OREGON STATE UNIVERSITY

2020 NASA SL TEAM

104 KERR ADMIN BLDG. # 1011

CORVALLIS, OR 97331

Critical Design Review

January 10, 2020

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Acronym Dictionary

ABS Acrylonitrile Butadiene Styrene. 22

AGL Above Ground Level. 14, 18, 201

AIAA American Institute of Aeronautics and Astronautics. 231, 249

APCP Ammonium Perchlorate Composite Propellant. 203

ASTM American Society for Testing & Materials. 29

ATU Avionics Telemetry Unit. 5, 60–66, 149, 233, 234

BEAVS Blade Extending Apogee Variance System. 1, 5, 7, 15, 17, 24–29, 31–37, 39–41, 46, 47, 60, 61, 130, 144, 159, 174, 176, 205, 245

BP black powder. 5, 8, 14, 15, 21, 54, 58, 59, 72–78, 195, 196, 217, 230–232

CAD Computer-Aided Design. 17, 19, 20, 22, 24, 26, 193, 235

CDR Critical Design Review. 16, 17, 203, 207

CFD Computational Fluid Dynamics. 20

CG Center of Gravity. 237

CNC Computer Numerical Control. 41, 44, 45, 88, 97, 124, 174

CO2 Carbon Dioxide. 15, 78, 204, 217, 231, 246

CSV Comma Separated Values. 62, 64, 234

DC Direct Current. 14, 137, 245

DDM Design Decision Matrix. 5, 18, 26, 27

DUO Dynamic Ultra Once-over. 236

DXF Drawing eXchange Format. 41, 44

EDM Electrical Discharge Machining. 34

ESD Electrostatic Discharge. 75, 196, 232

FAA Federal Aviation Administration. 158–160, 227, 230

FEA Finite Element Analysis. 35, 93, 94, 99

FMEA Failure Mode Effects Analysis. 5, 169, 172, 174, 177

FN Foreign National. 199

FOD Foreign Object Debris. 182

FPV First-Person View. 84, 87

FRR Flight Readiness Review. 186, 199, 201, 207, 209–212, 228

GPS Global Positioning System. 62–65, 84, 86, 87, 145–147, 149–151, 232

GUI Graphical User Interface. 60, 62, 64, 84, 85, 87, 233

HDPE High-Density PolyEthylene. 134

HPR High Powered Rocketry. 152

HPRSC High Power Rocket Safety Code. 157–160

HPSC High Power Safety Code. 157

HRIT Horizontal Rotating Index Tool. 43

HTML HyperText Markup Language. 65

HTTP HyperText Transfer Protocol. 66

HVAC Heating, Ventilation, & Air Conditioning. 42

I/O Inputs and Outputs. 38

I2C Inter-Integrated Circuit. 35, 37, 39, 60, 63, 64

ICE Innovative Composite Engineering. 19, 24, 249

ID Internal Diameter. 18, 246

IDE Integrated Development Environment. 60

IMU Inertial Measurement Unit. 87, 233

JHA Job Hazard Analysis. 42

LED Light Emitting Diode. 145, 149

LiPo Lithium Polymer. 138, 145, 149, 189, 212, 219, 245, 246

LoRa Long Range. 60, 87

LRR Launch Readiness Review. 228

MOSFET Metal–Oxide–Semiconductor Field-Effect Transistor. 134

MPRL Machine Product and Realization Laboratory. 42

MSDS Material Safety Data Sheet. 164, 166, 167, 229

MSS Machine Shop Safety. 165

NAR National Association of Rocketry. 157–160, 163, 203, 227, 229

NASA National Aeronautics and Space Administration. 14, 67, 108, 110, 158–160, 184, 199, 200, 203, 209, 212, 225, 229, 249

NFPA National Fire Protection Agency. 163, 165

NOAA National Oceanic and Atmospheric Administration. 232

NTS Not To Scale. 8, 71

OD Outer Diameter. 246

OSB Oriented strand board. 8, 98

OSGC Oregon Space Grant Consortium. 244, 249

OSRT Oregon State Rocketry Team. 9, 14–17, 19, 26, 31, 32, 38, 41, 48, 51, 55, 56, 59, 66, 68–71, 78, 81, 82, 84, 88, 89, 91, 94–97, 99, 104, 105, 107–109, 119, 120, 124, 126, 163, 165, 170, 184, 186–189, 198, 199, 201–203, 215, 229, 230, 233, 236, 237, 239–245, 248, 249, 251

OSU Oregon State University. 16, 19, 26, 88, 97, 124, 133, 165, 231, 233, 249

PCB Printed Circuit Board. 8, 35, 39, 40, 106, 107, 134, 145, 146, 149, 176, 180, 237, 245

PDR Preliminary Design Review. 15, 22, 31, 251

PID Proportional-Integral-Derivative. 175

PLA Polylactic Acid. 8, 98, 116, 117, 245

PPE Personal Protective Equipment. 41, 42, 44–47, 133, 194, 195

PWM Pulse Width Modulation. 37

RAC Risk Assessment Code. 5, 156–162, 164–168

RF Radio-Frequency. 18–20, 24, 60–62, 106, 107, 234

RPM Rotations per Minute. 43

RPN Risk Priority Number. 169–183

RRC3 Rocket Recovery Controller 3. 51, 59, 78, 79, 81, 82, 201, 206, 217

RSO Range Safety Officer. 131, 157, 166, 199, 203, 204, 209, 212, 216, 229, 230

SL Student Launch. 14

SMA Sub-Miniature Version A Connector. 138

SO Safety Officer. 157, 212, 216, 217, 228–230

STEM Science, Technology, Engineering and Mathematics. 199, 228, 251

STP Standard Temperature and Pressure. 197

TRA Tripoli Rocketry Association, inc. 157–160, 203, 229

USB Universal Serial Bus. 62, 65, 138, 145–147, 150, 151

USLI University Student Launch Initiative. 70, 81, 97, 184, 198

UV Ultraviolet. 167

1 Summary of Report

1.1 Team Summary

Table 1: Team Summary Chart

Team Name:	Oregon State University 2020 NASA Student Launch (SL) Team
Mailing Address:	104 Kerr Admin Bldg. #1011 Corvallis, OR 97331

Table 2: Team Mentor Summary Chart

Name of Mentor	Dr. Nancy Squires	Joe Bevier
Position within the OSRT	Team Advisor	Team Mentor
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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

1.2 Launch Vehicle Summary

The Oregon State Rocketry Team (OSRT) launch vehicle will be designed to safely deliver the payload to a target altitude and protect it during the recovery and landing process. It will complete this mission while maintaining reusability and the ability to be prepared for additional flights the same day. It will be reasonably user friendly while maintaining safe operations for the operators and bystanders. The launch vehicle currently is 109 in. in length and has an inner diameter of 6.25 in. The launch vehicle's current projected weight is 61 lbf. The current motor selection is the AeroTech L2200, which was chosen based on desired altitude and weight of the vehicle. The launch vehicle target altitude will be defined as 4000 ft apogee. The recovery system features one main and one drogue parachute. The drogue will deploy at apogee and the main will deploy at 600 ft Above Ground Level (AGL). The primary ejection system is black powder (BP) with a larger BP charge as a back-up. The launch vehicle will have an active airbrakes system to successfully reach the projected altitude. The launch vehicle is designed to launch on a 1515 rail.

1.3 Payload Summary

The OSRT payload will utilize a bi-axial rover system to complete the National Aeronautics and Space Administration (NASA) mission. The rover consists of a wooden panel and aluminum rod chassis, with a carbon fiber tail for support. The bi-axial wheels are powered by separate 12 V Direct Current (DC) motors. The wheels collapse to a diameter of 6.25 in. while stowed in the airframe, then expand to a diameter of 10 in. when ejected. This gives the rover increased ground clearance to avoid obstacles. When stowed in the launch vehicle the rover will be retained by a leadscrew ejection mechanism behind the nose cone. The payload will weigh 9.06 lbf.

2 Changes Made Since PDR

2.1 Vehicle Criteria Changes

Several revisions have been made to the launch vehicle since Preliminary Design Review (PDR). After testing with the subscale model the parachute bays were extended to ensure that parachutes of a larger size are able to fit. Several sealing bulkheads have been placed in key positions in the airframe, replacing bulkheads without sealing properties. This was done in order to ensure proper recovery deployment and accurate altimeter readings. The main recovery altimeter bay has also undergone updates. Both of the bulkheads have been replaced with self sealing ones and an aluminum mounting ring has been added for switch mounting and as a set screw attachment point. The altimeter bay no longer requires an inner shell and uses the coupler itself as the outer housing in the interest of reducing weight and complexity. The motor retainer has been switched to a commercially available Aero Pack quick-change retainer that mounts the thrust plate. The aft parachute mounting points have changed as well, to 2 separate mounts with reinforced supports while occupying a reduced cross-sectional area. For the recovery system, due to weight and space considerations, the custom Carbon Dioxide (CO2) charge system has been removed from the launch vehicle, and the parachutes will now be deployed solely with BP. Since the team is still dedicated to safety, new safety steps and devices have been implemented to ensure that the BP usage and assembly processes are as safe as they possibly can be.

2.2 Payload Criteria Changes

Since PDR, the OSRT payload has gone through a variety of changes. The collection system has been adjusted to a scoop-style design. Analysis of the simulated ice material, along with testing, has shown that a simpler design that does in not an auger was feasible. A scoop increases the simplicity of the system in addition to reducing the weight and risk of failure. The ejection and retention system has seen little change. The drivetrain has been revised to include spring mechanisms to actuate the spokes. Lastly, the chassis has a variety of revisions as a result of improvements noticed during prototyping.

2.3 Blade Extending Apogee Variance System (BEAVS) Electrical Changes

From PDR designs, some electrical components for the BEAVS system were changed. Specifically the pressure sensor, accelerometer, and motor. These sensors were changed from the MS580-14BA to the MPL3115A2 for the pressure sensor and from the MMA8452Q to the ADXL377 for the accelerometer. In both cases, the sensors were inaccurate and not sensitive enough to environmental changes as is required for the system to be accurate. Additionally, the accelerometer was not rated to withstand the launch forces and was likely to break during the initial take-off which would result in a failure to calculate apogee accurately. The motor was changed from the FIT0441 brushless motor to the HD-1235MG servo motor to better integrate with the rack and pinion mechanism design and simplify programming. This motor also provides a higher torque which is desirable.

2.4 Project Plan Changes

The subscale launch was pushed back a week because it was discovered the night before the originally planned launch that the parachutes would not be able to fit into the parachute bay. While the team could have made the system work, it was decided that instead of hastily throwing something together, the launch should be pushed out a week. This would allow the team to fix the subscale and have a proper launch. Since the subscale launch went so well, the team decided to spend time working to test, develop, and manufacture systems based off of the first subscale, and therefore, only a second launch was pursued.

The second subscale launch was pushed back to January 5th, the Sunday before Winter Term at Oregon State University (OSU). This date was chosen because the team tried to test the altimeters without doing another subscale launch, but then decided that, in order to test the altimeters in the most reliable way possible, another subscale launch was necessary. This launch was scrubbed. Refer to section 3.4 for details.

The Critical Design Review (CDR) rough draft due date was moved forward to December 22nd to allow the team more time to proofread. Additionally, this would give proofreaders more time to read and adjust the team's document. Also, the full scale recovery system ordering had to be extended due to the issues that OSRT had finalizing a rover weight. Finally, the portion of the team that would like to drive to Huntsville opted to leave around March 28th instead of the 23rd, so that was reflected in the project plan as well.

3 Vehicle Criteria

3.1 Selection, Design, and Rationale of Launch Vehicle

The OSRT 2020 launch vehicle is designed to deliver a payload to a specified apogee of 4000 ft and return it safely to the ground.

3.1.1 Launch Vehicle Layout Overview

Figure 1 is the current Computer-Aided Design (CAD) model of the launch vehicle design. The current model is subject to changes as needed during the manufacturing phase of the full scale model, however the general layout and overall design will not change post CDR submission.

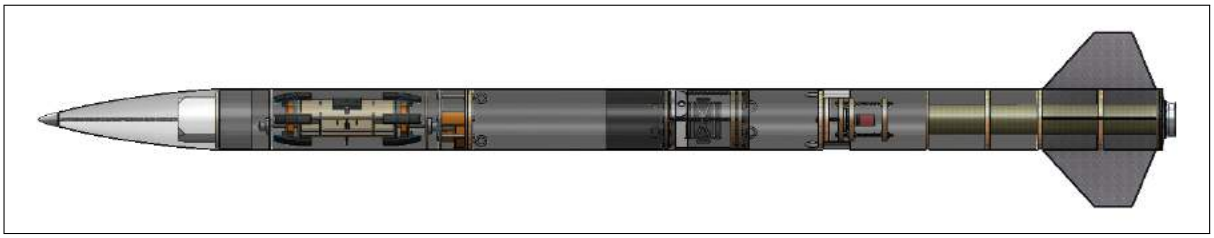


Figure 1: Launch Vehicle CAD Model

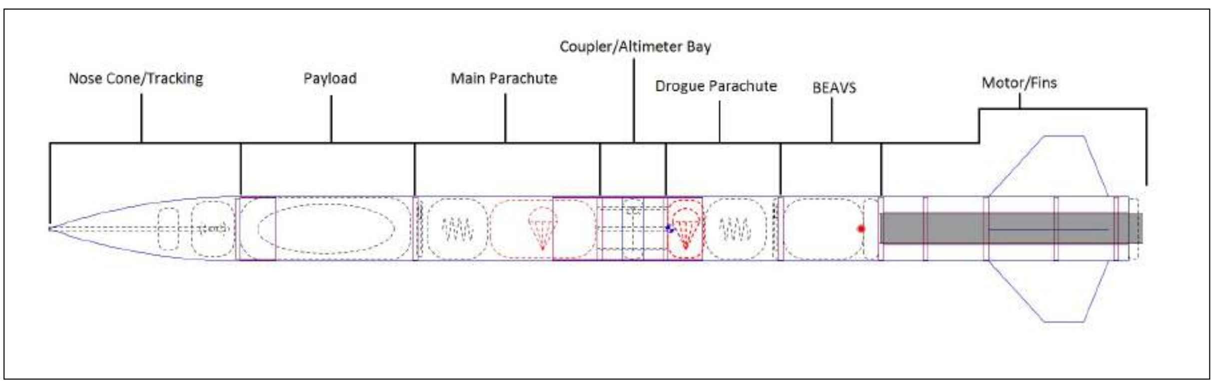


Figure 2: Launch Vehicle Layout

The launch vehicle is 109 in. long and 61 lbf. The layout shown in Figure 2 notes the position of the different sections of the launch vehicle. These sections are: nose cone assembly, payload bay in the fore section, main parachute bay in the fore section, altimeter bay in the central coupler, drogue parachute in the aft section, BEAVS bay, and motor bay in the aft section. The center of pressure is indicated with the red dot in Figure 2 at 81.13 in. from the nose cone, and the center of gravity is indicated with the blue dot in Figure 2 at 62.04 in. from the nose cone, giving a stability margin of 2.98 calibers. The subsections of the launch vehicle are described in detail below.

3.1.2 Mission Statement

The launch vehicle will successfully deliver the payload to the specified apogee of 4000 ft AGL, deploy the drogue parachute at apogee, deploy the main parachute at 600 ft, and then deliver the payload to the ground within a 2,500 ft radius of the launch site. The 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 will remain reusable after launch, able to be readied for another launch the same day without major changes or repairs.

3.1.3 Fore Section

The fore section of the launch vehicle houses the payload bay and the main parachute bay. This section will be made out of a blend of carbon fiber and fiberglass and has been calculated to weigh 7.71 lbf without the payload or parachutes installed. The airframe is 6.25 in. Internal Diameter (ID), 48 in. long and transitions from carbon fiber to fiberglass 20 in. from the end of the main parachute bay. The main purpose for this transition is to enable Radio-Frequency (RF) transparency between the base station and the payload deployment system because of RF transmission blocking properties of carbon fiber. The choice to have a transition over having an entire fiberglass section was due to the need to reduce as much weight as possible in the launch vehicle. Carbon fiber was chosen for the rest of the airframe because it is lighter for comparable strength, having a higher Young's Modulus than fiberglass, enabling it to be able to perform reliably when placed under high compressive stresses while reducing weight. Shown below is a decision matrix that was used to help determine the airframe tube material.

Table 3: Airframe Tube Material Design Decision Matrix (DDM)

Design		**Carbon Fiber**		**Fiberglass**	
Requirement	Weight	Rating (1-5)	Score	Rating (1-5)	Score
Strength	10	5	50	4	40
Availability	5	3	15	3	15
Weight	6	5	30	3	18
Manufacturablility	5	2	10	2	10
Total		105		83	

The fore section of the airframe has a single main bulkhead that is the mounting point for both the main parachute and the payload retention system, positioned on opposing faces. The bulkhead will be located at the point of airframe material transition, ensuring that the entire payload bay has access to RF transparent airframe. This will ensure communication between the payload and the ground station throughout the mission. The bulkhead is then secured to the airframe using G5000 RocketPoxy, with fillets on both sides to ensure a strong bond. The strength of this bond is essential as the payload retention system relies on the bulkhead to hold the weight of the payload during ascent and decent.

The maximum strength of an epoxy shear joint with a bead of epoxy approximately 0.25 in. in height and using the known properties of the bulkhead and the G5000 RocketPoxy that is being used during construction:

$$MaximumStrength = (\pi * 6.25 * 0.25 * 7,600 * 0.5) = 18,653lbf \tag{1}$$

This shows that strength of an optimal bond between the bulkhead and airframe to be significantly strong. 18,000 lbf is much more than the launch vehicle would be expected to withstand.

The Fore section airframe tube will be constructed by Innovative Composite Engineering (ICE), a local composite manufacturing company. This company was chosen because of the lack of facilities in the OSU manufacturing labs to construct the tubes and the good quality of the previous work they have done for the OSRT. Figure 3 shows a CAD model of the fore section of airframe with no parachute or payload integrated.

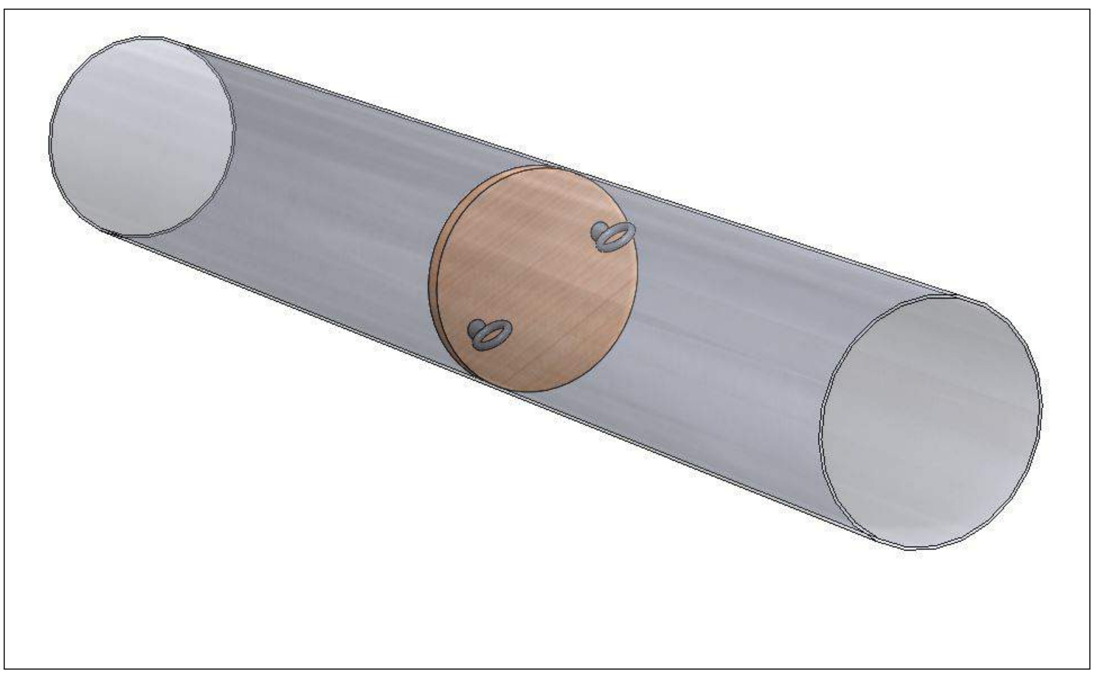


Figure 3: Fore Section Air-frame

3.1.4 Nose Cone

The nose cone selected has a tangent ogive profile with a rough length-to-width ratio of 3.5:1. The material will be fiberglass to assist RF transparency. The nose cone will be commercially purchased with an initial outer diameter of 7.5 in. to be resized to fit the airframe. The popularity of this shape is largely due to the ease of constructing its profile [19]. Computational Fluid Dynamics (CFD) testing has shown that at the anticipated subsonic speed of Mach 0.5, the ogive shape is seen as the most effective nose cone shape in decreasing drag on the overall vehicle. Figure 4 shows a CAD rendering of the nose cone.

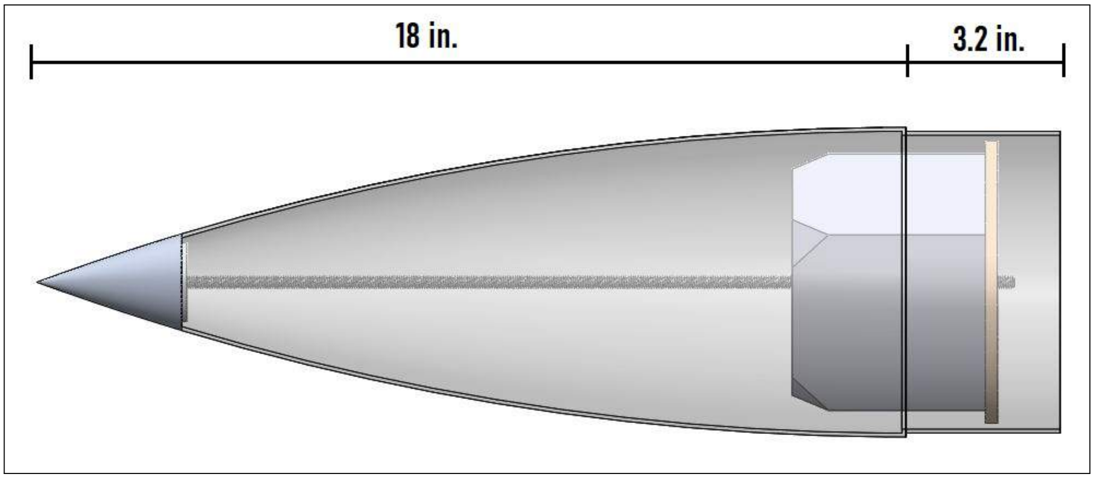


Figure 4: Nose Cone Assembly

The ogive nose cone shape can be characterized in Equations 2-4.

$$OgiveRadius = \frac{(OuterRadius)^2 + (Length)^2}{2(OuterRadius)} \tag{2}$$

$$y = \sqrt{(OgiveRadius)^2 - (Length - DistanceTip)^2} + (OuterRadius) - OgiveRadius) \tag{3}$$

$$y = \sqrt{\frac{(OuterRadius)^2 + Length^2}{2(OuterRadius)}^2 - (Length - DistanceTip)^2} + (OuterRadius - \frac{(OuterRadius)^2 + Length^2}{2(OuterRadius)}) \tag{4}$$

The nose cone will be re-manufactured because there is no commercial option for a nose cone with a 6.25 in. diameter. First, layers will be cut with a ply cutter and mold release will be applied to the coupler mold. The coupler mold will be used to layup a segment of coupler for the nose cone. The coupler will be resized to where it extends partially into the trimmed nose cone, then additional layers will be layed up between the coupler and the inside of the nose cone to secure it. After, it will go through a bagging process using ply and a breather, to ensure the plastic is holding the seal, to put in the composite oven. The shear pins will be threaded through the cylindrical fiberglass section of the airframe into the brass inserts in the nose cone. To allow for parachute attachment, a bulkhead will fit through the nose cone and will be secured with 2 M10 nuts and bolts, the smaller M10 nut will be towards the bulkhead to prevent a significant amount of self-loosening [7]. Eye bolts will be attached to the bulkhead with epoxy to allow parachute detachment points.

3.1.5 Main Coupler and Altimeter Bay

The main coupler is central to the design of the launch vehicle, tethering the fore and aft sections together during flight and recovery, along with housing the main recovery altimeter bay. The design is derived from several design iterations and testing completed during the subscale flights. The altimeter bay located within the coupler is completely removable from the coupler itself, enabling easier access to the altimeters for connecting BP deployment systems and adjusting altimeter settings. The coupler is estimated to weigh 4.75 lbs with electronics installed and has dimensions found in Figure 5.

Figure 5: Main Coupler and Altimeter Bay

The design includes a 15 in. long outer shell with a 2 in. switch band in the center. The switch band enables the altimeter bay to have access to the outer airframe for pressure equalization between the recovery bay and external atmospheric pressure while also giving access to arming switches. The length of the coupler enables it to fit into each the fore and aft airframe to a depth of 6.5 in., ensuring a structurally sound couple between sections. This coupler is designed to allow the fore and aft sections to be ejected independently off of the coupler, with the remaining sections retained using 4 shear pins on each section. This will allow the launch vehicle to utilise dual deployment, being able to deploy the drogue and main parachutes independently at any point during flight. The coupler separates the drogue and main parachute compartments, greatly reducing the chance that there will be tangling in the shock cords during the deployment of the recovery systems, as they are in different bays. This also allows altimeter bay access to both the drogue and main parachute bay for deployment charge wires. Using this design allows the launch vehicle to only need one recovery altimeter bay for two separate parachute bays, reducing complexity and weight of the overall launch vehicle. Figure 5 shows a CAD model of the coupler subsystem with the altimeter bay installed.

The center of the coupler houses the main recovery bay, shown in Figure 5, which is built as a separate unit from the structural coupler shell that houses it. The version present in the PDR included an inner shell around the bay but was redesigned as it was unnecessary to protect and seal the bay and added significant complexity to the manufacturing process. The altimeter bay is constructed of an altimeter mounting plate, held between two sealing bulkheads, assembled on 4 threaded rods. It is held in place with four set screws that are secured through the 2 in. switch band in the center of the coupler shell. The set screws will be secured through the switch band and coupler shell into an aluminum ring, which has mounting points for the switches as well. The aluminum ring will double as the fore compression ring for the fore sealing bulkhead to reduce part count, weight, and complexity. A gasket will be tightened between the ring and the bulkhead, compressing the gasket to seal the bay from the parachute bay. The aft compression ring in the altimeter bay will be constructed of plywood, as it is not providing support to the bay and only compressing the gasket. There will be an access hole in the center of both bulkheads to enable e-match wires to be threaded through. This will then be sealed with a bolt and washer, compressing a soft gasket to seal around the access hole and e-match wires. this will allow the parachute bay to pressurize. There is very little shear stress transferred through the set screws since the forces of launch travel through the outer coupler and the forces of recovery travel though the threaded rods of the coupler. The set screws only have to hold the altimeter bay in place during launch and recovery. The set screws do not support the mass of the launch vehicle. Because the coupler is crucial to the structural stability of the airframe during launch and descent while still needing to maintain a light weight, the coupler will be made of carbon fiber. The coupler itself will be laid up inside a section of fiberglass tube manufactured on the same mandrel as the airframe. This decision will ensure a perfect fit for the nonstandard tube size. The carbon fiber will be laid in alternating orientations of 0, 90, and 45 degrees. This allows for optimum strength in all directions. The switch band will be cut from a section of airframe that has been ordered over-sized for this exact purpose. The altimeter mounting plate will be 3D printed, as this allows for light and simple manufacturing. The mounting plate only needs to hold in place the altimeter and batteries, neither of which are heavy enough to need a stronger material than 3D printed Acrylonitrile Butadiene Styrene (ABS) plastic. The 9 V batteries that power the recovery system will be housed within commercially available battery enclosures designed specifically for the 9 V batteries. Figure 6 shows an exploded view of the coupler and altimeter bay without the recovery electronics present.

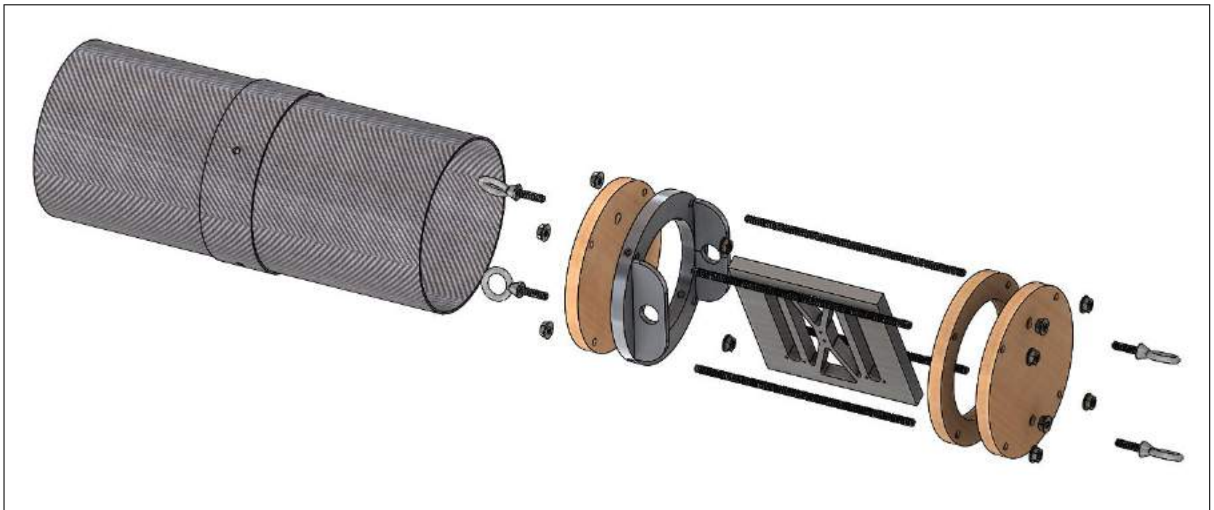


Figure 6: Main Coupler and Altimeter Bay Exploded View

There will be two eye bolts on each bulkhead of the altimeter bay that will distribute the stresses of the recovery system deployment, increasing the factor of safety of the connection. The bulkheads on either side of the bay are connected by 4 1/4 in. steel threaded rods that provide tensile strength to the system for parachute deployment, negating shear stresses in an epoxy joint and the outer tube. Originally designed with 6 threaded rods, the system was reduced to 4 in the interest of reducing weight after stress analysis determined the number was unnecessary. The rod materials had a Tensile strength of 150,000 psi, making 4 rods more than enough to maintain a high factor of safety. Given that the rods are 1/4 in. diameter, the max force they can hold can be calculated. This gives a factor of safety over the maximum possible calculated recovery forces exerted on the shock cords right after main parachute deployment.

$$MaxExpectedStress = \frac{F}{A} = \frac{7321.6}{4 * \frac{\pi}{4}\frac{1}{4}^2} = 37,290psi \tag{5}$$

$$SafetyFactor = \frac{MaxTensileStrength}{MaxExpectedStress} = 4.02 \tag{6}$$

This shows that the coupler is more than able to handle the maximum forces at main parachute deployment. The maximum forces will not be sustained through descent as the launch vehicle slows to its final descent speed. The decreasing speed will decrease the stress on the coupler significantly. The compressive launch forces will be passed through the switch band on the coupler, which will be cut from the airframe itself to ensure structural stability and a proper fit. Software simulations have been performed to validate calculations and ensure the factor of safety of the coupler before manufacture. This was confirmed during the subscale launch by using a scaled version of the coupler.

3.1.6 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 50 in. long and weighs approximately 20.08 lbf after motor burnout. The airframe tube itself is made out of the same carbon fiber that is present in the fore section, and also manufactured by ICE in the same manner. The aft section airframe tube will be made entirely of carbon fiber and therefore will not have RF transparency, it is not needed in the aft section. Since the aft section will house the BEAVS system it will have two slots cut out for the blades to extend through. The BEAVS system will be supported off of the BEAVS bulkhead, held in place by the aft parachute mounts. The mounts connect to the drogue parachute and tether the aft section to the rest of the launch vehicle during recovery. Because this is such a vital function, the contact area of the aft parachute mounts has been increased and will be epoxied to the airframe using G5000 RocketPoxy. Figure 7 shows a CAD model of this mount. This connection has been calculated to have a factor of safety of 8. From the design of the launch vehicle it is known that the aft parachute mounts have a contact area of $12.7in.^2$. The mounts will be constructed of aluminum as significant strength is required to tether the aft section to the rest of the launch vehicle while still trying to maintain a small amount of cross sectional area. Some of this cross sectional area has been reserved, as BEAVS needs to be able to slide into place in the airframe without additional external airframe access beyond the parachute bay. This will maintain the strength of the aft airframe while still allowing easy modification and access to the BEAVS system.

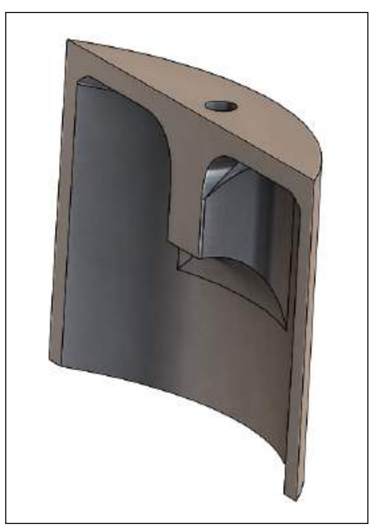


Figure 7: Aft Parachute Mount

The aft parachute mounting point is able to hold the maximum possible calculated forces that will be placed upon it. Additionally, it will satisfy the team requirement of all systems exceeding a safety factor of 2.

Figure 8 below shows the construction of the parachute retention and BEAVS bulkhead placement. There is a main bulkhead and a sealing bulkhead that will compress a gasket between when 4 1/4 in. fasteners are tightened, sealing the BEAVS bay off from the drogue parachute bay. This will enable the drogue parachute bay to pressurize for deployment, as the BEAVS bay fin cutouts leave it open to atmosphere.

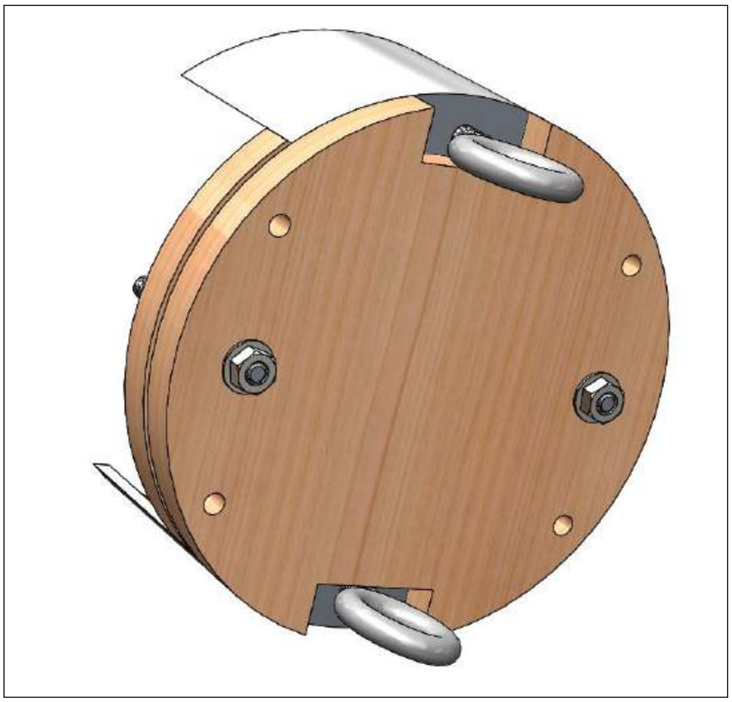


Figure 8: Aft Parachute and BEAVS Mounting Bulkhead Assembly

The motor bay in the aft section consists of a motor tube held in place with 4 centering rings, capped at the end with a thrust plate and quick-change motor retainer. The centering rings will be made of the same plywood as the bulkheads because the material is more than suitable and will reduce the amount of differing materials in construction. The centering rings only hold the motor tube in place during flight as the thrust plate transfers the forces of the motor directly to the airframe. The centering rings and motor tube will be held in place using G5000 RocketPoxy, ensuring that none of the components or motor will shift during flight. The fins will be attached through the airframe wall and epoxied to the motor tube. This will increase the strength of the connections between the fins and the airframe. It will also decrease the chance of damage to the aft section of the airframe upon landing due to the increased rigidity of the section. Figure 9 below shows the aft section of the launch vehicle.

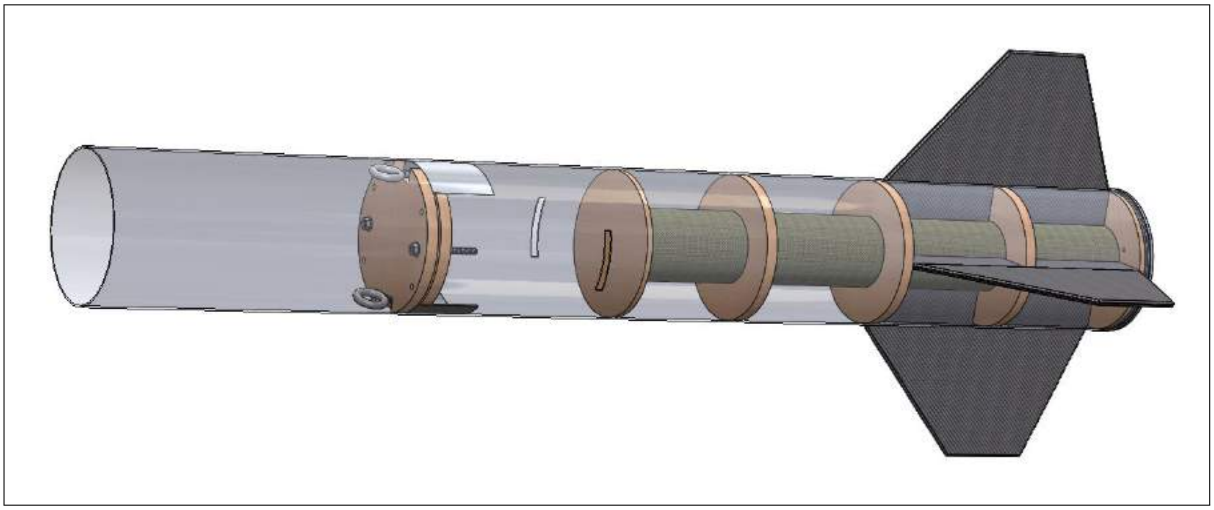


Figure 9: Aft Assembly

3.1.7 Motor Selection

Table 4 below shows the motor selection criteria used by OSRT to select a motor. OSRT ultimately decided to use the AeroTech L2200G motor.

Table 4: DDM For Motor Selection

Motor Performance Based on Current Rocket Measurements (diam. 6.41 in., length 109 in., mass 61 lb)									
Design		**AeroTech L2200G**		**Cesaroni L1685SS**		**AeroTech L1420R**		**Cesaroni L1410SK**	
Requirement	**Weight**	Rating (1-5)	Score	Rating (1-5)	Score	Rating (1-5)	Score	Rating (1-5)	Score
Expected Apogee	7	4	28	4	28	1	7	2	14
Cost	3	4	12	1	3	1	3	1	3
Availability	3	3	9	2	6	3	9	1	3
Max Thrust	6	4	24	3	18	3	18	3	18
Burn Time	8	4	32	4	32	4	32	3	24
Total			**105**		**87**		**69**		**62**

Expected apogee is necessary because a significant portion of the launch scoring is based on apogee accuracy. It is important to hone the CAD simulation to ensure that any apogee adjustments are within the capabilities of the BEAVS system. Accurate simulations will allow for more involved motor selection that will come closer to the expected apogee and allow the air-brake to make finite adjustments. A motor that can reach that apogee must be selected.

The cost of the motor is also relevant because OSU has access to donated and previously purchased motor components. There are various different sizes for level 2 rocket motors and if the motor selected does not have matching dimensions with those parts the cost will increase by hundreds of dollars. Another cost consideration is varying motor power propellant which can vary up to $100.

Availability is relatively less of a concern, although it must still be considered given that lack of availability can eliminate an option. Due to the high demand of this size of rocket motor during the competition, propellant reload and other motor parts must be sourced and confirmed for availability prior to selection. If a motor or its constituents are not readily available, it need not be considered. Ratings are determined by researching how many vendors offer the product and how many vendors, if any, are sold out.

Max thrust and burn time are fundamental for motor selection as each directly impacts and reflects motor performance. Necessary robustness of the motor retention system will vary slightly based on thrust forces from the motor of the rocket. Increased motor retention strength potentially brings more motors into feasible consideration. Initial simulations in OpenRocket show that thrust needed to carry the rocket to the necessary competition altitude can decrease with an increased motor burn time. Lower instantaneous thrust from the motor reduces stresses on the rocket structures, however, the BEAVS only activates after motor burn out. This sets a maximum constraint on motor burn time given that maximized use of the apogee control system will allow for an accurately controlled ascent. Thus, it is necessary to balance sustained structural integrity under launch forces, while simultaneously providing enough time post-burn for the BEAVS system to properly adjust apogee. It is also known that a higher thrust, shorter burn time will undergo more extreme drag forces due to higher velocity. This further increases the effectiveness of the apogee control system, which functions by modifying drag forces.

The motor selection DDM in Table 4 shows that based on the weights applied to each requirement, the AeroTech L2200G best fulfills the most important requirements. This motor will be 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.

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 10[11]. The thrust curve shows that over a burn time of 2.3 s the motor applies a maximum thrust of 697 lbf.

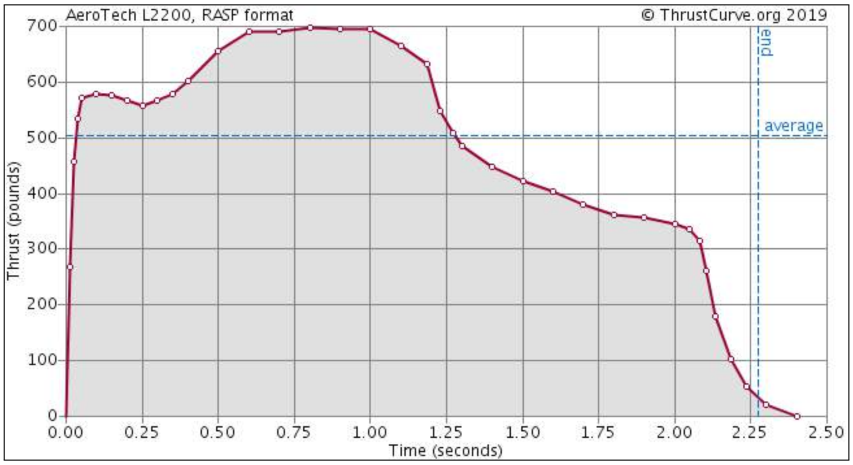


Figure 10: Motor Thrust Curve

With this motor selection and the current vehicle dimensions OpenRocket simulation estimates that the rocket will exceed the predicted apogee altitude by approximately 400 ft. It is optimal to have a motor that is predicted to exceed the necessary apogee since factors such as drag, varying wind speed, air density, and other inclement weather, can only be approximated and will reduce maximum altitude. A higher expected altitude is also preferred because it ensures that the motor can reach the predicted apogee while allowing the BEAVS system to reduce the altitude to match the prediction.

3.1.8 Motor Retention and Thrust Plate

The motor used in the final launch vehicle will utilise a thrust plate. This will enable forces from the motor to be transferred to the outer airframe tube without the need to travel through epoxy joints between the motor tube, centering rings, and airframe. Figure 11 below shows the thrust plate.

Figure 11: Thrust Plate

The thrust plate was designed for use with the Aeropack flange 75 mm motor retainer. The motor retainer will bolt through the thrust plate to a centering ring, securing it to both the thrust plate and the airframe. This assembly is shown below in Figure 12. The thrust plate was simulated to withstand and transfer the force to the outer airframe of the maximum force of the chosen motor to a factor of safety of 5 using SolidWorks software simulations. The motor tube itself will be made out of fiberglass and held in place using 4 centering rings and an end cap to separate it from the BEAVS bay.

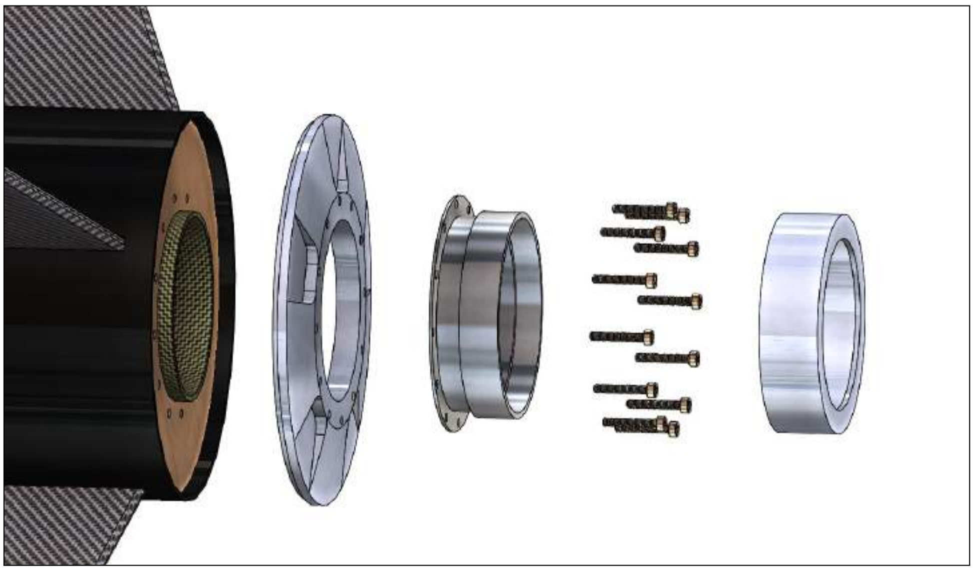


Figure 12: Motor Retaining Assembly

3.1.9 Fins

The launch vehicle will incorporate a set of 4 1/4 in. thick trapezoidal fins with a set fillet of 1/10 in. radius and leading/trailing edges for stabilization. The fins will be constructed to meet a shear modulus of $3.5 \cdot 10^6$ psi to ensure high torsional stiffness to reduce torsional vibrations and prevent lift forces from becoming greater than damping forces [9]. The shear modulus value will be verified using an American Society for Testing & Materials (ASTM) C273 tester.

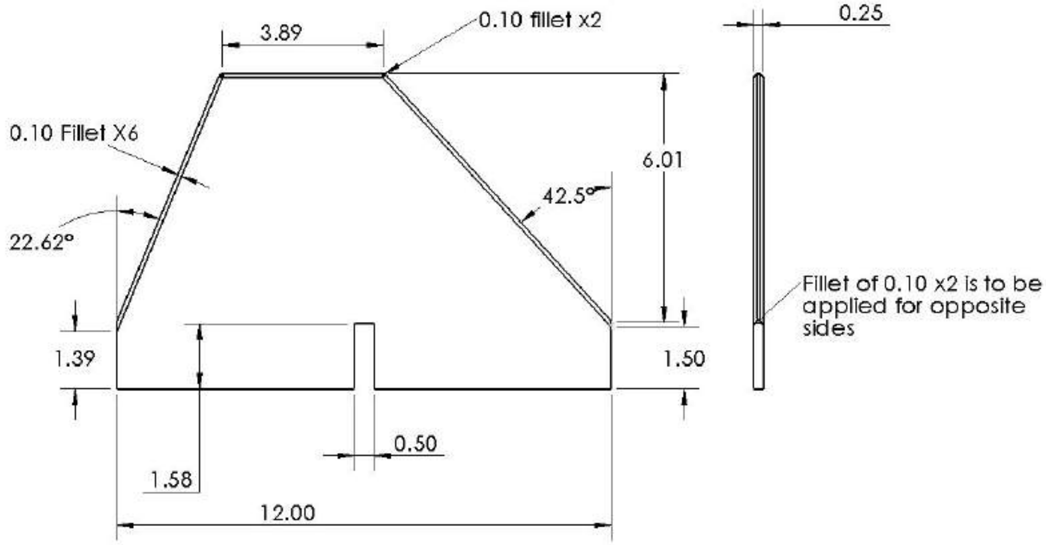


Figure 13: Fin Drawing

Figure 14: Fin Design with Epoxy Fillets

The maximum velocity for the launch vehicle has been calculated to be approximately 541 ft/s, shown in Equation 7.

$$V_f = 1.223 C_{s0} exp(0.4 \frac{h}{H}) \sqrt{\frac{G}{P_0}} \sqrt{\frac{2+B}{1+\lambda}} \left(\frac{T}{B}\right)^{\frac{3}{2}} \tag{7}$$

Fin flutter was calculated to be 4,331 ft/s. Fin flutter will be considered as a low concern. Calculations can be seen in Table 5 and Equation 8.

Table 5: Fin Flutter Equation Variables

V_f	Fin Flutter (ft/sec)
c_r	Root Chord (in.)
c_t	Tip Chord (in.)
b	Fin Height (in.)
t	Fin Thickness (in.)
G	Shear Modulus (psi)
H	Atmospheric Scale Height at Sea Level (ft.)
h	Altitude at Maximum Velocity (ft.)
P_0	Atmospheric Pressure at Sea Level (psi)
Cs, 0	Speed of Sound at Sea Level (ft/sec)
S	$\frac{1}{2}$ * (c_r+c_t) Fin area (in.^{2}])
λ	$\frac{c_r}{c_t}$ Fin Taper Ratio
B	$\frac{b^2}{S}$ Aspect Ratio
T	$\frac{t}{c_r}$ Normalized Thickness

$$V_f = 1.223 \cdot 1129 ft/sec \cdot exp(0.4 \frac{2700 ft.}{26500 ft.}) \sqrt{\frac{3.5 \cdot 10^6 psi}{14.7 psi}} \sqrt{\frac{2+0.76}{1+0.32}} \left(\frac{0.02}{0.76}\right)^{\frac{3}{2}} = \textbf{4,331 ft/s} \tag{8}$$

This set of fin design was chosen for the convenience of available manufacturing methods. The fins will be made out of three layers of carbon fiber sheets. The middle sheet will be cut out in a large honey-comb design to reduce weight, with thinner sheets bonded on either side. This will provide a very lightweight and strong fin that is suited to the aerodynamic and stability needs of the launch vehicle.

