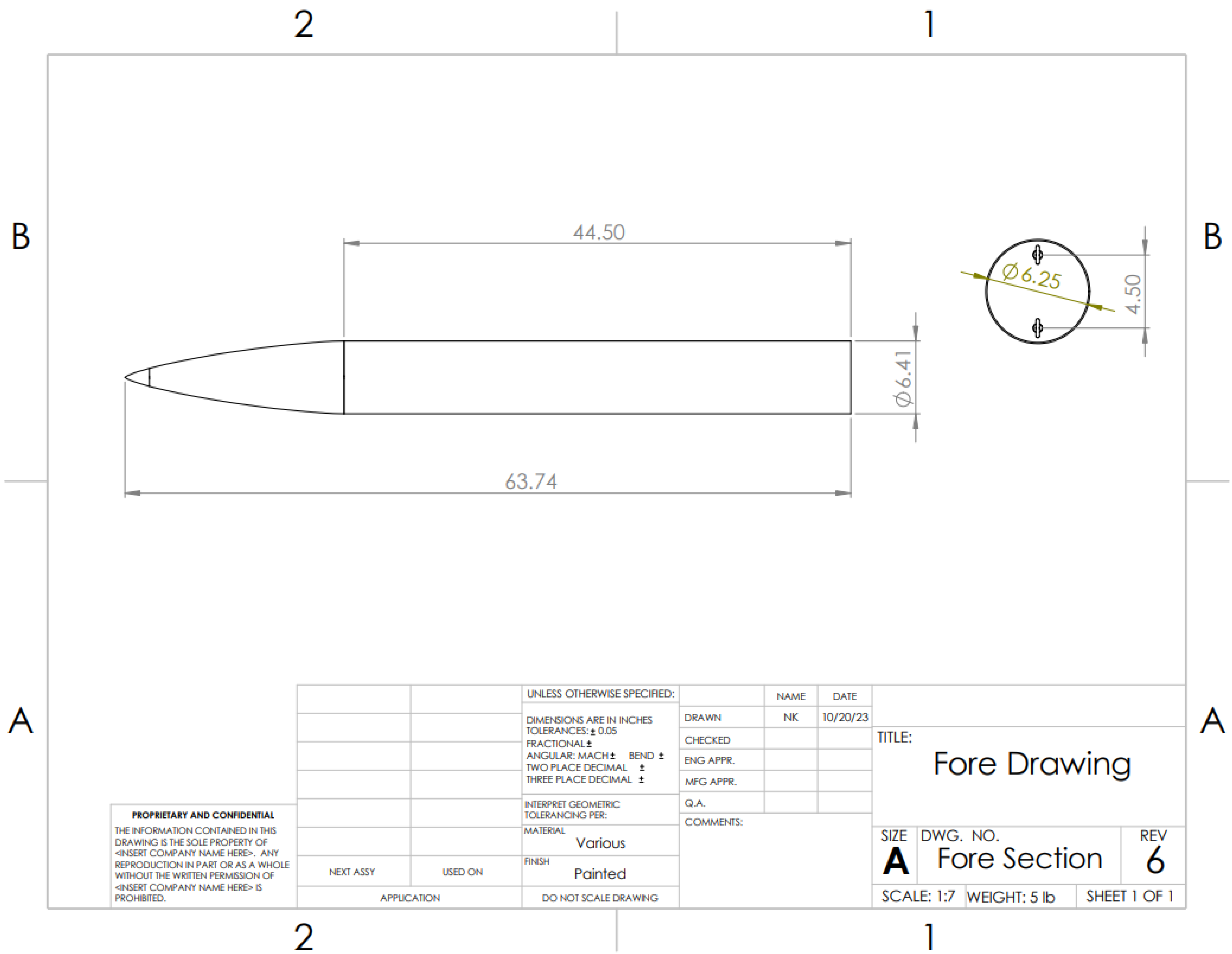

Figure 125: Fore Assembly

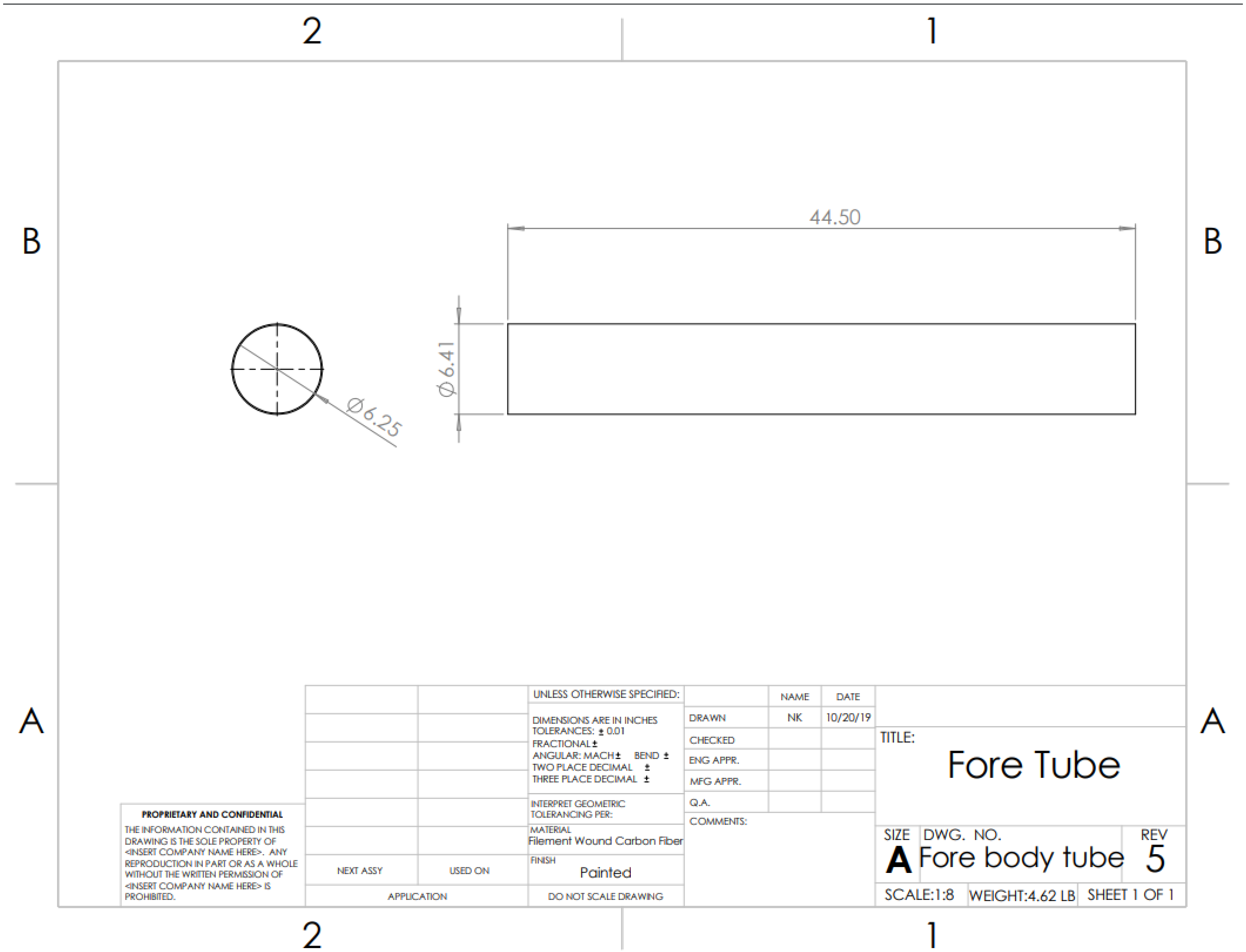

Figure 126: Fore Tube

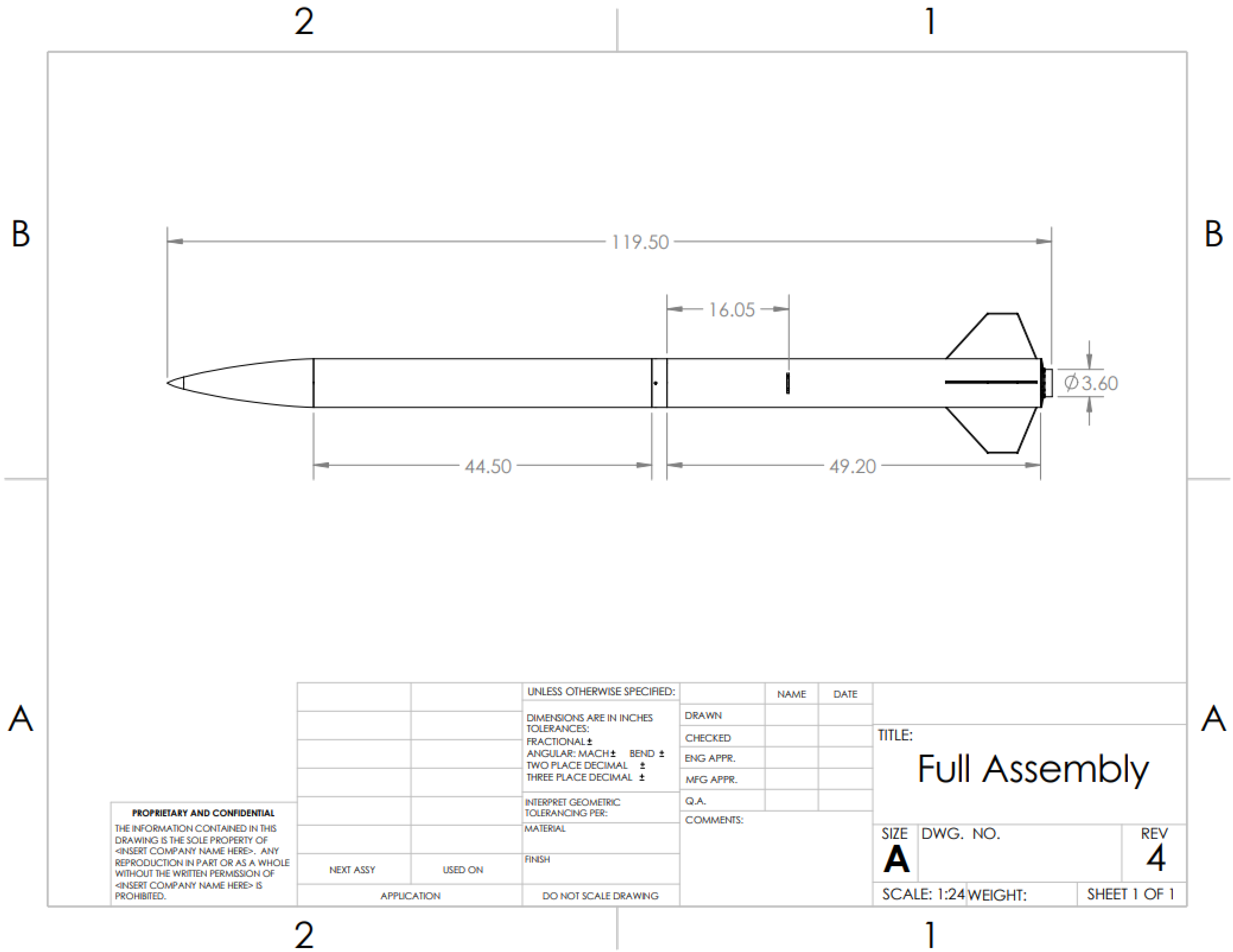

Figure 127: Full Assembly

8 Appendix B: Aero and Recovery Testing and Manufacturing

Black Powder Parachute Ejection Testing

Test Conductor Signature:__________ **Safety Officer Signature:** __________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Safety glasses must be worn while all times.
		- All electronics must either be removed or turned off within a 5 ft radius of the BP.
		- No personnel can be within 10 ft of the person conducting the test
		- All synthetic fiber clothing on the person conducting the test must be removed to the best extent possible
		- All jewelry on the person conducting the test must be removed
		- The person creating the BP charges must wear properly grounded ESD bracelets to minimize the amount of static electricity around the charges
		Prerequisite lists: N/A
	____	**Testing Equipment Needed:** BP Test Stand
	____	**Tools Needed:** All tools required for the construction of the BP charges, wire cutters, crimpers
	____	**Components Needed:** All materials needed for the construction of the BP charge, plumber's putty, duct tape, two wires that are 10 ft in length, parachutes
		Passing Condition: The BP charge ejects the parachute so that it is clear of the airframe without the charge itself leaving the airframe
		Testing Procedure:
1	____	Mount the static fire test tube to the mounting bulkhead that is attached to the testbed stand and fasten into place using the fastening screws.
2	____	Thread the rod through the center hole in the back of the testbed until the end through the static fire tube is approximately 1 inch from the end of the tube.