3.1.10 Sealing Bulkheads

For the purpose of sealing avionics bays and parachute bays off from each other, sealing bulkheads were a necessary component. These bulkheads will allow the avionics and BEAVS bay to remain at atmospheric pressure during flight while also allowing the deployment system to pressurize the parachute bays for deployment. To this end several iterations of sealing bays were designed since PDR. These bulkheads consist of layers of plywood and rubber o-rings. The o-rings will be placed in between a plywood bulkhead and a plywood sealing ring, with 4 through bolts to compress the 2 plywood parts together. This in turn will compress the o-ring, increasing its diameter beyond its original sides, sealing against the inside of the airframe tube. This design has been proven in previous OSRT launch vehicle designs.

3.1.11 Testing

Testing will be completed for validation of design, ensuring that the launch vehicle will operate as expected. Several testes will be conducted.

- Pressure testing of all sealing bulkheads to ensure pressurisation at their corresponding pressures required for parachute deployment.
- Tensile testing of the coupler avionics bay to validate calculations of structural stability during decent and recovery of the launch vehicle.
- Simulations of airframe buckling, determining the factor of safety at peak expected forces.
- Simulations of thrust plate forces at peak expected forces from the motor, and validation from full scale test launches.
- Simulation of apogee drogue deployment in pressure chamber to ensure proper venting airflow into altimeter bay.

These tests will be determine pass of fail by the requirements specified by team requirements and/or requirements specified on the testing instructions and checklists. Failure of any of these test will result in the respective subsystem or part needing to be optimised such that it will pass the testing procedure once administered again.

3.2 Selection, Design, and Rationale of BEAVS 2.0

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

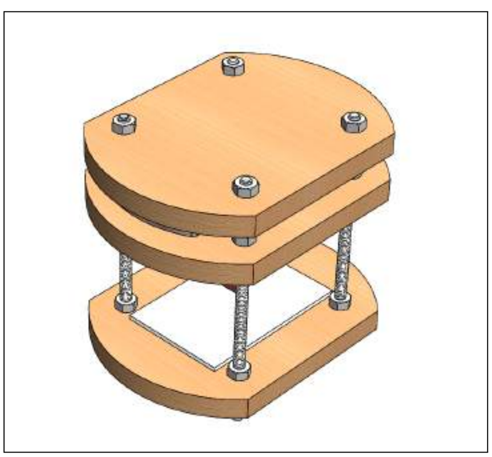


Figure 15: BEAVS 2.0 Fully Assembled for Integration

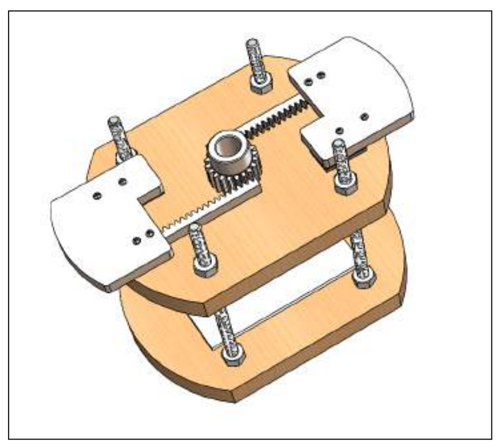


Figure 16: BEAVS 2.0 with Blades Extended

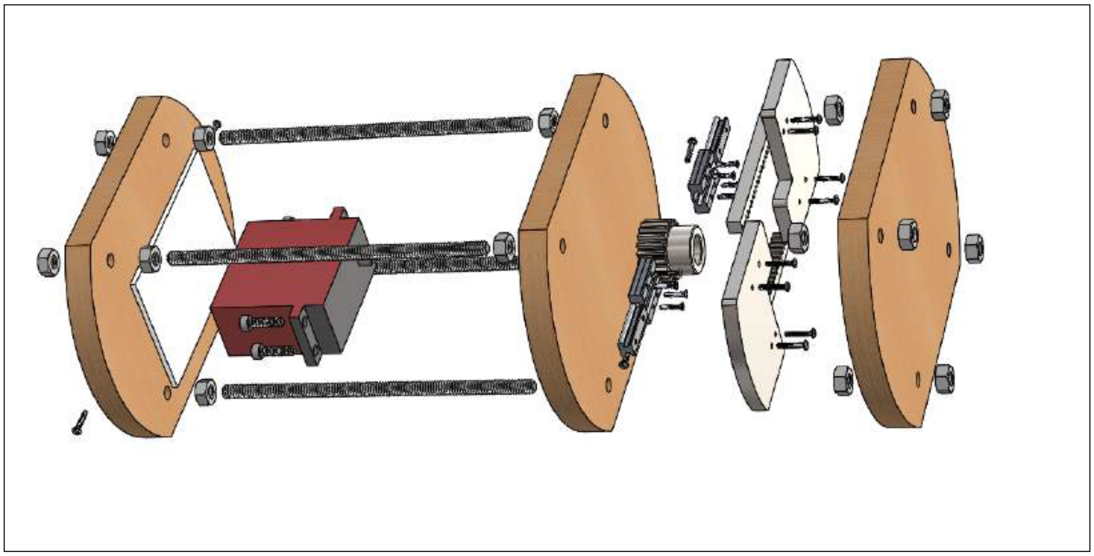
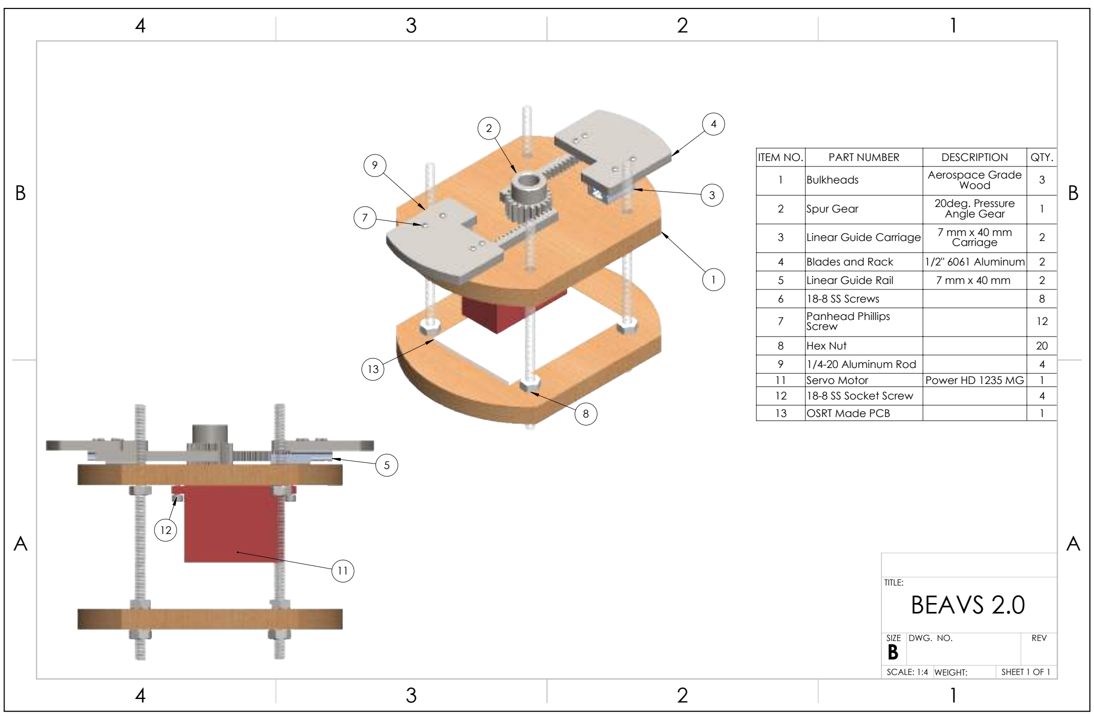


Figure 17: BEAVS 2.0 Exploded View



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Bulkheads	Aerospace Grade Wood	3
2	Spur Gear	20deg. Pressure Angle Gear	1
3	Linear Guide Carriage	7 mm x 40 mm Carriage	2
4	Blades and Rack	1/2" 6061 Aluminum	2
5	Linear Guide Rail	7 mm x 40 mm	2
6	18-8 SS Screws		8
7	Panhead Phillips Screw		12
8	Hex Nut		20
9	1/4-20 Aluminum Rod		4
11	Servo Motor	Power HD 1235 MG	1
12	18-8 SS Socket Screw		4
13	OSRT Made PCB		1

Figure 18: BEAVS 2.0 Sketch

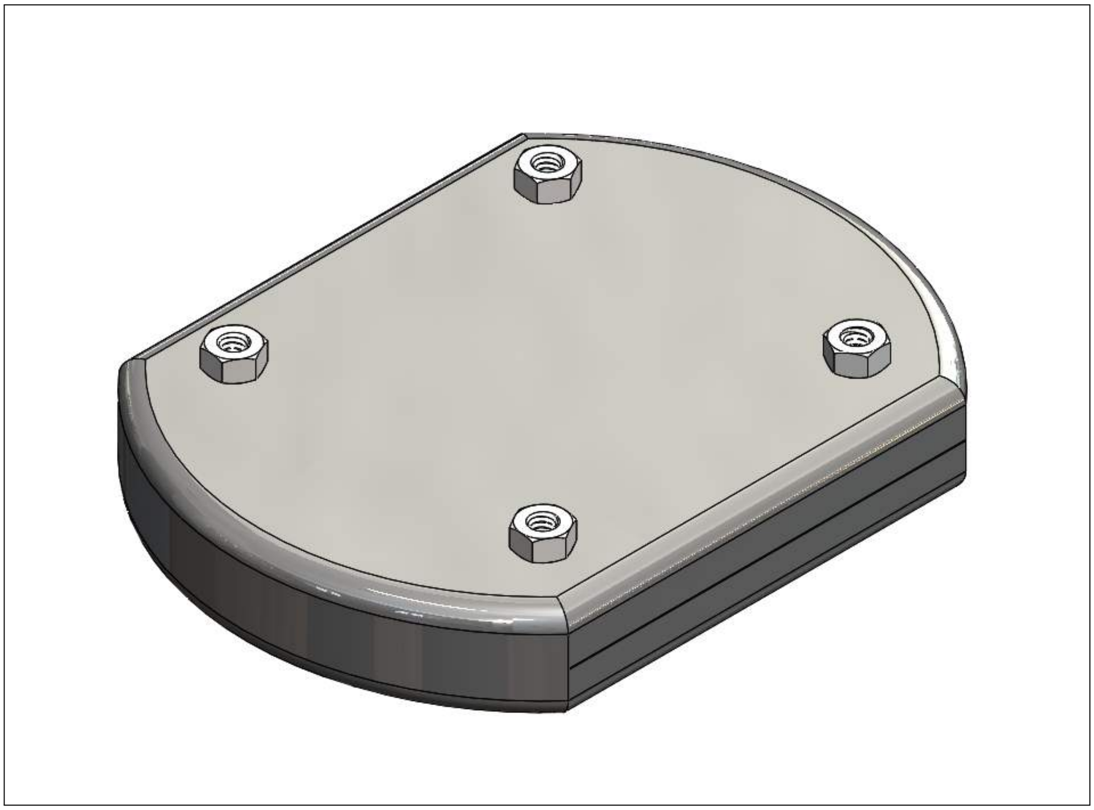


Figure 19: BEAVS 2.0 Sketch

3.2.1 BEAVS Mechanical System

The active mechanical system is a rack and pinion design housed aft the center of gravity shown in Figures 15 and 16. The two blades sit on a set of 7 mm linear guide rails. The gear is driven by a 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. The racks will be machined on a wire Electrical Discharge Machining (EDM) to match the pressure angle and pitch of the gear. The blades will be machined from 1/8 in. 6061 aluminum and will attach to the rack and linear guide rails. Vibration resistant screws were selected when dimensions and sizing permitted.

The gear will be driven by a servo motor, of which an attachment piece from the gear to the servo will be machined from aluminum. The attachment piece will act as a motor shaft through the gear and then attach to a platform located between the gear and the servo, similar to a plate.

The passive system pictured in 19 will be 3D printed and filled with sand. 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 threaded aluminum rods pictured 18. The ballast bay in the nose cone will attach to the single threaded aluminum rod located within the nose cone.

3.2.1.1 Finite Element Analysis (FEA) Testing

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:

$$D_{max} = C_d * \rho * V_{max}^2 * \frac{A}{2} \tag{9}$$

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:

$$D_{max} = 0.42 * 1.225 * 541.8^2 * 0.0016 \tag{10}$$

$$D_{max} = 765.3N \tag{11}$$

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

3.2.2 BEAVS Electrical System

The electrical system is comprised of a microcontroller, barometric pressure sensor, accelerometer, high torque servo motor, and step-down voltage regulator. The components will all be housed together on a custom designed, double layer Printed Circuit Board (PCB). The board was designed on KiCad and printed through OSHPark. The control technique of the motor will be discussed later in the control systems section. The pressure sensor and accelerometer will communicate with the microcontroller through Inter-Integrated Circuit (I2C) protocol.

In order to meet the requirements for the system, several blocks were designed. Each block performs a specific function and is modular enough to be implemented in other systems. For example, the regulated power block can be used within BEAVS, avionics, and payload. A diagram of these blocks can be seen in Figure 20 and their descriptions in Table 6.

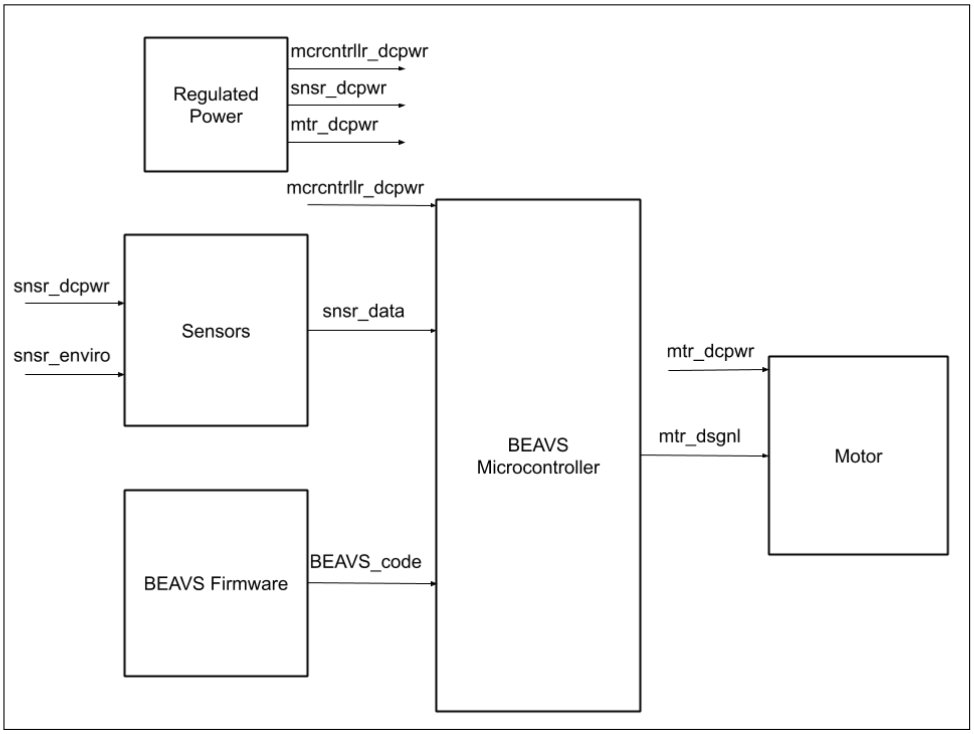


Figure 20: BEAVS Block Diagram

Block Name Name	Description
Regulated Power	This is the block that provides power to sensors and microcontrollers and motor.
Sensors	Collects information from the outside environment.
BEAVS Firmware	The BEAVS firmware block supplies code to BEAVS microcontroller. The code processes the information extracted from the sensors such as acceleration, barometric pressure, and 3-axis orientation. A set of data from each field at a given time is wrapped into a packet.
BEAVS Microcontroller	This takes and interprets data from the sensors, it is the physical microcontroller block.
Motor	The motor is given movement commands based on the calculation processes from the microcontroller.

Table 6: BEAVS Block Descriptions

The interfaces, the interactions between the blocks, are each defined by key properties. This also describe what is necessary for each block to interact with its neighbors. This information can be seen in Table 7.

Interface Name	Source	Destination	Properties
mcrcntrllr_dcpwr	Regulated Power	BEAVS Microcontroller	• Nominal Current: 10 mA • Peak Current: 250 mA • Minimum Voltage: 4.5 V • Nominal Voltage: 5 V
snsr_dcpwr	Regulated Power	Sensors	• Nominal Current: 10 mA • Peak Current: 30 mA • Maximum Voltage: 3.6 V • Minimum Voltage: 3.0 V • Nominal Voltage: 3.3 V
mtr_dcpwr	Regulated Power	Motor	• Nominal Current: 660 mA • Peak Current: 900 mA • Maximum Voltage: 7.4 V • Minimum Voltage: 4.8 V • Nominal Voltage: 7 V
snsr_enviro	Environment	Sensors	• Barometric Pressure - Max 25.8 inHg • Acceleration data
snsr_data	Sensors	BEAVS Microcontroller	• 10 Hz maximum frequency • I2C communication - Barometric Pressure • Analog - Acceleration • Maximum voltage: 3.3 V
BEAVS_code	BEAVS Firmware	BEAVS Microcontroller	• Clock rate: 180 MHz • Onboard microSD card log • 3-axis orientation, acceleration, and barometric pressure must be processed • Communicates with I2C
mtr_dsgnl	BEAVS Microcontroller	Motor	• Pulse Width Modulation (PWM) Signal

Table 7: BEAVS Interfaces

3.2.2.1 Microcontroller

The OSRT chose the Teensy 3.6 microcontroller primarily due to its size, amount of pins, and built-in microSD card module. Measuring 62.3 mm x 18.0 mm, the microcontroller is relatively small but comes with 62 Inputs and Outputs (I/O) pins.

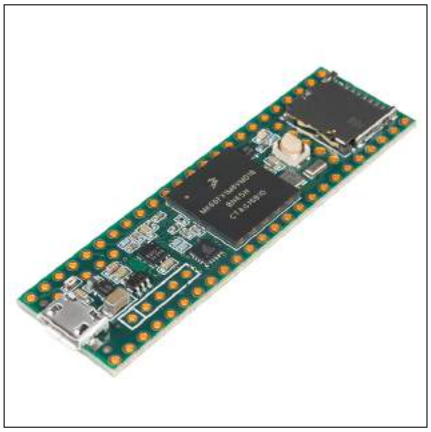


Figure 21: Teensy 3.6

This particular microprocessor requires a power supply capable of delivering 0.25 A at 5 V. Since the motor discussed later in this section requires 7.4 V to operate, a separate 5 V circuit must be regulated from a higher voltage source, using a step-down voltage regulator.

3.2.2.2 Step-Down Voltage Regulator

This circuit ensures that the Teensy 3.6 is connected to an appropriate voltage source. Capacitors provide power filtering and a step-down voltage regulator steps the voltage from 7.4 V to 5 V by dissipating power as thermal energy through a heat-sink.

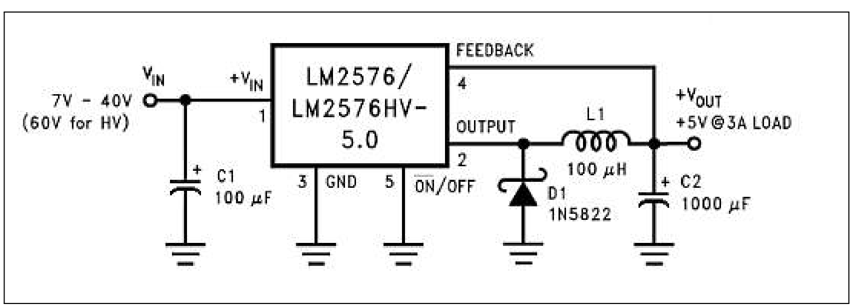


Figure 22: LM2576/LM2576HV 5V Step-Down Voltage Regulator

3.2.2.3 Sensors

The two sensors used for the BEAVS system are the MPL3115A2 Pressure Sensor and the ADXL377 Triple Axis Accelerometer. Both of these sensors will communicate with the microcontroller through I2C protocol. To integrate these better into the custom PCB and to ensure they can withstand the g-forces of the launch, the team decided to replicate the schematics shown in Figures 23 and 24 with surface mount components.

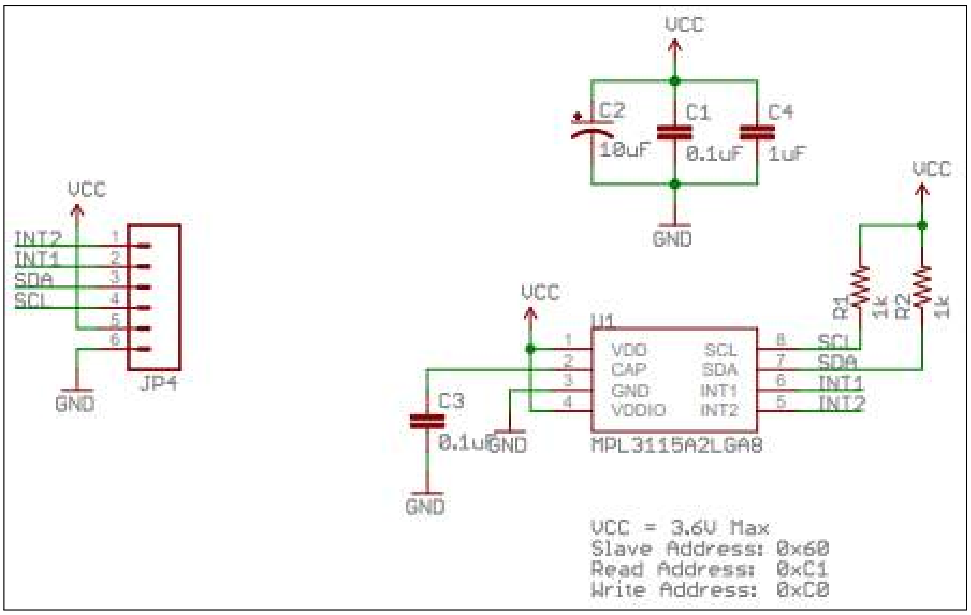


Figure 23: MPL3115A2 Pressure Sensor Schematic

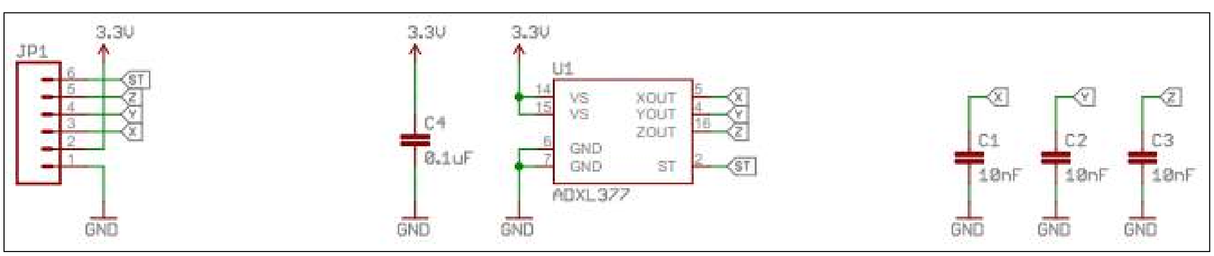


Figure 24: ADXL377 Triple Axis Accelerometer Schematic

3.2.2.4 Motor

A servo motor was chosen for the BEAVS System, specifically the Power HD-1235MG motor. This was chosen for its large torque and practicability with the rack and pinion design. The shaft of the motor will connect, using a custom machined connector, to the mechanism and can spin 165°to move the blades. The large forces of drag acting on the blades during the time of deployment helped determine that using the largest motor possible within reasonable size and weight constraints was necessary. Additionally, using this motor with the Teensy 3.6 microcontroller is extremely simple. The motor has three connectors; ground, power, and the control line. In contrast to some of the other motors compared, this type was the simplest and most reliable. Other motor types include stepper motors and brushless motors. A large implementation issue comes from the requirement of an encoder for position tracking as well as a motor driver device to process the commands given from the microcontroller which would take up valuable space and increase weight. After all of these considerations, our team decided that a high torque servo motor would be the most effective device to implement into the BEAVS system. The motor will be powered by a LiPo Battery that will be wired, using connectors on the PCB, directly.

An overall power budget of the BEAVS system for the final design can be seen in Table 8.

Block	**Component**	**Voltage (V)**	**Current (mA)**	**Power (mW)**
Microcontroller (Active)	Teensy 3.6	5	10.5	52.5
Microcontroller (Idle)	Teensy 3.6	5	4.5	22.5
Pressure Sensor	MPL3115A2	3.3	0.0032	0.01056
Triple Axis Accelerometer	ADXL377	3.3	.003	.0099
Power supply	5V regulator			307.8314026
Motor	HD-1235MG	7.4	900	6600
Total Power				9682.851

Table 8: BEAVS Power Budget

3.2.3 BEAVS Control System

To ensure the mechanical and electrical systems operate properly during flight, the control system must be reliable and efficient. The BEAVS control system will intake data from an accelerometer and a barometric pressure sensor and output the projected apogee altitude.

The program for BEAVS will not start until the altitude of the vehicle is equal to or pass the expected burnout altitude of the motor. Once the vehicle has reached the expected altitude, the microcontroller for BEAVS will begin taking in data from its connected sensors.

With the microcontroller is taking in data, the program will stay in a loop where data will be read twice a second to calculate the expected altitude. If the calculated altitude is higher than 4,000 ft, the blades will be extended for a specific amount of time based on the acceleration and current altitude. This process repeats until the velocity of the launch vehicle reaches zero. While the blades are extending from the retracted position, the program will not take in new data. Once the blades have been extended to the correct position, the program will jump out of the loop and continue taking in data to ensure the 4,000 ft altitude is reached.

OSRT is approaching the control system with preventative measures to ensure no mechanical, electrical, or control failures are experienced on launch day. The controls will have fail-safes implemented that prevent the brakes from activating during motor burn. The airbrakes will automatically deploy at 4,000 ft if the velocity is still greater than zero. If the change in position from the current altitude of the launch vehicle to the previous is negative (meaning it has reached apogee and has done its gravity turn), BEAVS will not deploy. If the expected apogee altitude is projected to be less than 4,000 ft from the launch rail, BEAVS will not deploy but will continue to collect and store flight data from the sensors in the integrated memory device on the microcontroller.

3.3 Manufacturing Plans

3.3.1 Structures

Fin 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, G10 fiberglass sheet,vacuum bagging, Teflon tape
	______	**Tools and Machines Needed:** Computer Numerical Control (CNC) router, sandpaper, CNC Ply cutter, Curing oven
	______	**Personal Protective Equipment (PPE) Required:** Safety glasses, ear plugs, nitrile gloves
		Manufacturing Procedure:
1	______	Prepare Drawing eXchange Format (DXF) file with desired fin shape.
2	______	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.**
3	______	Run DXF file and verify correct cut of carbon fiber sheets.
4	______	Place cut sheets in safe location away from heat sources.
5	______	Complete CNC Ply cutter shut down sequence.
6	______	Complete CNC Router start up sequence.
S	______	**Safety Consideration: - CNC Router uses sharp blades and requires training to use. Failure to properly start and operate machine could cause machine crash, damage to machine and or serious injury.**
7	______	Secure G10 fiberglass sheet to the CNC Router bed, using shop recommended method. (See shop attendant)
8	______	Load, verify, and run G-code for fin core manufacturing.
9	______	Verify fin cores cut correctly.
10	______	Complete CNC Router shut down sequence.
11	______	Place layer of vacuum bagging on work table, large enough for one fin. ring outer edge of vacuum bag with Teflon tape leaving approximately an inch on outside edge of tape.

Continued on next page

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#	Manufacturer Initials	Step Instructions
12	______	Arrange one side of fin carbon fiber layers on bagging material in predetermined layup order. Place the fin core on top of layers.
13	______	Place remaining fin layers on top of fin core in predetermined layup order.
14	______	Cover assembled fin sandwich with vacuum bag material with vacuum fitting installed and seal against 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, sand and cut off excess material. Verify fin is consistent with expected result.
18	______	Repeat for remaining 3 fins.

Nose Cone 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:** Nose cone, Centering Ring, Airframe
	______	**Tools and Machines Needed:** End Mill, Cutting Fixture, Acetone, Calipers, Sanding Belt
	______	PPE **Required:** Safety glasses, ear plugs, nitrile gloves, Respirator, Long Sleeves, Closed Toed Shoes
		Manufacturing Procedure:
S	______	**Safety Consideration: - Ensure all Heating, Ventilation, & Air Conditioning (HVAC) ventilation systems are on and filters are clean. Ensure operator and all nearby personnel have the above PPE. Ensure a Job Hazard Analysis (JHA) has been filled out and signed by a safety officer prior to manufacturing.**
S	______	**Safety Consideration: To enter the shop and use the equipment, all team members must be wearing safety glasses and closed toed shoes, have tied back loose clothing and long hair, removed loose jewelry, and be wearing certification name tag. The Machine Product and Realization Laboratory (MPRL) safety procedures should be reviewed prior to beginning work.**
1	______	Begin by marking the nose cone with a reference line indicating where it will be cut by inserting the centering ring shown in Figure 25 through the tip until it sits tightly on the outer surface of the nose cone.
2	______	Adjust the centering ring visually so that it sits concentric to the rest of the nose cone.
3	______	Push the nose cone with the attached centering ring inside the airframe until the two surfaces come in contact.

Continued on next page

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#	Manufacturer Initials	Step Instructions
4	______	Mark a circular line around the nose cone where the two surfaces come in contact. **Note:** this is not the cut line, only a reference line.
5	______	Note: Acquire fixture plate that will be 3D printed.
6	______	Clamp down Horizontal Rotating Index Tool (HRIT) to Bridgeport Vertical Mill work table.
7	______	Place Nose cone Fixture Insert into fixture plate and fasten it down with four radial set screws.
8	______	Clamp wide end of nose cone into HRIT.
9	______	Insert the tip of nose cone through the center ring in the cutting fixture.
10	______	Ensure the nose cone is parallel to the work surface and parallel to the table slots.
11	______	Clamp down the fixture.
12	______	With edge finding tip on the end mill, rotate the HRIT, ensuring that the tip follows the previously marked line on the nose cone. Adjust if necessary.
13	______	Move the work table in the x-direction so that the tip will be cutting the desired length of the nose cone.
14	______	Using a 1/4 in. end mill and Rotations per Minute (RPM) set to 1,500, cut into the nose cone, slowly rotating, leaving a 1/4 in. uncut section every 90 degrees.
15	______	When rotating is finished, the end mill should end flush with the initial slot.
16	______	Shut off the machine, unclamp the fixture and dispose of fiberglass dust appropriately.
17	______	With edge finding tip on the end mill, rotate the HRIT, ensuring that the tip follows the previously marked line on the nose cone. Adjust if necessary.
18	______	Using a fiberglass power trimmer, cut the 4 uncut sections.
19	______	Sand the cut edge until the nose cone can lay flat on a level surface.
20	______	Clean all tools and put all equipment away.

Figure 25: Nose Cone Fixture Insert

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
	____	**Tools and Machines Needed:** Sandpaper, CNC Ply cutter, Curing oven
	____	**PPE Required:** Safety glasses, ear plugs, nitrile gloves
		Manufacturing Procedure:
1	____	Prepare Airframe Tube Section by cleaning thoroughly with acetone.
2	____	Prepare DXF file with desired coupler sheet shapes.
3	____	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.**
4	____	Run DXF file and verify correct cut of carbon fiber sheets in accordance with layup schedule.
5	____	Complete CNC Ply cutter shut down sequence.
6	____	Spray mold release into interior of airframe tube section, failure to cover completely will bond coupler to airframe during curing.
7	____	Layup carbon fiber sheets inside of airframe section in accordance with layup schedule.
8	____	Place tube of bagging material greater in diameter then the interior of the coupler within the coupler, sealing with Teflon tape.
9	____	Cover exterior of coupler with bagging material, with vacuum fitting installed, sealing against inner bagging material using Teflon tape.
10	____	Vacuum air out of sealed assembly.
11	____	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.**
12	____	Remove from oven, de-bag, remove coupler from airframe section. Sand and cut off excess material. Verify coupler is consistent with expected result.
13	____	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.
14	____	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.**

Bulkhead/Centering Ring Manufacturing

Manufacturer Signature:____________ **Safety Officer Signature:** ____________

#	Manufacturer Initials	Step Instructions
		Safety Officer Checklist: - Ensure that all areas are clear of all foreign objects.

Continued on next page

continued from previous page

#	Manufacturer Initials	Step Instructions
		- 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:** Bulkhead Plywood
	______	**Tools and Machines Needed:** Sandpaper, CNC Router
	______	**PPE Required:** Safety glasses, ear plugs, nitrile gloves
		Manufacturing Procedure:
1	______	Secure plywood sheet to the CNC Router bed, using shop recommended method (See shop attendant).
2	______	Complete CNC Router start up sequence.
S	______	**Safety Consideration: - CNC Router uses sharp blades and requires training to use. Failure to properly start and operate machine could cause machine crash, damage to machine and or serious injury.**
3	______	Prepare, load, and verify G-code.
4	______	Run G-code, cutting out all specified bulkheads and centering rings.
5	______	Remove and verify parts from CNC Router bed.
6	______	Complete CNC Router shut down sequence.

Airframe Tube 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:** Airframe tube from manufacturer
	______	**Tools and Machines Needed:** Sandpaper, Tube cutting jig, pneumatic cutting wheel
	______	**PPE Required:** Safety glasses, ear plugs, nitrile gloves, face mask
		Manufacturing Procedure:
S	______	**Safety Consideration: - Fiberglass and carbon fiber dust is abrasive and dangerous to be inhaled. Weal dust mask and ensure proper dirty room start up procedure to ensure air filtration and safety.**
1	______	Secure tube cutting jig to composite sanding/cutting table with clamps. Secure tube into cutting jig.
S	______	**Safety Consideration: - This will take multiple people as tube is large and unwieldy. Ensure minimum of 3 people, two securing tube and one operating cutting tools.**
2	______	Secure tube cutting jig to composite sanding/cutting table with clamps. Secure tube into cutting jig.
3	______	Mark the place to bu cute with bright sharpie, using predetermined measurements.
4	______	Having one person supporting end of tube, and another Turing the tube at a constant rate, cut the tube by holding the edge of wheel to the tube, but rotating the tube not the saw.

Continued on next page

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#	Manufacturer Initials	Step Instructions
5	______	After tube is cut to size, sand edge flat, checking against machined tube edge using coupler to ensure alignment. Sand the raised points until uniform fit.

Fin and Airbrake Slot 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:** Cut to size aft airframe
	______	**Tools and Machines Needed:** Sandpaper, Carbide 1/4 end mill, and mill tube mounting hardware, shop vacuum
	______	PPE **Required:** Safety glasses, ear plugs, nitrile gloves, face mask
		Manufacturing Procedure:
S	______	**Safety Consideration: - Fiberglass and carbon fiber dust is abrasive and dangerous to be inhaled. Weal dust mask and ensure proper dirty room start up procedure to ensure air filtration and safety.**
1	______	Mount airframe on vertical mill using vertical rotary 3 jaw chuck, and custom machined tube stand.
2	______	Indicate tube using chuck mounted indicator to verify tube is flat and straight in relation to mill table. Adjust as necessary until indicating needle does not move more then proper specifications indicate.
S	______	**Safety Consideration: - Failure to ensure a straight cute will result in fins not being straight, leading to cor screwing during flight or other unwanted aerobatics. This poses a hazard to operators and bystanders and could cause injury in event of crash.**
3	______	Zero machine on center of tube and at aft most end of tube.
4	______	Mill a 12 inch long fin slot at recommended speeds and feeds, in the specified location on the part drawing. (See shop attendant if unsure of speeds and feeds)
S	______	**Safety Consideration: - Because of carbon fiber milling dust, have a secondary person following end mill as it mills with shop vacuum to vacuum dust as it is made, reducing mess and airborne particles to the air in the shop. This reduces hazard to others using the shop and the mill operators.**
5	______	Rotate tube 90 degrees and repeat until four fin slots have been milled.
6	______	Mill the BEAVS blade slots and mounting holes in accordance with the part drawing.
7	______	Note the two BEAVS blade slots will be 180 degrees apart unlike the fins.

Main Altimeter Bay Manufacture		
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:** For and Aft altimeter bay bulkheads, 4 cut to size threaded rods, one aluminum sealing/mounting ring, one wooden sealing ring, altimeter mounting plate, 4 lifting eyes, 20 washers, 20 nylon nuts, 2 sealing gaskets.
	______	**Tools and Machines Needed:**
	______	PPE **Required:** Safety glasses
		Manufacturing Procedure:
1	______	Place a threaded rod through each threaded rod hole on the altimeter mounting plate.
2	______	Place nylon locking nuts then nylon washers on with side of each threaded rod about 1/4 the length down.
3	______	Thread each rod through the aluminum securing ring on one side, and the wooden sealing ring on the other.
4	______	Place a sealing gasket around the threaded rods on top of sealing rings on both sides, then placing bulkhead on top on either side.
5	______	Place nylon washers then nylon locking nuts on with side of each threaded rod about tightening them till they are touching the wooden bulkheads.
6	______	Place nylon washers then nylon locking nuts on with side of each threaded rod about tightening them till they are touching the wooden bulkheads.
7	______	Place a lifting eye in each of the lifting eye holes on each of the bulkheads. Secure with a washer then nylon locking nut.

BEAVS Rack 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:** 2 x 1/2 in. thick 6061 aluminum bars
	______	**Tools and Machines Needed:** WireEDM, drill press, m2 tap.
	______	PPE **Required:** Safety glasses
		Manufacturing Procedure:
1	______	Place aluminum bar on WireEDM bench and secure with clamps or fixture.
2	______	Lock aluminum bar in place before starting up WireEDM machine.
3	______	Run through start up sequence on WireEDM.
		Continued on next page

continued from previous page

#	Manufacturer Initials	Step Instructions
4	______	Calibrate WireEDM to find edge and starting point on aluminum bar.
5	______	Run WireEDM through G-code sequence for design.
6	______	Unclamp piece and repeat with second aluminum bar.
7	______	Secure machined piece to drill press.
8	______	Drill 0.029 in. holes into rack.
9	______	Tap holes with m2 tap size.

3.4 Subscale Flight Results

The subscale flight was a success, launched in Brothers, Oregon on November 16th. The team arrived in Brothers at roughly 8:30 am and began integration. Integration took 2 hours to complete. The team had issues installing shear pins for the drogue parachute bay, as not all of the holes were aligned. OSRT had to take more time than expected to adjust the holes to make more of the shear pins fit. After the launch vehicle was fully assembled, the team waited for another two hours as the Electrical and Computer Engineering, and Computer Science members worked on getting the a new wireless ignition system functioning. Unfortunately, the team needed to connect a wire to the ignitor and run it all the way back to mission control. After laying the wire, the team was able to place the launch vehicle on the rail, successfully install the ignitor, and retreat behind the flight line. After all checklists were confirmed completed, the countdown commenced and the launch vehicle was launched, as shown in Figure 26.

Figure 26: Subscale Launch

The motor took 1.6 s to burn. Once the launch vehicle reached apogee, the primary charge deployed the drogue parachute. As the launch vehicle descended, the main parachute deployed at approximately 595 ft, as shown in Figure 27, and the launch vehicle landed with a kinetic energy of 31.38 ft-lbs.

Figure 27: Main Parachute Deployment

The landing kinetic energy was calculated by first calculating the velocity of the launch vehicle at each of the data points by using the equation:

$$Velocity = \frac{Altitude_2 - Altitude_1}{t_2 - t_1} \tag{12}$$

Velocity is in $^{ft}/_{s}$, altitude is in ft, and time is in s.

Next, the landing velocity was calculated by taking the average of the last eight seconds of the flight before landing. The landing velocity was calculated to be 8.02 $^{ft}/_{s}$.

After calculating the landing velocity, the mass of the launch vehicle was calculated by using the equation below:

$$mass = \frac{weight}{32} \tag{13}$$

The mass is in slugs, the weight is in lbf, and the denominator is the acceleration due to gravity, or 32 $^{ft}/_{s^2}$. Since the launch vehicle weighed 31.2 lbf, the mass of the launch vehicle was 0.975 slugs.

From there, the landing kinetic energy was calculated with the equation:

$$LandingKineticEnergy = .5 * mass * velocity^2 \tag{14}$$

From this, the landing kinetic energy was 31.38 ft-lbf, which is well below the allowed maximum kinetic energy of 75 ft-lbf.

Upon landing, the team took 10 minutes to recover the launch vehicle, as it landed just a short distance from the launch pad, and upon completing a post-flight inspection checklist, the launch was deemed highly successful, with all of the of parachutes deploying as intended, and the landing kinetic energy under half of the allowed maximum kinetic energy.

OSRT planned on doing another subscale flight on January 5th, 2020 to further test the altimeters and the recovery system to ensure their functionality, since the mission's success is highly dependent on the success of these two systems. However, due to a severe weather warning including forecasts of 3 to 7 in. accumulation of snow over the mountain pass that the team uses to reach the launch site and wind gusts of over 20 mph at the launch site, the launch was scrubbed by team advisors. Alternative testing of the altimeters is detailed in Section 3.17.6.

3.4.1 Flight Data

Table 9 shows the time, altitude and pressure collected from the two Missile Works Rocket Recovery Controller 3 (RRC3) Sport Altimeters from the subscale flight. Since measurements are taken by the altimeters every 0.05 seconds during the flight, the flight data has been trimmed to focus on the drogue and main parachute ejection points. The drogue and main back-up and primary ejection points have been highlighted in red.

Table 9: Subscale Altimeter Data

Back-up (Selected Data Around Events)				Primary (Selected Data Around Events)			
Time (s)	Altitude (ft)	Pressure (ksi)	Event	Time (s)	Altitude (ft)	Pressure (ksi)	Event
0	-0.0001195006	126.1250448	Launch	0	-7.44E-05	126.2265714	Launch
0.05	3.088944	126.110541	-	0.05	-7.44E-05	126.2265714	-
0.1	9.269819	126.0815334	-	0.1	6.1762	126.1975638	-
0.15	12.35975	126.0670296	-	0.15	9.263825	126.18306	-
0.2	18.54235	126.038022	-	0.2	12.35174	126.1685562	-
0.25	24.7261	126.0090144	-	0.25	18.53031	126.1395486	-
0.3	34.00296	125.965503	-	0.3	21.62097	126.1250448	-
0.35	40.18959	125.9364954	-	0.35	30.89091	126.0815334	-
0.4	49.47077	125.892984	-	0.4	37.07294	126.0525258	-
0.45	58.75455	125.8494726	-	0.45	46.3472	126.0090144	-
0.5	71.13821	125.7914574	-	0.5	55.62405	125.965503	-
-	—	—	Ascent	-	—	—	Ascent
10.05	1803.259	117.8868864	-	10.05	1772.707	118.1189472	-
10.1	1803.259	117.8868864	-	10.1	1772.707	118.1189472	-
10.15	1806.522	117.8723826	-	10.15	1772.707	118.1189472	-
10.2	1806.522	117.8723826	-	10.2	1775.966	118.1044434	-

Table 9 continued from previous page

10.25	1806.522	117.8723826	-	10.25	1775.966	118.1044434	-
10.3	1806.522	117.8723826	-	10.3	1779.224	118.0899396	-
10.35	1806.522	117.8723826	-	10.35	1779.224	118.0899396	-
10.4	1806.522	117.8723826	-	10.4	1779.224	118.0899396	-
10.45	1806.522	117.8723826	-	10.45	1782.484	118.0754358	-
10.5	1806.522	117.8723826	-	10.5	1782.484	118.0754358	-
10.55	1806.522	117.8723826	-	10.55	1782.484	118.0754358	-
10.6	1806.522	117.8723826	-	10.6	1782.484	118.0754358	-
10.65	1803.259	117.8868864	-	10.65	1782.484	118.0754358	-
10.7	1803.259	117.8868864	-	10.7	1782.484	118.0754358	-
10.75	1803.259	117.8868864	-	10.75	1782.484	118.0754358	-
10.8	1803.259	117.8868864	-	10.8	1782.484	118.0754358	-
10.85	1803.259	117.8868864	-	10.85	1785.743	118.060932	-
10.9	1803.259	117.8868864	-	10.9	1785.743	118.060932	-
10.95	1799.995	117.9013902	-	10.95	1785.743	118.060932	-
11	1659.984	118.5250536	-	11	1785.743	118.060932	-
11.05	1446.239	119.4823044	-	11.05	1487.234	119.3952816	Drogue
11.1	1806.522	117.8723826	-	11.1	1513.083	119.2792512	-
11.15	1809.787	117.8578788	-	11.15	1789.002	118.0464282	-
11.2	1806.522	117.8723826	-	11.2	1792.263	118.0319244	-
11.25	1806.522	117.8723826	-	11.25	1792.263	118.0319244	-
11.3	1803.259	117.8868864	-	11.3	1789.002	118.0464282	-
11.35	1803.259	117.8868864	-	11.35	1789.002	118.0464282	-
11.4	1803.259	117.8868864	-	11.4	1789.002	118.0464282	-
11.45	1803.259	117.8868864	-	11.45	1792.263	118.0319244	-
11.5	1806.522	117.8723826	-	11.5	1795.522	118.0174206	-
11.55	1806.522	117.8723826	-	11.55	1795.522	118.0174206	-
11.6	1809.787	117.8578788	-	11.6	1795.522	118.0174206	-
11.65	1809.787	117.8578788	-	11.65	1798.784	118.0029168	-
11.7	1803.259	117.8868864	-	11.7	1798.784	118.0029168	-
11.75	1799.995	117.9013902	-	11.75	1795.522	118.0174206	-
11.8	1803.259	117.8868864	-	11.8	1792.263	118.0319244	-
11.85	1799.995	117.9013902	-	11.85	1795.522	118.0174206	-
11.9	1799.995	117.9013902	-	11.9	1795.522	118.0174206	-
11.95	1799.995	117.9013902	-	11.95	1798.784	118.0029168	-
12	1799.995	117.9013902	-	12	1798.784	118.0029168	-
12.05	1799.995	117.9013902	-	12.05	1802.044	117.988413	-
12.1	1799.995	117.9013902	-	12.1	1802.044	117.988413	-
12.15	1796.733	117.915894	Drogue	12.15	1795.522	118.0174206	-
12.2	1845.71	117.698337	-	12.2	1792.263	118.0319244	-
12.25	1806.522	117.8723826	-	12.25	1789.002	118.0464282	-
12.3	1790.207	117.9449016	-	12.3	1782.484	118.0754358	-
12.35	1786.946	117.9594054	-	12.35	1779.224	118.0899396	-
12.4	1783.683	117.9739092	-	12.4	1779.224	118.0899396	-

Table 9 continued from previous page

12.45	1786.946	117.9594054	-	12.45	1775.966	118.1044434	-
12.5	1786.946	117.9594054	-	12.5	1779.224	118.0899396	-
12.55	1790.207	117.9449016	-	12.55	1779.224	118.0899396	-
12.6	1790.207	117.9449016	-	12.6	1779.224	118.0899396	-
12.65	1790.207	117.9449016	-	12.65	1779.224	118.0899396	-
-	—	—	Descent	-	—	—	Descent
31.85	633.2159	123.1807734	-	31.85	667.4355	123.1227582	-
31.9	633.2159	123.1807734	-	31.9	642.2413	123.2387886	-
31.95	630.0656	123.1952772	-	31.95	629.6523	123.2968038	-
32	630.0656	123.1952772	-	32	620.2112	123.3403152	-
32.05	623.7696	123.2242848	-	32.05	617.0662	123.354819	-
32.1	617.473	123.2532924	-	32.1	613.9213	123.3693228	-
32.15	614.3241	123.2677962	-	32.15	617.0662	123.354819	-
32.2	608.0312	123.2968038	-	32.2	617.0662	123.354819	-
32.25	604.8832	123.3113076	-	32.25	613.9213	123.3693228	-
32.3	601.7375	123.3258114	-	32.3	607.6307	123.3983304	-
32.35	604.8832	123.3113076	-	32.35	598.1979	123.4418418	-
32.4	633.2159	123.1807734	-	32.4	595.0529	123.4563456	-
32.45	693.1064	122.9052012	-	32.45	595.0529	123.4563456	-
32.5	740.4661	122.6876442	-	32.5	598.1979	123.4418418	-
32.55	664.7242	123.0357354	-	32.55	595.0529	123.4563456	-
32.6	604.8832	123.3113076	-	32.6	591.9102	123.4708494	-
32.65	592.3002	123.3693228	-	32.65	607.6307	123.3983304	-
32.7	601.7375	123.3258114	-	32.7	617.0662	123.354819	-
32.75	601.7375	123.3258114	-	32.75	601.3412	123.427338	-
32.8	598.5901	123.3403152	-	32.8	582.4819	123.5143608	-
32.85	545.1523	123.5868798	-	32.85	494.6087	123.9204672	Main
32.9	567.1448	123.4853532	-	32.9	529.103	123.7609254	-
32.95	623.7696	123.2242848	-	32.95	591.9102	123.4708494	-
33	598.5901	123.3403152	-	33	595.0529	123.4563456	-
33.05	589.1538	123.3838266	-	33.05	595.0529	123.4563456	-
33.1	582.8637	123.4128342	-	33.1	585.6237	123.499857	-
33.15	573.4318	123.4563456	-	33.15	566.7734	123.5868798	-
33.2	598.5901	123.3403152	-	33.2	579.3384	123.5288646	-
33.25	617.473	123.2532924	-	33.25	588.7659	123.4853532	-
33.3	642.6649	123.137262	-	33.3	579.3384	123.5288646	-
33.35	708.8854	122.8326822	-	33.35	560.4917	123.6158874	-
33.4	664.7242	123.0357354	-	33.4	551.0724	123.6593988	-
33.45	589.1538	123.3838266	-	33.45	566.7734	123.5868798	-
33.5	567.1448	123.4853532	-	33.5	573.0544	123.5578722	-
33.55	560.8608	123.5143608	-	33.55	576.1972	123.5433684	-
33.6	554.5761	123.5433684	-	33.6	573.0544	123.5578722	-
33.65	545.1523	123.5868798	-	33.65	551.0724	123.6593988	-
33.7	538.8706	123.6158874	-	33.7	535.3788	123.7319178	-

Table 9 continued from previous page

33.75	548.2927	123.572376	-	33.75	541.6538	123.7029102	-
33.8	554.5761	123.5433684	-	33.8	541.6538	123.7029102	-
33.85	554.5761	123.5433684	-	33.85	529.103	123.7609254	-
33.9	532.5901	123.644895	-	33.9	519.6926	123.8044368	-
33.95	520.0327	123.7029102	-	33.95	532.2398	123.7464216	
34	523.1725	123.6884064	-	34	554.2112	123.644895	-
34.05	516.895	123.717414	-	34.05	532.2398	123.7464216	-
34.1	529.4513	123.6593988	-	34.1	519.6926	123.8044368	-
34.15	560.8608	123.5143608	-	34.15	516.5552	123.8189406	-
34.2	608.0312	123.2968038	-	34.2	510.283	123.8479482	-
34.25	642.6649	123.137262	-	34.25	507.1483	123.862452	-
34.3	623.7696	123.2242848	-	34.3	507.1483	123.862452	-
34.35	589.1538	123.3838266	-	34.35	513.4199	123.8334444	-
34.4	570.2891	123.4708494	-	34.4	516.5552	123.8189406	-
34.45	564.0026	123.499857	-	34.45	513.4199	123.8334444	-
34.5	560.8608	123.5143608	-	34.5	504.0139	123.8769558	-
34.55	557.7173	123.5288646	-	34.55	494.6087	123.9204672	-
34.6	579.7201	123.427338	-	34.6	488.3427	123.9494748	-
34.65	639.5155	123.1517658	-	34.65	488.3427	123.9494748	-
34.7	642.6649	123.137262	-	34.7	485.2082	123.9639786	-
34.75	680.4897	122.9632164	-	34.75	478.9419	123.9929862	-
34.8	655.269	123.0792468	-	34.8	475.8102	124.00749	-
34.85	557.7173	123.5288646	-	34.85	478.9419	123.9929862	-
34.9	498.0715	123.8044368	-	34.9	478.9419	123.9929862	-
34.95	482.3929	123.8769558	-	34.95	494.6087	123.9204672	-
35	582.8637	123.4128342	Main	35	535.3788	123.7319178	-
-	—	—	Descent and Landing	-	—	—	Descent and Landing

3.4.2 Discussion

The subscale flight went very well, with the launch vehicle reaching apogee at 11.05 s, ejecting the drogue parachute at this time, and then igniting the back-up charge 1.1 s after that, staying within the maximum time allowed of an apogee event of 2.0 s. One interesting point was that the primary altimeter experienced a major increase in pressure, and therefore a major drop in altitude, during drogue ignition. The pressure then dropped back to where it was in about 0.1 s, therefore recording a more accurate altitude. This pressure change could have been caused by the pressure created in the adjacent parachute bay by the BP charges leaking into the altimeter bay, and was mitigated by a new bulkhead sealing design, which was tested, and is described in Section 3.17.6.