3	____	Secure the rod in place using a washer and locking nut in the back of the testbed.
4	____	Thread another locking nut on the rod in the static fire tube to the desired location and attach the variable bulkhead to the threaded rod.
5	____	Attach the leads of the e-match to the end of the threading wire and pull through the variable bulkhead, mounting bulkhead, and back of the testbed.
6	____	Using the 1.5 ft threaded rod, thread a locking nut and washer to one end.
7	____	Thread the rod through a bulkhead and secure in place with another washer and locking nut.
8	____	Repeat the last two steps on the other end of the threaded rod.
9	____	Place the testbed assembly on a level location. If needed, secure the testbed using sandbags.
10	____	Construct the BP charge as per the instructions in the Black Powder Charge Assembly checklist.
11	____	Crimp a quick release connector on the bare end of the e-match.
12	____	Feed the free end of the long wire through the bulkhead in the ejection tube and route the wires away from the test stand and out of the line of fire.
13	____	Fill the free area in the hole round the wire with plumber's putty and seal in the putty with duct tape.
14	____	Install the BP charges as directed in the Altimeters Checklist.
15	____	Install the parachute.
16	____	Plug in each of the quick release connectors attached to the 10 ft wires to the e-matches.

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#	Inspector Initials	Step Instructions
17	______	Attach the ejection tube to the static fire tube via sliding the coupler attached to the ejection tube into the static fire tube, and inserting shear pins into the holes to adhere the two sections together.
18	______	Clear the range.