3.4.2.1 Avionics Data

Table 10 shows the altitude, time, and GPS coordinates collected by OSRT's avionics system.

Table 10: Subscale Flight Avionics Data

Altitude (ft)	Time (s)	GPS Coordinates
4137.55	21:29:38.0	43.800041 -120.649986
4447.38	21:29:40.0	43.799973 -120.649918
4942.59	21:29:41.0	43.799953 -120.649918
5354.74	21:29:43.0	43.800121 -120.650024
5649.61	21:29:45.0	43.799854 -120.649986
5856.3	21:29:47.0	43.799534 -120.650002
5930.94	21:29:49.0	43.799526 -120.649994
5935.86	21:29:50.0	43.799427 -120.649956
5833.95	21:29:52.0	43.7993 -120.649956
5759.51	21:29:54.0	43.799465 -120.649925
5662.73	21:29:56.0	43.799507 -120.649849
5531.29	21:29:58.0	43.799519 -120.649712
5428.35	21:29:59.0	43.799538 -120.649673
5326.03	21:30:1.0	43.799591 -120.649696
5205.87	21:30:3.0	43.799633 -120.649696
5102.12	21:30:5.0	43.799767 -120.649712
5017.22	21:30:7.0	43.799896 -120.649765
4898.5	21:30:8.0	43.799953 -120.649818
4775.67	21:30:10.0	43.799976 -120.649826
4688.53	21:30:12.0	43.800011 -120.649796
4621.47	21:30:14.0	43.800072 -120.649719
4603.43	21:30:16.0	43.800247 -120.649773
4576.36	21:30:17.0	43.800266 -120.649765
4553.4	21:30:19.0	43.800365 -120.649887
4545.81	21:30:21.0	43.800373 -120.64991
4528.38	21:30:23.0	43.800453 -120.650017
4511.15	21:30:25.0	43.800526 -120.650093
4482.04	21:30:27.0	43.800636 -120.650177
4458.87	21:30:29.0	43.800724 -120.650269
4434.67	21:30:31.0	43.80072 -120.650322
4406.58	21:30:32.0	43.800694 -120.650291
4391.61	21:30:34.0	43.80069 -120.650261
4362.7	21:30:36.0	43.800697 -120.65023
4338.5	21:30:38.0	43.80072 -120.650169
4326.81	21:30:39.0	43.800743 -120.650139
4306.31	21:30:41.0	43.800793 -120.650047
4271.86	21:30:43.0	43.800888 -120.649971
4241.51	21:30:45.0	43.801006 -120.649902
4216.29	21:30:47.0	43.801144 -120.649879

Table 10 continued from previous page

4191.27	21:30:48.0	43.801208 -120.649857
4163.39	21:30:50.0	43.8013 -120.64978
4153.54	21:30:52.0	43.801338 -120.649704
4128.53	21:30:54.0	43.801353 -120.649658
4127.09	21:30:56.0	43.801365 -120.649658
4127.5	21:30:58.0	43.801365 -120.649666

The subscale launch vehicle was scaled as closely to $2/3$ of the full size launch vehicle as parts, manufacturing, and practicality allowed. Certain parts of the launch vehicle were not able to scale correctly, such as parachutes and motors. This was due to the nature of the commercially available motors to adhere to standard sizes, which did not scale perfectly. This propagated through the design of the subscale to the motor tube, thrust plate, and motor retainer. Other issues included commercially available airframe tubes in the correct size. While a $2/3$ scale of 6.25 in. is 4.16 in., the subscale used 4 in. tubes as that was the closest available tube without the need to order custom made tubes, which did not fit into the project budget or timeline. Other items that were not able to scale were altimeters and batteries. This is due to them only being available in one form factor, however the slight increase in weight over a scale version was negligible. The biggest problem with scaling the launch vehicle was the parachutes, and in turn the parachute bays. Because the size of the available parachutes at the time was larger then the ideal parachutes, the parachute bays needed to be larger. The final size of the subscale main parachute bay was 14 in. long, very similar in size to the full scale parachute, without the added diameter of the full scale. The drogue parachute bay, however, when first manufactured was too small to fit the drogue chute, a result of underestimation of the amount of room that shock cords required. This then resulted in the airframe getting extended with a spare coupler, leading it to be 26.5 in. long in the first launch. The added length was significantly more than it needed to be to ensure proper length of the coupler inside the airframe without coming into contact with the extending length of the coupler. The remaining parts of the launch vehicle were scaled as closely to $2/3$ as the OSRT manufacturing ability allowed.

3.4.3 Launch Day Conditions and Simulations

The launch was conducted on November 16th, 2019. The high temperature was 59 F, the low temperature was 25 F. The sky was slightly cloudy around the launch site, as seen in Figure 28, but not nearly enough to threaten the viability of launching. The wind was minimal, and the ground was bare and dry. The rail was set to point straight up with no offset.

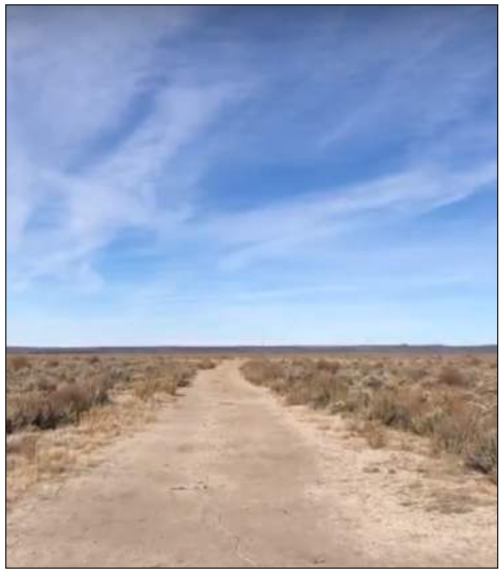


Figure 28: Launch Day Conditions

The simulation for the subscale flight is shown below in Figures 29 and 30. The simulation was conducted in OpenRocket. The conditions used for this simulation had the rail set to an angle of 0 degrees with a length of 138 in., the wind set to a speed of 2 m/s, a standard deviation of 0.2 m/s, and the international standard atmosphere conditions used.

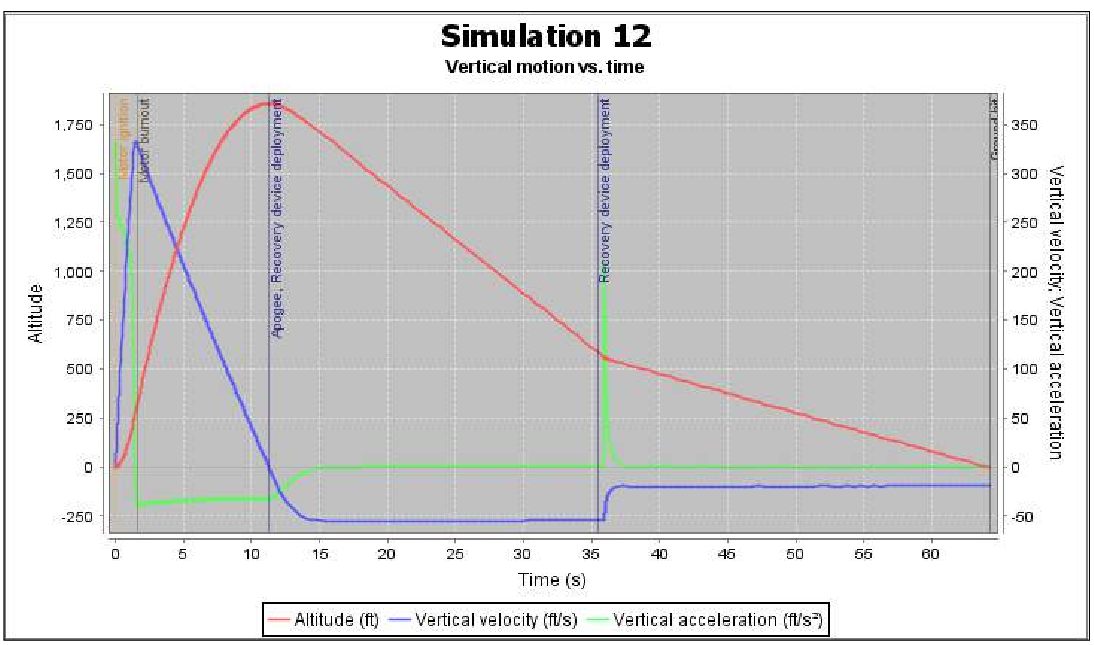


Figure 29: Subscale Simulation Graph

Name	Configuration	Velocity off rod	Apogee	Velocity at deployment	Optimum delay	Max. velocity	Max. acceleration	Time to apogee	Flight time	Ground hit velocity
Huntsvilleslugs	[K1100T-14]	92.2 ft/s	4450 ft	64.6 ft/s		554 ft/s	354 ft/s²	16.9 s	114 s	12.7 ft/s
Simulation 1	[K1100T-14]	72.4 ft/s	2030 ft	105 ft/s		345 ft/s	311 ft/s²	11.8 s	55.9 s	16.4 ft/s
Simulation 2	[K1100T-14]	94.5 ft/s	2396 ft	99.9 ft/s		384 ft/s	345 ft/s²	12.7 s	61.6 s	15.1 ft/s
Simulation 3	[K1100T-14]									
Simulation 4	[K1100T-14]	45.1 ft/s	2357 ft	45.1 ft/s		383 ft/s	345 ft/s²	12.5 s	89.8 s	14.7 ft/s
Simulation 5	[K1100T-14]	45.1 ft/s	2357 ft	45.2 ft/s		383 ft/s	345 ft/s²	12.5 s	88.3 s	15.8 ft/s
Simulation 6	[K1100T-14]	45.1 ft/s	2391 ft	47.9 ft/s		384 ft/s	345 ft/s²	12.6 s	84.3 s	16.7 ft/s
Simulation 7	[K1100T-14]	45.1 ft/s	2391 ft	50 ft/s		384 ft/s	345 ft/s²	12.6 s	82.8 s	16.8 ft/s
Simulation 8	[K1100T-14]	91.7 ft/s	2275 ft	50.8 ft/s		372 ft/s	335 ft/s²	12.4 s	79.1 s	17.1 ft/s
Simulation 9	[K1100T-14]	91.7 ft/s	2275 ft	50.8 ft/s		372 ft/s	335 ft/s²	12.4 s	75.3 s	19.5 ft/s
Simulation 10	[K1100T-14]									
Simulation 11	[K1100T-14]	88.6 ft/s	1857 ft	54.6 ft/s		332 ft/s	332 ft/s²	11.3 s	64.2 s	19.7 ft/s
Simulation 12	[K1100T-14]	78.5 ft/s	1857 ft	54.6 ft/s	9.7 s	332 ft/s	332 ft/s²	11.3 s	64.3 s	19.8 ft/s

Figure 30: Subscale Simulation Data

3.4.4 Subscale Flight Analysis

3.4.4.1 Parachutes

For the subscale flight, a 7 ft main toroidal parachute was used and set to deploy at 600 ft with a backup charge at 500 ft. For the drogue parachute, a 3 ft elliptical parachute was used and set to deploy at apogee and with a backup charge deploying the drogue 1 s later.

3.4.4.2 Recovery Integration

For the launch, as soon as the tables and tents were set up, the team started assembling BP charges, going through the checklist shown in Section 5. Four charges were created the launch. For the subscale flight, 2.0 g charges were made for the main and drogue primary charges, and 4.0 g charges were made for the main and drogue back-up charges. Then the altimeter assembly checklist was completed, where the altimeters' settings were checked to ensure they would ignite the BP charges at the right times and altitudes. The BP charges were also installed into the altimeters. From there, the BP charges for the main parachute were routed to the back of the main parachute bay, to push the parachutes out, and adhered to the bulkhead with a piece of duct tape. Duct tape was used as opposed to a more permanent method because the altimeter bay needs to be able to pull the primary and back-up BP charges out of the parachute bay, otherwise the parachute bay will be prevented from opening to the full length of the shock cord or the e-matches will rip out of the altimeter bay.

For the launch, the parachutes were folded on a separate table away from the rest of the assembly vehicle. The parachute folding checklists were followed. The drogue and main parachutes were then taped slightly shut so that assembly into the integration harness would be easier. The drogue and main parachute harnesses were then assembled using the recovery harness checklist. This involved checking all shock cords and tethers for correct butterfly knots, and the correct number of quick link attachments. After the harness was assembled, the tether quick links were attached into the bulkhead in both the fore and aft sections. The main parachute went first, folding the parachute around the nomex blanket and slowly pushing it into the fore airframe. The tether that was not attached was then quick linked to the coupler and enclosed in its own section. The drogue parachute was assembled the same way, attaching the quick links to the bulkhead and followed with folding the parachute around the nomex blanket and shoving that into the aft body tube. This was then attached via quick links to the coupler and closed.

3.4.4.3 Flight Profile Analysis

For the subscale flight, the simulation estimated that apogee would be reached at 1857 ft and 11.3 s. Flight data from the Missile Works RRC3 altimeters shows that the launch vehicle reached an apogee of approximately 1800 ft in 11.05 s, and flight data from the avionics shows that it reached an apogee of approximately 1800 ft in 11.0 s, as shown in Figure 31. Given that these measured values from both the RRC3 altimeter and the avionics agree so closely, and they are only about 57 ft and 0.3 s off of the simulated results, the team concluded that the simulation was set up and run accurately, and both the avionics and the altimeters were running accurately as well.

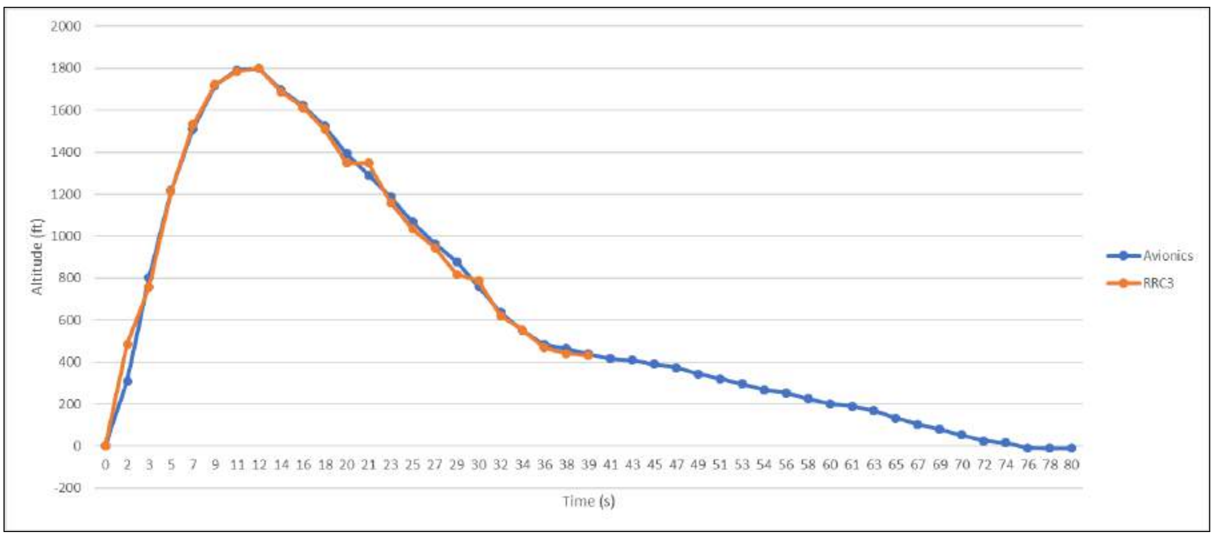


Figure 31: Subscale Flight Path

3.4.5 Changes to Full Scale Based on Subscale Flight

For the BP charges, one major thing to add would be quick release connectors to the e-matches so that the charges can be kept inside the airframe to detonate instead of detonating outside the airframe after being deployed. With quick release connectors, when the BP charges ignite and force their respective parachute bay to open, pulling the altimeter bay-end of the e-match out of the quick release connector. This way, the team will not have BP charges hanging outside of the airframe at any point in time.

For safety, one thing OSRT would like to do is create a "go" bag. Essentially, after the launch vehicle lands, this bag should have all of the needed items to safely disarm and disassemble any portion of the launch vehicle that could cause harm to personnel or the environment, including but not limited to, the motor and the BP charges. This way, the team can get to the launch vehicle faster and come prepared for anything.

3.5 Avionics

3.5.1 Avionics Overview

The avionics system consists of an Avionics Telemetry Unit (ATU) and ground station. The ATU will be located in the nose cone of the rocket, where the material is RF transparent. The ATU will collect, store, and transmit flight data. Acting as a sort of black box, flight data can be recovered after a flight to determine what went wrong and what went right. At the other end of data transmission is the ground station. The ground station will collect and receive information transmitted by the ATU. Using a Graphical User Interface (GUI), this will display live flight data. Here, secondary point-of-data storage will act as a redundancy if there are any issues with onboard data storage on the ATU.

3.5.2 Part Selection

Previous iterations of the avionics system used the Teensy 3.6 microcontroller. Preliminary designs for the ATU and ground station use the Teensy 3.6 because of its ease of development using the Arduino Integrated Development Environment (IDE). Additionally, programming through Arduino gave access to libraries for the sensor modules. There was consideration of an alternative microcontroller, the Texas Instruments EK-TM4C123GXL, to investigate Energia IDE given its similarities to the Arduino IDE. Compatibility was tested for by attempting to implement working Arduino code through the Energia IDE. While some basic functions like printing to the serial monitor was successful, differences in sensor libraries and how I2C is implemented proved a large discrepancy to eliminate the EK-TM4C123GXL. The Teensy 3.6 will continue as the microcontroller selected for the final avionics design. Two will be used: one for the ATU and one for the ground station.

Next is the transceiver. Tests were done with both Long Range (LoRa) and the XBee modules. The range tests both demonstrated good range, but LoRa proved more susceptible to interference. More testing is necessary to determine if the LoRa transceiver operates better over longer distances. A range test will be used by having two individuals each with a transceiver walk away from each other. The XBee was chosen for crucial operations, such as payload ejection and control, where interference or data loss can have large consequences. LoRa modules will be tested for avionics data transmission since more data is helpful, and the systems can handle some interference. LoRa modules are less expensive, so damage is more easily recuperated.

Barometric pressure sensors provide very important data, but it is difficult to get accurate information. Tests were done on two different barometric pressure sensors. This is especially important for BEAVS, since any variation in a correct reading could cause the blades to deploy prematurely or late. This would cause the wrong altitude to be reached. An offset existed on both devices, MS5803-14BA and BMP280. The BMP280 underestimated the altitude close to sea level. This was a consistent offset. The MS5803-14BA proved more unpredictable at lower altitudes.

3.5.3 *Avionics Requirements*

The avionics requirements are based off of specific competition requirements and team goals. Requirements 6.1.8 - 6.1.16 in Table 47 describes the team-derived requirements and the verification plans for the avionics system and will be designed according to these requirements.

In order to meet these requirements several blocks were designed. Each block is meant to perform a specific function and be modular enough to be implemented in another system. For instance, the same power supply block can be used in avionics, payload and BEAVS. A diagram of these blocks can be seen in Figure 32, and a description of each block can be seen in Table 11.

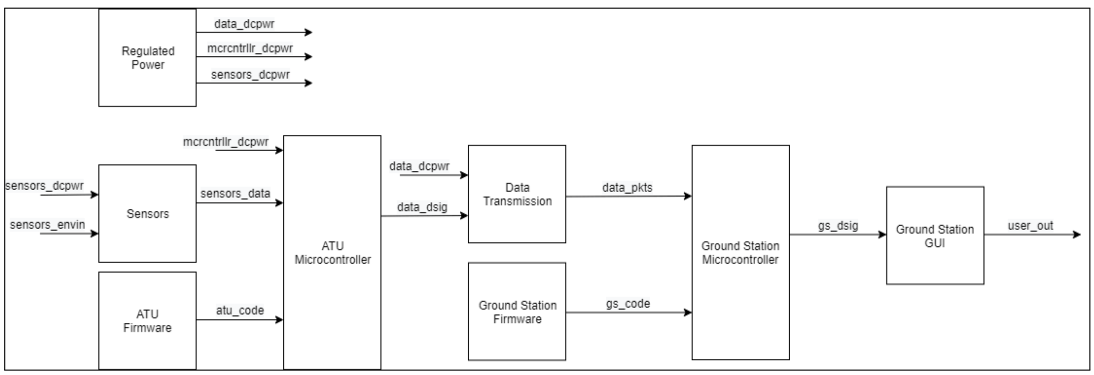


Figure 32: Avionics Block Diagram

Block Name	Description
Regulated Power	This is the block that provides power to sensors and microcontrollers. It is the same hardware on both the rover and the avionics
Sensors	Information from the outside environment.
ATU Firmware	The ATU firmware block supplies code to ATU microcontroller. The code processes the information extracted from the sensors such as acceleration, barometric pressure, and three-axis orientation. A set of data from each field at a given time is wrapped into a packet.
ATU Microcontroller	This takes and interprets data from the sensors; it is the physical microcontroller block.
Data Transmission	This will take in the packets from the microcontroller, and then sends it over RF to the base station.
Ground Station Firmware	The ground station firmware block is the code supplied to the base station microcontroller. Received packets undergo error processing. Successfully receiving a packet results in replying with an acknowledgment.

Ground Station Microcontroller	This is the microcontroller on the ground station that takes in the signal from the RF transceiver, and sends the input to the GUI.
Ground Station GUI	The ground station GUI block receives information from the ground station microcontroller through Universal Serial Bus (USB) and displays information to the user. Additionally, each packet of information is stored in a Comma Separated Values (CSV) file log.

Table 11: Avionics Block Descriptions

The interfaces, the interactions between the blocks, are each defined by key properties. This also describes what is necessary for each block to interact with its neighbors. This information can be seen in Table 12.

Interface Name	Source	Destination	Properties
data_dcpwr	Regulated Power	Data Transmission	• Nominal Current: 100 mA • Peak Current: 330 mA • Maximum Voltage: 5.2 V • Minimum Voltage: 4.8 V • Nominal Voltage: 5 V
mcrcntrllr_dcpwr	Regulated Power	ATU Microcontroller	• Nominal Current: 10 mA • Peak Current: 250 mA • Minimum Voltage: 4.5 V • Nominal Voltage: 5 V
sensors_dcpwr	Regulated Power	Sensors	• Nominal Current: 10 mA • Peak Current: 30 mA • Maximum Voltage: 3.6 V • Minimum Voltage: 3.0 V • Nominal Voltage: 3.3 V
sensors_envin	Environment	Sensors Block	• Barometric Pressure - Max 25.8 inHg • Global Positioning System (GPS) location - within 20 ft • Acceleration data

sensors_data	Sensors	ATU Microcontroller	• 10 Hz maximum frequency • I2C communication - Barometric Pressure • Serial communication - GPS data • Analog - Acceleration • Maximum voltage: 3.3 V
atu_code	ATU Firmware	ATU Microcontroller	• Clock rate: 180 MHz • Onboard microSD card log • 3-axis orientation, acceleration, GPS location, and barometric pressure must be processed • Communicates with I2C
data_dsig	ATU Microcontroller	Data Transmission	• Max Frequency: 48 MHz • Maximum Voltage: 5.2 V • Nominal Voltage: 5 V
data_packets	Data Transmission	Ground Station Microcontroller	• Datarate: 10 Hz • Messages: Acceleration, altitude, GPS coordinates • Packets with checksum and header • Frequency of transmission: 915 MHz

Table 12: ATU Interfaces

3.5.4 Avionics Testing

Each interface property involves a testing procedure, which will be detailed below.

3.5.5 Avionics Design Modifications and Final Design

The decision was made to change barometruc pressure sensors. After testing the BMP280 sensor and the MS5803 barometric pressure sensor, it was decided to change the sensor to the BMP280. The MS5803 sensor was not accurate at ground level or at the launch system as compared to the BMP280. These accuracy measurements were compared to the onboard altimeters the BMP280 had an error of 50 ft.

The teensy was decided to be used for all launches due to the ease of programming and less problems with code debugging. The power budget for the final design can be seen in Table 13.

Block	Component	Voltage (V)	Current (mA)	Power (mW)
Microcontroller (Active)	Teensy 3.6	5	10.5	52.5
Microcontroller (Idle)	Teensy 3.6	5	4.5	22.5
Pressure Sensor	BMP380	3.3	0.0032	0.01056
9 Axis accelerometer	ICM-20948	3.3	3.11	10.263
9 Axis accelerometer(sleep)	ICM-20949	3.3	0.0008	0.00264
GPS	MAX-M8Q	3.3	2.5	8.25
Transmitter (transmit)	RFM95-W	3.3	120	396
Transmitter (Standby)	RFM95-W	3.3	1.8	5.94
Indicator LEDs	green	3.3	60	198
Indicator LEDs	green	5	10	50
Power supply	5V regulator			307.8314026
Power supply	3.3V regulator			204.17452
Total Power		12	102.7476769	1232.972123

Table 13: Avionics Power Budget

3.5.6 Ground Station Electrical

The electrical properties of the Ground station is important since it defines its ability to interact with computers. These properties are defined in Table 14. These properties must all be met for the ground station to interact with the GUI and the ATU.

Interface Name	Source	Destination	Properties
gs_code	Ground Station Firmware	Ground Station Microcontroller	• Clock Rate: 180 MHz • Messages: Acknowledgements to received messages • Protocol: I2C
gs_dsig	Ground Station Microcontroller	Ground Station GUI	• Maximum Frequency: 48 MHz • Maximum Voltage: 5.2 V • Nominal Voltage: 5 V
user_out	Ground Station GUI	User Out	• Language: Python • Output: CSV file • Graphs of altitude and acceleration • Map plot

data_pkts	see Tab 12	see Tab 12	see Tab 12

Table 14: Ground Station Interfaces

3.5.7 Ground Station Design Modifications and Final Design

Following the subscale launch, some changes were made. There were some issues with GPS accuracy, so some calibration and adjustment took place. Additionally the primary programming language was changed from python to Node.js.

The design of the ground station is simple, involving a GPS unit, a transceiver, and a microcontroller. The data from the on board GPS is helpful for determining the direction and location of the rocket relative to the ground station, and thus more accurate drift distance can be calculated. It also has a transceiver which will receive information from the launch vehicle and transmit acknowledgements.The microcontroller will process some of this information and send it to the computer to visually display in the software application.

Powering this system will take place from a battery to ensure that the transmitter will not drain power from the computer. By completely separating this power system from the USB, the risk of damage to the computer and the system is minimized. See Figure 98.

3.5.8 Ground Station Software

The ground station software will be used to view altitude, latitude, longitude, speed, and barometric pressure data transmitted from the on board ATU. The software will also log this data into an Excel spreadsheet for use with an avionics simulator and for data analysis. Original software development of the ground station user interface was done in Python. However after further testing, the team recognized that there were several latency issues receiving data and updating the user interface in a timely manner. A software prototype was developed using Node.js; both performance and reliability appear to be greater than its predecessor. In turn, further development will be made using this runtime environment.

3.5.8.1 Usage and Description

The ground station software will utilize Node.js and is responsible for retrieving serial data from the ATU, writing data to an Excel spreadsheet, and displaying content to the user. The execution of the script will create a web server using port 8080 and allows for a user to navigate to hosted web content. Node.js will generate several web sockets to transmit live, serial information to JavaScript embedded within an HyperText Markup Language (HTML) web page. The user will then have the option to test serial communication, log ATU transmission data, and adjust the refresh rate of the dynamic interface content. Content that will be displayed includes altimeter, location, barometric pressure, time, and date information.

3.5.8.2 Dependencies

Several library package dependencies within the Node.js environment will be used to facilitate the needs of the ground control software:

- Express - allows for the creation of a web server hosted on a local machine
- HyperText Transfer Protocol (HTTP) - provides the necessary utilities to host web pages and content within the Express environment
- Socket.io - assists in passing data from the server to the client in real-time
- Serialport - a package that interfaces with serial ports on a computer
- Justgate/raphael.js - JavaScript gauges used to display incoming ATU data
- Jquery - a package to assist with dynamically displaying data to the user interface

3.6 Recovered Sections

The OSRT will recover the launch vehicle in a single recovered section. This single section will be heavier than two separate sections and will be easier and faster than a two-section launch vehicle. This launch vehicle will be less complex than a single recovered section. However, will require a lower landing velocity, and therefore a larger parachute, which makes integrating the recovery section more difficult. The vehicle overall is less complex, needing fewer avionics and complex tracking components.

3.7 Recovery Compartments

The OSRT will use a dual-deployment, dual-recovery system for the launch vehicle. This involves two separate recovery compartments: the fore section will house the main parachute and the aft will house the drogue parachute. At apogee, the drogue compartment will decouple and the parachute will release. At 600 ft the main section will decouple and the main parachute will release. This dual-compartment system involves more connections and more ejection charges, however, there is less chance for the parachutes to get tangled or fail to eject.

3.8 Parachute Canopy Shapes

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 reputable manufacturers to purchase both the drogue and main parachutes. 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. For the drogue parachute, the team decided to go with a elliptical parachute. This parachute has a coefficient of drag ranging from 1.5-1.6 and is stable at high speeds. This allows the parachute to slow the launch vehicle down to reasonable speeds before deploying the main.

Figure 33: Elliptical Drogue Parachute [6]

Figure 34: Toroidal Main Parachute [6]

3.9 Parachute Sizing

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

$$KE = F_{impact} = \frac{1}{2}mv^2 \tag{15}$$

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

$$D = \frac{1}{2}C_d\rho_{air}v^2A_r \tag{16}$$

From the NASA website [4], drag can be calculated using Equation 16. 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 15 into Equation 16 results in

$$D = W_{lv} = \frac{1}{2}C_d\rho_{air}v^2A_r \tag{17}$$

A_r can be calculated from Equation 18

$$A_r = \frac{1}{4}\pi(d_o^2 - d_i^2) \tag{18}$$

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 [6]. Equation 19 the simplified equation of area with this ratio.

$$A_r = \frac{6}{25}\pi d_o^2 \tag{19}$$

Combining Equation 17 with Equation 19 results in Equation 20

$$d_o = \sqrt{\frac{25W_{lv}}{3\pi C_d \rho_{air} v^2}} \tag{20}$$

With the current weight, the parachute diameter required for the launch vehicle is 12 ft. This will result in the descent speeds of vehicle being 13.1 ft/s. The impact force of the main vehicle is 73.2 ft-lbf. The drogue chute calculated resulted in a 18 in diameter elliptical parachute. With a coefficient of drag of 1.5, the speed from the drogue is 138.2 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	13.1 ft/s
Max Impact Energy with Parachutes 73.2	ft-lbf

Table 15: Vehicle Descent Rates and Energies

3.10 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 35: Shock Cord and Tether Materials

3.11 Packing Method

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 the official Fruity Chutes toroidal parachute packing method as listed on their website. 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.

3.12 Reduction of Zippering

The OSRT decided in order to reduce the load felt in the tether and shock cords, an artificial zipper would be used. Rick Newlands presents a method for reducing zippering called an artificial zipper [16]. The artificial zipper is a series of loops stacked on top of each other secured with blue masking tape. This is done with weaker tape material so that the shock cord still deploys and is not held together with tape during descent. This reduces the force and velocity of the snatch load experienced by the recovery components. A benefit to this reduced velocity and load is the decreased force that will be impacted on the edge of the airframe, thus decreasing the chance of zippering the airframe.

Figure 36: Artificial Zipper

3.13 Kinetic Energy Analysis

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 16 that the maximum kinetic energies felt stay well below the requirements given in the University Student Launch Initiative (USLI) student handbook.

Table 16: Kinetic Energy Analysis

Measurement	Fore Section	Coupler	Aft section
Weight	26.1	4.75	26.21
Velocity Main and Drogue	8.99 ft/s	3.83 ft/s	9.016 ft/s
Kinetic energy with Main and Drogue	36.5391 ft-lb	1.0876 ft-lb	36.647 ft-lb
Velocity with only Drogue	161.1 ft/s	68.75 ft/s	161.3 ft/s
Kinetic Energy with only Drogue	1054 ft-lb	348.4 ft-lb	1060 ft-lb
Velocity no parachutes	150 ft/s	64.2 ft/s	150.961 ft/s
Kinetic energy no parachutes	9255 ft-lb	304.8 ft-lb	9283 ft-lb

3.14 Expected Descent Times

The OSRT wrote a few MATLAB scripts and performed multiple simulations using OpenRocket to determine accurate descent times for the launch vehicle. For subscale launches the simulations in both MATLAB and OpenRocket were accurate within 4 seconds. The subscale came down under 90 s using a 3 ft elliptical drogue and a 7 ft toroidal main recovery system. The simulation for the OpenRocket full scale descent time can be seen in Figure 17.

3.15 Drift Calculation

Table 17: Drift Calculations

Wind Speed (mph)	0	5	10	15	20	Descent time (s)
Drift MATLAB (ft)	0	459	1100	1682	2100	63.2
Drift OpenRocket (ft)	12.4	653	1675	2023	2401	85.4

The difference in these calculations is likely due to the fact that the launch vehicle is tethered together, but can only be simulated in MATLAB as either one body piece, or three separate members with separate parachutes. Both scenarios were tested in MATLAB, but ultimately the launch vehicle simulated as one body under one drogue and one main resulted in closer estimates to the OpenRocket simulation. OSRT decided that OpenRocket is a more reliable source in the context of drift calculations.

3.16 Recovery Integration

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

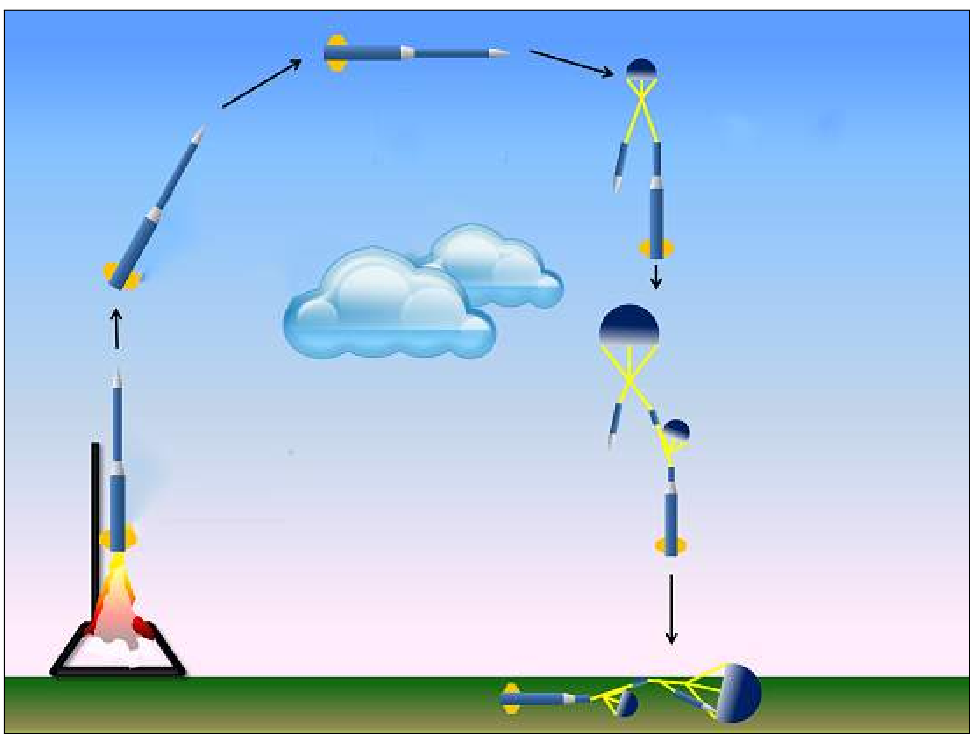


Figure 37: Rocket Simulated Flight Path (Not To Scale (NTS)) [18]

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 and forebody tube with enough force to withstand up to 10 G's. These bulkheads are secured with high strength epoxy to the sides of the body tube. The bulkheads have eyebolts that can withstand 50,000 lbf of impulse upon deployment of the parachute and tether system, from the aft bulkhead is a "tether" this is a 33 ft length of shock cord that connects from the aft bulkhead this is connected on both sides with two 1700lb quick links. On that tether 2/3 of the way to the section connecting to the coupler is a double butterfly knot connecting the drogue parachute shock cord to the tether. This connection from the shock cord to the drogue parachute involves a swivel connected to a 1200lb quick link. Inside the aft body tube will be one e-match and a single motor to connect to the ejection system. This match and the motor connection threaded through the avionic coupler section and into the aft body tube. The coupler itself has two eyebolts on either side each with a 1700lb quick link that attaches to the tether. In the fore section of the launch vehicle, there is a tether connecting from the coupler to the fore bulkhead via four 1700 lb quick links, two on either side. 1/3 down this section of the tether from the coupler side is a double butterfly knot connecting the 15ft main parachute nylon shock cord to the tether. Inside the forebody tube is a similar layout to the aft section with a single e-match and motor for the black powder charges. 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 of the parachute. Underneath both parachute connections will be a Nomex fire blanket to reduce any burning or damage done to the parachutes.

3.17 Ejection Charges

3.17.1 Black Powder Ejection Charges

Since all of the charges will now be made of BP, it was necessary to design and test BP charges. In order to calculate the initial necessary size of the charges, the following equation was used:

$$BP = 0.006 * l_{compartment} * d^2_{compartment} \tag{21}$$

$l_{compartment}$ for the subscale launch vehicle is the length of the parachute bay. The length of the main parachute bay was 14 in. and the length of the drogue parachute bay was 26.5 in. for the subscale launch. $d_{compartment}$ is the diameter of the parachute bay, which, for the subscale launch vehicle, is 3.9 in. For the launch, the team planned on using four #2-56 shear pins for both the drogue and main parachute bays. According to the High Power Rocketry Strength of Materials guide recommended by Apogee Rockets, which is where the shear pins that the team uses are sourced from, it takes an average total of 84.44 lbf to break the four pins, as shown in Figure 38 [17]. Since the bulkheads are approximately 11.94 in.^{2}, it takes approximately 7.07 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 38: Nylon Shear Pin Breaking Forces [17]

The coefficient of 0.006 in the BP equation is meant to allow the calculated amount of BP to create a pressure of 15 psi within a given space [8]. From this, if the bulkheads experience a pressure of 15 psi, the shear pins should break with a safety factor of 2.12. Therefore, the following BP charge sizes were used, as detailed in 18.

Table 18: Calculated BP Sizing

BP Charge	**Size (g)**
Subscale Main Parachute Primary Charge	1.28
Subscale Drogue Parachute Primary Charge	2.42

On the lower end, based off of how the coefficient of 0.006 produces 15 psi, in order to produce 7.07 psi, the coefficient is 0.002828, and therefore, the minimum size the charges need to be is detailed in Table 19.

Table 19: BP Minimum Sizing

BP Charge	**Minimum Size (g)**
Subscale Main Parachute Primary Charge	0.60
Subscale Drogue Parachute Primary Charge	1.14

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 to be used are listed in Table 20.

Table 20: Rounded BP Sizing

BP Charge	**Size (g)**
Subscale Main Parachute Primary Charge	2.0
Subscale Drogue Parachute Primary Charge	2.5

These charge sizes were then tested via the testing procedure outline seen in the Black Powder Parachute Ejection Testing. For the subscale flight, both the charges for drogue and main ejected their respective parachutes out of their respective bays, as seen in Figures 40 and 41. Therefore, both charges successfully passed their tests, and showed that the preliminary calculations were correct.

The full scale BP charge testing has yet to be completed with the quick release connectors has yet to be completed.

For back-up charge sizing, the charge sizes were simply doubled from primary charge size, so that the back-up charges were sized as in Table 21.

Table 21: BP Back-up Sizing

BP Charge	**Size (g)**
Subscale Main Parachute Back-up Charge	4.0
Subscale Drogue Parachute Back-up Charge	5.0

At this point, the assembly procedures were created for the individual BP charge construction and installation into the airframe of the launch vehicle, can be seen in the Black Powder Ejection Charge Checklist, and are further discussed in the next subsection. Given that during the test integration of the launch vehicle, the drogue parachute did not originally fit in the drogue parachute bay, and the bay had to be extended to the

26.5 in. length to fit the parachute, the team decided to decrease the drogue parachute primary charge size from 2.5 g to 2.0 g, and the back-up charge size from 5.0 g to 4.0 g. Since the minimum acceptable charge size was 1.14 g, this was still within the range of acceptability.

For the subscale flight, the finalized charge sizes were as follows in Table 22

Table 22: Subscale Finalized BP Sizing

BP Charge	**Size (g)**
Main Parachute Primary Charge	2.0
Drogue Parachute Primary Charge	2.0
Main Parachute Back-up Charge	4.0
Drogue Parachute Back-up Charge	4.0

During the subscale flight, both parachutes deployed at the correct times and correct altitudes using the primary charges, as seen in Table 9, and the back-up charges exploded after the parachutes left the bay.

For full scale, the diameter of the parachute bays is 6.25 in., the length of the main parachute bay is 20.2 in., and the length of the drogue parachute bay is 8.04 in. Given these numbers, the necessary charge sizes are as follows:

Table 23: Full Scale BP Sizing

BP Charge	**Size (g)**
Main Parachute Primary Charge	4.8 g
Drogue Parachute Primary Charge	1.9 g
Main Parachute Back-up Charge	9.6 g
Drogue Parachute Back-up Charge	3.8 g

Since the main parachute bay requires such large charges, unless the volume of the bay is cut down, a tool will be created to install the BP charges into the airframe of the launch vehicle without requiring the individual who is installing the BP charges to put their arm into the airframe with a maximum of 14.4 g of BP. This is done primarily as a safety precaution, because, while steps have been taken to mitigate the number of opportunities that the charges have to ignite prematurely, including twisting the e-matches and wearing Electrostatic Discharge (ESD) bracelets, with charges of sizes of this magnitude, the team does not want to take any risks that are not absolutely necessary.

3.17.2 Black Powder Ejection Assembly

The components used for the assembly of the BP sizing are as follows:

- 1/2-in. inner diameter surgical tubing

- 1/2-in. diameter silicone rubber rod
- FFFF g BP
- 3-ft long Firewire Initiator (e-matches)
- 8-in. long black cable ties
- 2 differently colored Sharpies

The 1/2-in. inner diameter surgical tubing selected was the McMaster-Carr Super-Soft Latex Rubber Tubing for Air and Water that has an inner diameter of 1/2 in. and an outer diameter of 5/8 in. Its maximum pressure that it can hold is 10 psi at a temperature of 72 degrees Fahrenheit. Given that the space within surgical tubing will at least be holding 2.0 g of BP, and given that the tubing has an inner diameter of 1/2 in., and the space within the surgical tubing is about 1.5 in. in length after the rubber stoppers are installed, from the BP sizing equation, the surgical tubing experiences a pressure of approximately 13,334 psi, which means that the surgical tubing will have no issue rupturing when the BP is ignited. The surgical tubing is used as the main object that houses the BP.

The 1/2 in. diameter silicone rubber rod selected was the McMaster-Carr High-Temperature Soft Silicone O-Ring Cord that has a diameter of 1/2 in. This silicone cord was primarily selected because it fits into the surgical tubing and is moderately inexpensive at $4.94 per foot. It is also relatively easy to cut and pull apart. The rubber rod is used like a cork at each end of the section of surgical tubing to ensure that the BP does not escape.

The FFFF g BP was selected because FFFF g is the finest grain BP and therefore, will burn the fastest out of the different grains of BP that are available for purchase. The BP is used as the primary object to create the pressure necessary to break the shear pins at the end of either the drogue or main parachute bay and force the respective parachute out.

The 3 ft long Firewire Initiator was selected because the other options that are available for sale by MJG Technologies Inc. are e-matches that are 1 ft, 7 ft, 10 ft, and 15 ft in length. The 1-foot e-match would be too short to reach the end of the parachute bays, and the lengths of 7 ft and above are overkill for these purposes, and would add unnecessary mass to the launch vehicle and, especially, unnecessary mass in the parachute bay. The e-matches are used to ignite the BP in each of the charges.

The 8-inch long black cable ties were purchased from Harbor Freight. These cable ties were selected because they were larger in size, and came in packs of 100 for the low price of $1.99. The cable ties are used to ensure that the rubber stopper does not fall out of the surgical tubing at any point during the flight, and to ensure that no BP escapes.

The two differently colored Sharpies were sourced from a member of the team's personal Sharpie supply, and are used to label the charges to ensure that they are not confused for one another, and to stripe the e-matches of the back-up charges to ensure that the back-up and primary charges are not confused for each other when installing the e-matches into the altimeters.

The assembly checklist for putting together the charges is provided in the Black Powder Ejection Charge Checklist.

3.17.3 Black Powder Ejection Charge Testing

To test for subscale, the team constructed a BP test bed, shown in Figure 39. The test bed has a bay that is adjustable in length by having the back bulkhead attached to a threaded rod that can be turned to move the bulkhead fore or aft. This allows for testing in bays of varying lengths. It also has an inner diameter of 3.9 in. and uses four shear pins to mimic the actual subscale launch vehicle as closely as possible. The BP charges were ignited according to the Black Powder Ejection Charge Checklist found in Section 6, with the exception that it did not utilize the quick release connectors. To connect the long wire with the e-match, the wires were simply wrapped around each other, and to keep them separate, the wrapped wires were duct taped to opposite sides of the ejection tube. Both the main parachute with a 2.0 g charge and the drogue parachute with a 2.5 g charge were ejected from the airframe and cleared it with a fair distance, as shown in Figures 41 and 40.

Figure 39: BP Charge Test Bed

Figure 40: BP Charge Test Bed After Drogue Ejection

Figure 41: BP and CO2 Ejection Charge Test Bed After Main Ejection

3.17.4 CO2 Ejection Charge Design

The primary charges for the full scale launch vehicle were intended to be CO2-based and not use the aid of BP to puncture the canister. However, due to a need to cut down both weight and length in the launch vehicle, the use of CO2 to eject the parachutes was scrapped for the lighter and smaller BP alternative. Also, since OSRT was unable to test the CO2 ejection system in the subscale launch, the team would prefer to use a method that they know is reliable with something as mission critical as parachute ejection. Therefore, since the team has a much better background with BP charges, and was able to successfully test them on the subscale flight, the team will only be using BP charges in the full scale launch vehicle.

3.17.5 Altimeters

In order to actuate the BP ejection systems, OSRT has opted to use the Missile Works RRC3 altimeters both for the primary and the back-up ejection charges of the main and drogue parachutes. While these altimeters are larger than other commercially available altimeters, such as the Stratologger CF, the team decided to use the Missile Works RRC3 altimeters because they are easy to program and reprogram anywhere without the use of a computer, and the team was also able to successfully connect these altimeters to computers, whereas they had significant difficulties connecting to the Stratologger CFs.

3.17.6 Altimeter Testing

Before flying in the subscale launch, the team tested the RRC3 altimeters in a vacuum chamber that could simulate the flight path of a launch vehicle. The team conducted the test as described in the Altimeter Testing checklist, and the set-up can be seen in Figure 42. The vacuum chamber depicted and mentioned is effectively a thick aluminum bucket with a valve that a suction hose can be attached to, a ring of rubber along the rim, and a 2-in.-thick acrylic lid, which is heavy enough to make a seal with the rubber along the bucket's rim. After the altimeters were switched to the "On" position, the lid was placed on the top of the bucket, and the suction hose was installed.

Figure 42: Altimeter Testing Vacuum Chamber Setup

Once the chamber pressure was brought back to atmospheric pressure, and the suction tube, lid, and the altimeter bay was removed, this test labeled as successful since all of the e-matches were ignited at the expected points, with the primary drogue charge igniting at simulated apogee, the back-up drogue charge igniting one second after that, the primary main charge igniting at 600 ft, and the back-up main charge igniting at 500 ft.