19	______	Touch the bare ends of the 10 ft lengths of wire to the positive and negative nodes of a 9 V battery to fire.
		Pass? (Y/N) ____________________

BEAVS 2.0 Manufacturing: Blades

Assembler Signature: ____________________ **Safety Officer Signature:** ____________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Wear safety glasses in the machine shop at all times
		- Wear gloves for pinching/minor cuts
		- Confirm any edges are sanded and finished, all fasteners tight
		- Clean workspace after completion of manufacturing
		Prerequisite lists:
		- OSU Machine Shop certification
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** End mill, belt sander, 4-40 tap
	______	**Components Needed:** $\frac{1}{4}$ in. 6061 aluminum bar, (2x) 7mm linear guide rails, (2x) steel racks
S	______	**Safety Consideration: - Failure to wear proper PPE may result in bodily injuries**
S	______	**Safety Consideration: - Failure to follow shop rules may result in harm to others and removal of machine shop access**
1	______	Secure $\frac{1}{4}$ in. 6061 aluminum bar on end mill vice
S	______	**Safety Consideration: Failure to secure material properly in vice may cause material to dislodge and result in harm to those in area**
2	______	Mill down material until squared dimensions are met, according to dimensioned sketch
3	______	Replace end mill piece with $\frac{3}{32}$ in drill bit and drill four holes in blade
4	______	Remove blades from end mill vice
5	______	Carefully round tips of blades on belt sander until desired radius is met
S	______	**Safety Consideration: - Objects heat quickly when being worked on belt sander**
6	______	Tap blade holes with 4-40 tap piece
7	______	Secure blades to linear guide rails and steel racks with 4-40 screws

Notes: ____

BEAVS 2.0 Manufacturing: Aluminum Bulkhead Reinforcement

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Wear safety glasses in the machine shop at all times - Wear gloves for pinching/minor cuts - Confirm any edges are sanded and finished, all fasteners tight - Clean workspace after completion of manufacturing **Prerequisite lists:** - OSU Machine Shop certification - BEAVS bulkheads **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	____	**Tools Needed:** End mill, belt sander, super glue
	____	**Components Needed:** $\frac{1}{4}$ in. 6061 aluminum block, Wooden bulkhead (x1)
S	____	**Safety Consideration: - Failure to wear proper PPE may result in bodily injuries**
S	____	**Safety Consideration: - Failure to follow shop rules may result in harm to others and removal of machine shop access**
1	____	Secure $\frac{1}{4}$ in. 6061 aluminum block on end mill vice
S	____	**Safety Consideration: Failure to secure material properly in vice may cause material to dislodge and result in harm to those in area**
2	____	Mill down material until squared dimensions are met, according to dimensioned sketch
3	____	Find center of block and drill out 3 in. circle
4	____	Remove piece from end mill vice and belt sand rounded sides until desired radius is met
S	____	**Safety Consideration: - Objects heat quickly when being worked on belt sander**
5	____	Super glue aluminum bulkhead onto wooden center bulkhead. Place weight on top while glue dries

Notes: ________________________________

Altimeter Testing

Test Conductor Signature:________________ **Safety Officer Signature:** ________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Safety glasses must be worn while all times. - Altimeters should not be turned on until right before entering the vacuum chamber - Do not breathe in the fumes due to e-match detonation - E-matches must be duct taped to the top of the altimeter bay as to not damage the walls of the vacuum chamber

Continued on next page

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#	Inspector Initials	Step Instructions
		Prerequisite lists: N/A
	______	**Testing Equipment Needed:** Vacuum chamber
	______	**Tools Needed:** All tools required for the construction and actuation of the altimeter bay
	______	**Components Needed:** All materials needed for the construction and actuation of the altimeter bay, duct tape
		Passing Condition: The e-matches are ignited at the correct times during the simulated flight
		Testing Procedure:
1	______	Assemble the altimeter bay as per the Altimeter and Coupler/Altimeter Bay checklists.
2	______	Duct tape the e-matches to the outside of the altimeter bay so that the live end of the e-matches sticks up into in the middle of the vacuum chamber.
3	______	Place the lid on the vacuum chamber.
4	______	Attach the vacuum pump to the inlet to the vacuum chamber.
5	______	Turn the vacuum lever the the "ON" position.
6	______	Wait until the chamber has a vacuum of -20 kPa to simulate ascent.
7	______	Slowly turn the lever on the vacuum chamber until the vacuum is stabilized to simulate apogee.
8	______	Vent the chamber so that returns to Standard Temperature and Pressure (STP) to simulate descent and landing.
		Pass? (Y/N) ____________________

BEAVS FEA Test Procedures

Assembler Signature:____________________ **Safety Officer Signature:** ____________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- N/A
		Prerequisite lists:
		- N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** BEAVS CAD Assembly, Solidworks software
S	______	**Safety consideration: Insufficient set up may produce false results**
1	______	Load BEAVS CAD assembly in Solidworks FEA.
2	______	Define attachment points.
3	______	Run FEA results.

BEAVS Controls Test Procedures		
Assembler Signature:________		Safety Officer Signature: ________
#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - N/A **Prerequisite lists:** - N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** BEAVS mechanical system, BEAVS electrical system, BEAVS controls system
S	______	**Safety consideration: Insufficient set up may produce false results**
1	______	Load BEAVS CAD assembly in Solidworks FEA.
2	______	Define attachment points.
3	______	Run FEA results.

EMBERS Testing		
Test Conductor Signature:________		Safety Officer Signature: ________
#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Safety glasses must be worn while all times. - All electronics must either be removed or turned off within a 5 ft radius of the BP. - No personnel can be within 10 ft of the person conducting the test - All synthetic fiber clothing on the person conducting the test must be removed to the best extent possible - All jewelry on the person conducting the test must be removed - The person creating the BP charges must wear properly grounded ESD bracelets to minimize the amount of static electricity around the charges - The EMBERS switch will always remain off while a battery is installed until the system is ready to be fired. **Prerequisite lists:** N/A
	______	**Testing Equipment Needed:** BP Test Stand, EMBERS
	______	**Tools Needed:** All tools required for the construction of the BP charges, wire cutters, crimpers, set of standard allen wrenches
	______	**Components Needed:** All materials needed for the construction of the BP charge, plumber's putty, duct tape, two wires that are 10 ft in length, parachutes, Shock Cord for the Drogue Parachute
		Passing Condition: The BP charge ejects the parachute so that it is clear of the airframe without the charge itself leaving the airframe **Testing Procedure:**