The next test of the altimeters was in the subscale launch, where the altimeters deployed the drogue parachute at apogee, ignited the back-up drogue charge at 1 s after apogee, deployed the main parachute at approximately 600 ft, and ignited the back-up main charge at approximately 500 ft.

Although the altimeters ignited the ejection charges at the right time for the first subscale launch, the team opted to try to further test the altimeters to ensure that they were not prone to any sporadic inaccuracies, such as malfunctioning every tenth launch or something as equally random and unexpected. The team decided to pursue this since these altimeters were used by both the 2018 and 2019 OSRTs, and therefore, could have sustained some sort of damage during one of those years that could cause them to malfunction sporadically. Because the team did not want to pursue another subscale flight, OSRT tried to come up with other ways to test the altimeter bay, including but not limited to:

- chartering a helicopter, to which the altimeter data from the RRC3 altimeters could be compared to the altimeter data from the helicopter,
- using approximately 75 helium balloons to lift the altimeter bay to roughly 400 ft, and tethering it to the ground via a known length of heavy duty fishing line to ensure that the altimeter bay does not escape,
- riding a ski lift of a known length up and down the side of a mountain,
- chartering a small plane to which the altimeter data from the RRC3 altimeters could be compared to the altimeter data from the plane,
- running up and down either the elevator or the stairs in a tall building with a known height in downtown Portland, Oregon,
- using the vacuum chamber, which is not quite as precise as would be preferred, especially given that the subscale is only flying to approximately 2000 ft in altitude, and therefore the change in atmospheric pressure is not very large,
- flying the altimeter bay on a drone up to 400 ft and back, to which the altimeter data from the RRC3 altimeters could be compared to the altimeter data from the drone.

Due to safety concerns, and the facts that e-matches would be going off at specified points during flight and that the altimeter bay, to someone who is unfamiliar with the USLI competition, looks vaguely like a bomb, OSRT opted to attempt to test the altimeter bay via the last option, with a drone. The drone chosen, based on availability, was a DJI Phantom 4, which has its own altimeter, and therefore, the team can reliably tell how high the bay is. The drone also has its own onboard camera that live-streams to the controller, and so, the team can also tell whether or not the e-matches ignite at the accurate times and altitudes.

Therefore, the team assembled the altimeter bay for a fourth time, and set the altimeters so that the main parachute e-matches would both ignite at 300 ft. This altitude was chosen because, legally, civilian drones can only fly up to 400 ft in altitude, and the lowest altitude that the RRC3 altimeters can deploy the main parachute at is 300 ft. The altimeter bay was then tied to the landing struts of the drone with rope, and the e-matches were positioned in a place that the on-board camera could see, while still being safe for the drone, altimeter bay, and the operators.

However, OSRT ran into a problem. The entire altimeter bay weighs about 2 lbf, which is too heavy for a DJI Phantom 4 drone to lift, even at full upward throttle. Therefore, the team contemplated the pros and cons of either trying to fly the altimeter bay with two drones or a bigger drone, and opted to try to find a bigger drone. OSRT reached out to a drone rental company then, but never heard back from them. In the meantime, the advisors suggested that the team simply do another subscale launch to test the altimeters and ensure that everything was working properly after making more holes in the section of airframe surrounding the altimeters. However, the team wanted to ensure that the altimeters were working properly before sending it up on another subscale launch, and therefore, decided to disassemble the altimeter bay, and strap the altimeters, battery packs, switches, and e-matches to the struts of the drone, which eliminated enough weight to be able to fly the system up to 400 ft with the drone. The interesting thing about this system was the unforeseen problems associated with the propellers. The propellers create a downwards force, particularly when attempting to lift off, meaning that there is increased airflow over anything that is below the propellers. Given that a moving fluid has a lower pressure than a static fluid, and the faster the fluid moves, the lower the pressure is, having the altimeters strapped to the struts of the drone impacted them negatively because they were getting the downdraft from the propellers, which caused their barometric pressure sensors to read atmospheric pressures that were incorrect. These incorrect pressures led to all sorts of issues up to and including misfired e-matches and e-matches that were not fired at all. After attempting several of these flights with no success, the team opted to test in a vacuum chamber again to make sure that the altimeters acted as predicted.

Since the other subscale launch was scrubbed due to weather, the team particularly focused on testing the altimeter bay in the vacuum chamber. Three tests were run, two in the fully assembled state and a third without the section of airframe covering the altimeters, by following the Altimeter Testing Checklist. The set-up can be seen in Figure 43. In each case for the fully assembled test set-up, the drogue charges went off at apogee and at 1 s after apogee, respectively, but the main parachute charges did not go off until the chamber was close to standard atmospheric pressure; however, the team could not tell what the pressure was due to the inexact gauge that was installed on the vacuum chamber. Since the main charges did the same thing two times in a row, and also went off extremely close to each other, OSRT decided to run a test just with the main e-matches attached and without the airframe to ensure that the main parachute ports were not malfunctioning. After placing the bay into the vacuum chamber and running the test for a third time, it was shown that the main charges go off at very low pressures, and very close together in the vacuum chamber, and therefore, the altimeters were behaving correctly. While this was the case during this test, the team decided that new RRC3 altimeters should be purchased due to the concern that these altimeters have been used many times throughout the years, and the team did not want to risk having them spontaneously malfunction during a flight due to their age or previously sustained damage, and threaten the safety of the spectators, the team, and the launch vehicle.

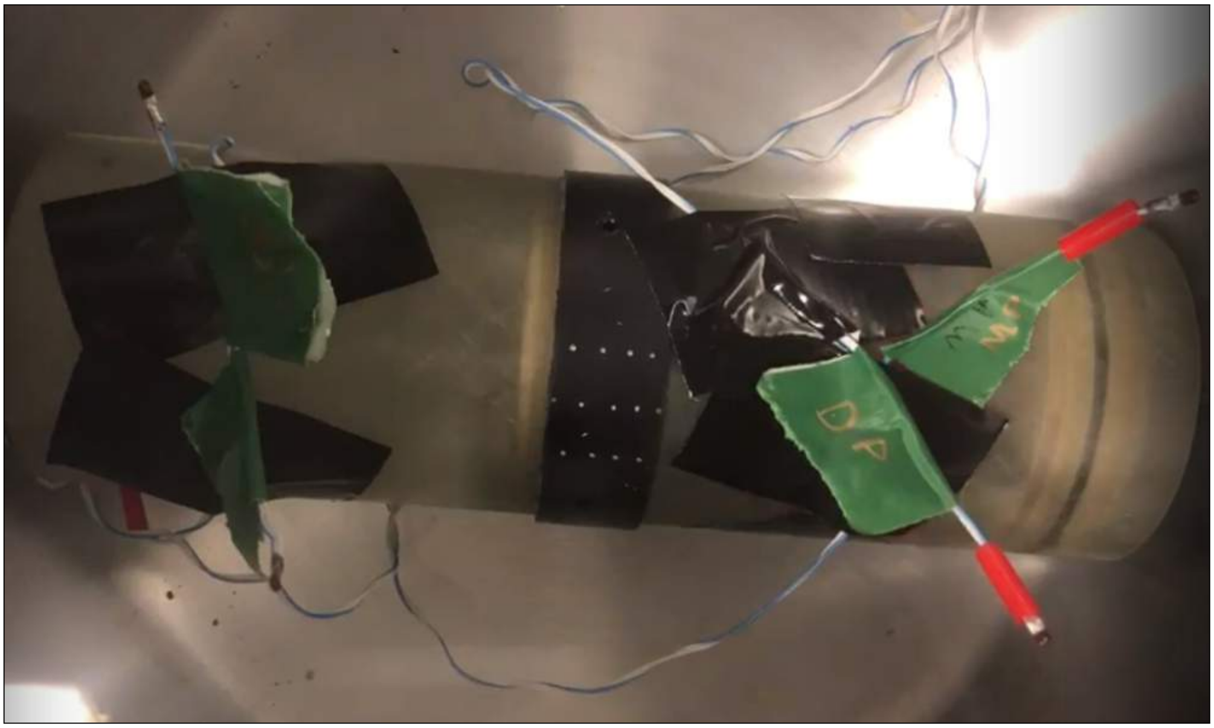


Figure 43: Altimeter Bay Test Set-Up, Full Assembly

4 Payload Criteria

4.1 Payload Objective

The main objectives of the payload is to survive 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 survive launch and landing of the flight vehicle, there must be a fail-safe retention system. 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 samples. To complete the challenge, it will have to drive at least ten linear feet away with the collected samples to signify a non-existent recovery operation.

The Payload for the OSRT will be a rover with expandable wheels, a beaver tail-shaped stabilizer, and a scoop like collection system. It will be ejected from the launch vehicle by means of a lead screw motor with a built-in retention system involving two circular plates, each with a threaded section 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. Once in position, there will be a linear forward motion provided by the wheels to drag the scoop just under the ground and collect the sample material. The sample will then be stored in the scoop in the storage position as the rover completes the challenge by driving ten linear feet from the collection site. OSRT designs will be discussed in the following sections along with supporting specifications, justification of concepts, and any relevant analyses.

4.2 Payload Electronics Overview

The payload involves the use of two different electronics systems, the payload rover system and the control station system. The rover system contains a Teensy 3.6 microcontroller, absolute orientation sensor, GPS sensor, and wireless First-Person View (FPV) camera. The control station system contains a GUI, Teensy 3.6 microcontroller and wireless XBee transceiver. Figure 44 shows the top-level blocks in the payload system.

Table 24: Payload System Requirements

Client Requirement	Engineering Requirement	Verification Plan
Teams may recover a sample from any of the recovery areas.	The payload must be able to move at least a quarter mile on one full charge.	Charge the battery for the payload fully, then operate the payload to go up to a quarter mile of distance. If the payload is still running after moving a distance of a quarter mile, then it meets the requirement.

Continued on next page

Table 24 – continued from previous page

Requirement	Verification Plan	Status
The recovered sample must be stored and transported to at least 10 linear ft from the recovery area.	The payload must be able to collect at least 10 mL of solid material.	The payload will be deployed on a bed of plastic BBs. The motors on the collection system will then be initialized by user input. The user may control the payload for half an hour. The collected material is measured in a beaker. If it is greater than or equal to 10 mL, then the system passes.
The payload system will visually display the location of the payload and the location of the designated sample areas.	There must be programmed GUI for accurately displaying the payload and the sample areas geographic data.	Multiple members from the team/class should be easily able identity data set within the GUI with no previous experience with the interface. Nine out of 10 users should be able to identity which data is which within 1 minute.
The electronic systems must be reliable.	See Table 47	Same as test for requirement in Table 47
The electronic systems must be reliable.	See Table 47.	Same as test for requirement in Table 47.

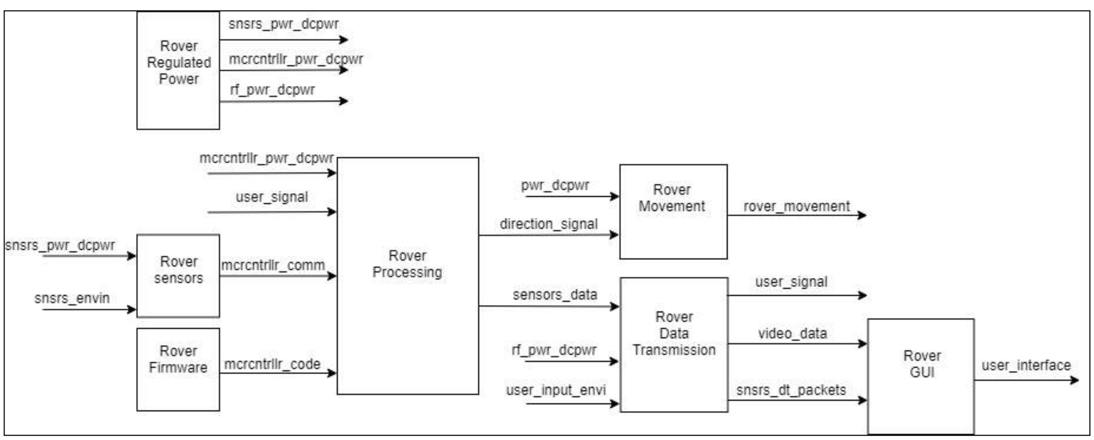


Figure 44: Payload Top Level Block Diagram

4.2.1 Rover Interfaces

Interface Name	Source	Destination	Properties
otsd_pyld_- _rvr_snsrs_envin	Outside	Rover Sensors	• three-axis orientation • GPS location • Temperature between 30°F and 100°F
otsd_pyld_- _rvr_mvmnt_ dcpwr	Rover Movement	Outside	• Nominal Current: 400 mA • Peak Current: 2.1 A • Maximum Voltage: 12.7 V • Minimum Voltage: 11 V

pyld_-_rvr_frmwr_ pyld_-_rvr_ mcrcntrllr_ data	Rover Processing	Rover Microcontroller	• Baud Rate: 180 MHz • Clock Frequency: 16 MHz • Rover direction control • Digital sensor input
pyld_-_rvr_ mcrcntrllr_ pyld_-_ rvr_ mvmnt_asig	Rover Microcontroller	Rover Movement	• Max PWM value: 255 • Min PWM value: 0 • Maximum Voltage: 3.3V • Minimum Voltage: 0.4V
pyld_-_ rvr_ snsrs_ pyld_-_ rvr_ mcrcntrllr_ comm	Rover Sensors	Rover Microcontroller	• Data-rate: 10 Hz • Protocol: I2C • Maximum Voltage: 3.3V

Table 25: Rover Interface Definitions

4.2.2 Rover Electrical Testing

Power testing will be an essential method to validate the voltage and current requirements. This will involve several verification methods. The estimated power requirements can be seen in Table 26.

Block	Component	Voltage (V)	Current (mA)	Power (mW)
Movement	DRV8847	12	1400	16800
Movement -Collection	DRV8847	12	700	8400
Transmission	XBee Pro	3.3	120	396
Transmitter (Standby)	XBee Pro	3.3	1.8	5.94
Microcontroller (Active)	Teensy 3.6	5	10.5	6.75
Microcontroller (Idle)	Teensy 3.6	5	4.5	36.75
9 Axis accelerometer	ICM-20948	3.3	3.11	10.263
9 Axis accelerometer(sleep)	ICM-20949	3.3	0.0008	0.00264
GPS	MAX-M8Q	3.3	2.5	8.25
Indicator LEDs	green	3.3	60	198
Indicator LEDs	green	5	10	50
Power	5V Regulator			192.3947013
Power	3.3V Regulator			142.901
Max Total				26247.25134
Total Power		12	102.7476769	1232.972123

Table 26: Rover Power Budget

With these power calculations the Rover can last at full power for 1.94 hours.

4.2.3 Rover Design Modifications and Final Design

The Schematics can be seen in the Appendix Figures 114, 115,116, 117, and 118. The initial design did not take into account the use of 3.3 V sensors that are now being used. This partially resulted after a series of tests took place to test the accuracy of the GPS data. Of the two sensors with a test PCB build around it. The MAXM8Q proved to have a higher accuracy in the field, and the SAM-M8Q was less accurate. This design also led to the changing of the transceivers to use XBee and not the LoRa originally designed for. The XBee has more consistent behavior when being operated at 3.3 V.

4.2.4 Control Station Electronics

The control station system's main components are a remote control and GUI. The GUI displays current rover GPS data, a current direction indicator, and wireless video data. The sensor data will be received via serial communication from XBee wireless transceivers. The GUI is programmed in C# using Windows .NET Framework.

4.2.5 Control Station Interfaces

Interface Name	Source	Destination	Properties
pyld_-_bs_sttn_g_pyld_-_rvr_dt_trnsmssn_rf	Rover Data Transmission	Rover GUI	• Datarate: 5 Hz • GPS data and gyroscope data • Protocol: XBee
pyld_-_bs_sttn_g_otsd_other	Rover GUI	User Interface	• Language: Written in C# • Inertial Measurement Unit (IMU) data • Video display • GPS location

Table 27: Control Station Interface Definitions

4.2.6 Control Station Testing

The GUI needs to correctly display data received from the XBee transceiver at a minimum of 5 times a second. The data transmitted through the XBee transceiver includes GPS location of rover and magnetometer data. Wireless video data will be transmitted via FPV camera.

4.2.7 Control Station Design Modifications and Final Design

The control system has been modified to maneuvering solely based on user input received via XBee wireless communication. The GPS guidance system has been removed due to uncertainty of the landing location of the launch vehicle. The GPS will still be on the rover, but it will be used only to advise the driver and not to automatically control the rover.

4.3 Payload Chassis

The rover chassis will consist of wooden panels supported by aluminum rods, shown in Figure 45. Four wooden disks, two panels, and two skeletal supports provide mounting surfaces for all electronics and rover components. Additionally, three tapped aluminum bars are used to support the overall structure. All of these members absorb any impact loading and protect the wooden structure from potential ground conditions. This design consists of components that can be laser cut from readily available materials, making it easy to manufacture and also easy to modify. This is important because the rover chassis must be able to adjust to any changes to the payload. This design offers abundant mounting surfaces for all components, making it easy to mount payload electronics. Laser cutting makes it easy to quickly cut custom panels for various payload configurations with the added benefit of making it possible to manufacture additional chassis with minimal effort. These possibilities allow OSRT to not only develop backup systems for competition, but to perform comprehensive tests on the chassis in regards to strength and durability. All the wooden components of the chassis fit together in a lock and key manner, making the design both easy to assemble and rigid. The structure is held together by six fasteners (two per aluminum rod).

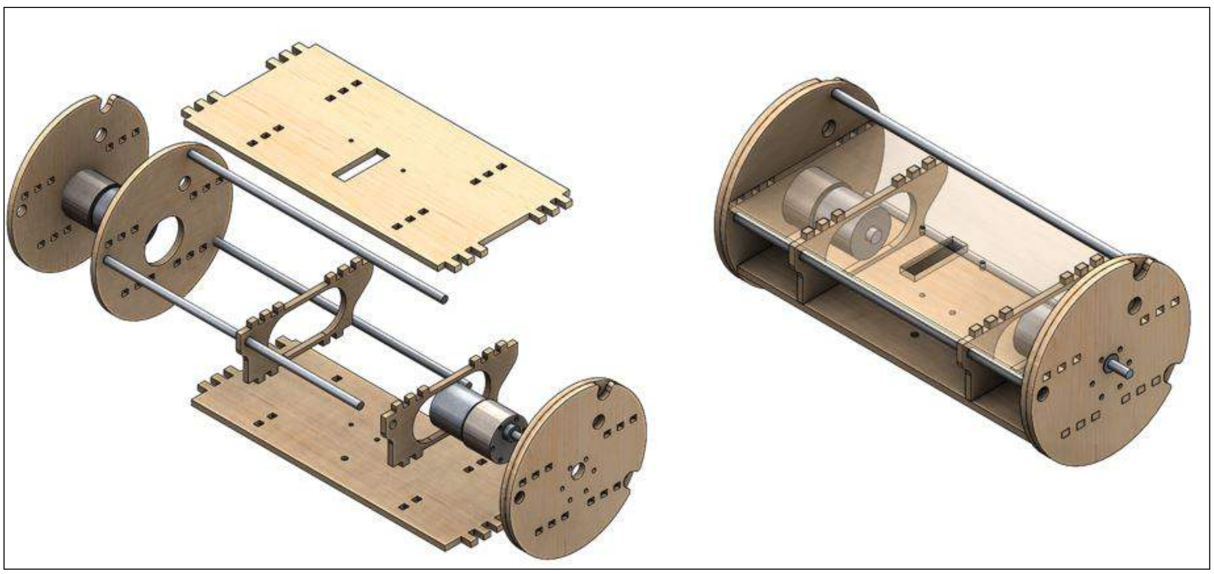


Figure 45: Chassis Design

In deciding the materials for the rover chassis, a number of factors were considered. Initially OSRT wanted a design that was easy to manufacture, requiring materials that could be machined in-house easily. OSU has access to laser cutting, wood CNC routers and three-axis CNC Fadal machines, and water jet equipment. This equipment would make it possible for OSRT to pursue a variety of designs; however, metals and composites presented additional challenges for machining. For this reason, polymers and natural materials were much more favorable. A design consisting of rod and sheet material was developed with a laser cutter or water jet equipment in mind. A more detailed analysis of the rod and sheet material was conducted to determine the most ideal materials. The sheet material in the chassis was identified as needing to be able to withstand impact, loading, and buckling. Cross members in particular were most vulnerable to buckling under flight forces, or fracturing in the event of a collision during the ground mission. Material analysis was conducted, using CES software, in the pursuit of identifying materials with lowest weight and cost that could handle these factors. The results of this analysis identified natural materials as being the best option. A similar study was done for the aluminium supports. The supporting rods need to be rigid in order to protect the rest of the chassis from deflection. These members must also be strong to withstand any and all loading during the mission. Again OSRT has conducted this study to identify the lightest and cheapest materials available that meet these requirements. This analysis showed aluminum alloys have the best combination of cost, weight, strength, and rigidity. As a result, wood has been chosen for the rover sheet material, and aluminum for the supports. An added benefit of these materials is that wood can be laser cut, and aluminum can be machined with little difficulty. A detailed technical analysis of the payload chassis can be found in 4.3.1.

The outer diameter of the chassis is currently 5.75 in. The inner diameter of the airframe will be 6.25 in. The chassis has a smaller diameter because the spokes of the rover wheels need to fold over the chassis when inside the airframe. The diameter was chosen because it gives the spokes enough room while at the same time providing enough room on the chassis for the collection, and electronic systems. The rover is currently 15 in. long. This length has been chosen to allow enough room for rover electronics. As the rover system becomes more defined, the length may adjust to better fit all components. Currently the chassis weighs 2 lb with the drivetrain motors attached.

4.3.1 Chassis Technical Analysis

4.3.1.1 Structure Material Selection

Description: The payload structure needs to be lightweight, strong, durable, and fracture resistant. To ensure an appropriate material is used, a material analysis has been conducted to select the optimal material for the structure components.

Analysis Details: The rover structure was separated into two component types: the rigid cylindrical members that support the rover and the sheet material that provides mounting surfaces for the electronics. Each was then analyzed in detail focusing on a variety of loading types and minimizing the mass and cost of the components.

Results: Wood is the optimal material for the rover sheet/panel material, and aluminum has been identified as the optimal material for the structural rods.

Assumptions:

- CES contains accurate material properties and cost information
- Panels are in pure compression

Analysis:

Weight and cost are serious concerns facing this year's payload. These parameters can vary widely depending on which materials are chosen for the rover chassis. To address this concern, a material analysis was done on the chassis design. The chassis was separated into two component types, the structural rods/beams ("B" in Figure 46), and the structural plates ("A" in Figure 46). The length and diameter of the rover is fixed due to space constraints. However, the rod diameter and plate thickness can vary. This parameter is determined by the material that were choose. Using CES software and methods described by Michael F. Ashby in "Material Selection in Mechanical Design" [2], the optimal materials for these components were defined .

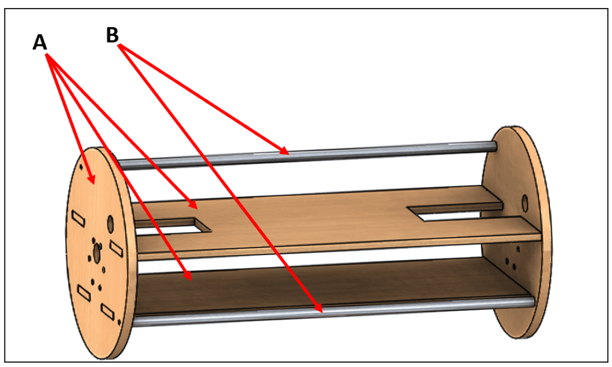


Figure 46: Chassis 11/20/2019

4.3.1.2 Chassis Plate Selection

Two structural constraints were used to analyze the plate components on the chassis. Firstly, the structure must be durable and able to survive impact. The chassis will likely experience impact forces during the launch, recovery, and ejection phases of the mission. The rover may hit objects when navigating to the objective. Secondly, these components will be subjected to bending and buckling, both in flight and on the ground. Bending may occur if the rover hits an obstacle on the ground. As a result, a stiffness constraint has been added to the analysis. These constraints are then related to mass and the cost of the rover to create a CES plot. Shown in Figure 47, are the constraints, objectives, and indices used in this analysis.

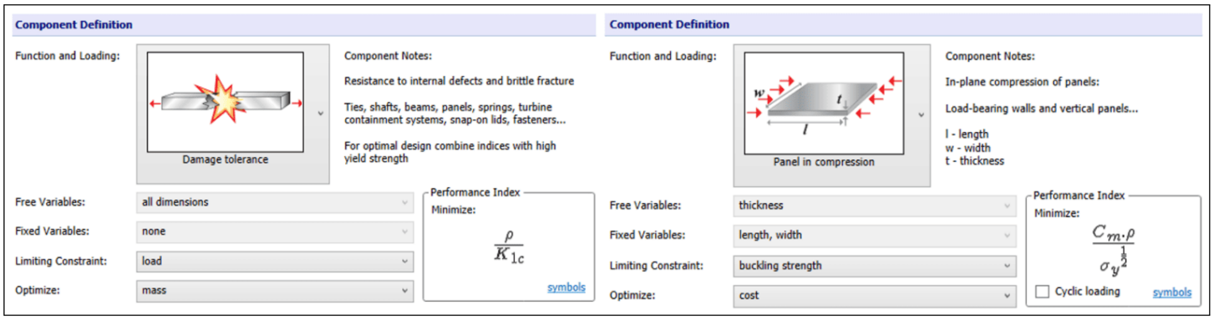


Figure 47: Chassis Plate Constraints

These indices were then used to develop the plot shown in Figure 48. The y-axis of this plot represents mass and fracture strength; the x-axis represents cost and material strength. Materials in the bottom left corner have the best combination of fracture resistance to weight and strength to cost ratio. Whereas materials in the top right corner are the heaviest and most expensive. Materials along the orange represent the best options for the chosen design.

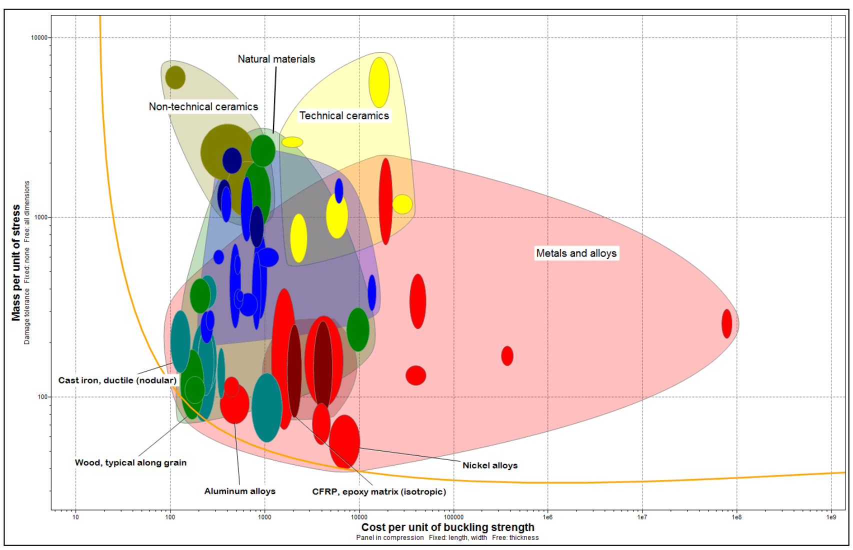


Figure 48: Chassis Plate CES plot

As seen in the plot, wood/natural materials have the best combination of strength, fracture resistance, cost, and weight. For reference, other common materials are also shown.

4.3.1.3 Chassis Rod Selection

A similar analysis was done for the structural rods in the chassis. These components hold the chassis together and absorb much of the in-flight forces. As a result, OSRT wants these components to be very stiff and strong. The constraints and indices can be seen in Figure 49.

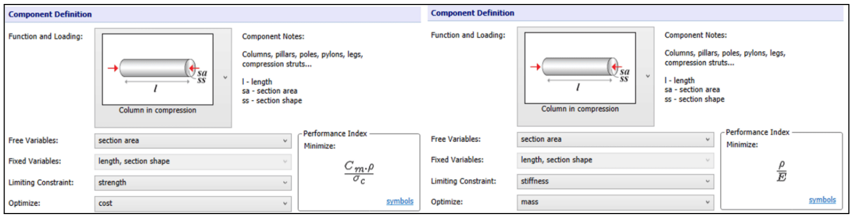


Figure 49: Chassis Rod Constraints

Seen in Figure 50 is a plot showing optimal materials for these rods. This graph shows carbon fiber and silicon carbide as being the optimal materials. Silicon carbide, however, is not feasible. This technical ceramic is much more susceptible to fracture than other materials and it is also difficult to machine. Carbon fiber has a similar issue. Aluminum on the other hand is easy to work with, readily available, much cheaper, and lies on the peak performance curve, with the only downside being a slightly increased weight and reduced rigidity.

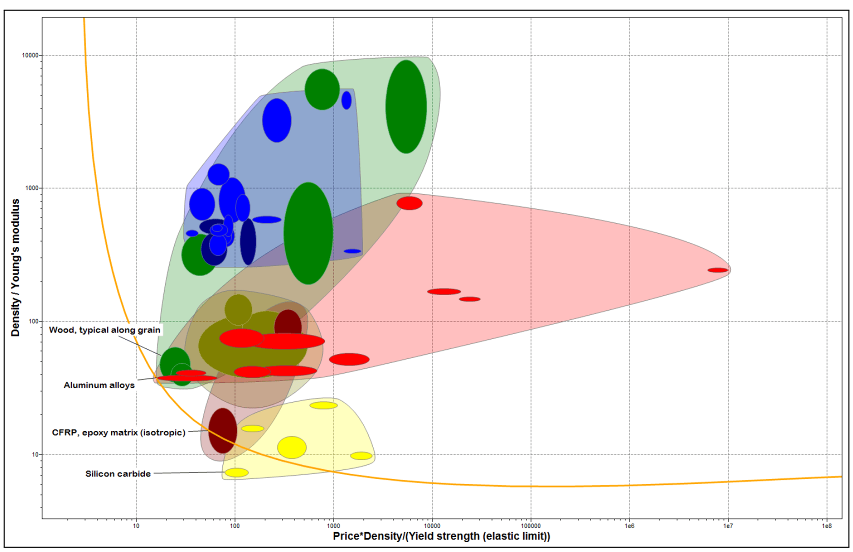


Figure 50: Chassis Rod CES

Due to manufacturing concerns, design simplicity, and cost, aluminum was chosen for these rods.

Summary: As a result of this analysis, the chassis will consist of the following materials.

- Chassis structural plate: Wood
- Chassis structural rods: Aluminum Alloy

4.3.1.4 Impact Resistance

Description: When the main parachutes deploy, the airframe will experience a jolt. These forces will potentially cause the payload to "slam" or hit part of the airframe. As a result, a drop test analysis has been done to simulate any force felt by the payload when the main parachute deploys. The goal of this analysis is to investigate how the payload will react to this type of loading and identify if design changes are needed to account for this situation.

Analysis Details: Using impact analysis, the rover was subjected to a 6 ft drop test. Depending on when the parachute deploys, the payload could see any number of forces. Due to this uncertainty a 6 ft height was chosen to see how the payload reacts to a substantial loading situation.

Results: The maximum stress seen in the payload is 10 ksi. This is below the yield stress of aluminum. As designed, most of the loading is absorbed by the aluminum rods. However, this stress does not allow for an acceptable safety factor required by the sensitive components on board the payload. The largest concern being how fasteners and electrical components will react. Due to this concern the payload retention system will be redesigned to better absorb impact loading.

Assumptions:

- Pure axial compression: While inside the launch vehicle, the rover will be held axially. As a result, all forces should be passed axially down the length of the rover.

Constraints: The rover is subject to purely axial loading. During the mission the payload will be retained within the airframe. The expandable wheels and lead screw will hold the rover within the airframe preventing it from moving in any ,direction other than axially.

4.3.1.5 Launch Forces

Description: During the high power rocket launch, rapid acceleration will result in loading on the rover chassis, an analysis has been conducted to identify possible points of failure and maximum stresses.

Analysis Details: Using a static FEA in SolidWorks the structure was subjected to a 20G (20 times the force of gravity) loading.

Results: Maximum stress of 4 psi, and deformation of 0.0002 in. The launch forces pose little concern in regards to the rover structure. Additional analysis should be done on the full rover assembly to ensure stability and identify forces on fasteners.

Assumptions:

- Pure axial compression: While inside the launch vehicle, the rover will be held axially; as a result, all forces should be passed axially down the length of the rover.

Constraints: For this analysis, the structure is fixed on one end. All members are welded to simplify the simulation. The components are made of representative materials (i.e. aluminum and balsa). To simulate the loading, the gravitational force was increased by 20 times the natural force seen on earth (32.2 lb/in^2).

Analysis:

The rover chassis must be able to survive the mission intact. Any failure in the chassis structure could lead to mission failure. If any structural member fails, then the rover drivetrain will no longer function. If any mounting surface breaks, then electrical components could be ripped from the chassis. Any bending or fracture in components is unacceptable.

The largest forces and stresses the chassis will see will be during rocket launch and recovery. Thrust due to the motor will cause stress in the chassis. When the parachutes deploy, the airframe and chassis will be subjected to a variety of shock forces. Black powder ejection will send a jolt through the airframe. When the parachute fully deploys, another jolt will pass through. A final jolt will occur when the rocket lands. These forces will likely be much greater than anything the rover sees on the ground. As a result, OSRT will focus its analysis on the rover under flight forces.

4.3.1.6 Chassis Impact Resistance

When the parachute is deployed, the airframe will see a shock loading. To simulate this, OSRT will analyze the chassis under an impact stress. Using a SolidWorks (FEA) the chassis has been tested to identify stress concentration, and deformation.

Analysis Parameters:

- Materials: Balsa sheet stock, aluminum 6061 rods
- Force: 6 ft drop

Since the chassis will be within the airframe when the parachute is deployed, the shock will occur axially through the rover. Shown in Figure 51 is the stress distribution in the chassis under this load. The figure shows that most of the stress is absorbed by the rods. Conceptually this makes sense, as the wood is a softer material and will more readily deform, whereas the aluminum will resist deformation and absorb the load.

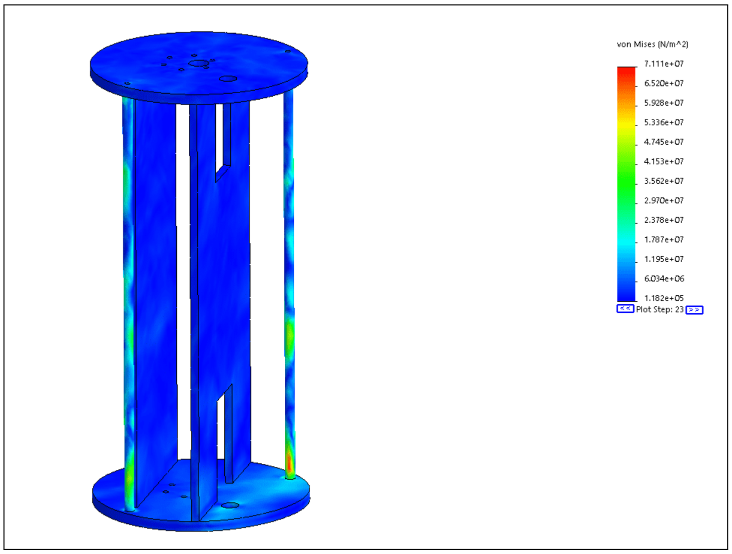


Figure 51: Chassis Impact Stress

This shows the rover experiences a maximum stress of roughly 10 ksi. This stress will increase as more components are added to the chassis. As a result, shock within the airframe poses a substantial risk to the rover. To mitigate this OSRT will add shock absorbing foam to the retaining lead screw bulkheads to mitigate shock forces on the rover during the recovery stage of the mission.

Launch Forces:

When the rocket launches it will rapidly accelerate causing stress to all components. The chassis will be stowed axially in the airframe and will be subjected to a compress stress. An initial analysis has been done to see how the chassis reacts to this type of loading. To compensate for the rover weight the simulation has been done with an exaggerated acceleration.

Analysis Parameters:

- Materials: Balsa plate, and aluminum rods.
- Gravitational force increased by 20x
- Chassis resting on fixed surface

To simulate the flight forces, the gravity acting on the rover has been increased by 20x. Figure 52 shows how the chassis reacts to this loading.

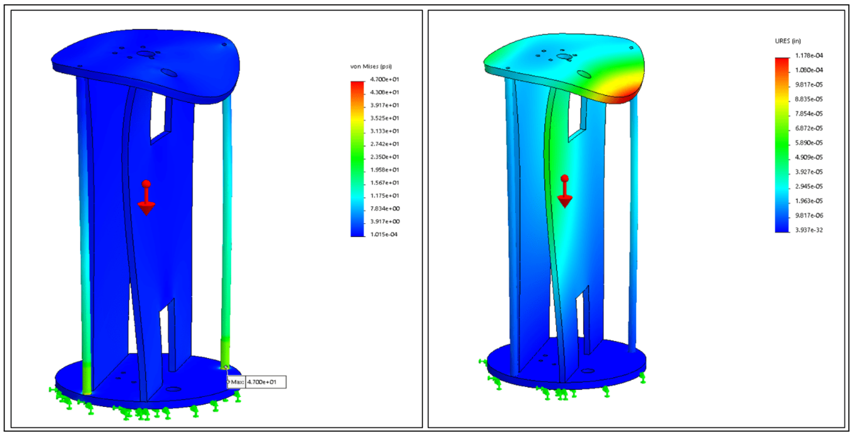


Figure 52: Chassis Under 20G Loading

Under a 20 G loading the chassis sees a maximum deflection of 0.00012 in. and a maximum stress of 47psi. This shows that most of the stress is absorbed by the aluminum rods as designed. These values will undoubtedly change when motors and electronics are added to the chassis.

Summary:

It is evident that shock felt by the rover poses a serious concern during the different stages of flight. However, forces felt during the initial launch period are not much of a risk. To reduce shock forces, a shock-absorbing feature could be added to payload retention. Foam could potentially be added to the mobile bulkheads to fill this role. This would restrict the payload's movement within the airframe, preventing shock loading.

This analysis shows that the chassis will be able to survive launch forces with minor design adjustments. Additional analysis needs to be done on how flight forces could affect components on board the payload. Components breaking from the chassis pose a larger risk than chassis structural failure.

4.3.2 Chassis Testing

Test: Payload Prototyping

Purpose: Test payload structure, design, and manufacturing process

Test Equipment: Laser cutter, lathe, assorted fasteners, and taps

Passing Protocols: NA

Safety Protocols: Safety glasses must be worn when working around or with power tools and other electrical equipment. Gloves must be worn when working with adhesives or other chemicals. All machine shop rules must be followed in addition to any OSRT specific requirements.

Checklist:

- Prototyping materials: Acrylic sheet, plywood, aluminum rods
- Safety glasses

Prototyping Process:

Initial prototypes for the rover chassis were designed to be made out of sheet and rod material. The plan was to CNC machine or cut the material, making it possible to rapidly make structure prototypes to test concepts and ideas. The reason for the focus on simple manufacturing is that new collection, ejection, retention, and electronic designs will require changes to the chassis and may require multiple prototypes to be made. By making the chassis easy to manufacture it will be possible to quickly make updated designs to work with other systems. This focus also makes it possible to do destructive testing with little consequence. The initial prototype was made using ¼ in. acrylic and 1/8 in. plywood that was cut using a laser cutter. The prototype and its laser cut parts are shown in Figure 53, pictures 1 and 2. The assembled initial prototype is shown in 53, picture 3.

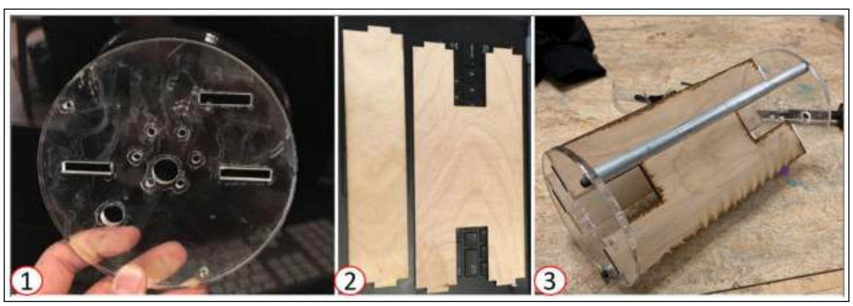


Figure 53: Chassis - Initial Prototype. Pictures 1 and 2 show PLA and wood components, respectively. Picture 3 shows the assembled parts, including the aluminum rods and screws.

The initial prototype functioned successfully. It was easy to assemble, cut in less than a day, and more than strong enough for the USLI mission. Additional tests with the laser cutter showed the laser to be accurate to within $\pm$ 0.001 in. when cutting wood. On the initial prototype the wood was a slip fit into the acrylic. In future revision OSRT attempted to tighten this tolerance. It was observed that the laser accuracy cutting the acrylic was less than ideal. The tolerances in the acrylic was wider than that of the wood and the laser did not maintain focus throughout the acrylic, resulting in a poor cut. A benefit of using these materials is that they were readily available in the OSU wood shop shown in Figure 54 allowing the team multiple attempts to manufacture a part with the desired specifications. OSRT has access to a variety of polymers, and plywood, in an array of thicknesses which makes testing material varied and plentiful.

Figure 54: Shop Materials. Picture 1 and 2 show assorted Polylactic Acid (PLA) sheet material. Picture 3 shows assorted plywood and Oriented strand board (OSB).

The second prototype was made entirely out of ¼ in. plywood, shown in Figure 55. A different slot-key method was used to hold the wood together. The tighter tolerance further increased the chassis rigidity. Unfortunately the tightened fit also made the prototype more difficult to assemble. A possible concern raised by this prototype was the possibility of damage to the wooded keys when separating the disks from the plates. The motors were mounted to this prototype showing that the tolerance for the laser is accurate to match the motor fastener pattern. Quality/flat plywood is required for future prototypes as uneven plywood does not cut as well on the laser. An additional concern is that cheap laminated plywood is not as strong as other possible natural materials and varieties of wood, leading to lower rigidity. The overall structure currently has enough rigidity to survive launch forces, so the wood will likely only be changed if it becomes an issue during future testing.

Figure 55: Chassis Second Prototype

This prototype additionally had conflicts between the rod fasteners and the wheel. This will be corrected with a countersink in the disks. Another problem found in this iteration was the motor shaft not being long enough to extrude through the wheel hub for mounting the wheels. To correct this issue OSRT will attempt to use a commercial coupler to mount the wheel hub. OSRT may also attempt to water jet cut a metal prototype using thinner material to compare weight and rigidity between designs, although currently a wooden design is still the leading option.

4.3.3 Chassis Summary

Analysis has shown wood and aluminum to present the ideal combination of mass and cost for their loading conditions. SolidWorks FEA has shown the current rover design and materials are capable of resisting both launch and recovery forces of the vehicle. Prototyping has been done to test the structures design in practice in addition to its ease of manufacture. Multiple prototypes have been made, each incorporating minor changes for increased performance. Destructive testing has not yet been done but is planned for future prototypes.

4.4 Payload Ejection and Retention

Payload ejection and retention will be handled by the same system, which is hosted inside of and to the aft of the payload bay. The system will consist of a motor, a gear box, and a lead screw attached to two pushers. Figure 56 shows the motor and gear box which are connected to the lead screw. This is also the area where the ejection/retention electronics will be stored.

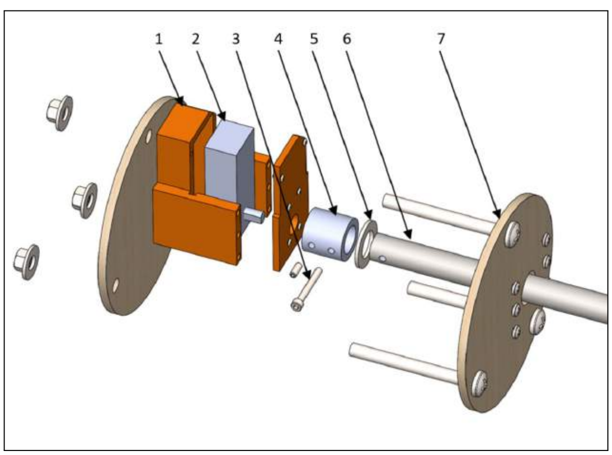


Figure 56: Ejection/Retention System

The pushers will push two accompanying plates on the aft and fore ends of the payload, which will serve a dual purpose. The pushers will retain the payload and be used to deploy it. The lead screw is off center, which reduces the difficulty of having the lead screw pass fully through the payload bay and the payload rover itself. The leading pusher will also force the nose cone off the front end of the launch vehicle, allowing the payload to exit behind it. When a pusher and accompanying plate reach the end of the lead screw they will unscrew themselves and fall off, allowing the payload to exit the airframe. The lead screw is shown in Figure 57.

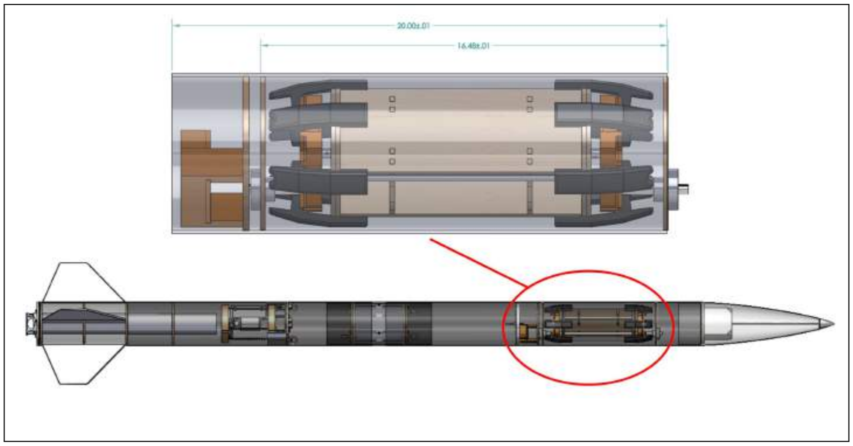


Figure 57: Lead Screw 3D View

When deploying the payload, the lead screw will push the nose cone off the front of the launch vehicle to make room for the payload to exit. Since the payload bay is between the ejection/retention system and the nose cone, there is added security to prevent unexpected early deployment. 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.

This lead screw based ejection/retention design was selected due to how safe and reliable the system is. By using a motor to push the payload out of the launch vehicle, there is no need to rely on good landing conditions to deploy the payload. The motor is strong enough to deploy the payload even if the launch vehicle lands on an incline. Additionally, by having the lead screw pass fully through the payload bay there is no need to use a linear actuator or similar type of motor. The system is simple and robust at the cost of having to drill a hole through the side of the payload to allow the lead screw to pass. This has already been accounted for throughout payload design and is already included in models of the payload as an off center hole. By requiring only one small motor and gear box to control the system, the system should be relatively lightweight.

When selecting materials for the ejection/retention system the primary aspects focused on were weight, strength, and price. The pushers, which are attached to the lead screw, will be purchased and made out of strong plastic. The plates push and retain the payload, will be made out of wood, which was selected due to its low cost and light weight. The payload is relatively light weight and will not need much strength to retain. Wood should be sufficiently strong to be more reliable than a comparatively thinner sheet of metal of the same weight, which could bend.

The payload ejection system will be 17 in. long. The lead screw ejecting the rover must be at least as long as the payload in order to have space to hold the entire payload. The maximum length of the payload is 17 in. but the payload may end up being smaller than the full 17 in. When sizing the lead screw motor two important design constraints were calculated. The time required to eject the payload was estimated along with the force provided by the lead screw. Equation 22 and 23 shown below were used to find these values.

$$Force = \frac{Torque * 2\pi * Efficiency}{Lead} \tag{22}$$

$$EjectionTime = \frac{Length}{RPM * Pitch} \tag{23}$$

Using these equations along with a lead screw efficiency of 60 percent (a low efficiency has been selected to account for friction), it will take 1.68 minutes to eject. The lead screw will push with a force of 29 lbf at the rated torque. At stall torque the lead screw will be able to push 117.4 lbf. To check these values, an online lead screw calculator was used. This calculator takes into account approximate friction and therefore reports slightly different values. The calculator output and inputs are shown in Figure 58. According to this calculator, using a torque of 2.4 lbf-in., the output force is 77 lbf. Either of these values found are more than enough to eject the payload.

Common Stepper Motor Typical Torque Ranges and Dimensions

Motor	Torque in N*cm	Dimensions	Shaft Diameter
NEMA 8	4	20mm sq	4mm,5mm
NEMA 11	11-13	27mmx sq	5mm
NEMA 14	9-15	35mmx sq	5mm
NEMA 17	44-54	42mmx sq	5mm
NEMA 23	180-300	57mmx sq	0.25 in
NEMA 34	200-1100	86mmx sq	14mm

Input

Force	77	◉lb ○oz ○g ○N
Pitch Diameter	0.25	◉in ○mm
Thread density	13	Threads per ◉in ○cm
Coefficient of Friction	0.15	(See table below)
Result Units	○N*m ○N*cm ◉lb*in ○oz*in	

Compute

Result

Torque (Raise)	2.42	(Selected Units)
Torque (Lower)	-0.509	(Selected Units)

Coefficient of Friction for Leadscrew Threads

Screw Material	Nut material			
	Steel	Bronze	Brass	Cast iron
Steel, dry	0.15 - 0.25	0.15 - 0.23	0.15 - 0.19	0.15 - 0.25
Steel, machine oil	0.11 - 0.17	0.10 - 0.16	0.10 - 0.15	0.11 - 0.17
Bronze	0.08 - 0.12	0.04 - 0.06	-	0.06 - 0.09

Equations:

These equations come from the Wiki article on force.

Torque(raise) = F*Dm/2*(L+u*PI*DM)/(PI*Dm-u*L)

Torque(lower)= F*Dm/2*(L-u*PI*DM)/(PI*Dm+u*L)

Figure 58: Lead Screw Force Calculator Results [12]

Recorded here are the technical specifications for the motor and lead screw being used for the ejection retention.