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#	Inspector Initials	Step Instructions
1	______	Mount the static fire test tube to the mounting bulkhead that is attached to the testbed stand and fasten into place using the fastening screws.
2	______	Thread the rod through the center hole in the back of the testbed until the end through the static fire tube is approximately 1 inch from the end of the tube.
3	______	Secure the rod in place using a washer and locking nut in the back of the testbed.
4	______	Thread another locking nut on the rod in the static fire tube to the desired location and attach the variable bulkhead to the threaded rod.
5	______	Attach the leads of the e-match to the end of the threading wire and pull through the variable bulkhead, mounting bulkhead, and back of the testbed.
6	______	Using the 1.5 ft threaded rod, thread a locking nut and washer to one end.
7	______	Thread the rod through a bulkhead and secure in place with another washer and locking nut.
8	______	Repeat the last two steps on the other end of the threaded rod.
9	______	Place the testbed assembly on a level location. If needed, secure the testbed using sandbags.
10	______	Construct the BP charge as per the instructions in the Black Powder Charge Assembly checklist.
11	______	Attach the BP charge to the EMBERS, ensuring that the switch is in the OFF position.
12	______	Attach EMBERS to the airframe.
13	______	Loop the wires to the EMBERS pull tab and secure the loop with a cable tie.
14	______	Attach the quick link at the end of the 33 ft drogue parachute shock cord to the loop and lay it out in front of the test stand so that it stretches out to its full length.
15	______	Install the parachute.
16	______	Clear the range, having everyone stand out of the line of fire, and ensuring that the person doing the pull test is at least 33 ft away from the front of the test stand.
17	______	Do a count down and yank the shock cord away from the test stand to actuate EMBERS.
		Pass? (Y/N) ____________________

Pre-Launch OpenRocket Simulation

Assembler Signature:____________________ **Safety Officer Signature:** ____________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - N/A **Prerequisite lists:** - N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** OpenRocket software
1	______	Launch OpenRocket software and open current version of rocket simulation
2	______	Ensure all weights, geometries, and parachute sizes are accurate
3	______	Ensure drogue and main parachute ejection altitudes are accurate
4	______	Ensure launch day conditions such as wind speeds, latitude and longitude, and ground level altitude are accurate

Continued on next page

Table 46 – continued from previous page

#	Inspector Initials	Step Instructions
5	______	Select current motor choice and run simulation to collect simulated data
6	______	Plot or examine relevant data
7	______	Save simulation to compare with post-flight data

Pre-Launch Matlab Simulation

Assembler Signature:______________________ **Safety Officer Signature:** ______________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - N/A **Prerequisite lists:** - N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** Matlab software
1	______	Open Matlab scripts titled: "Parachutes", "Updated_Descent_Rates", "air_density_function"
2	______	Update scripts with current launch parameters and conditions such as parachute sizes, altitudes, and wind speeds
3	______	Run Scripts
4	______	Compare results with OpenRocket simulations

Avionics Sensor Testing

Assembler Signature:______________________ **Safety Officer Signature:** ______________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - N/A **Prerequisite lists:** - N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** Arduino IDE, Teensy 3.6, assembled PCB, XBee
1	______	
2	______	Open Avionics test code in Arduino IDE
3	______	Place the Teensy in the correct header pins
4	______	Plug the Teensy 3.6 into the computer using a microUSB cable
5	______	Upload the program to the Teensy.
6	______	Open the serial port and check raw sensor data.

9 Appendix C: Launch Vehicle

Coupler Shoulder Length Verification Test

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - **Prerequisite lists:** - **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	_____	**Tools Needed:** Safety Glasses
	_____	**Components Needed:** Couplers located at in flight separation points
S	_____	**Safety consideration: Insufficient coupler lengths will reduce stability and security of in flight separation points.**
S	_____	**Safety consideration: Fiberglass edges can be sharp and splinter, ensure edges have been sanded down before attempting measurement.**
1	_____	Zero out caliper reading with instrument jaws in fully closed position.
2	_____	Extend caliper from the leading edge of the coupler's switch-band, all the way to the terminating edge of the coupler support shoulder.
3	_____	Make note of the current reading of the caliper.
4	_____	Repeat this zeroing and measuring process twice and average the results for a more consistent measurement of the shoulder.
5	_____	Repeat this zeroing, measuring, and averaging process for the other coupler shoulder.

Fore Shoulder Length: ____________________

Aft Shoulder Length:____________________

Coupler Manufacturing

Manufacturer Signature:________________ **Safety Officer Signature:** ________________

#	Manufacturer Initials	Step Instructions
		Safety Officer Checklist: - Ensure that all areas are clear of all foreign objects. - Ensure that all machines are being used appropriately. - Ensure that that all loose jewelry and clothing is removed and long hair is tied back. **Prerequisite lists:** N/A
	_____	**Materials Needed:** Carbon fiber pre-preg, vacuum bagging, Teflon tape, Airframe Tube Section

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#	Manufacturer Initials	Step Instructions
	_____	**Tools and Machines Needed:** Sandpaper, CNC Ply cutter, Curing oven
	_____	**PPE Required:** Safety glasses, ear plugs, nitrile gloves
		Manufacturing Procedure:
6	_____	Prepare Airframe Tube Section by cleaning thoroughly with acetone.
7	_____	Prepare Drawing eXchange Format (DXF) file with desired coupler sheet shapes.
8	_____	Complete CNC Ply cutter start up sequence.
S	_____	**Safety Consideration: - Ensure proper vacuum pressure, failure to do so will result in failure of cut and movement of composite material.**
9	_____	Run DXF file and verify correct cut of carbon fiber sheets in accordance with layup schedule.
10	_____	Complete CNC Ply cutter shut down sequence.
11	_____	Spray mold release into interior of airframe tube section, failure to cover completely will bond coupler to airframe during curing.
12	_____	Layup carbon fiber sheets inside of airframe section in accordance with layup schedule.
13	_____	Place tube of bagging material greater in diameter then the interior of the coupler within the coupler, sealing with Teflon tape.
14	_____	Cover exterior of coupler with bagging material, with vacuum fitting installed, sealing against inner bagging material using Teflon tape.
15	_____	Vacuum air out of sealed assembly.
16	_____	Cure in Curing oven in accordance with manufacturers recommendations.
S	_____	**Safety Consideration: - Curing oven is extremely hot, failure to properly operate will result in injury.**
17	_____	Remove from oven, de-bag, remove coupler from airframe section. Sand and cut off excess material. Verify coupler is consistent with expected result.
18	_____	Cut 2 inch switch band from carbon fiber airframe tube, ensuring a flat surface by checking its seating against a machined ed of airframe on the coupler. Sand until seating is flat.
19	_____	Using G5000 Rocket Epoxy, epoxy the switch band in center of coupler.
S	_____	**Safety Consideration: - Failure to position switch band correctly could create unstable launch vehicle configuration requiring re-manufacturing.**

Component Accessibility Verification Test		
Assembler Signature:________		Safety Officer Signature: ________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist:
		- Wear gloves during measurement as residue inside airframe can be harmful (composite dust, blackpowder residue etc)
		Prerequisite lists:
		- N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	____	**Tools Needed:** Safety Glasses, Ruler, Gloves, Flathead Screwdriver
	____	**Components Needed:** Nose cone Bulkhead Fastener, Payload Fore Bulkhead Fastener, BEAVS Fasteners, BEAVS Power Switch, Avionics Coupler Fasteners, Midsection Avionics Power Switches
S	____	**Safety consideration: Avoid sharp edges on recently manufactures airframe components**
S	____	**Safety consideration: Avoid forcing hand into tight airframe locations as you can get stuck, or damage airframe**
1	____	Ensure the launch vehicle is in 'precombination' state where all non-recovery components are installed but the full airframe is still in the fore and aft sections, with the midsection avionics bay installed in the separate central coupler.
2	____	Locate the component currently being tested for accessibility.
3	____	Using a ruler, measure the depth from the component to the edge of the nearest airframe opening. In the case of bolts or other fasteners, this measurement should be taken to the bottom of the bolt or flush against the bulkhead or surface it retains, to better reflect the use condition of tightening or loosening.
4	____	Put on gloves to simulate proper safety conditions experienced in the field.
5	____	Access the component in its typical use case. For bolts, this consists of being able to lightly tighten, and fully unfasten the fasteners. For avionics switches, use the flathead screwdriver to toggle the switch state.
6	____	Make note of any tightness, tugging on gloves, contortion of hands, or other difficulty in these operations.

Structural Integrity Verification Test		
Assembler Signature:________		Safety Officer Signature: ________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist:
		- N/A
		Prerequisite lists:
		- N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	____	**Tools Needed:** Solidworks CAD Program
	____	**Components Needed:** full-scale launch vehicle CAD assembly

Continued on next page

Table 52 – continued from previous page

#	Inspector Initials	Step Instructions
1	______	Load the launch vehicle CAD assembly.
2	______	Ensure all parts are correctly defined for materials to ensure accurate simulation results.
3	______	Define force on launch vehicle from motor thrust plate equivalent to the maximum projected motor force of 31,000 N, the projected maximum force for the 'worst-case' motor size.
4	______	Run the CAD simulation for structural integrity.
5	______	Make note of any safety factors below 2 for structural failure.
6	______	Verify during full-scale test launch.

Bulkhead Pressurization Verification Test

Assembler Signature:______________________ **Safety Officer Signature:** ______________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - N/A **Prerequisite lists:** - N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Solidworks CAD Program
	______	**Components Needed:** bulkhead CAD assembly of drogue and main bay
1	______	Load the bulkhead CAD assembly.
2	______	Ensure bulkhead and supports are made of the correct material to ensure accurate simulation results.
3	______	Define pressure on the bulkhead using estimated peak pressure provided by Recovery subteam For the drogue bay: 15.654 psi For the main bay: 23.481 psi
4	______	Run simulation on bulkhead for structural failure.
5	______	Determine any failure points or areas with a safety factor below 2.
6	______	Verify CAD simulation by pressure testing bulkheads using pressure tester based off of the subscale pressure tester.
7	______	Attach pressure tester to airframe and pressurize to testing pressure. Verify minimal leakage.