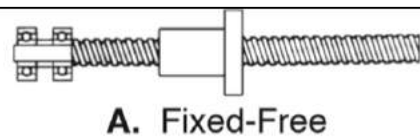
Motor: RB-Dfr-673, 6 VDC 160 rpm, 38.89 oz-in Worm Gear Motor

- Operating Voltage: 3 - 9 V
- Rated Voltage: 6 V
- No-load Speed: 160 rpm
- No-load Current: 40 mA
- Rated Speed: 128 rpm
- Rated Current: 250 mA
- Rated Torque: 0.6 lb-in.
- Rated Power: 1.3 W
- Stall Torque: 2.43 lb-in.
- Stall Current: 1.7 A
- Reduction Ratio: 1:37.3
- Weight: 0.363 lb

Lead Screw:

- Material: 304 Stainless Steel
- Right-handed
- Single start: 0.0787 in. per turn
- Diameter: 0.3 in.

Using the equation in Figure 59 the lead screw critical speed was calculated as 1778 rpm. Since the motors max speed is only 160 rpm, there is little concern of the lead screw reaching its critical speed.



$$C_S = F\,(4.76 \times 10^6)\,\frac{d}{L^2}$$

where:

C_S = critical speed (rpm)
d = root diameter of screw (inches)
L = length between supports (inches)
F = end support factor (see diagram)
case **A.**: 0.36
case **B.**: 1.00
case **C.**: 1.47
case **D.**: 2.23

Figure 59: Lead Screw Critical Speed Results [3]

Results:

Ejection time = 1.68 minutes to move 17 in.

Maximum force = 77 lbf

Critical speed = 1778 rpm

The ejection time and critical speed do not calculate the friction between the rover, pushers, lead screw, and the airframe. Instead, a blanket 60% effeciency has been applied to these 2 equations. The maximum force does take into account the friction between the lead screw and nuts using the stall torque of the motor. Compared to the 117 lbf maximum force found when doing the calculations by hand this lower value will be used going forward as it is more conservative and more than enough for payload ejection. Regarding total required ejection force, OSRT currently plans to use 4, 5 lb shear pins to fasten the nose cone to the airframe. This means the motor must be capable of applying a 20 lb force to remove the nose cone in addition to the force required to lift the payload, ignoring friction. 77 lbf should be more than enough for this, but in the case that more force is needed an identical worm gear motor with a more aggressive gear ratio will be used. This possible alternate motor would have more torque than the current one which should resolve any additional force requirements. The lower rpm on the alternate motor would lead to an increased time to deploy which although important is nowhere near as important as an ejection being successful.

Safety Factor: To calculate the safety factor of the lead screw the weakest connection will be investigated. The lead screw itself could theoretically fail tensely although this is prohibitively unlikely with an approximate 31 kpsi tensile yield strength (0.3 in. Diameter 304 Stainless Steel). The lead screw could bend, which would result in the payload being unable to properly eject. This would be a problem, but is not a safety concern. The coupler could possibly slip from the motors d-shaft. To protect against this the coupler will be made to press flush against the fore bulkhead minimizing the possibility for the coupler to slip. The motor coupler could fail which would cause the entire ejection/retention system to become unanchored and able to freely rattle within the airframe. This is the most likely point of failure which the team has discovered and a possible safety concern. The most likely means of failure in the coupling is the steel pin that holds the lead screw to the coupler shown in Figure 60, at arrow 4. The lead screw is held onto the coupler using a steel through pin which could possibly snap. OSRT has identified this as the most likely point of failure for this system, and as such it will determine the safety factor of the entire ejection/retention system.

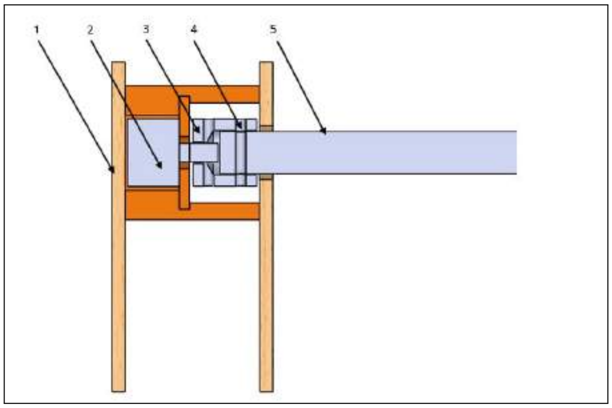


Figure 60: Lead Screw Connection

The steel pin can fail due to fatigue, or it can shear. OSRT will use new pins before each launch to reduce the possibility of fatigue failure. This way, OSRT can focus purely on double shear failure. Shown in Figure 61 is an example of double shear failure.

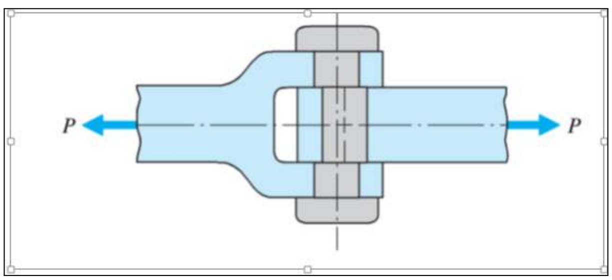


Figure 61: Lead Screw Pin

The worst case scenario is the payload coming loose within the airframe. This could happen during the recovery stage of the mission when the main parachute opens. The parachute opening will cause a large jolt force to be transmitted through the shear pin. The rover will be no heavier than 20 lbf so using a safety factor of 2 the loading will be 40 lbf. The equation shown below will be used to calculate the strength of the through pin. This equation was referenced from Shigley's Mechanical Engineering Design [5].

$$\tau = \frac{F}{A} \tag{24}$$

Pin area is 2 times the cross sectional area of the pin, the force is 40 lbf, and the shear stress must be less than the maximum shear stress of the material.

Pin material: Steel

Yield strength of steel: 58,000–80,000 psi

Pin Diameter: 0.125 in.

Current stress in the pin is 1629 psi, which means a safety factor of 35.

Using a steel 1/8 in. pin there will be a safety factor of 35. This is an acceptable result.

4.4.1 Payload Ejection Electronics

To deploy the payload a student-designed electrical system will be implemented. The system will receive an RF signal to initiate ejection and drive the ejection motor until ejection has been completed as verified by the light sensing circuit. The circuit schematic is shown in Figure 62. The PCB layout is shown in Figures 63a and 63b, showing the front and back respectively.

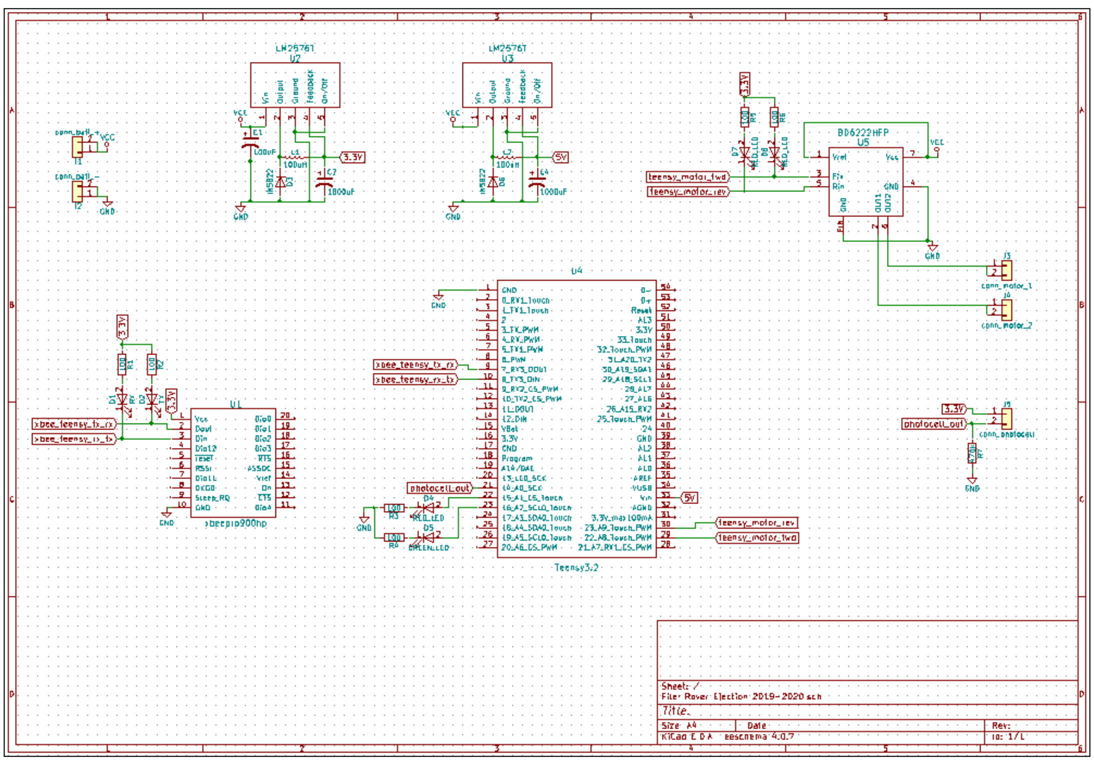
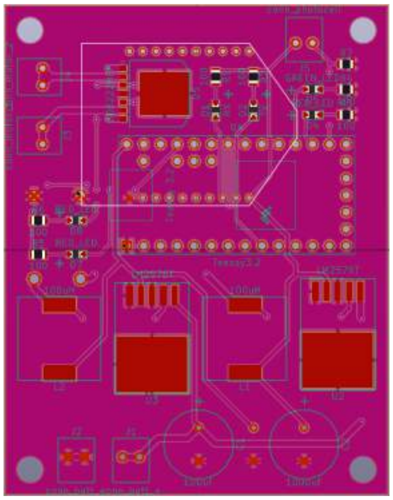
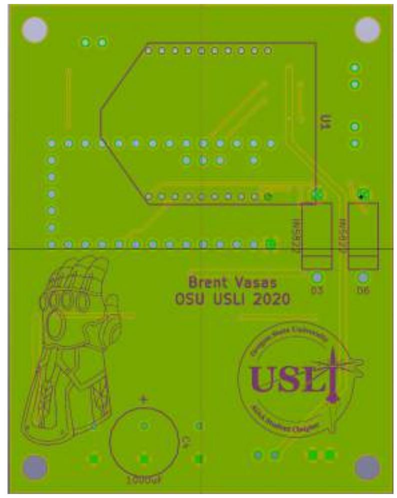


Figure 62: Payload Ejection Electronics Schematic



(a) Ejection PCB Front



(b) Ejection PCB back

Figure 63: Rover Ejection PCB

The RF transceiver will be a Digi XBee-PRO 900HP receiving a 900 MHz signal using the DigiMesh networking protocol. This networking protocol allows for subnets to be easily implemented, which has been proven to prevent most RF interference. This is a concern for OSRT because many teams will be using the 900 MHz frequency band at competition and interference must be avoided to ensure the system functions as intended.

The ejection circuit will use a Teensy 3.2 microcontroller to verify that the correct control signal was received and to control the H-bridge motor driver which will be used to drive the ejection motor. This is the motor that will rotate the lead screw and eject the payload. Upon ejection commencing, the photocell circuit will be monitored for a change in resistance, indicating an increase in light and the payload exiting the airframe.

4.5 Payload Collection

4.5.1 Initial Payload Collection Designs

The payload collection Designs have changed from the drill type ideas to scoop type ideas because it will be easier to design and will secure the sample from falling out of the payload as it drives away to complete the challenge. Two main scoop designs and an adhesive design were made and tested with the method below. The design that proved more reliable and easiest to manufacture can be seen in Figure 68.

4.5.2 Payload Collection Design Testing

Testing Procedure: Collection System Concept Testing.

Purpose: Testing Collection System Concepts, Functionality, Feasibility.

Test Equipment: Simulated ice, collection system prototypes.

Testing Procedure: Each collection system concept will be tested for its functionality. Begin by pouring the airsoft BBs into a bin to simulate the collection zone. Then using prototypes for each concept, test the idea feasibility. As a group, test each idea and discuss concerns. Use the prototypes to test if concerns are valid. Taking pictures of each test for documentation.

Passing Condition: Collecting at least 15 mL and storing securely.

Safety Protocols: Safety glasses must be worn when working around or using power tools or electrical equipment. Gloves must be worn whenever working with adhesives or any other chemicals.

Checklist:

- Develop and prototype a variety of designs
- Purchase needed items to test concepts
- Testing must be done in a group to ensure proper discussion and all concerns are addressed

The OSRT has developed a variety of collection system concepts that required testing before the final decision could be made. A scoop, a dragging scoop, and an adhesive system were collectively decided to have the highest likelihood of success. To test these systems, prototypes were made and supplies were purchased. OSRT began by developing a collection test bed seen in Figure 64. This consisted of plastic BBs with similar dimensions as the simulated ice samples NASA will be using at competition.

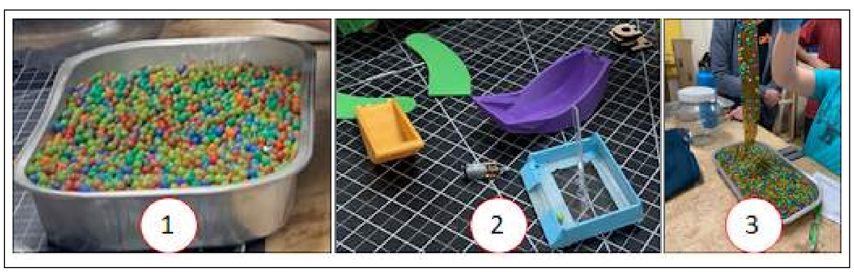


Figure 64: Payload Collection Testing

OSRT needs to develop a system capable of collecting 10 mL of simulated ice, and carry it away from the collection site. To do this a system capable of both collecting and retaining the sample is required. The simulated ice will consist of small rectangular or cylindrical plastic, with a length of approximately 0.2 in. To simulate this OSRT will be using airsoft BBs. This material consists of spherical plastic with a diameter of roughly 0.2 in. Shown in Figure 65 is the simulated material OSRT will be using, the amount that needs to be collected, and then that amount inside of one of the collection system prototypes.

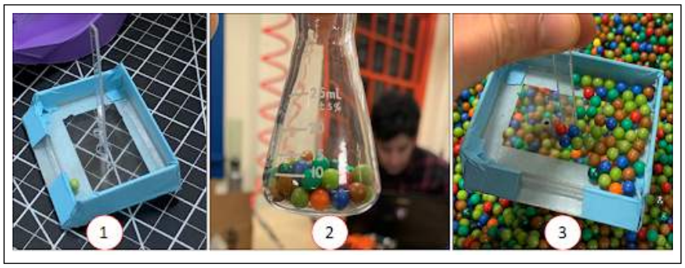


Figure 65: Payload Collection Samples

Adhesive Concept: OSRT investigated the use of adhesive for collecting the ice sample. The theory was that an adhesive could be pushed, dragged, or dropped into the collection zone. The samples would stick to the adhesive and stay there for the duration of the mission. This concept offers a simple solution to this year's challenge, however it was not determined to effectively collect the sample. In testing, OSRT used fly paper to simulate an adhesive shown in Figure 64. In testing, the fly paper was initially dropped onto the test bed to test if this concept was feasible without the application of force. This was shown to effectively collect the sample. However when the fly paper was shook the BBs began to fall off. A number of the BBs were retained but not enough to meet the 10 ml requirement. Another test was done pressing the fly paper into the test bed. This was shown to increase the number of BBs collected, however it did not significantly improve the retention.

Dragging Scoop Concept: OSRT investigated the use of a dragging scoop system. For this concept a linear actuator will push a scoop vertically into the samples. As the rover moves, the scoop will slowly dig into the simulated ice and collect the samples. When full, the system will retract until it is flush with the bottom of the rover, retaining the samples. The system is shown in Figure 64, and shown in Figure 66 is how the system will work. For testing, OSRT immersed the scoop in the material, then pushed it forward, testing the reactionary forces. The reason for this test was to see the force on the scoop. OSRT was concerned that this force and the moment it would cause could lead to instability in the rover. Specifically, this moment would cause the rover to tip forward, preventing it from moving. As shown in the test, it required minimal force to push the scoop through the material.A second test was conducted, pushing the scoop vertically into the material. The concern being that the large surface area on the bottom of the scoop would make it difficult to push the scoop into the material. OSRT found that the force required was less than 1 lbf. A third test was conducted to test the capacity of the scoop. As shown in Figure 65, the scoop is more than capable of storing the required material.

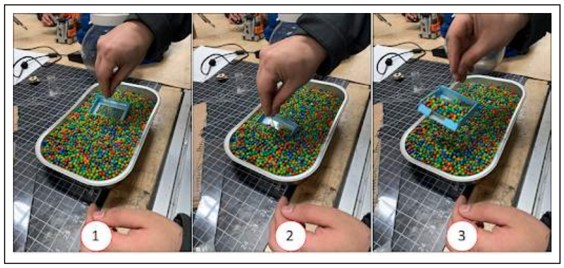


Figure 66: Dragging Scoop Design

Scoop Concept: The third concept tested was a classic scoop. This system would consist of a scoop that would be rotated using a single motor. Concerns regarding this system include sample retention and the amount of material collected. A motor will rotate the scoop, down from the rover, into the material, then it will press the scoop flush against the bottom of the rover, retaining the sample. To test this system, a variety of prototypes were printed as shown in Figure 64. A scoop was tested operated by hand, shown in Figure 67, and then again using a motor.

Figure 67: Classic Scoop Design

Conclusion: The classic scoop and dragging scoop concepts were shown to viable options for this system. The classic scoop may have difficulties collecting and retaining the material. The round BBs may present different behavior than the material NASA will provide for use at the competition. The fly paper test did not show conclusive evidence of its viability. The adhesive concept showed some potential and may be incorporated in some way to the other systems to increase likelihood of success at competition. The team will has decided that the dragging scoop concept will be used and its specifications will be discussed below. Further testing will be done after a prototype is made for this design.

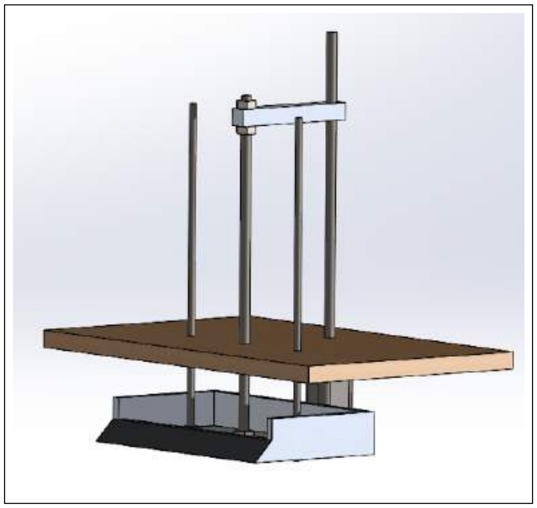


Figure 68: Payload Collection Device

4.5.3 Payload Collection Design

The payload collection design includes a box-shaped scoop with a ramp and an opening facing toward the front of the payload. A single threaded rod is coupled to another threaded rod by means of a bracket. One rod will be 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. Two additional rods will be attached to the scoop to serve as support and keep the scoop orientated. A hole pattern for all rods will be made in the payload chassis and the motor will be mounted on the chassis as well. The dimensions, materials, and integration can be seen in Figure 112 and 113 in the appendix. The design has been completed and is ready to be manufactured and assembled for testing. The manufacturing techniques can be seen in payload manufacturing. Testing will be done once the prototype has been built and will include driving the payload through a test bed and collecting samples with the use of the payload collection device.

4.5.4 Payload Collection Interactions

The volume of the scoop is approximately 18 mL. The weight of the collection device will be 0.17 lbf. This is due to the use of thin stainless steel rods and aluminum for the scoop and bracket. The collection device will be very light weight in comparison to the other payload subsystems but will still serve its purpose effectively. The motor for the collection device will draw power and signal from the payload's battery and electronics. The collection device will be mounted on the chassis of the payload and holes will be made in the Chassis to make room for the collection device. The collection device will make use of the payload drivetrain in order to collect material once the collection device has been activated and lowered. The collection device will not interact with the ejection and retention system and will fit within the dimensions of the allowed space in the launch vehicle. The collection device will fit within the airframe and will not interact with the airframe. It will be attached to the chassis of the payload, which will have its own retention system mentioned in Section 4.4.

4.5.5 Payload Collection Justifications

The collection scoop will be made from aluminum in order to keep the system light weight but also maintain strength and rigidity needed for the mission. Aluminum will also be fairly easy to machine the geometry of the scoop. The bracket coupling the two main threaded rods will be made of machined aluminum to remain light weight as well as serve its purpose. The two rods coupled by the bracket will be stainless steel to provide strength in the vertical motion of the collection device. The two support rods will also be made of stainless steel in order to provide strength to the collection device. All fasteners will be hex head nuts in sizes respective to the rods they will be placed on and some will be included with the motor to mount it to the payload chassis. The motor will be a 6 V lead screw motor that was chosen by the result of the following payload collection technical analysis.

4.5.6 Payload Collection Technical Analysis

4.5.6.1 Motor Selection

Description: The payload collection device needs to lift its own weight as well as the weight of the collected samples. To ensure an appropriate motor is used, a torque analysis has been conducted to select the optimal motor for the collection device.

Analysis Details: A motor was chosen to be analyzed based on the design specifications. Steel on steel has a coefficient of friction (μ) ranging from 0.15 to 0.25 and so a value of 0.20 was used. The pitch diameter (d) is 3 mm, the thread lead (l) is 0.5 mm, and the force that the motor would see is approximately 0.2 lbf or 0.89 N. Using the following equation,

$$Torque = F\left(\frac{d}{2}\right)\frac{l+\pi*\mu*d}{\pi*d-\mu*l}, \tag{25}$$

the torque needed is 0.000341 N-m or 0.003022 lbf-in.

Results: The motor has a rated torque of 0.64 kg*cm (0.56 in-lbs), which is plenty of torque to lift the collection device with samples.

Assumptions: Middle range for coefficient of friction is assumed.

4.6 Payload Drivetrain

4.6.1 Drivetrain Design

The proposed design for the drivetrain wheels includes six folding spokes attached to a hexagonal central hub using small 1 in. butt hinges.

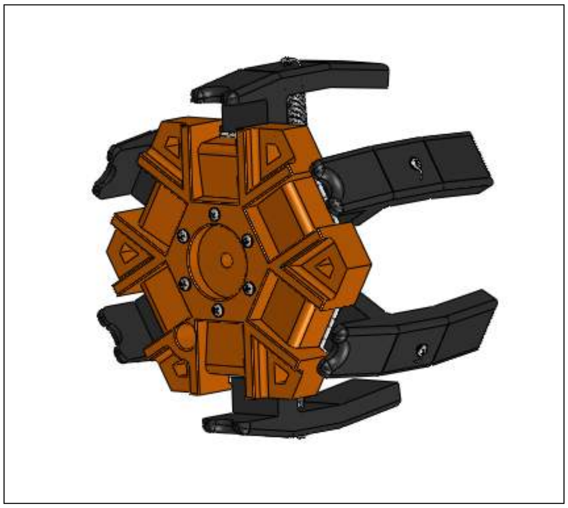


Figure 69: Folding Wheel Collapsed

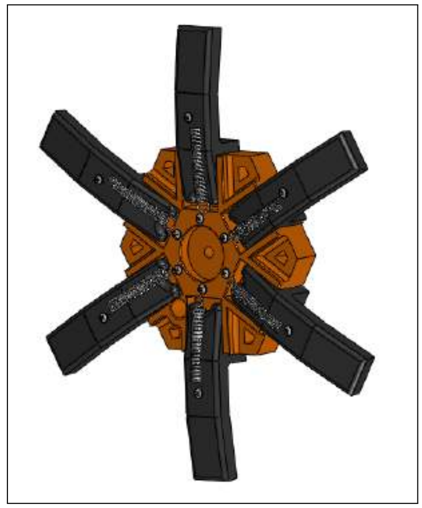


Figure 70: Folding Wheel Expanded

When in their folded position (Figure 69), the spokes lie parallel to the wheel's axis of rotation and fold around the rest of the payload vehicle. The overall diameter in this position is less than the required 6.25 in., meaning that it can be transported inside the team's rocket.

The wheels unfold (Figure 70) via the 1-in. hinges and springs pulling them open. The springs will either be located within the hinges themselves or between the smaller side of the hinge and the inner hexagon of the hub. In the case of the latter, the spring will be stretched when the wheel is in the folded position and guided by the semi-circular notch at the inner end of the spoke. In both cases, the springs will continuously attempt to open the spokes farther, regardless of the position they are in. For the sake of redundancy, both springs may end up being used.

The spokes have no latches or similar means to keep them closed or open. When the wheels are in the folded position and are being transported within the rocket, the spokes are kept in place using only the inner wall of the rocket body. When the payload vehicle is deployed, the spring-loaded spokes will no longer be constrained and will open automatically. Each spoke has a mechanical stop on its inner end that butts into a special groove on the hub. When open, each spoke is designed to be a few degrees past vertical, using the weight of the payload vehicle (high-end estimate at 15 lb) to keep it open.

When in their open position, the spokes fit into a set of slots that are supported along the hub's sides with short walls. This helps distribute the forces applied to the spokes to the rest of the hub when the motors are running.

The shape of the spokes is rectangular with the long edge running perpendicular to the axis of rotation. The shape provides greater strength in the direction of applied forces and moments from the wheels turning while also reducing unneeded material in the direction that only experiences the weight of the vehicle. Load-bearing edges are rounded to prevent stress concentrations.

Last year's payload vehicle utilized a drivetrain that ran through a separate bearing fixed to the vehicle's frame, giving the wheels greater rigidity and strength to resist bowing under the payload's weight. In contrast, this year's wheel assembly is attached directly to the motor's D-shaft using a 6 mm coupler (Figure 71). This is justified for the following reasons: the payload vehicle chassis is significantly lighter than last year's design, and the selected motors are larger and more capable of carrying a load.

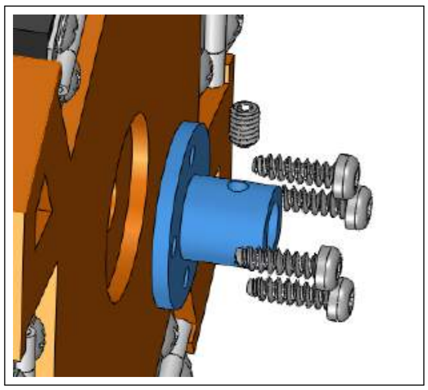


Figure 71: D-Shaft Coupler Assembly

Each wheel assembly has 61 individual parts, as listed in Table 28.

Table 28: Parts per Wheel

Component	Material	Weight(lbf)	Count (per wheel)	Subtotal Weight (lbf)
Hub	PLA plastic	0.39	1	0.39
Spoke	PLA plastic	0.06	6	0.36
Spring	Steel	0.03	6	0.18
Hinge	Brass	0.019	6	0.114
Screws	Steel	.001	36	0.036
Screws(long)	Steel	0.001	4	0.004
Coupler	Aluminum	0.01	1	0.01
Set Screw	Steel	<0.001	1	0
			Total Weight	0.95

4.6.2 Drivetrain Technical Analysis

4.6.2.1 Wheel Spoke Analysis

Description: This analysis will justify the chosen dimensions for the spoke component of the wheel assembly by analyzing the forces experienced by the them. All equations came from Shigley's [5].

Analysis Details: The analysis was performed assuming that the payload's weight was at the high end of its specified window at 15 lbs and that the motors were outputting their highest possible torque (stall torque) at 36.430 in-lbs [1].

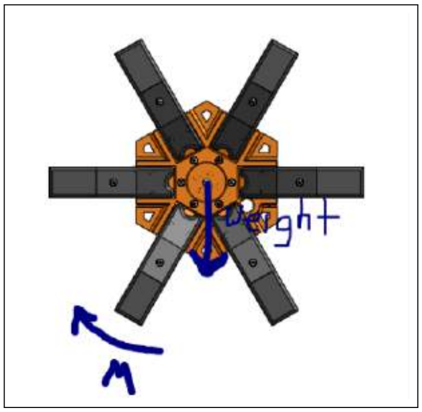


Figure 72: Side View of Applied Weight and Torque

Figure 73: Front View of Applied Weight and Torque

Normal and shear stresses were examined for applied forces and moments. The following equations were used: Normal Stress:

$$\sigma = \frac{F}{A} \tag{26}$$

Shear Stress:

$$\tau = \frac{V}{A} \tag{27}$$

Normal Stress from Bending:

$$\sigma = \frac{My}{I} \tag{28}$$

Max. Shear Stress:

$$\tau = \frac{3V}{2A} \tag{29}$$

Where F = applied force, V = applied shear , A = cross-sectional area, M = applied moments, y = distance from center plane and

$$I = \frac{bh^3}{12}$$

.

Hand-written work can be found in Section 9.3.1.

Stresses from bending (as applied tangent to the wheel's face)

Normal

Stress (max. weight of rover) = 586 psi

Stress (stall torque) = 568 psi

Max. Total = 1154 psi

Shear

Stress (max. weight of rover) = 64 psi

Stress (stall torque) = 62 psi

Max. Total = 126 psi

Stresses from bending (as applied perpendicular to the wheel's face)
Normal stress (max. weight of rover) = 85.4 psi
Shear stress (max. weight of rover) = 3.27 psi

Stresses (as applied radially to the wheel's face)
Normal stress (max. weight of rover) = 38.2 psi
Shear stress (max. weight of rover) @ 45^o plane = 19.1 psi

Results: Most maximum stresses lie on different planes. The normal bending stress applied tangentially to the wheel's face is of a higher order of magnitude than the other stresses; therefore, factor of safety is calculated just for that location.

Parts that are 3D printed with PLA filament with 100% infill have a minimum ultimate tensile strength of 50 MPa (7252 psi) [13].

Factor of safety = 7252 psi / 1154 psi = 6.3

Assumptions:

- Material removed from a fillet has a negligible effect on cross-sectional area
- Spoke can be idealized as a rectangular prism
- No sharp impacts as the rover is driving

4.6.2.2 Wheel Hub Analysis

Description: This analysis will justify the chosen dimensions for the hub of the wheel assembly by analyzing the forces experienced by the component. All equations came from Shigley's [5].

Analysis Details: This analysis was performed assuming a component has failed, allowing a spoke to pivot and only constrained by the side walls nesting the spoke. The side walls are assumed to be experiencing pure shear stress. Angles are approximated to be 90 degrees for the sake of analysis.

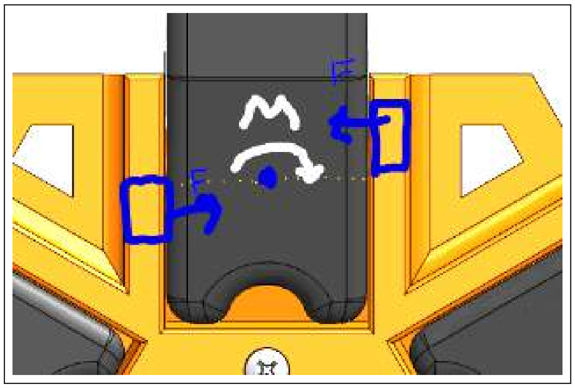


Figure 74: Spoke and Hub Interface Illustrated with an Applied Moment, Front

The equation for shear stress (Equation 27) was used to find the V value.

See Section 9.3.1 for the handwritten work.

Shear stress = 1457 psi

Since the applied moment from the maximum weight of the rover is approximately the same as the motor's stall torque, the moment, and therefore, the shear stress should be doubled.

Corrected shear stress = 2914 psi

Results: The minimum ultimate tensile strength of parts 3D printed with PLA filament is approximately 7252 psi[13]. The factor of safety, then, is 7252/2914 = 2.5.

Assumptions:

- Pure shear
- Side walls experience uniform pressure

4.6.2.3 Hinge Analysis

Description: This analysis will examine the hinge component. All equations came from Shigley's [5]. The hinge being analyzed is a 1-in. butt hinge with a 1 mm hinge pin (See Figure 75).

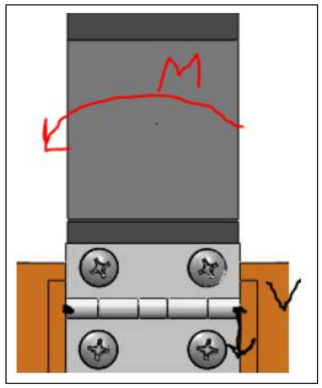


Figure 75: Spoke and Hub Interface Illustrated with an Applied Moment, Back

The analysis focuses on the shear stress on one side of the hinge pin when the applied moments are rotated about the other side of the pin.

Analysis Details:

The equation for shear stress (Equation 27) was used to calculate V. V = 36.43 lb.

A is calculated assuming a 1 mm hinge pin. A = 0.0012174 in.

Shear stress = 29,925 psi

The hand-written work can be found in Section 9.3.1.

Results:

The average yield strength of brass is 255 MPa, or 36,985 psi [14]. The factor of safety, then, is 1.2. Following the same equation, the factor of safety for a mild steel (yield strength = 50763 psi [15]) pin is 1.7.

Assumptions:

- Pure shear
- Force is applied only to the pin
- Force is applied at the edge of the pin

4.6.2.4 Motor Torque Analysis

Description: This analysis will examine the motor to ensure that it can deliver the needed torque to move the rover. Like the other analysis for drive-train, the motors will be analyzed assuming the full weight of the rover is applied to one spoke and that the weight of the rover is 15 lb.

Analysis Details: To move the rover, the motors must rotate the wheels and "walk" from spoke to spoke. Since the spokes form a hexagon instead of a circle, the motors must lift the rover over the spokes six times every rotation. As such, a motor must overcome the moment that results from the rover's weight. Operating load = 37.5 in-lb. The hand-written work can be found in Section 9.3.1 .

Results: The stall torque of the motors is 36.430 in-lb, less than the needed torque to overcome the weight of the rover. However, this analysis assumes the absolute worst case scenario: A heavy rover and one-motor operation. The rover will likely only weigh around 10 pounds, pushing the applied moment down to 25 in-lb. Ideally, each motor will take on approximately half of the weight of the rover, cutting the theoretical operating load in half.

Assumptions:

- Specs on website are correct
- Heavy rover

4.7 Rover Tail

The rover will be supported by a carbon fiber tail. This tail will wrap around the rover while inside of the airframe. Once ejected, the tail will unfurl and provide a support for the rover whilst driving. The tail will balance the rover, forcing the motors to turn the wheels. Then, the tail will drag along the ground while driving. This is the same concept OSRT used with last year's rover. However, minor changes have been made to the assembly to account for changes to the structure. Shown in Figure 76 is the tail attached to the rover chassis. The tail consists of a custom cut carbon fiber sheet attached to a spring hinge.

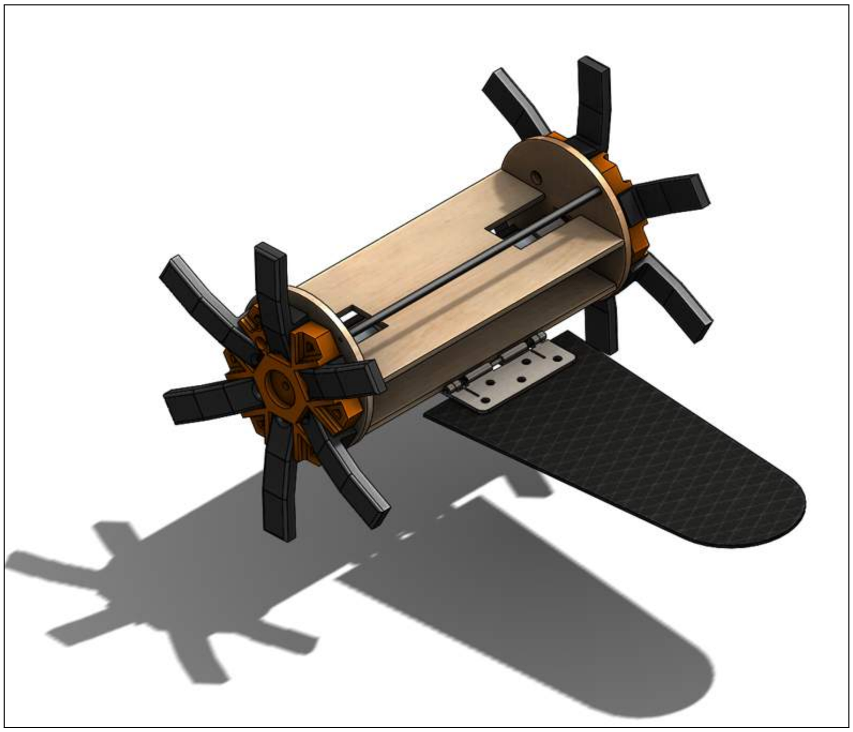


Figure 76: Rover Tail

4.8 Payload Assembly

Shown in Figure 77 is OSRT's rover design for this year's payload. The chassis is transparent to show mounting surfaces and collection system integration. The wheels affix to either side of the chassis. Currently they are held on purely by the motor coupler. If this proves ineffective, a bearing will be added for additional support. Motors, batteries, electronics, and the collection system then affix to the chassis itself. Not shown is the battery electronics, and tail. Shown in Figure 78 an exploded view of the rover assembly. Then shown in Figure 102 is a complete payload assembly.

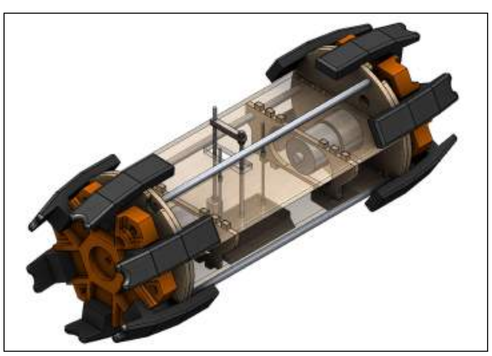


Figure 77: Rover Design

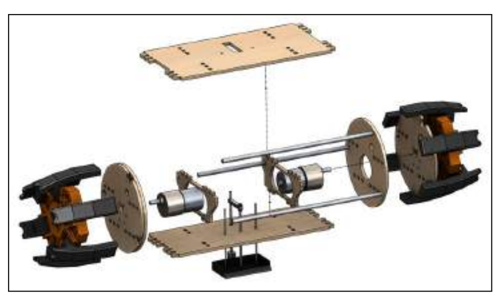


Figure 78: Rover Exploded View

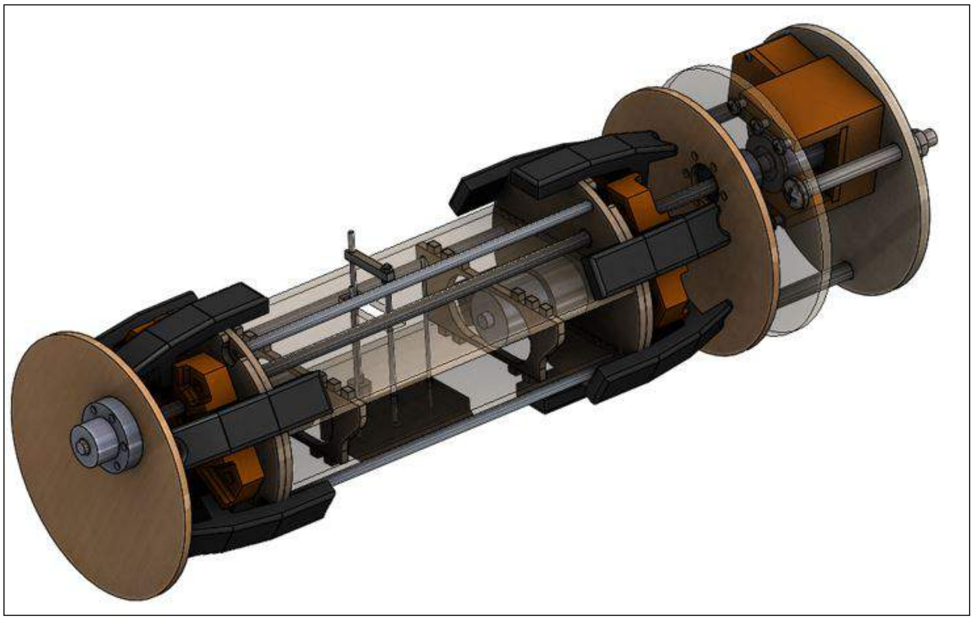


Figure 79: Payload Assembly

Figure 80 shows the payload within the airframe. The payload is located in the fore-section of the airframe between the nose cone and the parachute bay bulkhead. The entire payload system is 20 in. long. The length of the payload has changed to accommodate various designs using different collection systems and electronics. Currently this length is variable, and is limited only by the available space in the airframe. The benefits of a longer rover versus a shorter rover have not been investigated. Currently this value is purely driven by internal components, due to space requirements.

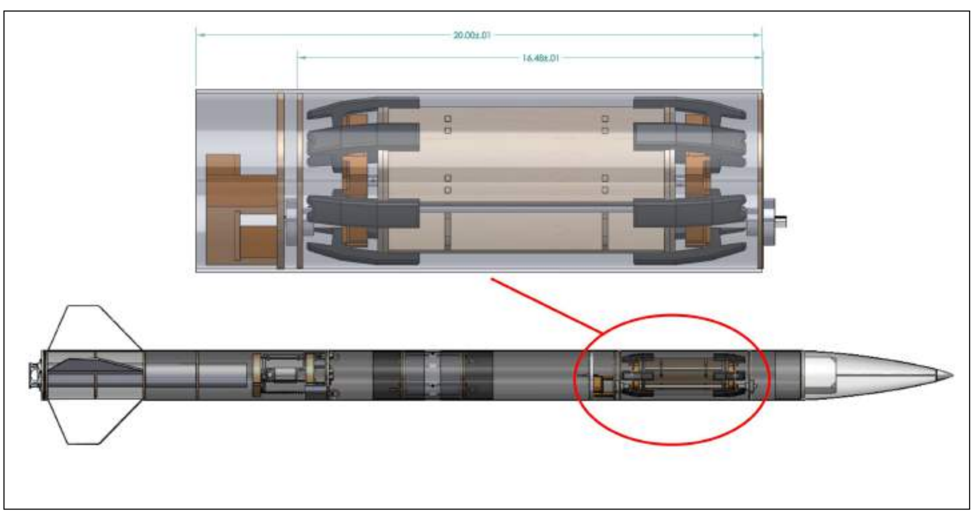


Figure 80: Rover Within Rocket

Figure 81 shows the payload interface to the airframe. Arrow 1 shows the fore parachute bay bulkhead. This is where the ejection system connects to the airframe, using three fasteners. The ejection system motor and electronics, motor, and lead screw coupler are sandwiched between two bulkheads, labeled as bulkheads 1 and 7 in the figure below. This is the only fastened interface between the airframe and the payload. The payload is first retained by the lead screw and lead screw coupler using the bulkhead pointed out by arrow 7. Then the nose cone serves as a fail-safe retention mechanism. The nose cone is held using shear pins, and serves only as a fail-safe in the event of a failure in flight. Then Table 29 summarizes the weight of all payload components, with a total weight depicted at the bottom right.

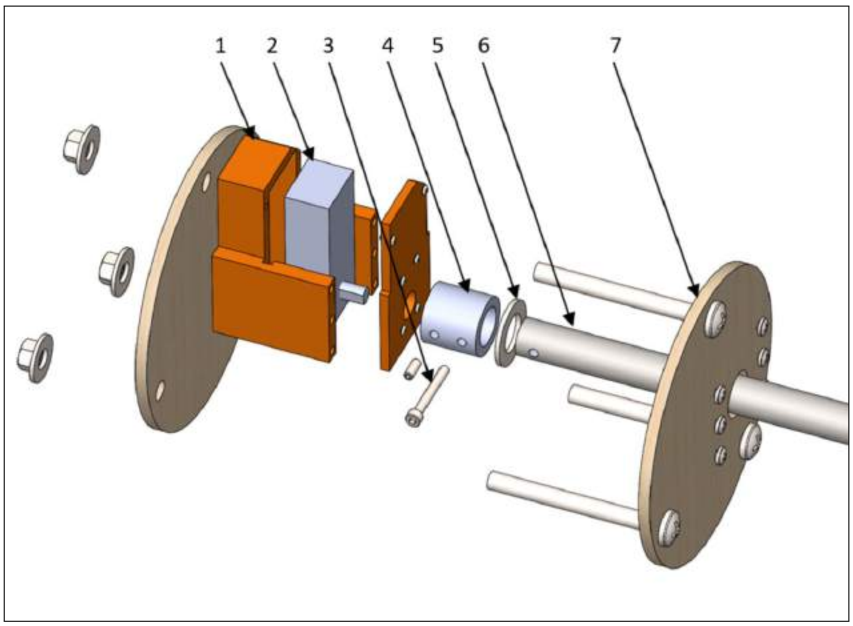


Figure 81: Payload Airframe Interface

Component	Material	Weight (lbf)	Count	Subtotal Weight (lbf)
Collection System	Metal, Aluminum	0.17	1	0.17
Wheels	ABS, Metal, Rubber	0.95	2	1.9
Ejection System	Wood, ABS	1.47	1	1.47
Structure	Wood, Aluminum	1.07	1	1.07
Tail	Carbon Fiber, Stainless Steel	0.94	1	0.94
Rover Electronics	NA	0.25	1	0.25
Rover Battery	NA	0.92	1	0.92
Rover Motor	NA	0.47	2	0.94
Ejection Electronics	NA	0.12	1	0.12
Ejection Battery	NA	0.92	1	0.92
Ejection Motor	Metal	0.364	1	0.364
			Total Weight	9.06

Table 29: Rover Components

4.9 Payload Manufacturing

The payload has a variety of parts requiring onsite manufacturing by the OSRT team. In preparation for this, components have been designed with manufacturing in mind. Each part has been made to reduce manufacturing difficulty, cost, and time. Specifically, parts have been designed to be made with readily available CNC equipment. Required equipment for payload manufacture can be found listed below, and drawings for each payload component can be found in the Appendix (9).

Required Equipment:

- 2-Axis Laser Cutter
- 3D Printer
- Metal Lathe
- Milling Machine
- Standard tap set
- Standard drill set

Currently, OSRT has manufactured prototypes for the drive-train and structure subsystems. These prototypes have illustrated the functionality of the designs, but also they have allowed the team to walk through the manufacturing process. While walking through the process, minor improvements for both logistics and design have been identified. As a result, OSRT has developed a dedicated manufacturing forum for posting jobs. As of yet the team has not run into any difficulty reserving time on equipment. Currently the team is using personnel 3D printers, and a OSU provided laser. The laser is currently underutilized by OSU and OSRT predicts no difficulties accessing the equipment in the future, meaning that OSRT has constant access to nearly all equipment required to manufacture the payload.

4.9.1 Component Manufacture

The payload structure, shown in Figure 103 consists of plywood plate material, and aluminum rods. The plywood plates detailed in Figures 104, 105, are laser cut from 3/16 in. plywood. This is done on a 2-axis CNC laser, and takes less than an hour to make all the wooden parts. Currently these designs do not include mounting holes for electronic and collection systems. However, these parts can be easily re-cut with different hole layouts. The inner and outer retaining rings (PS1-3 and PS1-4 Figure 105) are then glued together. The supporting rods are made using 1/4 in. aluminum rod stock. The rods are cut to length on a chop-saw, holes are drilled on a lathe, and then the holes are tapped manually.

The payload drive-train, shown in Figure 106 consists of an array of fasteners, purchased parts, and 3D printed parts. The Hub and spokes are currently being printed using personal 3D printers. The 3D printed parts are detailed in Figure 108, 107. Once printed these parts are tapped by hand (6-32) for all fasteners.

The payload ejection system, shown in Figure 109 consists of wooden bulkheads, a 3D printed motor housing, a custom coupler, and purchased parts. The bulkheads, detailed in Figure 110 are laser cut on the same equipment used for the payload structure. The motor hosing shown in 111 is 3D printed. The lead screw coupler shown in Figure 111 is machined from steel rod stock. The holes will be drilled on a lathe.The part will be cut to length on a chop saw, ground to a rough length belt sander, and the final holes will be drilled on a manual mill. Then a hole will be drilled through the lead screw on a drill press. This is so it can be fastened to the coupler by a pin rather than a set screw.

The payload collection system, shown in Figure 112 consists of an aluminum scoop, aluminum bracket, and stainless steel support rods. The scoop shown in Figure 113 will be machined out of aluminum on a manual mill. The aluminum bracket shown in Figure 113 will be machined on a manual mill. The supporting rods consist of stainless bar stock that will be cut to length on a chop saw, then threaded by hand using a dye kit.

5 Safety

5.1 Mitigation

5.1.1 Safety Checklists

In order to mitigate a number of hazards associated with the launch vehicle, primarily concerning stored-energy components like the ejection systems, all assembly and operation steps for a subscale or full scale launch require a suite of checklists, which serve as a method for establishing a chain of accountability for each component, as well as a place to establish best practices for consistent and safe operation of the launch vehicle during development and competition. To ensure that the mitigation strategies employed by the team are properly followed, each checklist requires three signatures for completion: the primary signature of the certified team member performing the installation or activation of the part, a second member of the same subteam capable of performing the installation, and a signature from a safety officer who has confirmed the correct installation or preparation of a component through a series of tests prescribed at the top of the checklist.

The checklists shown below are expected to mitigate the majority of assembly-specific hazards such as pinch points, abrasion on machined edges, and electrical shocks, but do not completely cover the more general environmental or personnel hazards like dehydration, tracked in the other safety analyses performed.

5.1.2 General Mitigation Steps and Revisions

During the subscale test launch, there were no significant safety incidents, no injuries, and no outstanding damage to the launch vehicle or environment. Despite this, the safety team implemented a number of revisions and additional measures to ensure a maximal amount of oversight and redundancy in the safety procedures used by this project.

The most important of these new additions to safety protocol for the OSRT team is the creation of the 'on duty' specification for the safety team.

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.

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.