Eyebolt Retention Ruring Recovery

Assembler Signature:______________________ **Safety Officer Signature:** ______________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Minimal safety concerns during computer simulation - During test launch follow all safety procedures and regulations - Ensure checklists are followed and marked off - Follow all guidelines set by RSO

Continued on next page

Table 54 – continued from previous page

#	Inspector Initials	Step Instructions
		- Verify checklists with safety officer - Wear any required PPE **Prerequisite lists:** - N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	_____	**Tools Needed:** N/A
	_____	**Components Needed:** Solidworks, Eyebolt and Bulkhead, CAD assembly.
S	_____	**Safety consideration: Insufficient set up may produce false results**
1	_____	Load the bulkhead CAD assembly
2	_____	Ensure bulkhead and supports are made of the correct material to ensure accurate simulation results
3	_____	Define pressure on the bulkhead using estimated peak recovery forces provided by Recovery subteam
4	_____	Run simulation on bulkhead and eyebolt for structural failure
5	_____	Determine any failure points or areas with a safety factor below 2.
6	_____	Verify simulation during test launch of full scale launch vehicle

Airframe RF Transparency Test

Assembler Signature:_____________________ **Safety Officer Signature:** _____________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Do not integrate any other system except electronic systems into airframe i.e. energetic system - Wear any required PPE - During test launch follow all safety procedures and regulations - Ensure checklists are followed and marked off - Follow all guidelines set by RSO - Verify checklists with safety officer **Prerequisite lists:** - N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	_____	**Tools Needed:** N/A
	_____	**Components Needed:** Integrated Launch vehicle
S	_____	**Safety consideration: Insufficient set up may produce false results**
1	_____	Integrate all transmitting and receiving systems into the airframe
2	_____	Check that all receivers and transmitters are communicating correctly.
3	_____	Ensure viable connection at 5ft, 25ft, and 50ft.
4	_____	Connection must also be ensured through test launches, or verified to be due to issues other then launch.

Airframe Exterior Holes Test		
Assembler Signature:________		**Safety Officer Signature:** ________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Minimal safety concerns during integration launch - Enlarging Venting will require standard PPE - Avoid sharp edges on launch vehicle airframe holes **Prerequisite lists:** - N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** Fully Integrated launch vehicle, pressure calculations
S	______	**Safety consideration: Insufficient set up may produce false results**
1	______	Analyse number of altimeters and calculate required hole area for each isolated section of the launch vehicles.
2	______	Determine maximum allowable pressure gradient for accurate altimeter readings within 10% of actual barometric pressure. (This will be based on the rate of ascent of the launch vehicle (corresponding to change in pressure over time) and the rate at which that pressure gradient can equalize between the interior and exterior of the vehicle through the venting holes.)
3	______	Determine the number of non venting holes required for arming and other required subsystem external access holes.
4	______	Ensure no other external holes in air frame.

Fin Impact Durability		
Assembler Signature:________		**Safety Officer Signature:** ________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Minimal safety concerns during integration launch - During test launch follow all safety procedures and regulations - Ensure checklists are followed and marked off -Follow all guidelines set by RSO - Verify checklists with safety officer - Wear any required PPE **Prerequisite lists:** - N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Instron Tensile Tester
	______	**Components Needed:** Test Fin
S	______	**Safety consideration: Insufficient set up may produce false results**

Continued on next page

Table 57 – continued from previous page

#	Inspector Initials	Step Instructions
1	______	Perform Instron testing on composite coupons of the same material as the fin to confirm properties where datasheet is not provided. Instron testing will follow procedure and standards outlined in ASTM D3039.
2	______	Load the CAD model of a fin.
3	______	Ensure all material selections are correct, and that properties match with Instron findings or datasheet specifications
4	______	Apply simulated forces on the fin at the rearmost tip, forward tip, and halfway along the trailing edge at 90 degrees orthogonal to the fin plane
5	______	Simulate results and note factor of safety for structural failure
6	______	Repeat tests with angles of 45 degrees and 0 degrees relative to fin plane
7	______	Verify CAD simulations with calculations from data collected during full scale vehicle test launch

Rover Chassis Drop Testing

Test Conductor Signature:________________ **Safety Officer Signature:** ________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Safety glasses must be worn
		- Structure must be free of batteries
		- No personnel can be within 5 ft of the person conducting the test
		Prerequisite lists: N/A
	_____	**Testing Equipment Needed:** Camera, tape measure
	_____	**Tools Needed:** Tape Measure, Camera
	_____	**Components Needed:** Payload Chassis (Make sure internals are not installed)
		Passing Condition: N/A, Dropping until failure
		Testing Procedure:
1	_____	Assemble the payload chassis. Make sure all internals such as batteries, motors, and electronics are NOT installed.
2	_____	Find a location free of bystander's to perform the drop test
3	_____	Set up cameras for filming the drop test to record how the chassis fails in real time
4	_____	Vertically extend tape measuring height to measure the drop height
S	_____	**Ensure test area is clear of bystanders.**
5	_____	Lift the payload chassis to the specified drop height and release it (repeat till chassis failure).
6	_____	Record Drop Height ________________
7	_____	Record Drop Height ________________
8	_____	Record Drop Height ________________
9	_____	Record Drop Height ________________
		Prototype weight ________________
10	_____	Once the chassis has failed stop the test and disassemble the chassis to identify where the failure occurred and how the chassis could be strengthened.