The latest update to the safety team equipment is the 'go-bag', created after concerns were raised about the potential for a longer-distance retrieval effort than was required during the successful subscale launch. The go-bag consists of a lightweight assortment of supplies intended to be a miniaturized version of the kit used in final assembly and launch preparation, including equipment like gloves, a face shield, and screwdrivers capable of disarming the on board altimeter system. In the event that the safety of the launch vehicle is in question once its landing site has been located, 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. 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 Safety Team Checklists

5.2.1 Safety and Site Management

Site Setup Checklist

Assembler Signature: __________ **Safety Officer Signature:** __________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:

Continued on next page

Table 30 – continued from previous page

#	Inspector Initials	Step Instructions
		- Watch for trip hazards while walking site.
		- Verify launch rail is on level, stable ground
		- Confirm that energetics storage is properly located
		- Confirm presence of on-duty safety vest
		Prerequisite lists: N/A
	______	**Tools Needed:** N/A
	______	**Components Needed:** Launch Rail, Tables, Tents, Burn Bin, Garbage Bin
		Site Setup
1	______	Walk site, locating separate areas for energetics storage and worktables.
2	______	Set up tables and shelter for workspaces.
3	______	Transport launch rail to the designated launch location.
4	______	Clear launch rail site of snow, debris, and loose material.
S	______	**Safety consideration: If the launch rail is assembled on unsteady ground it may settle abruptly when exposed to launch forces, resulting in an unintended launch angle.**
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.
8	______	Sufficient safety glasses and gloves are available at each workstation.
9	______	Face shields and heavy gloves are ready for use in energetics assembly stages.
10		Distribute team communicators to each team lead. Set to channel **3**.
	______	Payload
	______	Structures/Propulsion
	______	Aerodynamics/Recovery
	______	Ground Control
	______	Safety
	______	Payload

General Safety Launch 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 in the Notes section.
		- Prioritize approval of staging and assembly area so other teams can work.
		Prerequisite lists: Site Setup Checklist
	______	**Tools Needed:** N/A
	______	**Components Needed:** N/A
		Site Setup
1	______	Weather conditions permit operation of launch vehicle.

Continued on next page

Table 31 – continued from previous page

#	Inspector Initials	Step Instructions
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.
		Meet with Range Safety Officer
5	_____	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: __________
6	_____	Confirm that the proposed altitude of launch is valid for the FAA waiver.
		Launch
7	_____	Confirm each subteam checklist is completed: Payload Initials: __________ Structures/Propulsion Initials: __________ Aerodynamics/Recovery Initials: __________ Avionics Initials: __________
8	_____	No greater than 5 team members transporting vehicle to launch site.
9	_____	Confirm that the Structures subteam representatives sent to the range have completed their launch preparations. Structures/Propulsion Initials: __________
10	_____	Rail correctly angled away from populated areas for prevailing conditions.
11	_____	All personnel clear from range.
		Launch and Recovery
12	_____	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.
13	_____	Track descent of launch vehicle. Notify work teams if they are to seek shelter. Confirm landing and the full discharge of all onboard energetics.
14	_____	Ensure group in charge of recovering launch vehicle is correctly dressed for a potential long walk through brush and uneven terrain.
15	_____	Thank the RSO for their time.

Site Cleanup Checklist

Assembler Signature:____________ **Safety Officer Signature:** ____________

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Fire fully extinguished - Walk site for signs of trash/debris/etc **Prerequisite lists:** N/A

Continued on next page

Table 32 – continued from previous page

#	Inspector Initials	Step Instructions
	______	**Tools Needed:** Shovel
	______	**Components Needed:** N/A
		Site Setup
1	______	Dispose of used motor components in burn bin
2	______	Disassemble launch ignition system
3	______	Take down worksite shelter tents
4	______	Extinguish fire. Use shovel to turn coals and ensure fully extinguished.
S	______	**Safety consideration: Smouldering coals left over from insufficient extinguishing could ignite wildfires.**
5	______	Return all tools to their toolboxes and storage bins.
6	______	Return all safety gear to storage boxes.
7	______	Fold up and store tables.
8	______	Turn off and stow all team communicators
9	______	Sweep launch site for garbage on ground.
10	______	Sweep gathering area/firepit site for garbage on ground.
11	______	Sweep work site for garbage on ground.

5.2.2 Structures and Propulsion

Motor Installation 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:** Wire Strippers, Multimeter
	______	**Components Needed:** Aft Body Section, Motor, 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.**
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.

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.

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 - 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.**

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#	Inspector Initials	Step Instructions
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 Range Safety Officer (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.

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:** - 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.**

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#	Inspector Initials	Step Instructions
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.

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

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#	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, Wire strippers, Safety Goggles, Walkie Talkies
	______	**Components Needed:** Armed launch vehicle
S	______	**Safety consideration: Rough handling or water damage to board may short electrical systems and ruin the entire PCB.**
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 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.

Nose Cone Structures Manufacturing Checklist

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Wear gloves for pinching/minor cuts and adhesive damage avoidance
		- Wear dust mask
		- Confirm any edges are sanded and finished, all fasteners tight
		- Workspace clean after completion of manufacturing
		Prerequisite lists:
		- OSU Machine Shop certifications
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Epoxy spreader, Vacuum, Paper Plates, Sharpie marker
	______	**Components Needed:** Nose cone body, Nose cone tip, Nose cone tube coupler, Threaded rod
S	______	**Safety consideration: Not wearing proper PPE could result in hand and/or eye irritation.**
S	______	**Safety consideration: Improper ventilation can result in headache and/or dizziness**
1	______	Take fore nose cone coupler and wipe down any possible dust accumulated from workspace.
2	______	Apply epoxy on coupler.
3	______	Insert coupler in nose cone.
4	______	Wait 6-8 hours.
5	______	Insert bulkhead in threaded rod and eye bolts.
6	______	Apply epoxy at point where threaded rod and bulkhead and eye bolts meet.
7	______	Wait 6-8 hours.

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#	Inspector Initials	Step Instructions
8	______	Apply necessary ballast or fore tracking inside nose cone.
9	______	Insert threaded rod with bulkhead and screw on nose cone tip.

Nose Cone Avionics Installation Checklist

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Wear gloves for pinching/minor cuts and adhesive damage avoidance - 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 - Ensure all fasteners on Avionics Bay and threaded rod are tightened fully - Nose cone bulkhead must be flush and level **Prerequisite lists:** - N/A **ALL** checklists 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, Nose cone Bulkhead, ¼" nut (2x), Avionics board, LiPO battery, PCB set screws (4x), Latch bolt (should be left in frame when stored)
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: 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.**
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.**
1	______	Align PCB with the four set screw holes on the side of the avionics frame **not** covered with transparent acrylic. Align the board so that the rear-protruding Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET) are seated in the slots cut into the High-Density PolyEthylene (HDPE) mounting board.
2	______	Fasten set screws. 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 screw on each end of the PCB.

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#	Inspector Initials	Step Instructions
3	______	Remove the topmost bolt (the Latch Bolt) from the frame on the battery cage side of the avionics bay.
4	______	Swing the acrylic pane clockwise until the battery slot is accessible.
5	______	Slide the LiPo battery into the battery cage, positioned so the wire leads protrude at the top of the cage, facing right such that when the pivot bar is resting horizontally it does not impede these wires.
6	______	Move the pivot bar back into its horizontal orientation, such that the latch hole re-aligns with the hole in the black plastic backing of the battery cage.
7	______	Re-insert the latch bolt, and hand-tighten the latch nut on the opposite side of the black plastic plate to lock the pivot bar in place and prevent the battery from moving.
S	______	**Safety consideration: An improperly tightened bolt may shake loose during launch vibrations and allow the LiPo battery to fall free, damaging components.**
8	______	On-site personnel responsible for avionics will now connect the LiPo battery to the avionics board and confirm functionality. Avionics Functionality Initials: _______
9	______	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 .
10	______	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.
11	______	Move the full avionics frame up against the previously placed nut.
12	______	Press nose cone bulkhead up against the bottom of the avionics frame and tighten the bulkhead fasteners.

5.2.3 *Payload Checklists*

Payload Chassis Assembly

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Safety glasses must be worn during assembly of any components .
		Prerequisite lists: N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Allen Wrenches
	______	**Components Needed:** 1/4-20 1 in. long fasteners, chassis parts as listed in chassis drawing (structure center plate, structure bottom plate, structure end plate, structure body rod, structure end plate outside, structure brace).
1	______	See structure drawing for assembly reference.
2	______	Connect wooden plates together using slip fit connections. All components are asymmetrical will only fit one way.
3	______	Fasten all three aluminum rods to one of the circular mounting plates (there should be two circular mounting plates that consist of two separate glued together disks).

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#	Inspector Initials	Step Instructions
4	______	slide disk-rod assembly through the structure assembly (the mounting plate is asymmetrical and should only fit on one side).
5	______	Fasten the other mounting disk to the assembly, clamping all the parts together.

Payload Drivetrain Assembly

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Safety glasses must be worn during assembly of any components . **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Allen Wrenches
	______	**Components Needed:** 6-32 1/4 in. long fasteners, drivetrain parts as listed in Snowflake2 drawing (hub, spokes, spring hinges, motor coupler, set screws, extension springs).
1	______	See Snowflake2 drawing for assembly reference.
2	______	Connect spring hinge to spoke using 2 X 6-32 1/4 in. long fasteners. Hinge needs to be oriented as shown in Snowflake2 drawing (hinge needs to fold facing end with U groove). Repeat for each spoke.
3	______	Fasten spoke hinge to hub using 2 X 6-32 fasteners. Repeat to for each spoke.
4	______	connect hub to coupler using 4 X fasteners.

Payload Collection Assembly

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Safety glasses must be worn during assembly of any components . - Confirm tightness of fasteners
	Prerequisite lists: N/A	
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Wrenches
	______	**Components Needed:** Collection scoop, collection bracket, 6 V lead screw, hex nuts, 2 mm threaded rods, 3 mm threaded rod.
S	______	**Safety consideration: Ensure motor is disconnected from power to prevent unexpected actuation or pinched digits.**
1	______	See Collection Assembly Drawings for assembly reference.

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#	Inspector Initials	Step Instructions
2	______	Connect Scoop to both all thread rods as shown in the drawing. Thread a hex nut onto both rods, then slide the all thread through the outer most through holes, then using a second hex nut clamp the scoop onto the all thread.
3	______	Connect the larger all thread rod to the collection bracket, using hex nuts to sandwich it onto the all thread. Then connect the rod to the scoop in the same way, sliding the rod through the middle hole in the scoop.

Payload Rover Assembly

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Safety glasses must be worn during assembly of any components . **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Allen wrenches
	______	**Components Needed:** 2X wheel assemblies, 2X 12V DC motors, 1X collection assembly
S	______	**Safety consideration: Ensure motor is disconnected from power to prevent unexpected actuation or pinched digits.**
1	______	See Rover Assembly Drawing for assembly reference.
2	______	Connect both DC motors to the rover structure. The motors fit inside the wooden chassis, with the motor shafts extruding out of the either end.
3	______	Fasten each wheel assembly to the motors, using set screws to connect the motor couplers to the motor shafts.
4	______	Slide the collection assembly into the payload chassis. The scoop should fit flush underneath the structure bottom plate (balloon #2 in chassis drawing).

Payload Ejection/Retention Assembly

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Safety glasses must be worn when assembling any components . **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Allen wrenches
	______	**Components Needed:** Lead screw, motor mount 1, motor mount 2, lead screw coupler, assorted fasteners, lead screw nuts, coupler bulkhead, 2X push plates, payload, lead screw motor, gear box.

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#	Inspector Initials	Step Instructions
S	______	**Ejection/Retention system has many pinch points. Watch where your fingers are when assembling.**
1	______	See Retention Assembly Drawing for assembly reference.
2	______	Slide motor mount 2 into motor mount 1, then connect lead screw motor.
3	______	Using the lead screw coupler connect the motor to the lead screw. Connect the motor shaft to the coupler using a set screw.
4	______	Connect the lead screw to the coupler using a fastener as a pin. Secure the lead screw using a hex nut.
5	______	Fasten the motor lead screw assembly to the coupler bulkhead.
6	______	Fasten the lead screw nuts to the push plates.
7	______	Thread one of the push plates onto the lead screw such that the nut is facing the motor. Then slide the payload down the lead screw. Secure the payload by threading the second push plate onto the lead screw behind it. The payload should be sandwiched between the two push plates.

Payload Electronics Assembly

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Safety glasses must be worn when assembling any components .
		- Batteries must be plugged in correctly.
		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, Allen wrench, electrical tape, screw driver
	______	**Components Needed:** Payload PCB, 11.1V Lithium Polymer (LiPo) battery, teensy 3.6, XBee, assorted fasteners, GPS antenna, XBee antenna.
S	______	**All breakout boards must be installed correctly.**
1	______	See Retention Assembly Drawing for assembly reference.
S	______	**Ensure ground and 5 V and ground and 3.3 V are not shorted on the teensy.**
S	______	**Ensure USB power and input power are not connected on teensy 3.6.**
2	______	Place the teensy 3.6 into the largest female pin headers.
3	______	Place the XBee into the smaller female pin headers.
4	______	Connect the GPS antenna to the Sub-Miniature Version A Connector (SMA) connector.
5	______	Connect the XBee antenna to the XBee antenna connection.
S	______	**When checking battery voltage do not touch the two leads together. It will cause electrical shock.**
6	______	Check the battery voltage. Battery Voltage: ____
S	______	**When installing battery voltage ensure it is plugged in fully and correctly. Incorrect installation can cause damage to person and parts.**
7	______	Once the battery is plugged in, ensure the power LEDs for 11 V, 5 V and 3.3 V are on. Ensure the GPS light is on. If not, recheck the battery voltage.

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#	Inspector Initials	Step Instructions
8	______	Unplug battery.
S	______	**If screws are not tightened then it could lose connection.**
9	______	Install board into Rover chassis, and screw down anchoring screws.
S	______	**Incorrect matching of motor terminals will result in incorrect controls.**
10	______	Screw Motor leads into corresponding screw terminals.
11	______	Install battery into slot.
12	______	Plug the battery into the electronics again.

Payload Rocket Integration

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Safety glasses must be worn during assembly of any components. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** Allen wrenches
	______	**Components Needed:** Payload assembly, fore section of the airframe
1	______	Slide payload assembly into the payload compartment of the airframe (this is the side that the nose cone attaches to).
2	______	Using 3X 1/4-20 fasteners, connect the fore bulkhead to the payload. Insert the fasteners through the parachute compartment, aligning the holes in the payload to the holes in the bulkhead.

5.2.4 Aero/Recovery Checklists

Main Parachute Packing Checklist

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

Note: there are two of these checklists at launch, one for the fore parachute and one for the aft parachute.

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: -Ensure REMOVE BEFORE FLIGHT tag is placed under the tape holding the parachute closed and the shroud lines together. There should be two tags. **Prerequisite lists:** N/A **ALL** checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** one 144 in. Standard Iris Parachutes, 5.5x7.7 Kevlar/Nomex blanket, masking tape, and two red REMOVE BEFORE FLIGHT tags.

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#	Inspector Initials	Step Instructions
S	______	**Ensure all sharp objects, heat sources, and corrosive materials are removed from work space. Work space should be clear of any items not related to harness and parachute prep. Failure to follow all steps will result in complete mission failure due to recovery failure.**
1	______	Gather all the shroud lines in your hand with the parachute lifted off the ground. Grab the shrouds about 3 ft below the start of the parachute.
2	______	Take the parachute to an open area.
3	______	Run with the parachute until it inflates to ensure the shrouds are not tangled and the parachute is not ripped.
4	______	Let the parachute deflate and carefully take the parachute to the folding station.
5	______	Lay out parachute so that the shrouds are below it.
6	______	Locate the left and right shroud lines, these are bundled together by a rubber piece close to the swivel.
7	______	Gather four shrouds to the right, four shrouds to the left, and four 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 two middle shrouds on top and two middle shrouds on bottom. Take two 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.
11	______	Ensure that the gores laying on top of each other are opposite colors (yellow and black).
12	______	Pull on the center shroud lines until the spill hole is 3/4 to the bottom of the parachute.
13	______	Ensure the gores are still aligned by opposite colors on the top and bottom of the parachute.
14	______	Take the closest gore to the center and fold the stitched line onto the center line. Repeat this process for one side of the canopy until all the gores are folded. While doing this process, collect the shroud lines to each gore and ensure that they all lay on top of each other, aligned just to the side of the center line. With each fold, ensure the top and bottom of the parachute gores are still aligned.
15	______	Repeat the previous step for the opposite side.
16	______	Ensure the resulting gores left are opposite colors.
17	______	Flatten the folded canopy as much as possible by pushing out all the air.
18	______	Lay the shock cords into a third of the parachute and fold the canopy in thirds over the cords, similar to folding a letter. Take the right side of parachute and fold it 2/3 of the way to the other side. Fold the left side over to the end of the right side.
19	______	Ensure the canopy is folded into a long rectangular shape, fold down from the top into thirds until parachute is a small rectangle .
20	______	Pack the folded canopy in and on the Nomex blanket, ensuring there is a small piece of blue tape to hold the parachute closed.
21	______	Make sure the Kevlar/Nomex blanket is threaded through the shock cord and the tether and shock cords are wrapped in the blanket.

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#	Inspector Initials	Step Instructions
22	______	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.
23	______	Ensure all masking tape has a REMOVE BEFORE FLIGHT tag attached directly to it.

Drogue Parachute Packing Checklist

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

Note: there are two of these checklists at launch, one for the fore parachute and one for the aft parachute.

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		-Ensure REMOVE BEFORE FLIGHT tag is placed under the tape holding the folded parachute closed.
		Prerequisite lists: N/A
		ALL checklists below must be completed and verified by an inspector for Safety Officer's sign-off.
	______	**Tools Needed:** N/A
	______	**Components Needed:** One 30 in. X-form drogue parachute, one swivel, masking tape, and one red REMOVE BEFORE FLIGHT tag.
S	______	**Ensure all sharp objects, heat sources, and corrosive materials are removed from work space. Work space should be clear of any items not related to harness and parachute prep. Failure to follow all steps will result in complete mission failure due to recovery failure.**
1	______	Get the 30 in. X-form drogue parachute (check the marking on center square to check size).
2	______	Ensure there are no tears in the parachute nylon.
3	______	Ensure shroud lines are untangled.
4	______	Inspect the shroud lines for burns or tears and ensure there is no fraying.
5	______	Secure the drogue to a swivel using a cow hitch so that the center of the shrouds (marked in black) are in the center of the hitch. Tape the hitch to the swivel with masking tape.
6	______	Pull the drogue up and ensure the shrouds are not tangled.
7	______	Fold the parachute in half so two 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 third 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 third line of the chute so the swivel is at the bottom again.
12	______	Fold the left third of the chute over the shroud lines, only 1-2 in. 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 "30 in."; place a REMOVE BEFORE FLIGHT tag under the tape. This tag should be labeled #1 (for the fore) and #4 (for the aft).

Drogue 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 Nomex blanket. - Parachute is packed well and there is no canopy showing. - Ensure two tags are on the assembly. **Prerequisite lists:** - Drogue Parachute Packing Checklist. - Main Parachute Packing Checklist. **ALL** steps below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** N/A
	______	**Components Needed:** One packed 30 in. X-form drogue assembly, masking tape, one Kevlar blast protector, sharpie, one 44 ft nylon shock cord, 6 1200lbf yield quick links, 4 standard quick links, 1 6 ft Kevlar sleeves, Kevlar cord, One 16ft nylon cord (tethered to bulkheads.)
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.
2	______	Make sure on each bulkhead in the fore section and coupler that there is a three 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 third quick link, on fore section and to the coupler side with a butterfly loop refereed to as loop #1.
5	______	Get one 44 ft nylon shock cord riser .
6	______	Inspect the riser 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 tow-thirds of the way from the main body bulkhead 5ft from the coupler. 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 to this loop, this is now loop #3. Ensure 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 finish packing the cord from the coupler into the bay, making sure all charges and blast lines are ready.

Main Recovery Harness Checklist

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

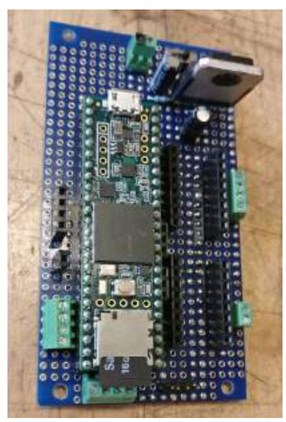
#	Inspector Initials	Step Instructions
	______	**Safety Officer Checklist:** - Check recovery harness for damage. - Shroud lines are protected in Nomex blanket. - Parachute is packed well and there is no canopy showing. - Ensure two remove before before flight tags are on the assembly. **Prerequisite lists:** - Main Parachute Packing Checklist. **ALL** steps below must be completed and verified by an inspector for Safety Officer's signoff.
	______	**Tools Needed:** N/A
	______	**Components Needed:** one packed 144 in. Iris Ultra Torodial Parachute, masking tape, One Kevlar blast protector, sharpie, two 16 ft nylon shock cord, 6 1200 lbf yield quick links, 4 standard quick links, 1 3 ft Kevlar sleeve, Kevlar cord.
S	______	**Safety Consideration: Check the main packing looks correct, and that a REMOVE BEFORE FLIGHT tag is placed under the tape holding it closed.**
1	______	Get 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.
2	______	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 refereed to as loop #4.
5	______	Get one 16 ft nylon shock cord riser .
6	______	Inspect the riser 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 coupler. This loop is for the main parachute and will be referred to as loop #5.
8	______	Ensure a short Kevlar sleeve is located after loop#1. It should be secured just next to loop
9	______	Place the main swivel on a high load quick link, make a new loop at the top of the shock cord above loop #5 and attach this quick Link to this loop this is now loop #6. Ensure quick link is tightened all the way down.
10	______	Tape an artificial zipper along the nylon cord between loops #5 and #6. 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 #5 .
13	______	Pack the second cord and the packed main parachute into the parachute bay above loop.
14	______	Finish packing the cord from the coupler into the bay, making sure all charges and blast lines are ready.

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 **Prerequisite lists:** - Prefield Inspection - Preflight Inspection - Aft Airframe **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.
	______	**Components Needed:** Aft airframe, 4x radial bolts.
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 a microSD 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	______	Ensure blades are fully retracted before power supply is turned on.
5	______	Plug in battery.
6	______	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**
7	______	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.**
8	______	Ensure radial bolts are removed from bulkhead.
9	______	Slide mechanism into aft section of the airframe, on top of the aft ballast.
10	______	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.**
11	______	Secure radial bolts into bulkhead with 1/8 in. hex key.

Ground Station Checklist

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - All electronics are securely attached to the PCB - Power Light Emitting Diode (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:** glsBRIC unit, PCB with GPS, XBee "Scooby," LiPo battery, 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 micro USB power pads on the bottom are connected.**
1	______	Teensy should be installed into the larger pin slot with the microSD card oriented off of the board, facing the 4-pin green screw terminal. The microSD card should be installed into the Teensy's microSD card slot.



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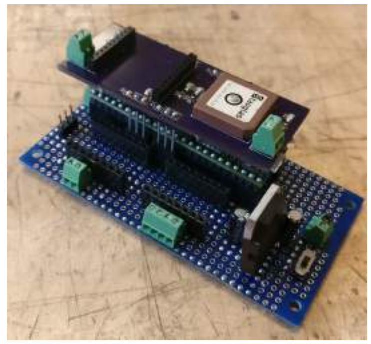
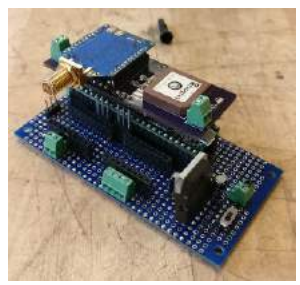
#	Inspector Initials	Step Instructions
2		The PCB with the GPS should be installed directly above and inline with the Teensy such that the GPS is over the micro USB connector. 
3		The XBee should be installed into the pins on the PCB board with the GPS over the microSD card, and so that the antenna jack is over the 2-pin green screw terminal. 
4		Screw the smaller end of the antenna adaptor onto the antenna jack of the XBee.
5		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.**

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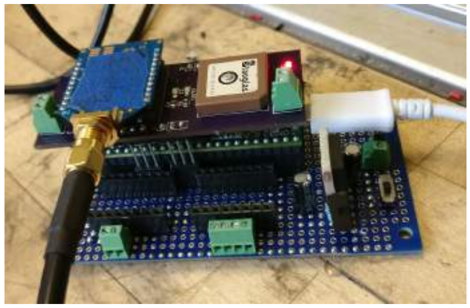
#	Inspector Initials	Step Instructions
6	______	Insert a micro USB cable into the computer and plug the micro USB end into the Teensy 3.6. 
7	______	Check lights. The light on the GPS should start flashing immediately. Additionally the light by the XBee should start flashing.
8	______	Open a serial port,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

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 9 V battery has adequate charge (8.0 V or more). **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, tiny flat-head screwdriver, tiny Phillips screwdriver, pen, notebook, sharpie
	______	**Components Needed:** 2 Missileworks RRC3 Altimeters (1 "P1" Altimeter, 1 "B1" Altimeter), 4 e-matches, 2 9 V batteries, printed instruction manual (for quick reference if necessary), Plumber's Putty, Duct Tape.
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.**

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#	Inspector Initials	Step Instructions
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.**
6	______	Ensure that DIP switch 4 is in the OFF position. This switch is located next to the program button.
7	______	Turn 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 ft 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 ft, set it to 200 ft 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 ft for the primary altimeter, and 500 ft for the secondary altimeter by listening to the beeps. There should be 6 beeps for the primary and 5 beeps for the secondary.
14	______	If the main deployment altitude is **not** set to 600 ft for the primary and 500 ft for the back up, press the program button either 6 times for the primary or 5 times for the back up after the very low frequency beep.
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) and on number 2 for back up (Drogue at apogee + delay and Main at Altitude).
18	______	If the Deployment Mode setting is not set to 1 for the primary and 2 for the back up, press the program button either 1 time for the primary or 2 times for the back up 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 eject at apogee, resulting in loss of launch vehicle.**
20	______	For the back up altimeter: Flip the switches so that the first, second, and third switches are ON and the fourth switch is OFF.

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#	Inspector Initials	Step Instructions
21	____	For the back up altimeter: If the Drogue Delay is **not** set to 1 second, press the program button 1 time after the very low frequency beep.
22	____	For the back up altimeter: 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.**
23	____	Turn off altimeters.
S	____	**Safety Consideration: Not turning off the altimeters may lead to premature detonation of black powder charges.**
24	____	Install the 2.5 g black powder charges into the primary altimeter in the Main and Drogue ports 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.
25	____	Install the 4.0 g black powder charges into the back up altimeter in the Main and Drogue ports by feeding the wire end of the e-matches through the bulkhead and into the correct port.
26	____	Adhere the e-match line to the inside of the coupler, once the altimeter bay is installed, via duct tape.
S	____	**Safety Consideration: If the e-match is not firmly adhered to the inside of the coupler, it may be pulled out by the parachute ejection process and damage the altimeter.**
27	____	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.
S	____	**Safety Consideration: If the charge is too firmly attached to the bulkhead, the parachutes may not fully eject.**

Avionics 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:** ATU unit, LiPo battery, battery voltage checker, electrical tape, microSD card, MPL3115A2 altimeter, Teensy 3.6, XBee "Shaggy," Ultimate GPS, PCB
S	____	**Safety Consideration: - Ensure that battery is at maximum capacity before insertion into launch vehicle; Acceptable range: >7.7 V**
1	____	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**

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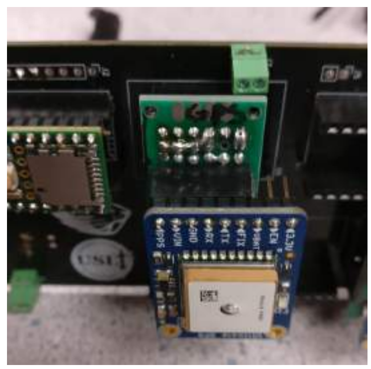
#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: - Ensure that the Teensy VIN and USB power pads on the bottom are not connected. If they are and it is plugged into a computer it could result in destruction of the USB port or the computer.**
2	______	Teensy should be installed into the larger pin slot with the USB connector oriented off of the board.
3	______	Ultimate GPS breakout should be on the smallest green protoboard marked GPS. The protoboard should be installed so that the GPS marked area is directly over the green jumper on U6. The PPS pin should be on the side with the black line. 3.3 V and EN pins should hang off the protoboard. It should be installed directly above the Teensy into the board so that the body of the GPS breakout hangs partially over U8. 
4	______	The barometric pressure sensor should be installed on the longer protoboard marked MPL. It should be oriented such that six pins of the protoboard plug into the six pins of U7, and two pins plug into U2. The MPL3115A2 should be installed so the body of the board is facing towards the GPS. 
5	______	The XBee should be installed such that the antenna jack is pointing towards the MPL3115A.
		Continued on next page

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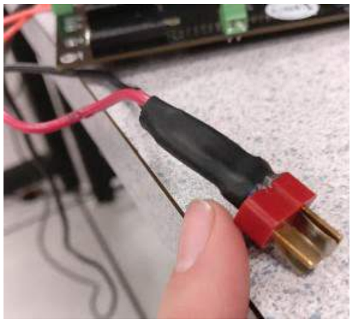
#	Inspector Initials	Step Instructions
S	____	**Safety Consideration: - When plugging the battery in make sure the connections go all the way into the correct slots. Insecure connections can result in electrical shock and shorting.**
6	____	At least 30 minutes before launch, plug the battery into the power connection. The light on the GPS should start flashing immediately. 
7	____	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 micro 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.**

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 pen. - 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, and two differently colored sharpies.
	____	**Components Needed:** Surgical Tubing, Rubber Stopper Material, cable ties, 4F black powder, e-match

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#	Inspector Initials	Step Instructions
S	______	**Safety Consideration: - All steps must be carried out by High Powered Rocketry (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 ft 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.**
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 four three-inch piece of surgical tubing.
7	______	Insert one rubber stopper into one end of one piece 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 2.5 g of black powder for the primary charge.
12	______	Record charge name and 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 in. 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.

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#	Inspector Initials	Step Instructions
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.**
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.
29	______	Insert another rubber stopper into another end of one piece 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 2.5 g of black powder for the primary charge.
34	______	Record charge name and 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 in. 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.**

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#	Inspector Initials	Step Instructions
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.
51	______	Insert another rubber stopper into another end of one piece surgical tubing so that it is completely housed within the tubing.
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 4.0 g of black powder for the back-up charge.
56	______	Record charge name and 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 in. 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.

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#	Inspector Initials	Step Instructions
72	______	Remove label tag on the e-match and set aside charge.
73	______	Insert another rubber stopper into another end of one piece surgical tubing so that it is completely housed within the tubing.
74	______	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.**
75	______	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.**
76	______	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.**
77	______	Measure 4.0 g of black powder for the back-up charge.
78	______	Record charge name and mass: ______________ / ______________
79	______	Insert tip of measuring cup into the open end of the surgical tubing.
80	______	Pour half of the black powder into the surgical tubing. Set the rest aside for later.
81	______	Unwrap the e-match.
82	______	Clip copper leads at the fold with a wire cutter.
83	______	Twist the e-match so that it looks like blue and white candy cane striping.
84	______	Remove the red cover from the live end of the e-match, and slide it six in. down the e-match to ensure that it stays on the outside of the charge.
85	______	Bury the live end of the e-match into the black powder that is currently in the surgical tubing.
86	______	Insert tip of measuring cup into the open end of the surgical tubing.
87	______	Pour the remaining black powder into the surgical tubing, further covering the e-match.
88	______	Set aside measuring cup.
89	______	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.**
90	______	Firmly tighten a cable tie around the outside of the surgical tubing and the newly installed rubber stopper.
91	______	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.**
92	______	Remove cable tie tails with tin snips.
93	______	Write the charge name and size on the surgical tubing in sharpie.
94	______	Remove label tag on the e-match and set aside charge.

5.3 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 Code in Table 32 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 Code given that predicts the total reduction in hazard rating after these mitigation strategies are successfully employed.

Table 32: Risk Assessment Code (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 33: Environmental Hazard Analysis

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
Motor catches fire	Direct exposure extreme to 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 National Association of Rocketry (NAR) High Power Rocket Safety Code (HPRSC) 7 and Tripoli Rocketry Association, inc (TRA) HPRSC 6-5.	Launch rail will be angled against the wind direction to counteract wind speeds. Preflight checklists and rail setup completed.	1E
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 as per NAR HPRSC 7 and TRA HPRSC 6-5. Range Safety Officer (SO) cancels flight under high wind conditions as per TRA High Power Safety Code (HPSC) 1-1.2 .	Complete all pre-launch safety checklists, especially RSO communication.	3D

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Table 33 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
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 workspace	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 Federal Aviation Administration (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
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	Redundant calculations and simulations. Launch only in accordance with safe flight conditions of FAA, NAR, TRA, and NASA	3D

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Table 33 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
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.	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.	Completion of required safety checklists.	3E
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.	3D

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Table 33 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
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.	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.	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.	2E
Hazardous material in launch debris	Improper motor burn or excessive expelling of shrapnel or fuel leak from the motor.	Fire hazard for launch and surrounding brush and chemical hazard to wildlife and people.	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.	2D

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Table 33 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
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.	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 verifications pre-flight.	3D
Launch vehicle breaks apart	Zippering or insufficient structural integrity.	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.	2E
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

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Table 33 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Verification Mitigation	Post-RAC
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 prelaunch verifications.	2D

5.4 Personnel Hazard Analysis

Mitigation of dangers to the launch vehicle, environment, and project timeline are irrelevant if the safety, comfort, and efficiency of personnel working on the project cannot be assured. Any loss of team members to debilitating hazards, either from physical injuries, exposure to toxins, or other incident may impact all other aspects of the project by restricting available skillsets or delaying work, and threatens the reputation of OSRT; 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 34, each hazard has been assigned a probability and severity, as detailed in Table 39, 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 unpredictable interactions due to human interaction.

In many instances, observation of critical rules and requirements previously identified by the safety team are sufficient to fully mitigate some hazards, for example in the proper storage of launch vehicle motors outlined by National Fire Protection Agency (NFPA) 1127 and the ignition wire installation and operation procedure NAR requires. Adapting these practices for other hazards will create a consistent mitigation technique that maximizes the safety of personnel by being familiar to implement and easy to recall through repetition. An example of this adaptation process is in the lockout procedure used for avionic electronics: using the same practices NAR requires to prevent active ignition wires can be used to prevent electric shock in other subcomponent operations.

Table 34: Personnel Hazard Analysis

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Mitigation Verification	Post-RAC
Laceration	Sharp and/or rough Edges left on fabricated parts. Sharp metal chips in machine shop from improper clean up	Minor injuries, difficult part fitting	3C	Team members will wear protective gear and will clean workplace thoroughly	Completion of safety checklists, safety officer component inspections	3D
Heatstroke	Long-term exposure to heat in field work or poorly ventilated workshops	Permanent brain damage	2C	Hydration, paired/supervised work, education on warning signs	Shelter setup completed and adequate water supplies maintained, briefings at team meeting on symptoms.	1D
Frostbite	Low temperature exposure during field work or in composite freezers	Loss of coordination, damage to extremities	1D	Proper clothing, weather forecast data, training	Clothing and shelter checks during site setup, symptom briefings in pre-departure meeting presentation	1D
Hypothermia	Low temperature exposure during field work or in composite freezers	Dysfunctional physical coordination	1D	Proper clothing, 'no-go' thresholds for extreme weather	Enforcement of proper clothing at work sites, weather forecast before final confirmation of departure, site readiness checklists	5D
Epoxy 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)[10]	Manufacturing checklist completion and safety officer spot-test for concentrated epoxy scent	5D

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Table 34 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Mitigation Verification	Post-RAC
Particulate Detonation	Fine particles like sawdust may detonate when exposed to flame	Eye damage and burns	2D	Clean workspaces regularly, keep areas ventilated, control ignition sources, wear safety glasses as per OSU's Machine Shop Safety (MSS) rule 1	Compliance with manufacturing checklists and safety equipment requirements	3D
Sleep Deprivation	Insufficient rest disorients workers and increases frequency of other hazards	Difficulty concentrating	2B	Reasonable work expectations, paired/supervised work, self care expectations	Wellness surveys, briefings on effects and symptoms, maintain snack supplies	4C
Tripping	from falling over discarded objects or exposed cables	Bruises or other injuries	3C	Keep workspaces clean, walk site before use to note danger regions	Completion of cleanup stage in manufacturing checklists, site setup checklists.	3D
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.	3D
Car Accident	Traffic incidents can range from minor delays to severe injury	Property damage, injury and or fatalities	1E	Well-rested drivers, OSRT transportation in good repair and known weather forecasts	Vehicle inspections completed, road condition checked as part of the final launch abort decision	3D
Cutting Tool Misuse	Improper education for saw blade use or faulty equipment	Damage to worker extremities and components	1D	Check safety guards, only trained operators of tools as per OSU's MSS rule 13, safety gear	Manufacturing checklist safety signoffs, proof of shop certification for personnel	4D
Premature Ignition	Faulty charge wiring; shear pins do not break	Accidental firing of launch vehicle motors could strike personnel with high-speed debris or 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

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Table 34 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Mitigation Verification	Post-RAC
Pinch of fingers or skin when securing fasteners, seating couplers, or closing bulkheads	Haste during assembly, excess force requirements for seating components, miscommunication	Bruising or scratches visible on skin	4B	Proper tool usage, clear handholds or grip points, use multiple people where needed	Completion of checklist procedures, enforced use of gloves	5D
Spray Paint	Inhalation of toxic fumes	Incapacitation of user which could lead to hospitalization	2C	Ventilated spaces and use of masks as per product instructions and MSDS	Manufacturing site maintenance and ventilation procedures, safety officer spotcheck during use of fume-generating materials	4E
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, use of pre-task plans to warn of hazards or establish ladder use	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, pre-task plan hazard identification	4D
Struck by Launch Vehicle	Improper structural integration and flight path analysis. Falling debris or uncontrolled launch vehicles carry significant kinetic energy	Fatality	1E	Stay alert, listen to RSO, maintain clear range boundaries	Preflight checklist completion, RSO verbal confirmation of rail status	5E
Electrical Shock	Discharge of firing circuits or other on board electronics	Mild to moderate electrocution of nearby persons	2D	Lockout-tagout procedures, insulated wiring, and inspect batteries and connections	Devices may be shaken without connections coming loose and devices run without creating visual arcing or audible snapping/sparking/sizzling	4E

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Table 34 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Mitigation Verification	Post-RAC
Mental Health	Consistent high-stress environments can cause attrition of personnel	Depression, anxiety, nervousness	3B	Emphasis on team cohesion, work-life balance and self care	Communication between team members, wellness survey	4D
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 of sunscreen usage for traveling personnel	5D
Splinters	Wood fragments lodged in skin can cause infections	May cause infection	3C	Use gloves and sand down edges of wood	Manufacturing checklists and visual/tactile inspection of all wood components	5E
Ergonomic Strain	Back, wrist, and finger strain from awkward angles, lifting, and exerting excessive force on shrouded parts	Injury, sore muscles and joints	3C	Subcomponent accessibility, correct tool for given task, proper lifting and carrying techniques	Accessibility tests in accordance with engineering specifications, proof of shop and tool certification for personnel	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 survey, enforcement of proper footware for work site personnel	4E

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Table 34 – continued from previous page

Risk	Cause	Effect	Pre-RAC	Mitigation Strategy	Mitigation Verification	Post-RAC
Wildlife Attack	Field work may involve regions with wild animals, including possible rabies vectors	Animal inflicted wounds and possible infection	2D	Avoid deep foliage, wear long pants, walk don't run	Completion of site setup inspection checklist, enforcement of proper attire for work sites	4D

5.4.1 *Failure Modes & Effects Analysis*

Risk Priority Number (RPN) is a the product of severity, occurrence, and detection. Higher scores in this category indicate a greater effect of the given failure mode.

Table 35: Structures Failure Mode Effects Analysis (FMEA)

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	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.

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Table 35 – continued from previous page

System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
	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 21.
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 perfectly.	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 35 – 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 36: 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.
	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.

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System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
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.
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 37: 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.
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.
				BEAVS 2.0 Electrical System				

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Table 37 – 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	Intaking noisy data misaligned with venting holes	6	5	5	150	Implement a Kalman filter and Proportional-Integral-Derivative (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 38: 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.

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System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
	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 Coupler	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.
	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.

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System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
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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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 as calculated in Figure 58
	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.

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System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
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
	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

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System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
	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 unpowered	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 unpowered	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
Auger	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

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System	Failure Mode	Failure Effect	Failure Cause(s)	Severity	Occurrence	Detection	RPN	Mitigation
	Sample falls out of auger	No sample collected	Not enough friction between auger and sample	7	5	6	210	Design sample retention system as per Requirements 4.3.4 and 6.6
	Failure to dig into soil	No sample collected	Not enough weight behind rover	7	6	3	126	Angle auger to gain mechanical advantage as per Requirement 6.4
Auger servo	Jam	No sample collected	Misaligned Parts	7	4	6	168	Ensure proper assembly as per a checklist and repeated tests on auger rotation as per Requirement 6.13
	Auger Rotates when digging	No sample collected	Servo torque fails to hold auger in position	7	4	1	28	Scale servo appropriately during testing as per Requirement 6.13

5.5 Project Risks Analysis

The size and scope of the USLI competition requires that project health be measured on metrics beyond simply creating a workable design for the launch vehicle. Deadlines, funding, allocation of talent, component sourcing, and administrative requirements are all essential components of the project, and must be accounted for in any testing or forecasting of success. A similar, simplified Risk Assessment Matrix can be used for managing overall project risks, with a greater emphasis on recognizing the warning signs of an impending project issue. Much of the project-level mitigation will still begin or partially rely on the same assembly-level and testing-level checklists, due to their ability to incorporate quality control and rules compliance on a per-item basis.

Table 39: Risk Assessment Matrix

	Impact		
Likelihood	**1 - High**	**2 - Medium**	**3 - Low**
A - High	1A	2A	3A
B - Medium	1B	2B	3B
C - Low	1C	2C	3C

Table 40: Risk Analysis

Risk	**Likelihood and Impact Rating**	**Mitigation Technique**
Timeline pushed backward	3A	Break up large deadlines into smaller, more manageable, internal checkpoints that can be accomplished more readily.
OSRT cannot raise enough money to finance the project	1C	OSRT will reach out to as many potential donors as possible and look for frugal ways to construct the launch vehicle and payload, including, but not limited to, finding companies to donate old materials and sorting through scrap bins around campus.
Mistake in manufacturing causes a part's completion to be delayed	2B	Procedure checklists and blueprints will be created prior to manufacturing to ensure that careless or misinformed errors are not made.
Poor weather at the launch site causes the launch to be moved backward to another day.	2B	Be prepared to launch both earlier and later in the selected day to be able to take any possible opportunity of the flight waiver opening.
Team member's illness causes manufacturing to be delayed	2B	Ensure that more than one individual on the team is certified to work on any necessary machine and understands the relevant part drawings and procedure checklists.
Delay in part delivery and/or damaged orders	2B	Place orders as soon as possible and from reputable carriers
Launch vehicle does not comply to NASA USLI operational requirements	1C	Compliance will be checked and ensured at every milestone and design decision, with simulations and calculations to verify launch vehicle adherence to operational requirements

Table 40 – continued from previous page

Risk	**Likelihood and Impact Rating**	**Mitigation Technique**
Team members create more goals and team derived operational requirements then reasonably feasible	1C	Project scope will be defined by every subteam and verified by team leads in all milestones
Lack of funding requires team members to fund their trip out of pocket, causing some members to not be able to attend launches	2c	Possible sponsors will be reached out too, and spending on materials greatly monitored

6 Testing Plans

This section contains details for all test that OSRT plans to complete before Flight Readiness Review (FRR). Each test has a checklist, that contains all required information to perform said test. This includes: Safety officer checklists, prerequisite checklists, required testing equipment, required tools, required components, test passing conditions, and steps for the testing procedure. Preceding each test checklist is a short description of the test. Justifying its importance, then discussing the result criteria. This will detail what qualifies as an acceptable result, and will discuss how OSRT will respond to an undesirable test result. A summarized list of OSRT testing can be found in Table **??**.

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	Succesful	
	Chassis FEA	Complete	Succesful	
	Chassis Prototyping	Complete	Succesful	
	Wheel Prototyping	Complete	Succesful	
	Collection Prototype Testing	Complete	Succesful	
	Drop Testing	In Progress	N/A	
	Drive Testing	In Progress	N/A	
	Battery Life Testing	In Progress	N/A	
	Ejection System Testing	In Progress	N/A	
	Retention Strenght Testing	In Progress	N/A	
	Retention Robustness Testing	In Progress	N/A	
Structure Testing	Radial Bolt	In Progress	N/A	
	Launch Vehicle Test Plate	In Progress	N/A	
	Vehicle Thrust Plate	In Progress	N/A	
	Pressure Testing of Parachute Bays	In Progress	N/A	
	Pressure Testing of Coupler Altimeter Bay	In Progress	N/A	
Altimeter Testing	1	Complete	Succesful	
	2	Complete	Succesful	
	3	Complete	Succesful	

The "Rover Chassis Drop Test" is required to test the strength of the rover chassis. In flight the rover will experience force due to rabid acceleration, then it will experience a jolt when the parachutes deploy. OSRT need to first ensure the rover structure is strong enough to survive these forces, to do this drop testing has been chosen to quantify chassis durability. This purpose of this test is to identify the height, and with it kinetic energy, and impact force that causes a structural failure in the chassis. If the chassis is found to be to fragile, it will require a change in chassis design (change in thickness and material type). This will result in a change in payload weight that could have a severe effect on the launch vehicle stability, requiring redesign of other components to compensate. If possible this test will be repeated for the rover assembly to test the rigidity of the assembly, and more importantly the rigidity of fasteners, and electrical connections. Passing conditions for these test have not yet been designed. The purpose of this test is to identify if the failure point of the system.

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 structure
		Passing Condition: NA
		Testing Procedure:
1	_____	Collect 1 fully assembled payload structure
2	_____	Find a location free of bystander's to perform drop testing
3	_____	Set up cameras filming the drop test
4	_____	Vertically extend tape measuring height
5	_____	lift rover to a specified drop height and release it (repeat till component failure)
6	_____	Record Drop Height ________________
7	_____	Record Drop Height ________________
8	_____	Record Drop Height ________________
9	_____	Record Drop Height ________________
		Maximum drop height ________________
		Prototype weight ________________

The purpose of the "Rover Drive Test" is to stress the rover assembly. By putting the rover in a variety of terrains and driving it around, OSRT can identify the situations where the rover gets stuck. It is impossible to predict every scenario that might cause the rover to fail, by testing the system OSRT can identify improvements to the system. This test is failed whenever the rover gets stuck. These situations will be documented and discussed as a team. Each failure will be investigated, in the hope of identifying improvements to the rover that will prevent the event from happening again. Any redesign will be focused on the rover itself, and should have little effect on rest of the payload, and launch vehicle.

Rover Drive Testing		
Test Conductor Signature:__________		Safety Officer Signature: __________
#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Safety glasses must be worn
		- Weather appropriate attire must be worn to protect from inclement weather
		- If testing in a field boots must be worn to reduce risk of ankle sprains/twists
		Prerequisite lists: NA
	______	**Testing Equipment Needed:** NA
	______	**Tools Needed:** NA
	______	**Components Needed:** Functional Rover prototype with controls
		Passing Condition: Rover is capable of navigating terrain
		Testing Procedure:
1	______	Pre-plan drive testing location (where is it happening in a field, lawn, indoors, etc..) Terrain type: __________
2	______	Once at location turn on rover and connect to remote controller
3	______	Drive rover over terrain, taking pictures and videos showing the rovers performance in the terrain.
		Passing Condition Met (Y/N): __________

The purpose of "Collection Testing" is to reduce risk to mission success. Mission succes requires the collection system to work as expected, as a result the system must be tested before it is used in the field. To test this conditions will be replicated as closely as possible. Passing conditions for this test is successfully collection and retention of 10ml of simulated ice material. A failure when conducting this test may result in redesign of the collection system, and rover. Worst case scenario is a new collection system must be used. In preparation for such a situation OSRT has developed a backup scoop system.

Collection Testing		
Test Conductor Signature:__________		Safety Officer Signature: __________
#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Safety Glasses must be worn
		Prerequisite lists: N/A
	______	**Testing Equipment Needed:** Bin filled with simulated ice material
	______	**Tools Needed:** Wrenches
	______	**Components Needed:** Prototype Rover
		Passing Condition: Rover Collects 10 mL of simulated ice
		Testing Procedure:
1	______	Assemble rover system, turn on electronics, and prep for remote control. Rover system must include a fully functional collection system
2	______	Place Rover in a bin large enough for the rover to move around in.
3	______	Remotely actuate collection system (lower scoop, drive forward to collect ice sample, and retract system to store sample.
		Passing Condition Met (Y/N): __________

The purpose of the "Rover Battery Life" test is to determine how long the rover can function at full output till battery failure. This test is required to verify the rover system functions as expected. Power budget predicts that the rover can run for 2hr, however drive train performance can impact that greatly. Depending on torque requirements to drive the rover, efficiency of the wheels, and terrain power requirements are hard to accuratly predict. This test will ensure the rover can operate for the duration of the ground mission. Failure to pass this test may require major changes to the rover systems. Requiring changes in motors, wheels design, and the electrical system. Currently the solution will be adding an extra battery to the system, however space constraints on the rover make this difficult to do.

Rover Battery Life Testing		
Test Conductor Signature:__________		**Safety Officer Signature:** __________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist:
		- Wear safety glasses when working with rover
		Prerequisite lists: N/A
	____	**Testing Equipment Needed:** Stopwatch
	____	**Tools Needed:** LiPo Battery Charger
	____	**Components Needed:** Functional Rover Prototype
		Passing Condition: Rover drives for longer than 1 hr
		Testing Procedure:
1	____	Connect rover battery to LiPo charger to ensure, the battery is fully charged.
2	____	Once fully charged connect battery to rover, and turn on rover electronics.
3	____	Start stopwatch, then connect rover to wireless controller.
4	____	Drive rover at full speed until battery failure. Time until failure
		Passing Condition Met (Y/N): __________

The purpose of "Payload Ejection Testing" is to ensure proper function of the ejection system. The Ejection system involves a variety of factors that can be easily analysed analytically. Factors like friction between components, effects of lead screw straightness, and lead screw force calculations. As a result testing is required to ensure lead screw system functions as expected. There are a number of factors that could cause the ejection system to gail this test. OSRT has planned for some of these failures but many could result in a large amount of redesign of payload systems, requiring re-manufacture of all payload systems. The most likely point of failure stalling in the worm gear motor. If this occurs an identical motor with a different gear ratio can be easily substituted, however this would double the time required to eject the payload from the airframe.

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
		Continued on next page

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#	Inspector Initials	Step Instructions
	______	**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 %): ____________________

The purpose of "Payload Retention Testing" is to ensure the payload will not pre-maturely eject from the airframe in flight. This is required to show that the ejection assembly functions as expected, and to meet safety requirements. Failure to meet this test will require redesign of the retention system. Redesign however should be limited to lead connectors, and require minimal re-manufacture.