Collection Testing

Test Conductor Signature:________________ **Safety Officer Signature:** ________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Safety Glasses must be worn
		Prerequisite lists: Payload Collection Assembly
	_____	**Testing Equipment Needed:** Bin filled with simulated ice material
	_____	**Tools Needed:** LiPo Battery Charger
	_____	**Components Needed:** Prototype Rover and remote control
		Passing Condition: Rover Collects 10 mL of simulated ice
		Testing Procedure:
1	_____	Place payload in a bin large enough for the payload to move around in.
2	_____	Ensure payload is fully charged, turn on electronics, and prep for remote control. Rover system must include a fully functional collection system

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#	Inspector Initials	Step Instructions
3	____	Remotely actuate collection system (lower scoop, drive forward to collect ice sample, and retract system to store sample. **Passing Condition Met (Y/N):** ____________

Payload Ejection System Testing

Test Conductor Signature:____________ **Safety Officer Signature:** ____________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Ensure that all areas that move are clear of foreign objects.
		- Ensure that that the batteries are installed correctly.
		- Ensure that that all loose jewelry and clothing is removed and long hair is tied back.
		Prerequisite lists: Payload Ejection/Retention Assembly
	____	**Testing Equipment Needed:** Payload Ejection Test Bed
	____	**Tools Needed:** One 3/16-in. Hex Key Allen Wrench
	____	**Components Needed:** One Payload Ejection System, 1 Payload Prototype, 1 Test Airframe
		Passing Condition: The payload is fully ejected in 2 minutes. System must eject properly in 90% of tests.
		Testing Procedure:
1	____	Follow the Payload Ejection/Retention Assembly Checklist to install the payload ejection system into the test airframe. Ensure system is securely fixed to the test airframe. The following steps will double check that this process has been completed successfully and can be followed when conducting repeating the test.
2	____	Remove the leading push plate and set the rear push plate into position next to the motor. If payload prototype is already installed this step has already been completed.
3	____	Install the payload prototype within the ejection system. If payload prototype is already installed this step has already been completed.
4	____	Replace the leading push plate. The payload prototype should be contained within the 2 push plates. If payload prototype is already installed this step has already been completed.
S	____	**Safety Consideration: - The payload ejection system contains numerous pinch points, keep fingers clear.**
5	____	Connect the ejection/retention electronics.
6	____	Eject the payload. Repeat process until satisfied with number of tests.
		Passing Condition Met (Y/N, Successful Ejection %): ____________

Payload Retention System Strength Testing

Test Conductor Signature:____________ **Safety Officer Signature:** ____________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:

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#	Inspector Initials	Step Instructions
		- Designate an area to be the area of the test. This area must be open and clear of obstacles and spectators.
		- This test must be conducted by at least two members. Ensure that all participants are wearing safety glasses. Spectators must be standing outside the designated test area.
		Prerequisite lists: N/A
	______	**Testing Equipment Needed:** Payload Ejection System.
	______	**Tools Needed:** Weights Totaling 25 lbf.
	______	**Components Needed:** One payload ejection system, one payload prototype, one test airframe.
		Passing Condition: The payload ejection system shows no damage after loading 25 lbf. The payload ejection system shows no damage after dropping 25 lbf a small distance (about 1 in.) into the system.
		Testing Procedure:
1	______	Prepare the ejection/retention system by putting the push plates in their respective starting positions, one next to the motor and one by the end of the lead screw.
2	______	Hold the ejection/retention system from the motor, allowing the lead screw and attached push plates to hang. Keep system below head level at all times.
3	______	Second participant loads weights onto the low hanging push plate where the payload would naturally rest. Load until damage, failure, or 25 lbf loaded.
S	______	**Safety Consideration: - Keep feet and body clear of hanging system. If the system fails the weight will be dropped and could hurt participants.**
4	______	Remove all weight and inspect system for damage. Stop testing if any damage is found and record the test as a failure.
5	______	Prepare to load the full 25 lbf at once. Prepare to drop the weight from a small height (about 1 in.) to simulate in flight jolt forces.
S	______	**Safety Consideration: - Previous clearances must be maintained. Ensure again that feet and bodies are clear of the space below the hanging system and that spectators are outside the testing area. After checking the system for damage it is possible that participants and spectators have moved closer.**
6	______	Carefully drop the weight from a short height (about 1 in.) to simulate in flight jolt forces.
7	______	Record test results. If damage was found record in detail.
		Passing Condition Met (Y/N): ____________________

Drivetrain Testing

Test Conductor Signature:____________________ **Safety Officer Signature:** ____________________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Safety Glasses must be worn
		Prerequisite lists: Payload Collection Assembly
	______	**Testing Equipment Needed:**NA
	______	**Tools Needed:** NA
	______	**Components Needed:** NA

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#	Inspector Initials	Step Instructions
		Passing Condition: Wheel Assemblies remain firmly attached to motor shafts
	Testing Procedure:	
1	______	Ensure that the wheels are correctly attached to motors
2	______	Jostle the wheel assembly in the axial direction. Turn slightly as this is done to test different angles
3	______	Repeat for both wheels
		Passing Condition Met (Y/N): ____________________