Payload Retention System Strength Testing

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Designate a 10 ft by 10 ft area outside 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:

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#	Inspector Initials	Step Instructions
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): ____________________

The purpose of robustness testing is to ensure that the ejection and retention system can retain the payload during launch and does not prematurely eject the payload. The testing procedures are shown in "Payload Retention System Robystness Testing". This demonstrates the necessary conditions on the electronics, so that they will not eject the payload without a signal from the transmitter.

Payload Retention System Robustness Testing

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist:
		- Ensure testing area is free of clutter.
		- Ensure that all test participants are wearing safety glasses.
		Prerequisite lists: Payload Ejection/Retention Checklist, Nose Cone Structures Installation Checklist. Prerequisite Checklists Might Require Additional Tools and Equipment.
	______	**Testing Equipment Needed:** Payload Ejection System, Payload Prototype or Payload Substitute, Nose Cone or Nose Cone Substitute, Test Airframe.
	______	**Tools Needed:** One 3/16-in. Hex Key Allen Wrench.
	______	**Components Needed:** One payload ejection system, one payload prototype, one test airframe.
		Passing Condition: The payload or payload substitute must be retained.
		Testing Procedure:
1	______	Follow the instructions found in the Payload Ejection/Retention Checklist to load the payload into the ejection/retention system.

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#	Inspector Initials	Step Instructions
2	____	Follow the instructions found in the Nose Cone Structures Installation Checklist to affix the nose cone to the test airframe.
3	____	Without providing power to the ejection/retention system, attempt to dislodge the payload by turning and shaking the test airframe.
S	____	**Safety Consideration: - Ensure surroundings are free of clutter and spectators. Do not wildly shake. Remain in control of the test airframe at all times. It is possible that the payload will be shaken out of the test airframe.**
4	____	Remove the nose cone and inspect the payload for damage (If payload prototype was used).
5	____	Repeat testing process while purposefully increasing the number of errors during payload installation.
S	____	**Safety Consideration: - When increasing the likelihood of failure it is even more important to ensure that the test area remains clear and that the test participant remains in control of the airframe at all times.**
6	____	Purposefully install the push plates incorrectly, facing the wrong direction and/or in the incorrect position. Reinstall nose cone. Test.
7	____	Purposefully do not install the push plates. Reinstall nose cone. Test.
8	____	Install and load the ejection/retention system correctly. Do not reinstall the nose cone. The payload ejection/retention system should be visible. Test.
9	____	Remove the ejection/retention system. Place the payload into the ejection/retention bay. Reinstall nose cone. Test.
10	____	Record test results and sub-test results. If the payload fell out at any point or any system received damage, the overall test is a failure. Record any damage received in detail. **Passing Condition Met (Y/N):** ____________

The purpose of "Radial Bolt Testing" is to ensure that the altimeter bay retention system is robust enough to stand up to the forces of launch and recovery. The goal is to test the amount of force that the system can sustain before failure occurs. This will be passed if the system stands up to 50Gs of force on the system. The expected outcome is a pass as the retaining mechanism has a very large safety factor over the max expected force on the system.

Radial Bolt Testing

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

#	Inspector Initials	Step Instructions
		Safety Officer Checklist: - Safety glasses must be worn - Safety gloves must be worn **Prerequisite lists:** N/A
	____	**Testing Equipment Needed:** Instron
	____	**Components Needed:** airframe, bulkhead, retention ring, or machine screws
		Passing Condition: If the force required to cause failure is less than the worst case expected recovery force of 50 G, the test is considered a failure. Modifications of the design must be made and tested again. **Testing Procedure:**

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#	Inspector Initials	Step Instructions
1	______	
		Cut small section of excess airframe for destructive testing.
2	______	Machine radial bolt holes in airframe test section
3	______	Assemble bulkhead into airframe test section with six machine screws, equally spaced radially along the bulkhead.
4	______	Prepare Instron machine
5	______	Mount assembly into Instron machine
6	______	Conduct compression test using the Instron machine to measure the force required to cause failure in any component present in the system (airframe, bulkhead, retention ring, or machine screws).
7	______	l Record maximum force data.

The "Testing of Launch Vehicle Thrust Plate" is aimed at verifying a simulated factor of safety on the thrust plate over the max expected force from launch. It is designed to ensue the thrust plate will not buckle when subjected to transferring the motor forces to the airframe. This will be a success if the factor of safety is greater then 2. Failure to do so will result in a redesign of the thrust plate.

Testing of Launch Vehicle Thrust Plate		
Test Conductor Signature: ______________		**Safety Officer Signature:** ______________
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Ensure testing area is free of clutter. - Ensure that all test participants are wearing safety glasses. - During test launch follow all safety procedures and regulations **Prerequisite lists:** N/A.
	______	**Testing Equipment Needed:** CAD models of launch vehicle.
1	______	Load the launch vehicle CAD assembly. Ensure all parts are correctly defined for materials to ensure accurate simulation results.
2	______	Define force on launch vehicle from motor thrust plate equivalent to the maximum projected motor force of 3,100 N, the projected maximum force for the 'worst-case' motor size.
3	______	Run the CAD simulation for structural integrity Make note of any safety factors below 2 for structural failure.
4	______	Verify during full scale test launch.
5	______	In order to pass TP3 the results of the CAD simulation must show all factors of safety equal to or greater than 2. **Passing Condition Met (Y/N):** ______________

The purpose of "Pressure Testing of Parachute Bays" is to ensure the pressurization of the parachute bays for the deployment of the recovery system. This vital to ensure proper deployment and requires verification of calculations. The aim is to determine at what pressure does the seal fail, and ensure that it is greater then the required pressure to deploy the recovery systems.

Pressure Testing of Parachute Bays		
Test Conductor Signature: ______		Safety Officer Signature: ______
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Ensure testing area is free of clutter. - Ensure that all test participants are wearing safety glasses. - During pressure testing, wear safety goggles and face mask as failure of bulkhead could lead to flying debris. Ensure people in the vicinity are aware of test and are not in the immediate vicinity of test. - Complete test in the Propulsion-Lab if necessary as instructed by shop workers or safety officer. **Prerequisite lists:** Manufacture of Fore and Aft sections, and respective bulkheads.
	______	**Testing Equipment Needed:** 6.25 inch pressure tester, compressed air tire tool.
S	______	**Safety Consideration: - Pressurising sections of airframe has possibility to lead to seal failure that could cause flying particles or pieces of failed bulkhead. Failure to wear proper PPE and follow proper safety protocols could lead to serious injury**
1	______	Integrate the Fore and aft parachute bays without parachutes.
2	______	Attach the pre-made pressure testing cap to the end of the airframe.
3	______	Using a standard tire filling tool attached to compressed air line, pressurize the sections of the airframe to their respective pressures defined by ejection calculations.
4	______	For the drogue bay: 15.654 psi. For the main bay: 23.481 psi. **Fore section successfully Pressurize?** ______ **Aft section successfully Pressurize?** ______
5	______	Stop pressurizing and record pressure loss after several lengths of time. **Fore section pressure after 5 seconds** ______ **Aft section pressure after 5 seconds** ______ **Fore section pressure after 10 seconds** ______ **Aft section pressure after 10 seconds** ______ **Fore section pressure after 15 seconds** ______ **Aft section pressure after 15 seconds** ______ **Passing Condition Met (Y/N):** ______

The purpose of "Pressure Testing of Coupler Altimeter Bay" is to ensure the sealing off of the recovery altimeter bay. This is required to accurately deploy parachutes at the correct altitude. Because of the vital function, it requires verification of calculations. The aim is to determine at what pressure does the seal fail, and ensure that it is greater then the required pressure to deploy the recovery systems.

Pressure Testing of Coupler Altimeter Bay		
Test Conductor Signature: ______		Safety Officer Signature: ______
#	**Inspector Initials**	**Step Instructions**
		Safety Officer Checklist: - Ensure testing area is free of clutter. - Ensure that all test participants are wearing safety glasses.

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#	Inspector Initials	Step Instructions
		- During pressure testing, wear safety goggles and face mask as failure of bulkhead could lead to flying debris. Ensure people in the vicinity are aware of test and are not in the immediate vicinity of test. - Complete test in the Propulsion-Lab if necessary as instructed by shop workers or safety officer. **Prerequisite lists:** Manufacture of Coupler, altimeter bay, and respective bulkheads.
	______	**Testing Equipment Needed:** 6.25 inch pressure tester, compressed air tire tool.
S	______	**Safety Consideration: - Pressurising sections of airframe has possibility to lead to seal failure that could cause flying particles or pieces of failed bulkhead. Failure to wear proper PPE and follow proper safety protocols could lead to serious injury**
1	______	Integrate the coupler and altimeter bay.
2	______	Attach the pre-made pressure testing cap to the end of the coupler.
3	______	Using a standard tire filling tool attached to compressed air line, pressurize the sections of the airframe to their respective pressures defined by ejection calculations.
4	______	Aft end of coupler: 15.654 psi. Fore end of coupler: 23.481 psi. **Fore section successfully Pressurize?** ____________________ **Aft section successfully Pressurize?** ____________________
5	______	Stop pressurizing and record pressure loss after several lengths of time. **Fore section pressure after 5 seconds** ____________________ **Aft section pressure after 5 seconds** ____________________ **Fore section pressure after 10 seconds** ____________________ **Aft section pressure after 10 seconds** ____________________ **Fore section pressure after 15 seconds** ____________________ **Aft section pressure after 15 seconds** ____________________ **Passing Condition Met (Y/N):** ____________________

Testing the size of the BP charges is necessary to ensure that the charges are large enough to open their respective parachute bay, eject the parachutes within the bay, and separate the quick release connectors between the BP charge and the altimeter. If the BP charge is unable to do this, then it must be sized up in increments of 0.1 g until the charge can open the bay and deploy the parachute. Once the appropriate size is found, then the calculations must be adjusted so that accurate formulas can be derived for future BP charge sizing. The goal is to show that the calculated BP charge size can completely deploy the parachute, and the variable in this test is the amount of BP.

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.

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#	Inspector Initials	Step Instructions
		- 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:**
	_____	**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, quick release connectors, 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.
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.

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#	Inspector Initials	Step Instructions
		Pass? (Y/N) ________

Testing the altimeters is necessary to lessen the chances of them spontaneously malfunctioning during a flight, and to ensure that the altimeter bay configuration allows for the altimeters to function properly. If the altimeters cannot ignite the e-matches at the right altitudes and times, then the altimeter bay configuration will need to be changed, and if the altimeters can still not accurately ignite the e-matches, then the altimeters will need to be replaced. The goal is to show that the altimeters are functional after several test flights, and the variable is the number of times the flights can be run without error.

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
		Prerequisite lists: N/A
	____	**Testing Equipment Needed:**
	____	**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) ________

7 Project Plan

7.1 Project Requirements Verification

Shown in Tables 41-46 is a breakdown of all USLI competition requirements outlined in the handbook, a brief description of how OSRT plans to verify these requirements will be completed, and the current status of the verification implementation.

7.1.1 General Requirements

Table 41: General Requirement Verification Matrix

Requirement	**Verification Plan**	**Status**
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.	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.
1.1.2 The team will submit new work.	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.

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Table 41 – continued from previous page

Requirement	**Verification Plan**	**Status**
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.	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.	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.
1.4 The team must identify all team members attending launch week activities by the Critical Design Review.	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.
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.	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 through FRR
1.6 The team will establish a social media presence to inform the public about team activities.	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.
1.7 Teams will e-mail 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.	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.

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Table 41 – continued from previous page

Requirement	Verification Plan	Status
1.8 All deliverables must be in PDF format.	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.	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.
1.10 In every report, the team will include a page number at the bottom of each page.	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.
1.11 The team will provide any computer equipment necessary to perform a video teleconference with the review panel.	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.	Not complete - This will be completed before each video teleconference, and is accounted for in the timeline in the video teleconference schedule of each deliverable.
1.12 The team will use a launch pad provided by Student Launch's launch services provider.	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.	In progress - This will be incorporated into the launch vehicle designs, and is accounted for in the timeline with the launch vehicle design schedule, but will officially be completed at the competition launch.
1.13 The team will identify a "mentor".	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.

7.1.2 Vehicle Requirements

Table 42: Vehicle Requirement Verification Matrix

Requirement	Verification Plan	Status
2.1 The launch vehicle will deliver the payload to an apogee between 3,500 ft and 5,000 ft AGL.	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.	In progress - The team's declared target altitude is 4,000 ft, however, this will be competed once the full scale launch vehicle and payload are built and flown in both a test full scale flight before competition, and during competition, both of which are accounted for in the project timeline.
2.2 Teams shall identify their target altitude goal at the Preliminary Design Review milestone.	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.
2.3 The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner.	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.
2.4 The launch vehicle will be designed to be recoverable and reusable.	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 subscale flights have demonstrated how the design is both recoverable and reusable, as, with both flights, the launch vehicle was recovered intact, and could have been flown again on the same day after each launch. This will be completed when the full scale launch vehicle is built and flown prior to the FRR submission deadline, and is accounted for in the timeline.

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Requirement	Verification Plan	Status
2.5 The launch vehicle will have a maximum of four (4) independent sections.	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.
2.5.1 Coupler/airframe shoulders, which are located at in-flight separation points, will be at least one body diameter in length.	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.
2.5.2 Nose cone shoulders, which are located at in-flight separation points, will be at least 1⁄2 body diameter in length.	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.
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.	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.
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.	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.

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Requirement	Verification Plan	Status
2.8 The launch vehicle will be capable of being launched by a standard 12 V direct current firing system.	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.	Not complete - This will be completed when the motor has been integrated and successfully launched within the team's full scale launch vehicle with a standard 12 V direct current firing system, and is accounted for on the timeline in the integration and launch schedules.
2.9 The launch vehicle will require no extraneous external circuitry or special ground support equipment to initiate launch.	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.	Not complete - This will be completed when the motor has been integrated and launched once without extraneous external circuitry at the full scale test launches, which is accounted for on the timeline in the integration and launch schedules.
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).	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 motor has been selected, as shown in the propulsion section, and has been purchased after approval of a NAR mentor.
2.10.1 Final motor choices will be declared by the CDR milestone.	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 L2200.
2.10.2 Any motor change after CDR must be approved by the NASA RSO.	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.	Not completed - This will be completed when the launch vehicle is launched at competition, but if needed, is incorporated on the timeline in the modifying/repairing the launch vehicle section.

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Requirement	Verification Plan	Status
2.11 The launch vehicle will be limited to a single stage.	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.
2.12 The total impulse provided by a college or university launch vehicle will not exceed 5,120 N-sec (L-class).	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.
2.13 Pressure vessels on the vehicle will be approved by the RSO.	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.	In progress - The only pressure vessels involved with the launch vehicle are standard CO2 canisters, and therefore, a RSO signature will be incorporated in all CO2 canister-related checklists.
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.	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.	Completed - The pressure vessels used in this launch vehicle are standard, off-the-shelf, disposable CO2 canisters, which meet the 4:1 safety factor.
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.	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 - As per the handbook clarification provided by Fred Kepner on December 9th, 2019, since the CO2 canisters will be pierced and vented directly into their respective parachute bays in one movement, a valve is not necessary.
2.13.3 The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	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.	In progress - This will be complete when the tanks are incorporated into the parachute ejection charge system and go through testing, which is accounted for in the timeline in the recovery design, manufacturing, and testing schedules.

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Requirement	Verification Plan	Status
2.14 The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit.	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.	In progress - Completed in current design with a rail exit stability of 3.12. This will be completed at each deliverable submission and is accounted for in the timeline in the compiling and editing schedule of each deliverable.
2.15 Any structural protuberance on the launch vehicle will be located aft of the burnout center of gravity.	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.
2.16 The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	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.	In progress - This will be completed when the manufacturing and testing of the launch vehicle, recovery system, and payload are completed, and is accounted for in the timeline in the launch vehicle, recovery, and payload manufacturing and testing schedule.

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Requirement	Verification Plan	Status
2.17 All teams will successfully launch and recover a subscale model of their launch vehicle prior to CDR.	The team will have three subscale launches to test the launch vehicle and recovery system designs, which will all be photographed and signed off by two members in every checklist leading up to the launch, one on Saturday, November 9th, another on Saturday, November 30th, and a third on Sunday, December 15th.	Completed - The team successfully launched and recovered a subscale model of the launch vehicle on November 16th, 2019. The team also did not successfully launch, but successfully recovered, the subscale model during their launch on December 15th. The third subscale launch had to be scrubbed due to road and weather conditions out to the launch site.
2.17.1 The subscale model should resemble and perform as similarly as possible to the full scale model.	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 $^{2}/_{3}$rds 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.	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.	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.

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Requirement	Verification Plan	Status
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.	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 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 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 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.	Not completed - This will be completed at full scale launches in February, and has been accounted for in the timeline in the scheduled launch and, if needed, the modify/repair schedules as well.

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Requirement	Verification Plan	Status
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.	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.	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- cale 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.	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.
2.18.1.7 Teams shall fly the launch day motor for the Vehicle Demonstration Flight.	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.

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Requirement	Verification Plan	Status
2.18.1.8 The vehicle must be flown in its fully ballasted configuration during the full scale test flight.	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.	Not completed - This will be completed when the vehicle has a fully ballasted full scale flight in February, which has been accounted for in the timeline in the integration schedule and the February launch days' schedules.
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.	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.	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.	Not completed - This will be completed when a successful flight is completed and the proof is submitted in the FRR report, and has been accounted for in the timeline in the February launch days' schedules and in the compiling and editing schedule for the FRR deliverable.

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Requirement	Verification Plan	Status
2.18.1.11 Vehicle demonstration flights must be completed by the FRR submission deadline.	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 1st and the second on Saturday, February 22nd.	Not completed - 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 launch days and their respective integration days.
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.	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 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.

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Requirement	Verification Plan	Status
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.	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.
2.18.2.4 The payload flown must be the final, active version.	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 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.

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Requirement	Verification Plan	Status
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.	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 will be allotted, if necessary, to ensure that the FRR Addendum is completed by the time it is due.
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.	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.	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.	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 43: Vehicle Prohibition Verification Matrix

Requirement	**Verification Plan**	**Status**
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.	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 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 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.	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	Verification Plan	Status
2.22.5 The launch vehicle will not utilize a cluster of motors.	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 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.	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).	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. All future design iterations will utilize less than 10 percent ballast for all flight conditions.
2.22.9 Transmissions from onboard transmitters will not exceed 250 mW of power (per transmitter).	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.

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Requirement	Verification Plan	Status
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 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 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.

7.1.3 Recovery System Requirements

Table 44: Recovery System Requirement Verification Matrix

Requirement	**Verification Plan**	**Status**
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.	The team has designed the recovery system to deploy its drogue parachute at apogee and its main parachutes at 600 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.	In progress - The recovery system design as been finalized and was tested successfully in the subscale launch on November 16th, 2019. This will be compete when the system is manufactured and implemented into the full scale launch vehicle, which will launch and complete its recovery sequences at the correct altitudes. This has been accounted for in the timeline in the design, ordering, manufacturing, and testing schedule of the recovery system, as well as in the integration and launch schedules for the full scale launches.

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Requirement	Verification Plan	Status
3.1.1 The main parachute shall be deployed no lower than 500 feet.	The team has decided to deploy the parachute at 600 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.	In progress - The subscale recovery system was able to deploy the main parachute a little below 600 ft on November 16th, 2019, however for this requirement to be completed, the recovery system will be manufactured, and implemented into the full scale launch vehicle, which will complete its recovery sequence at the correct altitudes. This is accounted for in the timeline in the recovery system ordering, manufacturing, and testing schedules, along with the integration and launch schedules of and full scale launch vehicles.
3.1.2 The apogee event may contain a delay of no more than 2 s.	The team will set the apogee event to contain as little to no delay as possible during the subscale launches in order to allow for both a CO_2 and BP charge to fire. The CO_2 will fire first, as that is what the team is trying to perfect, but until it is perfected, a back-up black powder charge will be ignited 2 s later to ensure that the drogue parachute is deployed. This is what the system will be set to while it is being assembled, which will be completed by checklists, which will be signed by the team member in charge of this system, the Team SO, and the Recovery Team Lead, and the process will be photographed as well as in the event that the team needs to reexamine the parachute ejection charge set-up.	In progress - The primary altimeter is set to deploy the drogue parachute at apogee, while the back-up altimeter is set to deploy the drogue parachute at apogee plus one second. This will be completed when the subscale and full scale launches complete their apogee events within the first two seconds of reaching apogee. This is accounted for in the timeline in the integration and launch day schedules of the subscale and full scale launch vehicles.

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Requirement	Verification Plan	Status
3.1.3 Motor ejection is not a permissible form of primary or secondary deployment.	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.	In progress - A motor retention system has been initially designed, as seen in the vehicle specifications section, however, this requirement will be completed when the motor retention system's design is further developed and finalized, the system is built, and has successfully completed one subscale launch. All of this is accounted for in the timeline in the launch vehicle design, component ordering, and manufacturing schedules, as well as in the integration and launch day schedules.
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.	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.	Not 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.
3.3 Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	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, greatly reducing the kinetic energy of of landing to below 75 ft-lbf

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Requirement	Verification Plan	Status
3.4 The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	The team will purchase and install at least four different altimeters, one for each ejection charge and one for each back up ejection charge.	Not completed - This requirement will be complete when altimeters are purchased, tested, and installed. This is accounted for in the timeline in the recovery system design, ordering, manufacturing, testing, and launch vehicle integration schedules.
3.5 Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.	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.	Not completed - This requirement will be completed when a battery has been selected and purchased for each altimeter and installed. If these batteries are LiPo batteries, this will be completed when the battery is also properly marked and labeled. This has been accounted for in the timeline in the recovery system design, ordering, manufacturing, and testing schedules
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 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.	Not completed - This requirement will be complete when the avionics bays are laid out, built, and tested to ensure that the arming switches are easy to find and turn on. This has been accounted for in the timeline in the recovery and launch vehicle designs, ordering, manufacturing, and testing schedules.

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Requirement	Verification Plan	Status
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).	The team will ground test the arming switches to ensure that they cannot be disarmed by flight forces.	Not completed - This requirement will be completed when arming switches are selected, purchased, and tested. This has been accounted for in the timeline in the recovery design, ordering, manufacturing, and testing.
3.8 The recovery system electrical circuits will be completely independent of any payload electrical circuits.	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.	Not completed - This requirement will be complete when the payload and recovery system electrical circuits are designed and manufactured so that the recovery electrical system does not rely on the payload electrical system. This has been accounted for in recovery system design, ordering, and manufacturing schedules.
3.9 Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	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.	In progress - While shear pins have been selected, this requirement will be complete when shear pins have been purchased, tested, and installed in the launch vehicle. This has been accounted for in the timeline in the recovery system ordering and testing schedules, and integration schedules of the launch vehicle.

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Requirement	Verification Plan	Status
3.10 The recovery area will be limited to a 2,500 ft. radius from the launch pads.	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.	In progress - The altitude at which the main parachutes deploy has been selected, as shown in the recovery system section. Therefore, this requirement will be complete when the recovery system components are purchased and assembled to deploy at 600 ft. This has been accounted for in the timeline in the recovery system design, ordering, and manufacturing schedules.
3.11 Descent time will be limited to 90 seconds (apogee to touch down).	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.	In progress - The altitude at which the main parachutes deploy has been selected, therefore, this requirement will be complete when the recovery system components are purchased and assembled to deploy at 600 ft. This has been accounted for in the timeline in the recovery system design, ordering, and manufacturing schedules.

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Requirement	Verification Plan	Status
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 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.	In progress - The size of the recovery system is already determined through initial recovery system designs, however, this requirement will be completed when the active electronic tracking devices are purchased and installed. This has been accounted for in the timeline in the recovery system's design, ordering, manufacturing, and testing schedules, and the team's integration system.
3.12.1 Any section or payload component, that lands untethered to the launch vehicle, will contain an active electronic tracking device.	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.	In progress - The size of the recovery system is already determined through initial recovery system designs, however, this requirement will be completed when the active electronic tracking devices are purchased and installed. This has been accounted for in the timeline in the recovery system's design, ordering, manufacturing, and testing schedules, and the team's integration system.

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Requirement	Verification Plan	Status
3.12.2 The electronic tracking device(s) will be fully functional during the official flight on launch day.	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.	In progress - the type of electronic tracking device has already been determined through initial recovery system designs, however, this requirement will be completed when the active electronic tracking devices are purchased and installed. This has been accounted for in the timeline for recovery system's design, ordering, manufacturing, and testing schedules. It has also been accounted for in the team's integration system.
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 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.	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.

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Requirement	Verification Plan	Status
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 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.
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.	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 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 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.

7.1.4 Payload Requirements

Table 45: Payload Experiment Requirement Verification Matrix

Requirement	Verification Plan	Status
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.	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 initial payload design is small enough to be launched inside a launch vehicle, however this requirement will be completed when the payload design is finalized and it is built and tested. All of this has been accounted for in the timeline, the payload design, ordering, manufacturing and testing schedules.
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.	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 initial payload design, as depicted in the payload section, is small enough to fit all required hardware for operation into the airframe of the launch vehicle, however this requirement will be completed when the payload design is finalized and built and has been integrated with the launch vehicle. This is accounted for in the payload design, ordering, manufacturing, and testing schedules.

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Requirement	Verification Plan	Status
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.	The team will design, build, and test a payload that can navigate to the recovery site and dig down 3 in. below the surface in order to access an ice sample.	In progress - The initial payload design has been completed, and is depicted in the payload section. This requirement will be completed when the payload design is finalized and built, the payload test bed is designed and built and the payload navigation and digging capabilities are tested. This has been accounted for in the proposed timeline in the payload design, ordering, manufacturing, and testing schedules.
4.3.3 The recovered ice sample will be a minimum of 10 mL.	The team will design a payload that has an ice sample storage capacity of at least 15 mL to ensure that it can collect and store the required amount of ice.	In progress - The ice collection system has an initial design, as depicted in the ice collection system section, but this requirement will be completed when the ice collection system design is finalized, built, and its storage capacity is tested. All of this is accounted for in the proposed timeline in the payload design, ordering, manufacturing, and testing schedules.
4.3.4 Once the sample is recovered, it must be stored and transported at least 10 linear feet from the recovery area.	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.	In progress - The design has been worked on, but needs to be finalized and the payload needs to be built and tested. All of this has been accounted for in the proposed timeline.

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Requirement	Verification Plan	Status
4.3.5 Teams must abide by all FAA and NAR rules and regulations.	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.	In progress - The payload is being designed to FAA and NAR standards. This design time has been accounted for in the proposed timeline.
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.	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.	In progress - The design needs to be finalized, built, and tested. All of this has been accounted for in the proposed timeline.
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.	The team will design, build, and test a payload retention system that will retain the payload until it is intended to be deployed.	In progress - The payload retention system design needs to be finalized, built, and tested. All of this has been accounted for in the proposed timeline.
4.3.7.1 A mechanical retention system will be designed to prohibit premature deployment.	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.	In progress - The payload retention system design needs to be finalized, built, and tested. All of this has been accounted for in the proposed timeline.
4.3.7.2 The retention system will be robust enough to successfully endure flight forces experienced during both typical and atypical flights.	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.	Not completed - The payload retention system needs to be finished and built before it can be tested. Testing is accounted for in the proposed timeline.
4.3.7.3 The designed system will be fail-safe.	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.	In progress - The payload retention system design needs to be finalized, built, and tested. All of this has been accounted for in the proposed timeline.

7.1.5 Safety Requirements

Table 46: Safety Requirement Verification Matrix

Requirement	Verification Plan	Status
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.	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.	In progress - Checklists will be developed and finalized with the designs. This portion of the design process has been accounted for in the proposed timeline.
5.2 Each team must identify a student SO who will be responsible for all items in section 5.3.	The team will identify a student SO by September 14th, 2019.	Completed - The team student SO is Wyatt Hougham.
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.	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.	In progress - The designs will be approved as they are finalized. The safety team is working on drafting up documents to help the subteams complete them more efficiently and effectively, and the SO is working on training members of the safety team, and members of the team in general, so that they can act as SO in the event that the SO is unable to.
5.3.2 Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The safety team will work alongside the subteams to develop procedures that are both safe and effective for construction, assembly, launch, and recovery activities.	Not completed - This will start after the designs are finalized, and is accounted for in the construction time for each portion of this project.

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Requirement	Verification Plan	Status
5.3.3 Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	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.	In progress - Hazard analyses have been started, and the rest of the binder will be created as subteam's designs become finalized and as they create construction plans, and has been included in the timeline.
5.3.4 Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	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.	In progress - Hazard analyses have been started, and failure modes and analyses and procedures will be created as the designs are finalized and construction procedures are created. The construction of these safety documents is included in the design and construction phases of the timeline.
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.	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.	Not completed - This will be completed as needed, and therefore will not be included in the timeline.

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Requirement	Verification Plan	Status
5.5 Teams will abide by all rules set forth by the RSO.	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.	In progress - The safety team is in the process of familiarizing themselves with the FAA rules and is included on the timeline as looking over last years documentation and working on research and design of the launch vehicle, recovery system, and payload.

7.1.6 Team Derived Requirements

Table 47: Team Derived Requirement Verification Matrix

Requirement	Verification Plan	Status
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.	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.
6.1.2 All back-up BP charges will be twice the size of the calculated and tested primary BP charge.	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.	In progress - The charge sizes have been calculated and tested for the subscale launch vehicle, and the checklists have been written for the subscale launch vehicle. This will be complete when BP tests for the full scale launch vehicle have been completed and the checklist is initialled and signed where appropriate during integration.

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Requirement	Verification Plan	Status
6.1.3 All BP charges will be able to deploy the parachute within their respective bay.	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.	In progress - The 2.0 g BP charges were able to deploy both the drogue and main parachutes in ground tests and in the subscale flights. .
6.1.4 The BP charges must remain in the airframe at all times during launch.	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, but need to be tested. This will be competed when the quick release connectors pass testing.
6.1.5 The CO_2 ejection system must be able to be affixed to the launch vehicle and not hinder airframe section separation.	The team will design the CO_2 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 BP charges so that the charges will remain inside the airframe at all times after they are created.	In progress - The CO_2 ejection system has been designed so that it is connected to its respective bulkhead with four bolts, and the quick release connectors will be incorporated when they are received.
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.	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 American Institute of Aeronautics and Astronautics (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.

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Table 47 – continued from previous page

Requirement	Verification Plan	Status
6.1.7 All live BP charges must be kept away from all sources of electricity, including static electricity.	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.
6.1.8 The internal batteries must be able to power the avionics system for at least 5 hours continuously.	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 specified in Table 12. This should be consistent over 5 hours.	In progress - 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.	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 Administration (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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Table 47 – continued from previous page

Requirement	Verification Plan	Status
6.1.10 The avionics system must transmit and receive data at a range of at least 1 mile.	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.	In progress - Subscale designs successfully transmitted and received data at least 1 mile away. This will be complete once tests pass on the final avionics design.
6.1.11 The avionics system must survive forces of at least 10 Gs.	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 IMU to record acceleration. The current design survived launch forces, but more than one launch is desired to prove it.
6.1.12 The avionics system must accurately transmit data at 32 degrees Fahrenheit.	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.	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 47 – continued from previous page

Requirement	Verification Plan	Status
6.1.14 Data packets sent must be accurate at least 90% of the time as compared to data received onboard.	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.	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.
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.	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.
6.2.1. Team can deploy and operate rover from up to ½ mile away.	Test rover and ejection systems at appropriate distance.	In progress - Electrical system and rover controls are currently being designed to be controlled remotely.
6.2.2 Rover collection system must be capable of digging into sample material.	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.	In progress - Scoop system is being designed with motor that is capable of pushing down into the sample material.
6.2.3 Rover wheels must be able to expand to increase ground clearance.	Rover will be observed being ejected from the airframe to confirm that the wheels expand.	In progress - Designs have been developed which allow for the wheels to expand upon exiting the airframe.

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Table 47 – continued from previous page

Requirement	Verification Plan	Status
6.2.4 Rover Collection system must be designed to securely retain at least 10 mL of sample material.	System will be tested to ensure sample material is securely stored during transport.	In progress - Seal is being designed for collection system that will mount on the underside of the chassis.
6.2.5 Payload system must consistently use standard fasteners.	The team will assemble the payload using only Imperial tools.	In progress - currently all system utilize imperial fasteners however a full system prototype is currently being developed for assembly.
6.2.6 Payload team must be able to manufacture the chassis within 1 day. An easily assembly will greatly simplify integration and testing.	Payload assembly will be timed during full scale launch integration prep.	Incomplete - This will be done once a complete prototype has been developed.
6.2.7 Payload ejection must be completed within 2 minutes of activation.	The team will test payload ejection for success as well as completion time. Successful ejection will still be the most important aspect.	In progress - Payload Ejection is being constructed to prepare for testing.
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.	When testing the retention system different possible situations will be tested to identify possible safety concerns.	In progress - Payload Retention is being constructed to prepare for testing.
6.2.9 Payload drivetrain wheels must be able to fit inside the rocket body.	The team will test the payload assembly to ensure it can fit within the 6.25 in. diameter rocket.	In progress - Prototype wheels and chassis have been constructed. This will be tested and has been accounted for in the project plan.
6.2.10 Payload drivetrain wheel assemblies must be light weight.	The team will test this requirement by weighing the finalized wheel assembly.	In progress - CAD model shows that each wheel assembly weighs less than 1 lbf each. Final weight is pending on finalized design and final construction
6.2.11 Payload drivetrain wheels must be easy to construct.	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.

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Table 47 – continued from previous page

Requirement	Verification Plan	Status
6.3.1 Both full scale and subscale launch vehicles will be checked post flight for defects or wear.	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.	Incomplete - Will be completed before first subscale launch and improved on for each consecutive launch. with documentation available for review at any point to verify launch readiness.
6.3.2 OpenRocket simulations will be performed prior to each launch to hit a predetermined altitude.	OpenRocket will be used to verify apogee and the weight adjusted accordingly before every flight using the measured weight of the launch vehicle.	Incomplete - Will be completed before each launch, before arriving to and on the launch site.
6.3.3 Two step Dynamic Ultra Once-over (DUO) verification of checklists prior to flight will be completed for both full scale and subscale launches.	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.	Incomplete - Will be completed during each launch with documentation available for review at any point to verify launch readiness.
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.	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.	In progress - Full scale manufacture is in progress but the required components are not completed.
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.	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.	In progress - The required hole sizes and number have been calculated, but not constructed as OSRT is waiting on material orders and will be completed when construction has finished.
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.	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.	In progress - Full scale manufacture is in progress but the required components are not completed.
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.	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.	In progress - Full scale manufacture is in progress but the required components are not completed.

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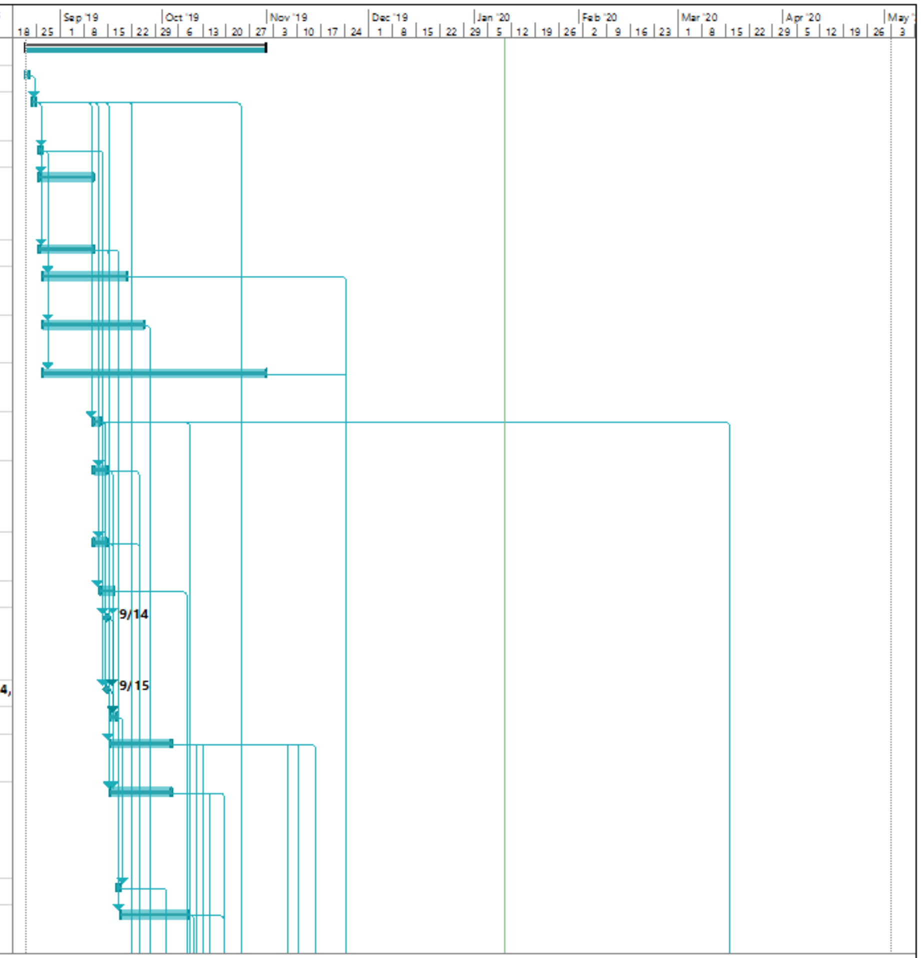
Table 47 – continued from previous page

Requirement	Verification Plan	Status
6.3.8 The coupler must be manufactures 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.	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.	In progress - The coupler design has been finalized, however manufacture is not complete, and CG will be calculated after manufacture is completed.
6.4.1 Maintain a minimum safety factor of 2 on all systems.	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.
6.4.2 All screws and threaded rods will be analyzed for stress to ensure proper structural integration.	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.
6.4.3 All materials to be used for the manufacturing process will have credible analyzed properties.	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.
6.4.4 The safety officer will verify and check all preflight checklists prior to launch.	Checklists will require the signature of a safety officer before launch of launch vehicle.	Incomplete - Will be completed prior to each launch with documentation available to verify launch readiness.
6.4.5 When no existing tool will allow for manufacturing within desired specifications, OSRT will manufacture such a tool.	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.
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 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.
6.4.7 All PCBs used in the launch vehicle will use electrical potting material to cover components.	Electrical potting material will be confirmed to be present on all PCBs during launch vehicle integration via checklists.	Incomplete - Potting will be done once PCBs have arrived and are assembled.

7.2 Project Plan

ID		Task Mode	Task Name	Duration	Start	Finish	% Complete	Predecessors
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 Meeting	1 day	Sat 8/24/19	Sat 8/24/19	100%	2
4	✓		Budget Seminar	1 day	Mon 8/26/19	Mon 8/26/19	100%	3
5	✓		Aero/Recovery and Structures/Propulsion Research	12 days	Mon 8/26/19	Tue 9/10/19	100%	3
6	✓		Payload Design Development	12 days	Mon 8/26/19	Tue 9/10/19	100%	3
7	✓		Material Outsource from Budget/Finance	19 days	Tue 8/27/19	Fri 9/20/19	100%	4
8	✓		Budget/Finance Compiles OSGC Grant	22 days	Tue 8/27/19	Wed 9/25/19	100%	4
9	✓		Budget/Finance Requests for Funds/Cold Calling	48 days	Tue 8/27/19	Thu 10/31/19	100%	4
10	✓		Review Previous Safety Entries and MSDS	2 days	Wed 9/11/19	Thu 9/12/19	100%	3
11	✓		Structures/Propulsion Preliminary Design Development	4 days	Wed 9/11/19	Sat 9/14/19	100%	6
12	✓		Recovery System Design Development	4 days	Wed 9/11/19	Sat 9/14/19	100%	6
13	✓		**L1 Certification Launch**	**2 days**	**Fri 9/13/19**	**Mon 9/16/19**	**100%**	**3**
14	✓		**Project Plan and Preliminary Budget from Each Subteam Due**	**0 days**	**Sat 9/14/19**	**Sat 9/14/19**	**100%**	**6,11,12**
15	✓		**Proposal Rough Draft Due**	**0 days**	**Sun 9/15/19**	**Sun 9/15/19**	**100%**	**6,11,12,14,4,**
16	✓		Edit and Compile Proposal	2 days	Mon 9/16/19	Tue 9/17/19	100%	15
17	✓		STEM Engagement Contacts Schools	14 days	Mon 9/16/19	Thu 10/3/19	100%	3
18	✓		Design Refinement of Payload, Structures/Propulsion, and Aero/Recovery Systems	14 days	Mon 9/16/19	Thu 10/3/19	100%	6,11,12
19	✓		**Submit Proposal**	**1 day**	**Wed 9/18/19**	**Wed 9/18/19**	**100%**	**16**
20	✓		Simulate Payload Design Concepts	14 days	Thu 9/19/19	Tue 10/8/19	100%	6



Project: CDR Project Plan.mpp
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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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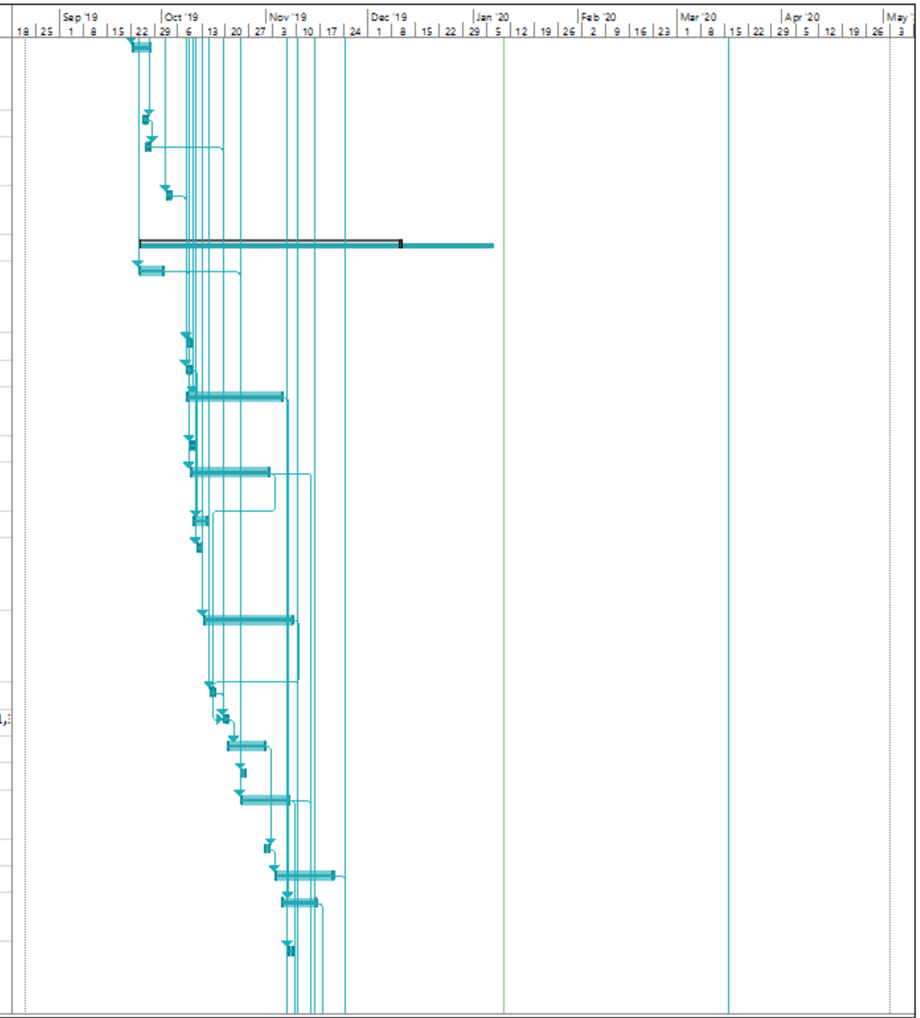
Figure 82: OSRT Project Plan 1/5

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	% Complete	Predecessors
21	✓		STEM Engagement Supply Procurement and Lesson Plans #1, 2, and 3 Development	5 days	Mon 9/23/19	Fri 9/27/19	100%	3
22	✓		**OSGC Rough Draft Due**	**1 day**	**Thu 9/26/19**	**Thu 9/26/19**	**100%**	**8**
23	✓		**Submit OSGC Team Experience Proposal**	**1 day**	**Fri 9/27/19**	**Fri 9/27/19**	**100%**	**22**
24	✓		**Awarded Proposals Announced**	**1 day**	**Thu 10/3/19**	**Thu 10/3/19**	**100%**	**19**
25	✓		**Preliminary Design Phase**	**55 days**	**Wed 9/25/1!**	**Tue 12/10/19**	**100%**	
26	✓		Order Subscale Recovery System and Launch Vehicle Components	5 days	Wed 9/25/19	Tue 10/1/19	100%	11,12
27	✓		**Kickoff and PDR Q&A**	**1 day**	**Wed 10/9/1!**	**Wed 10/9/19**	**100%**	**24**
28	✓		**L2 Certification Testing**	**1 day**	**Wed 10/9/1!**	**Wed 10/9/19**	**100%**	**13**
29	✓		Order Payload Prototype Components	20 days	Wed 10/9/19	Tue 11/5/19	100%	20
30	✓		Heatstroke Briefing	1 day	Thu 10/10/1!	Thu 10/10/19	100%	10
31	✓		Manufacture and Test Subscale Recovery System	17 days	Thu 10/10/19	Fri 11/1/19	100%	26
32	✓		**L1/L2 Certification Launch**	**2 days**	**Fri 10/11/19**	**Mon 10/14/1!**	**100%**	**28**
33	✓		Pre-football STEM Engagement with the OSU Alumni Center	1 day	Sat 10/12/19	Sat 10/12/19	100%	17
34	✓		STEM Engagement Supply Procurement and Lesson Plans #4, 5, 6, and 7 Development	20 days	Mon 10/14/19	Fri 11/8/19	100%	17
35	✓		Finalize Altitude Calculations	1 day	Wed 10/16/1	Wed 10/16/1!	100%	18
36	✓		**PDR Rough Draft Due**	**1 day**	**Sun 10/20/1**	**Sun 10/20/19**	**100%**	**18,20,23,31,:**
37	✓		Edit and Compile PDR	9 days	Mon 10/21/1	Thu 10/31/19	100%	36
38	✓		**Social Media Presence Due**	**1 day**	**Fri 10/25/19**	**Fri 10/25/19**	**100%**	**3**
39	✓		Manufacture Subscale Launch Vehicle	10 days	Fri 10/25/19	Thu 11/7/19	100%	26
40	✓		**Submit PDR**	**1 day**	**Fri 11/1/19**	**Fri 11/1/19**	**100%**	**37**
41	✓		**PDR Video Teleconfrences**	**13 days**	**Mon 11/4/1!**	**Wed 11/20/1!**	**100%**	**40**
42	✓		Manufacture and Test Payload Prototype	8 days	Wed 11/6/19	Fri 11/15/19	100%	29
43	✓		Pre-football STEM Engagement with the OSU Alumni Center	1 day	Fri 11/8/19	Fri 11/8/19	100%	17



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

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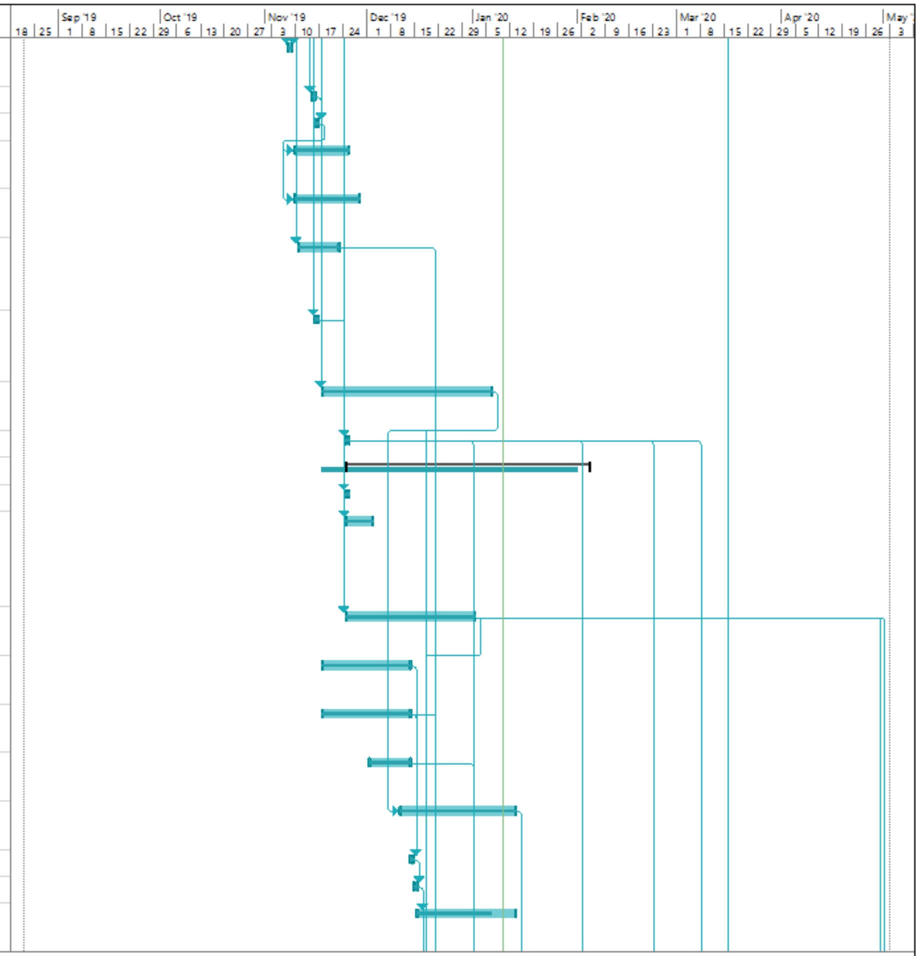
Figure 83: OSRT Project Plan 2/5

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	% Complete	Predecessors
44	✓		Distribute PTPs and Full-Team Safety Brief	1 day	Fri 11/8/19	Fri 11/8/19	100%	31,39
45	✓		Subscale Integration	1 day	Fri 11/15/19	Fri 11/15/19	100%	31,39
46	✓		**Subscale Launch #1**	**1 day**	**Sat 11/16/1**	**Sat 11/16/19**	**100%**	**45**
47	✓		Modify/Repair Subscale Launch Vehicle and Design	12 days	Sun 11/10/19	Mon 11/25/19	100%	46
48	✓		Modify/Repair Subscale Recovery System and Design	15 days	Sun 11/10/19	Thu 11/28/19	100%	46
49	✓		STEM Engagement Supply Procurement and Lesson Plans #8 and 9 Development	10 days	Mon 11/11/19	Fri 11/22/19	100%	17
50	✓		Pre-football STEM Engagement with the OSU Alumni Center	1 day	Sat 11/16/19	Sat 11/16/19	100%	17
51	✓		Modify Payload Prototype and Design	36 days	Mon 11/18/19	Mon 1/6/20	100%	42
52	✓		STEM Engagement Evaluation	1 day	Mon 11/25/1	Mon 11/25/1	100%	50
53			**Critical Design Phase**	**52 days**	**Mon 11/25/1**	**Tue 2/4/20**	**60%**	
54	✓		**CDR Q&A**	**1 day**	**Mon 11/25/1**	**Mon 11/25/1**	**100%**	**41**
55	✓		Determine Manufacturing Company for Outsourced Materials for Full Scale Launch Vehicle	6 days	Mon 11/25/19	Mon 12/2/19	100%	7
56	✓		Budget/Finance Cold Calls and Follows Leads	28 days	Mon 11/25/19	Wed 1/1/20	100%	9
57	✓		Modify/Repair Subscale Recovery System and Design	20 days	Mon 11/18/19	Fri 12/13/19	100%	
58	✓		Modify/Repair Subscale Launch Vehicle and Design	20 days	Mon 11/18/19	Fri 12/13/19	100%	
59	✓		Order Full Scale Launch Vehicle Components	10 days	Mon 12/2/19	Fri 12/13/19	100%	
60	✓		Order Full Scale Payload Components	24 days	Wed 12/11/19	Mon 1/13/20	100%	51
61	✓		Subscale Integration	1 day	Sat 12/14/19	Sat 12/14/19	100%	57,58
62	✓		**Subscale Launch #2**	**1 day**	**Sun 12/15/1**	**Sun 12/15/19**	**100%**	**61**
63			Order Full Scale Recovery System Components	21 days	Mon 12/16/19	Mon 1/13/20	75%	62



Project: CDR Project Plan.mpp
Date: Fri 1/10/20

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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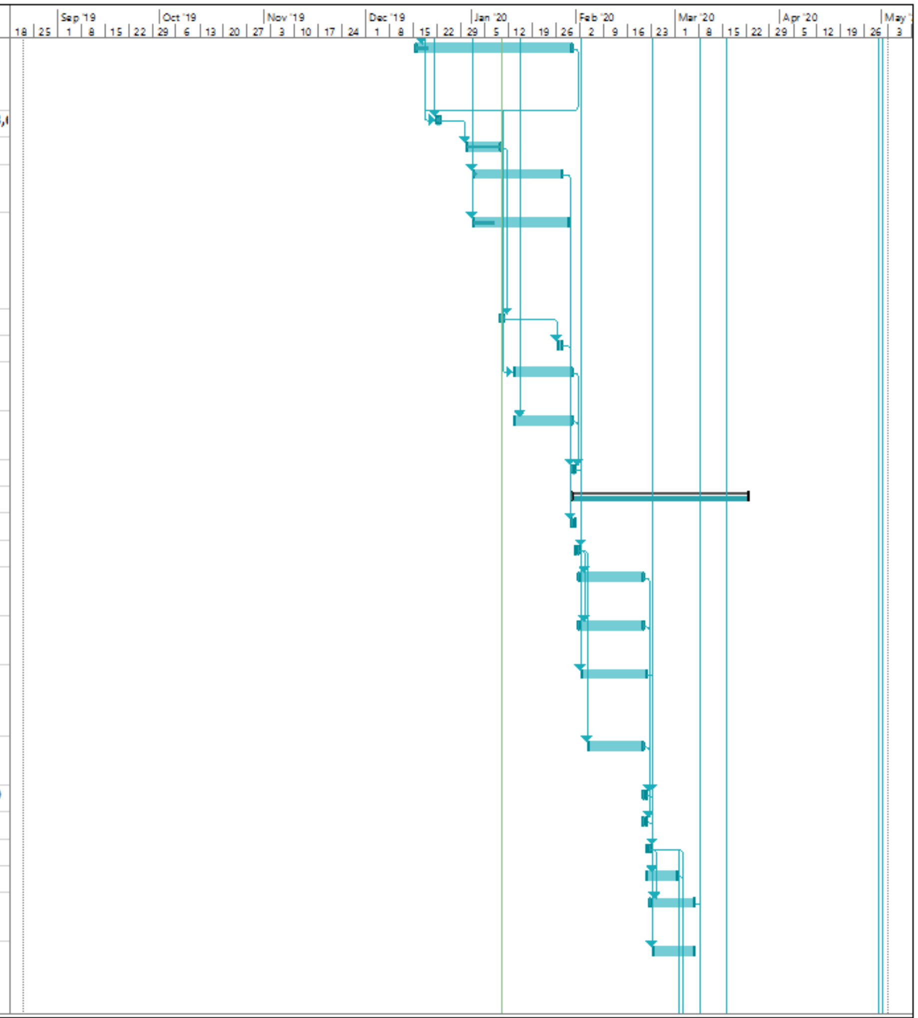
Figure 84: OSRT Project Plan 3/5

ID		Task Mode	Task Name	Duration	Start	Finish	% Complete	Predecessors
64			Manufacture and Test Recovery System for Full Scale Launch Vehicle	34 days	Mon 12/16/19	Thu 1/30/20	10%	62
65	✓		**CDR Rough Draft Due**	**1 day**	**Sun 12/22/1**	**Sun 12/22/19**	**100%**	**49,51,56,58,(**
66	✓		Edit and Compile CDR	8 days	Tue 12/31/1	Thu 1/9/20	100%	65
67			Maunfacture Full Scale Launch Vehicle	18 days	Thu 1/2/20	Mon 1/27/20	5%	59
68			STEM Engagement Supply Procurement and Lesson Plans #10, 11, 12, and 13 Development	20 days	Thu 1/2/20	Wed 1/29/20	20%	52
69	✓		**Submit CDR**	**1 day**	**Fri 1/10/20**	**Fri 1/10/20**	**100%**	**66**
70			**CDR Video Teleconfrence**	**1 day**	**Mon 1/27/2(**	**Mon 1/27/20**	**0%**	**69**
71			Modify and Test Full Scale Recovery System and Design	13 days	Tue 1/14/20	Thu 1/30/20	0%	64
72			Manufacture Full Scale Payload	13 days	Tue 1/14/20	Thu 1/30/20	0%	60
73			Full Scale Integration	1 day	Fri 1/31/20	Fri 1/31/20	0%	67,71,72
74			**Final Readiness Phase**	**37 days**	**Fri 1/31/20**	**Sun 3/22/20**	**0%**	
75			**FRR Q&A**	**1 day**	**Fri 1/31/20**	**Fri 1/31/20**	**0%**	**70**
76			**Full Scale Launch #1**	**1 day**	**Sat 2/1/20**	**Sat 2/1/20**	**0%**	**73**
77			Modify/Repair Full Scale Recovery System and Design	15 days	Sun 2/2/20	Thu 2/20/20	0%	76
78			Modify/Repair Full Scale Launch Vehicle and Design	15 days	Sun 2/2/20	Thu 2/20/20	0%	76
79			STEM Engagement Supply Procurement and Lesson Plans #14, 15, and 16 Development	15 days	Mon 2/3/20	Fri 2/21/20	0%	52
80			Modify/Repair Full Scale Payload and Design	12 days	Wed 2/5/20	Thu 2/20/20	0%	76
81			**FRR Rough Draft Due**	**1 day**	**Fri 2/21/20**	**Fri 2/21/20**	**0%**	**77,78,79,80**
82			Full Scale Integration	1 day	Fri 2/21/20	Fri 2/21/20	0%	77,78,80
83			**Full Scale Launch #2**	**1 day**	**Sat 2/22/20**	**Sat 2/22/20**	**0%**	**82**
84			Edit and Compile FRR	7 days	Sat 2/22/20	Sun 3/1/20	0%	81
85			Modify/Repair Full Scale Payload and Design	11 days	Sun 2/23/20	Fri 3/6/20	0%	83
86			STEM Engagement Supply Procurement and Lesson Plans #17 and 18 Development	10 days	Mon 2/24/20	Fri 3/6/20	0%	52



Project: CDR Project Plan.mpp
Date: Fri 1/10/20

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

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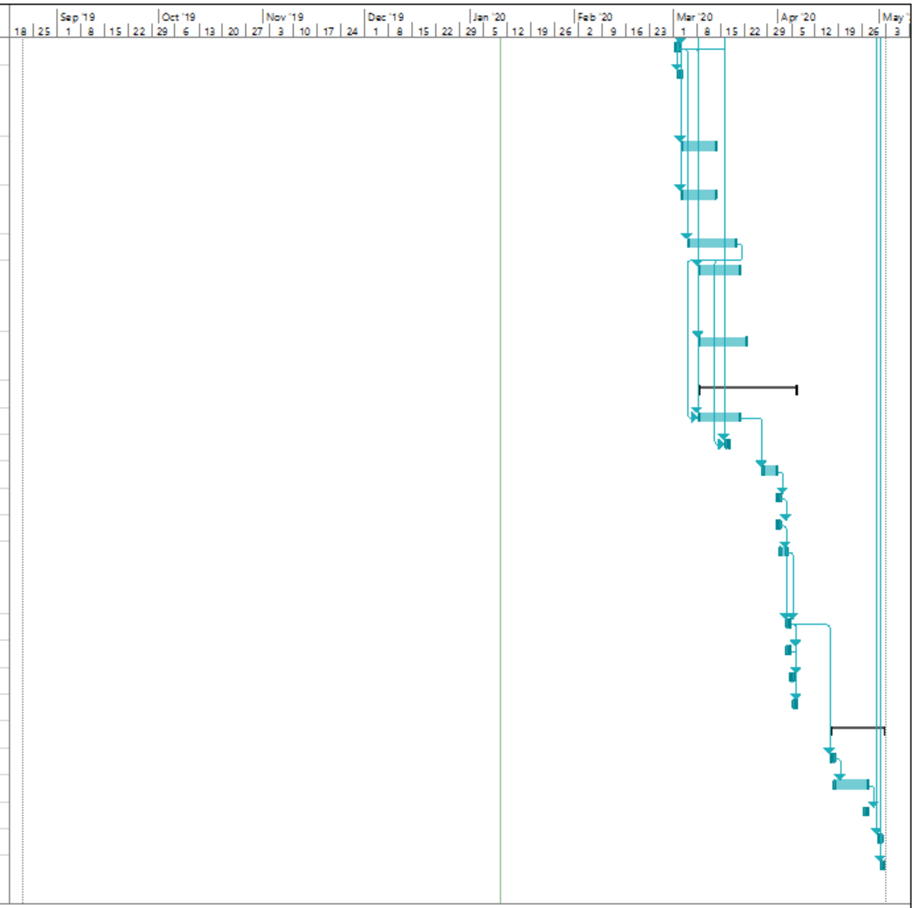
Figure 85: OSRT Project Plan 4/5

ID		Task Mode	Task Name	Duration	Start	Finish	% Complete	Predecessors
87			**Submit FRR**	**1 day**	**Mon 3/2/20**	**Mon 3/2/20**	**0%**	**84**
88			Purchase Unexpected Replacements for All Subteams	1 day	Tue 3/3/20	Tue 3/3/20	0%	83
89			Repair Full Scale Launch Vehicle	8 days	Wed 3/4/20	Fri 3/13/20	0%	83
90			Repair Full Scale Recovery System	8 days	Wed 3/4/20	Fri 3/13/20	0%	83
91			**FRR Video Teleconferences**	**10 days**	**Fri 3/6/20**	**Thu 3/19/20**	**0%**	**87**
92			STEM Engagement Supply Procurement and Lesson Plans #19 and 20 Development	10 days	Mon 3/9/20	Fri 3/20/20	0%	52
93			Final Modification and Testing of Full Scale Payload	11 days	Mon 3/9/20	Sun 3/22/20	0%	85
94			**Competition Phase**	**21 days**	**Mon 3/9/20**	**Mon 4/6/20**	**0%**	
95			Pack for Competition	10 days	Mon 3/9/20	Fri 3/20/20	0%	87,91
96			Huntsville Safety Brief	1 day	Tue 3/17/20	Tue 3/17/20	0%	10,87,91
97			Drive to Huntsville	3 days	Sat 3/28/20	Tue 3/31/20	0%	95
98			Arrive in Huntsville	1 day	Wed 4/1/20	Wed 4/1/20	0%	97
99			**LRR**	**1 day**	**Wed 4/1/20**	**Wed 4/1/20**	**0%**	**98**
100			Meet with RSO/Launch Safety Preparation and Oversight Implementation	2 days	Thu 4/2/20	Fri 4/3/20	0%	99
101			**Launch Day**	**1 day**	**Sat 4/4/20**	**Sat 4/4/20**	**0%**	**99,100**
102			Award Ceremony	1 day	Sat 4/4/20	Sat 4/4/20	0%	101
103			**Backup Launch Day**	**1 day**	**Sun 4/5/20**	**Sun 4/5/20**	**0%**	**101**
104			Leave Hunsville	1 day	Mon 4/6/20	Mon 4/6/20	0%	102
105			**Post Launch Phase**	**11 days**	**Fri 4/17/20**	**Sat 5/2/20**	**0%**	
106			**PLAR Rough Draft Due**	**1 day**	**Fri 4/17/20**	**Fri 4/17/20**	**0%**	**101**
107			Edit and Compile PLAR	7 days	Sat 4/18/20	Mon 4/27/20	0%	106
108			**Submit PLAR**	**1 day**	**Mon 4/27/2(**	**Mon 4/27/20**	**0%**	**107**
109			Thank you Letters to Donors	1 day	Fri 5/1/20	Fri 5/1/20	0%	56
110			Catalogue Materials for Future Teams	1 day	Sat 5/2/20	Sat 5/2/20	0%	56



Project: CDR Project Plan.mpp
Date: Fri 1/10/20

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

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Figure 86: OSRT Project Plan 5/5

7.3 Project Budget

Table 49 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 48.

Table 48: 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 49: Budget

Quantity	Object	Cost per Unit	Vendor	Total Cost
Aerodynamics and Recovery				
2	8 ft Main Parachute	$348.15	Fruity Chutes	$696.30
2	7 ft Main Parachute	$296.96	Fruity Chutes	$593.92
8	Drogue Parachute	$55.97	Fruity Chutes	$447.76
10	Shock Cord (per yard)	$23.13	Fruity Chutes	$231.30
6	Shear Pins	$5.50	Home Depot	$33.00
4	Nomex Fire Proof Blankets	$27.00	Fruity Chutes	$108.00
15	Quick Release Hooks	$4.10	Apogee components	$61.50
6	Descenders	$81.43	Apogee components	$488.58
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
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 DC Motor	$19.90	DFRobot	$19.90
1	Teensy 3.6 Microcontroller	$29.25	Sparkfun	$29.25
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

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Quantity	Object	Cost per unit	Vendor	Total Cost
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
5	12gm CO2 Cartridge (each)	$4.50	Tinder Rocketry	$22.50
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
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	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
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

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Quantity	Object	Cost per unit	Vendor	Total Cost
			Recovery Total:	$4,711.18
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
#	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
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
			Payload Total:	$859.00
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

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Quantity	Object	Cost per unit	Vendor	Total Cost
4	Fiberglass sheets	$6.50	Fiberglass Supply Depot	$26.00
1	Plywood	$43.50	Aircraft Spruce Co	$43.50
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
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
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
			Structure/Propulsion Total:	$8,618.24
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				

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Quantity	Object	Cost per unit	Vendor	Total Cost
#	Office Supplies	#	As Needed	$100.00
			Administrative Total:	$100.00
Safety				
#	Office Supplies, Stickers, PPE, High Vis. Clothing/Material	#	As Needed	$200.00
			Safety Total:	$200.00
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

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.

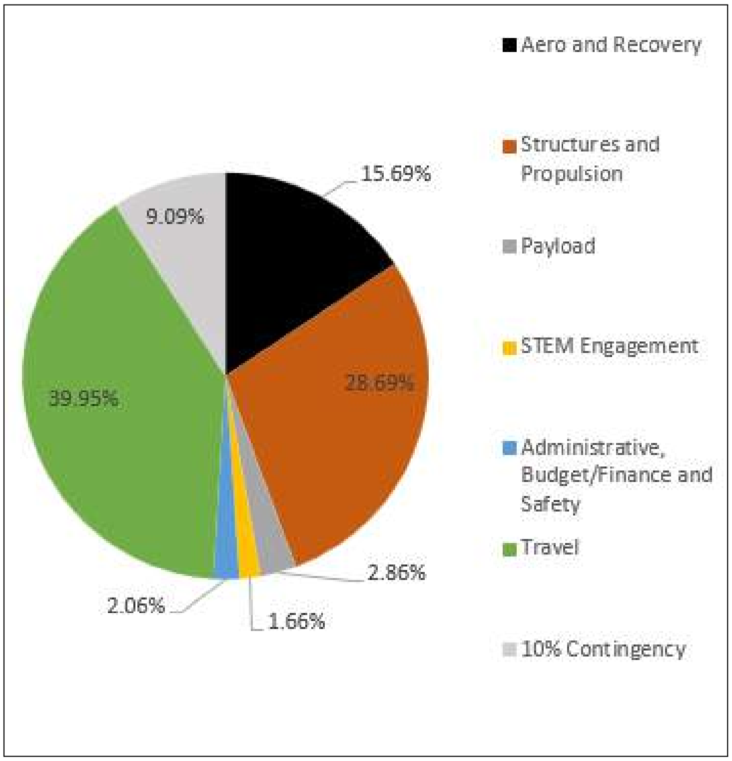


Figure 87: Budget Allocation

Eight budget categories are presented in Figure 88 to compare the updated budget amount with the money spent.

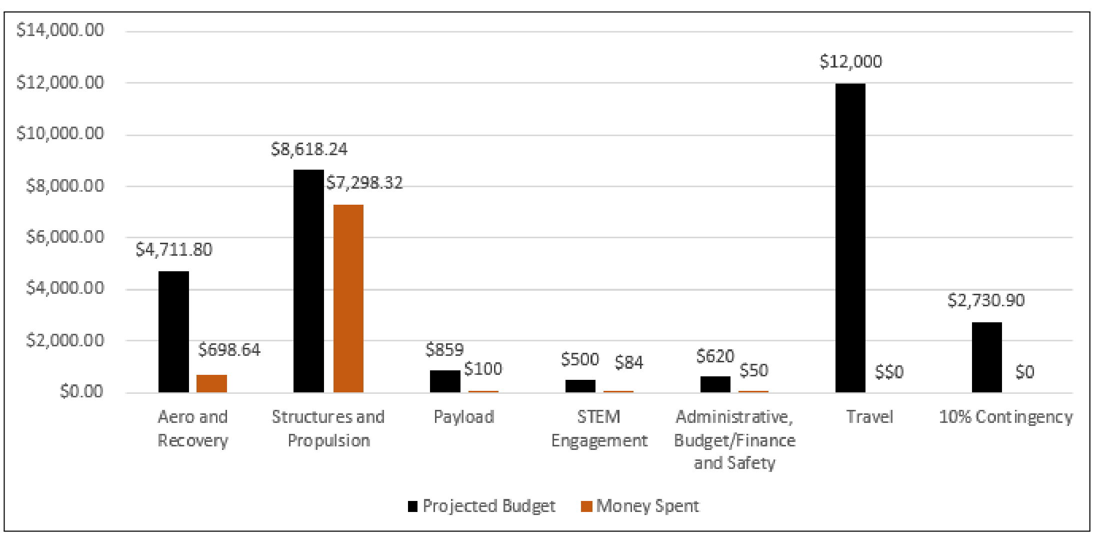


Figure 88: Projected Budget and Money Spent

7.4 STEM Engagement

OSRT has completed multiple STEM Engagement events since PDR. There are also more events planned. OSRT has currently reached 1,428 students through the team's STEM Engagement efforts and has a goal of reaching at least 2,500 students.

The events that OSRT has organized since PDR include multiple sports tables and going to several K-8 schools to present lesson plans. The sports tables included a display giving general information about the team along with various physics demonstrations and the option to create paper airplanes. Many people were interested in the physics demonstration. One demonstration had a bicycle wheel that showed how changing the direction of force would cause the force to be pushed back to the user as well and have the user spinning along with the bicycle wheel. The first school that OSRT went to was Franklin K-8 school in Corvallis, Oregon. OSRT presented a full lesson plan, including an evaluation, where the 8th-grade students created baking soda and vinegar rockets. The lesson plan was a success and the 8th-graders really enjoyed it. The next school OSRT went to was Saint Thomas More Catholic School in Portland, Oregon. There OSRT presented another full lesson plan, including an evaluation, where the 8th-grade students created their own direct current motor. OSRT presented to them the supplies, a general explanation on how the motor would work, and direction as needed. The motors that the students built functioned as their evaluation. OSRT was also able to visit Monte Vista High School in Danville, California where there was a presentation on the team given to a class of seniors. OSRT is proud to state to have broadened its STEM Engagement efforts to not only the entire Willamette Valley in Oregon, but also outside of the state of Oregon.

8 References

[1] URL: https://www.robotshop.com/en/12v-100rpm-583-oz-in-brushed-dc-motor.html.

[2] M. F. Ashby. *Materials Selection in Mechanical Design, 5th Ed.*

[3] *Ball and ACME Lead Screw Technical Information*. URL: https://www.google.com/url?sa=t\&rct=j\&q=\&esrc=s\&source=web\&cd=1\&ved=2ahUKEwjtu7H4l5PmAhXJvp4KHb5BBvEQFjAAegQIBRAC\&url=https\%3A\%2F\%2Fwww.sdp-si.com\%2FD810\%2FPDFS\%2FBall\%2520And\%2520Acme\%2520Lead\%2520Screw\%2520Technical\%2520Info.pdf\&usg=AOvVaw22Q8jQqx-TR0hwQKE6JznO.

[4] Tom Benson. *Velocity During Recovery*. URL: https://www.grc.nasa.gov/WWW/k-12/VirtualAero/BottleRocket/airplane/rktvrecv.html.

[5] R. Budynas and J. Nisbett. *Shigley's Mechanical Engineering Design (McGraw-Hill Series in Mechanical Engineering) 10th Edition*.

[6] Fruity Chutes. *Iris Ultra Standard Chutes*. URL: https://fruitychutes.com/buyachute/iris-ultra-standard-chutes-c-29/.

[7] Bill Eccles. *The Use of Two Nuts to Prevent Self Loosening*. URL: https://www.boltscience.com/pages/the-use-of-two-nuts-to-prevent-self-loosening.pdf.

[8] *Ejection Charge Calculator*. URL: http://www.rimworld.com/nassarocketry/tools/chargecalc/index.html.

[9] Emma Renee Fraley. *Design, Manufacturing, and Integration of Fins for 2017-2018 OSU ESRA 30k Rocket*. URL: https://ir.library.oregonstate.edu/downloads/6108vh38q?locale=en.

[10] Glenmarc Industries Inc. *G5000 RocketPoxy MSDS*. URL: https://www.apogeerockets.com/downloads/MSDS/ROCKETPOXY_MSDS.pdf.

[11] C. Kobel. *Simulator Data*. URL: http://www.thrustcurve.org/simfilesearch.jsp?id=1333.

[12] *Lead Screw Force and Torque Calculator*. URL: https://daycounter.com/Calculators/Lead-Screw-Force-Torque-Calculator.phtml.

[13] *Material Property Testing of 3D-Printed Specimen in PLA on an Entry-Level 3D Printer*. URL: https://www.researchgate.net/publication/272623242_Material_Property_Testing_of_3D-Printed_Specimen_in_PLA_on_an_Entry-Level_3D_Printer#:~:targetText=PLA\%20filament\%20was\%20also\%20tensile,58\%20MPa\%20and\%2054\%20MPa.

[14] *Matweb: Overview of materials for Brass*. URL: http://www.matweb.com/search/datasheet_print.aspx?matguid=d3bd4617903543ada92f4c101c2a20e5.

[15] *Matweb: Steel, General Properties*. URL: https://www.matweb.com/search/datasheet.aspx?matguid=10e1c14130cd4ed6ae64b85723be53af&n=1&ckck=1.

[16] *Parachute Recovery System Design for Large Rockets*, pp. 1–10. URL: http://www.aspirespace.org.uk/downloads/Parachute%20recovery%20system%20design%20for%20large%20rockets.pdf.

[17] *Shear Pins*. URL: https://web.archive.org/web/20131026023457/http://www.rocketmaterials.org/datastore/cord/Shear_Pins/index.php.

[18] Western Rocketry Team. *WestRocketry*. URL: http://westrocketry.com/mach1/project.html.

[19] *THE DESCRIPTIVE GEOMETRY OF NOSE CONES*. URL: https://www.rocketryforum.com/attachments/nosecone_eqn2-pdf.336812/.

9 APPENDIX

9.1 Structures

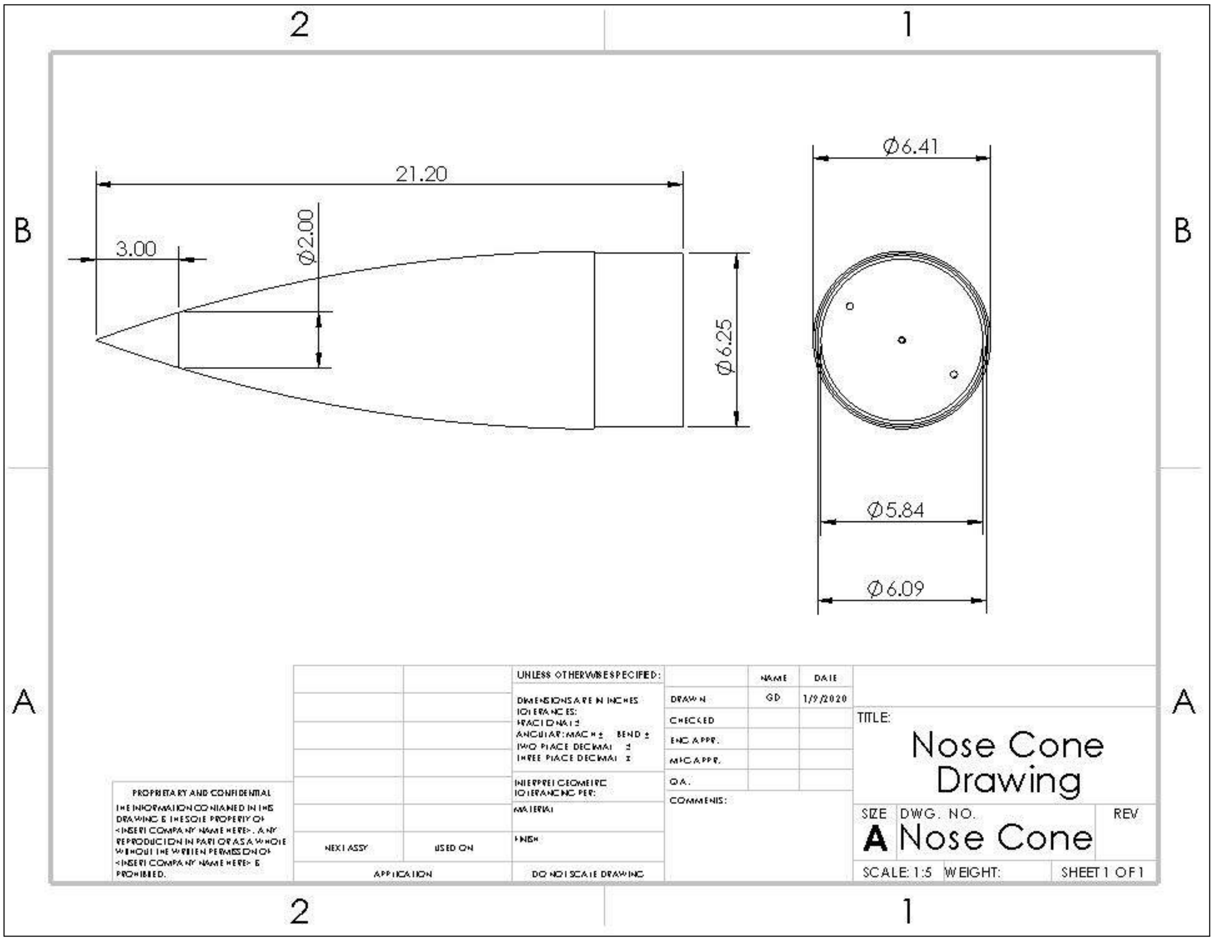


Figure 89: Nose Cone Drawing

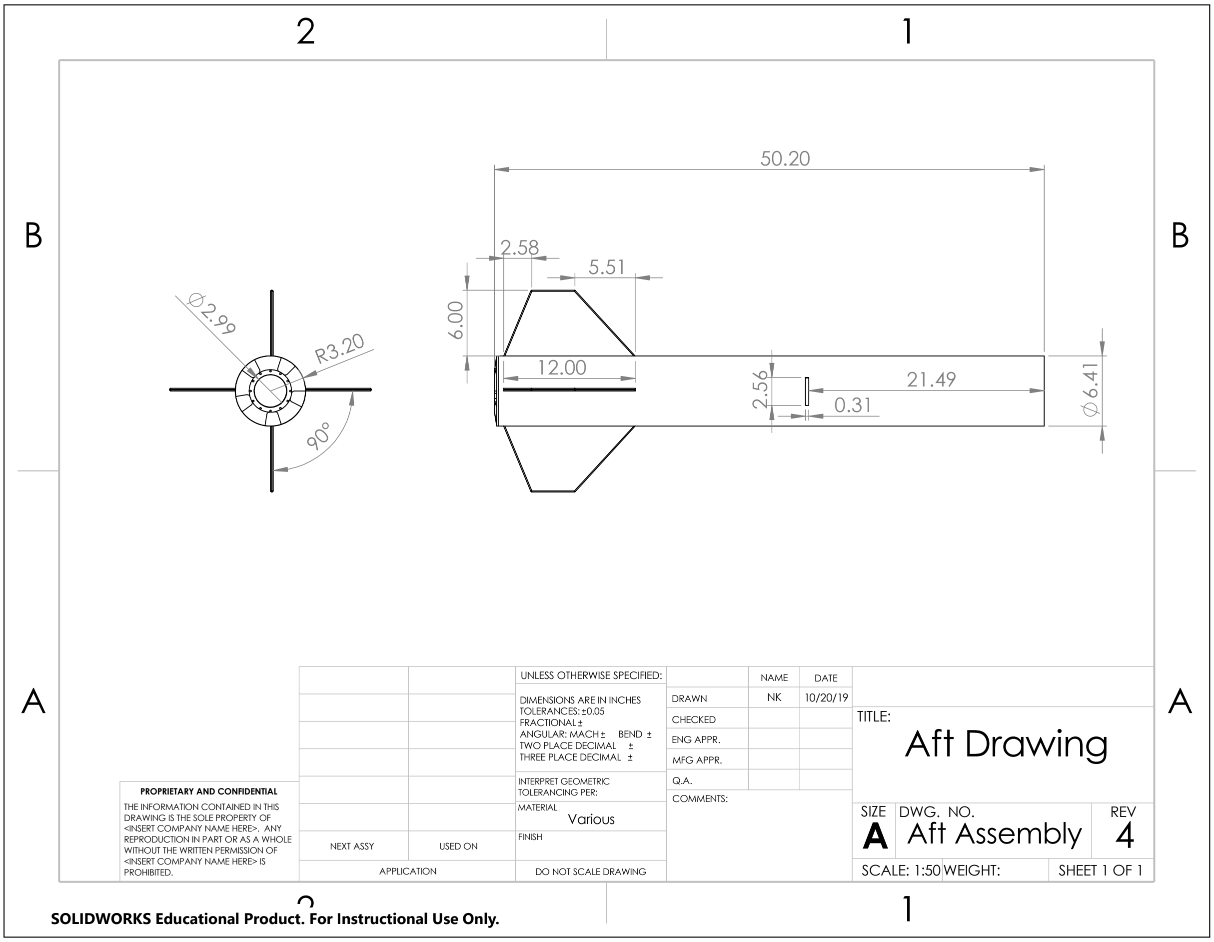


Figure 90: Aft Section Assembly

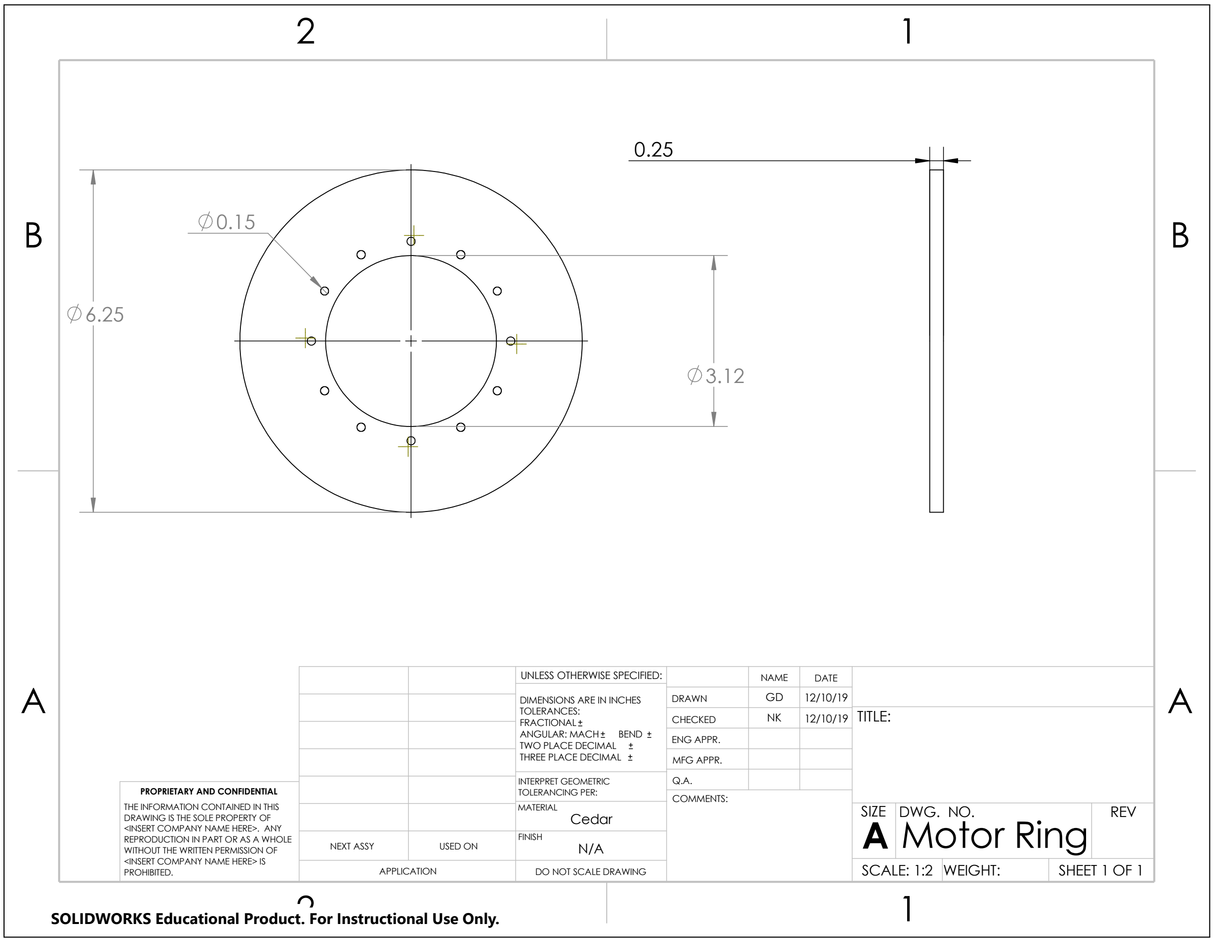


Figure 91: Aft Motor Retainer Mounting Ring

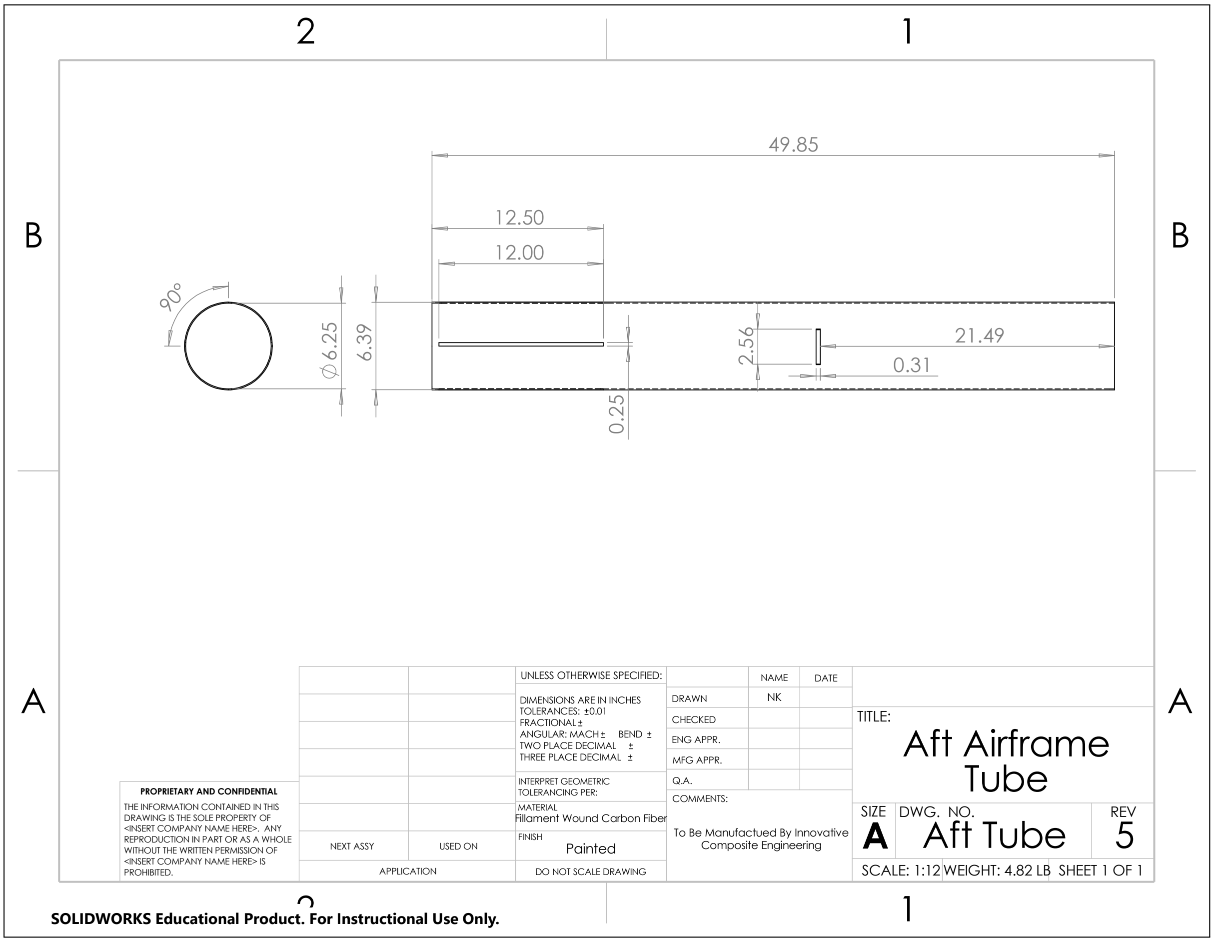


Figure 92: Aft Airframe Tube

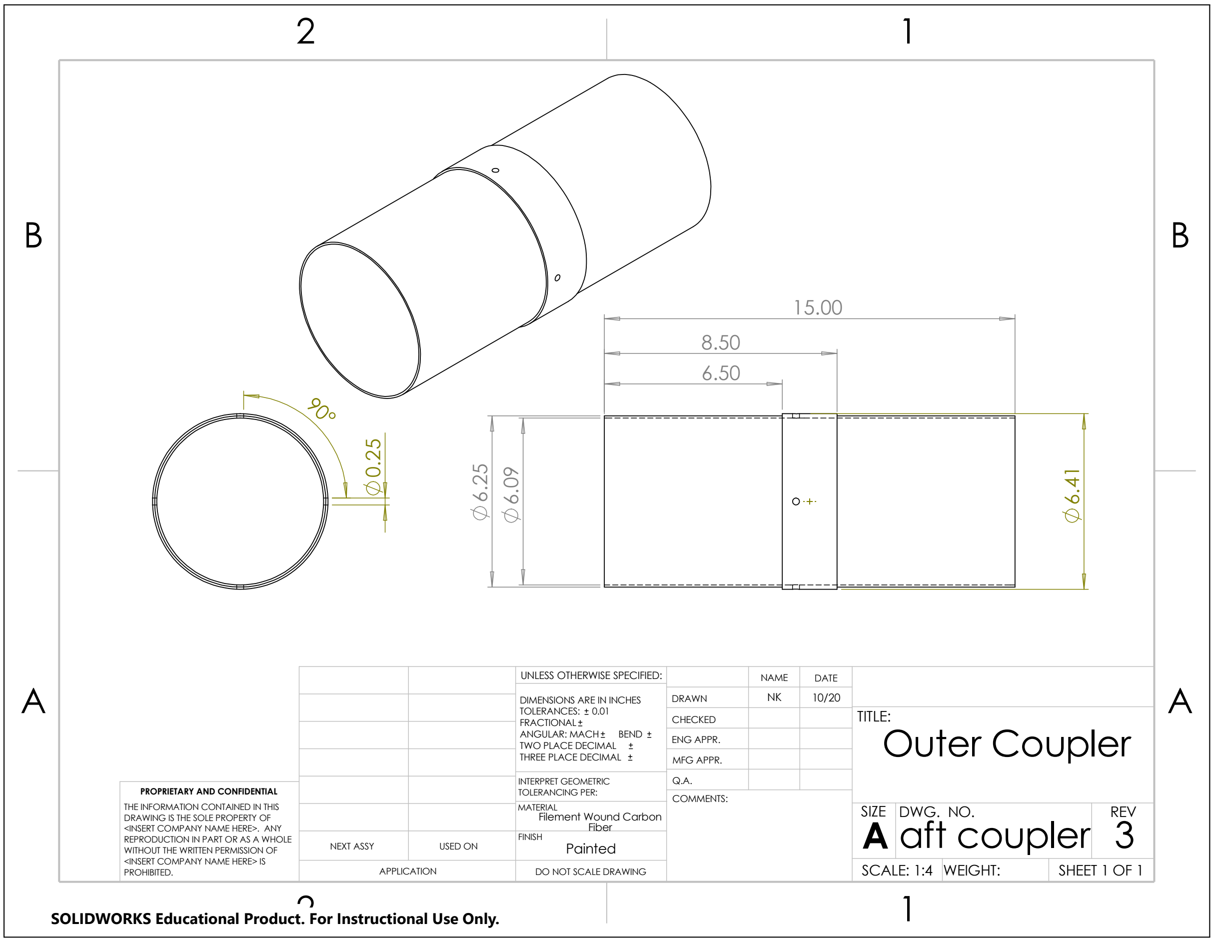


Figure 93: Coupler

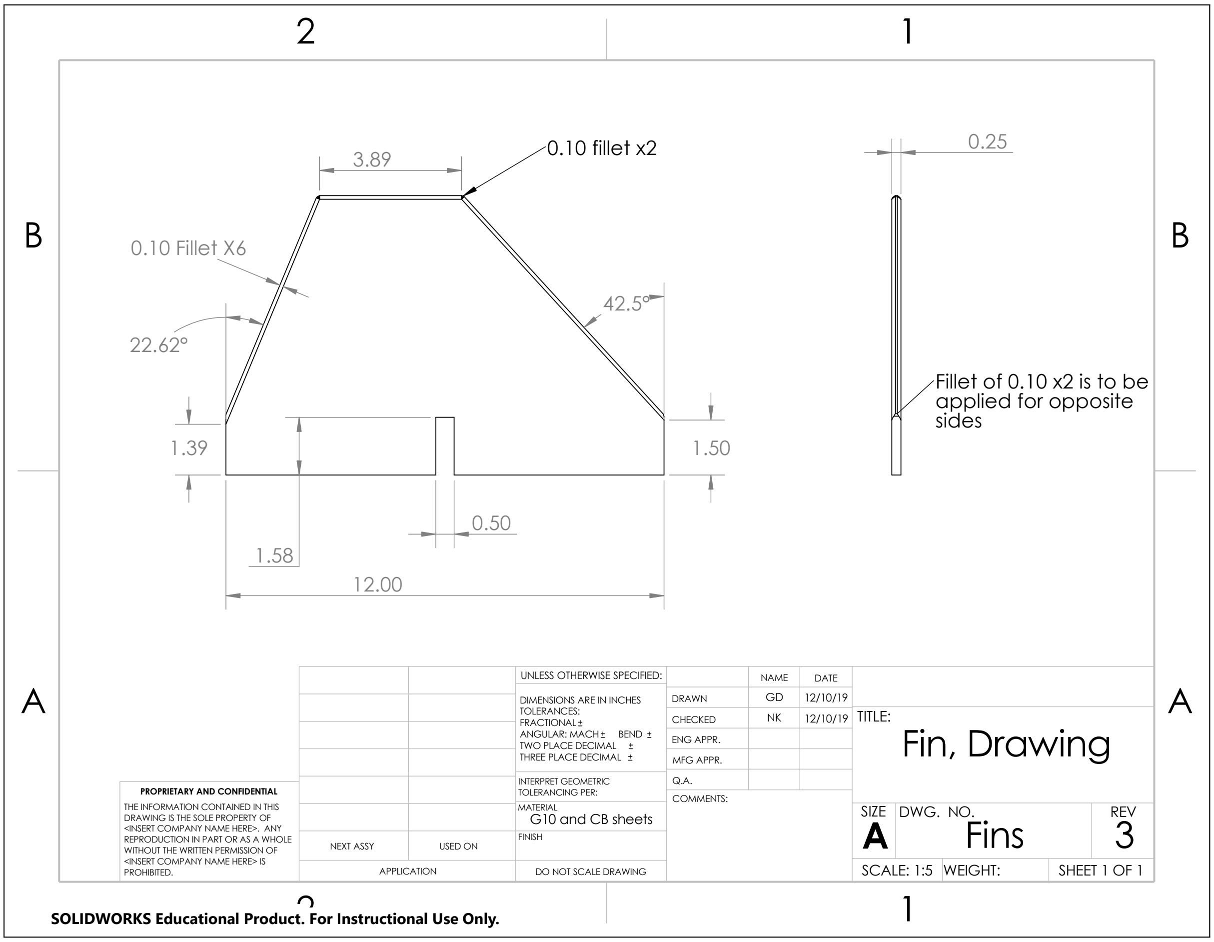


Figure 94: Fins

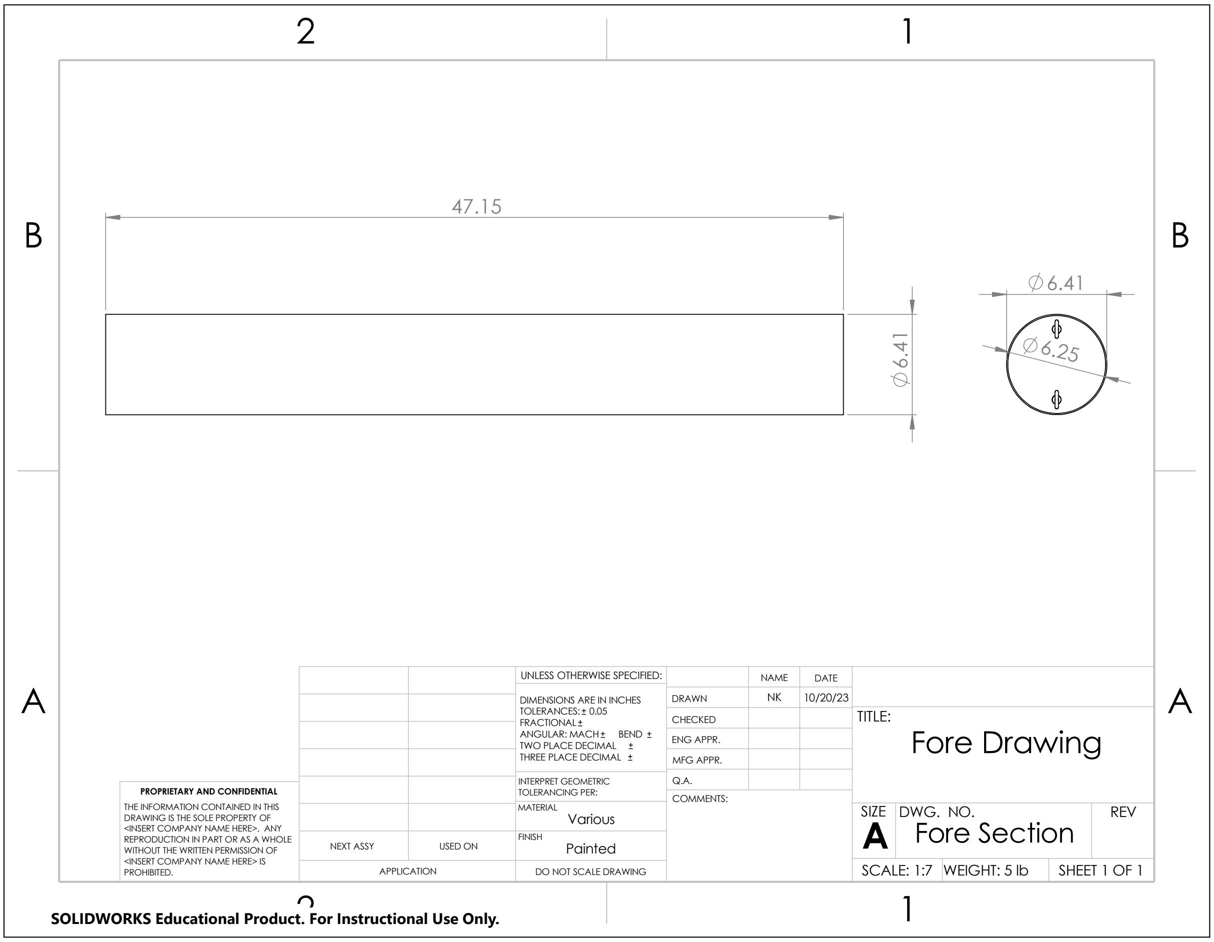


Figure 95: Fore Section

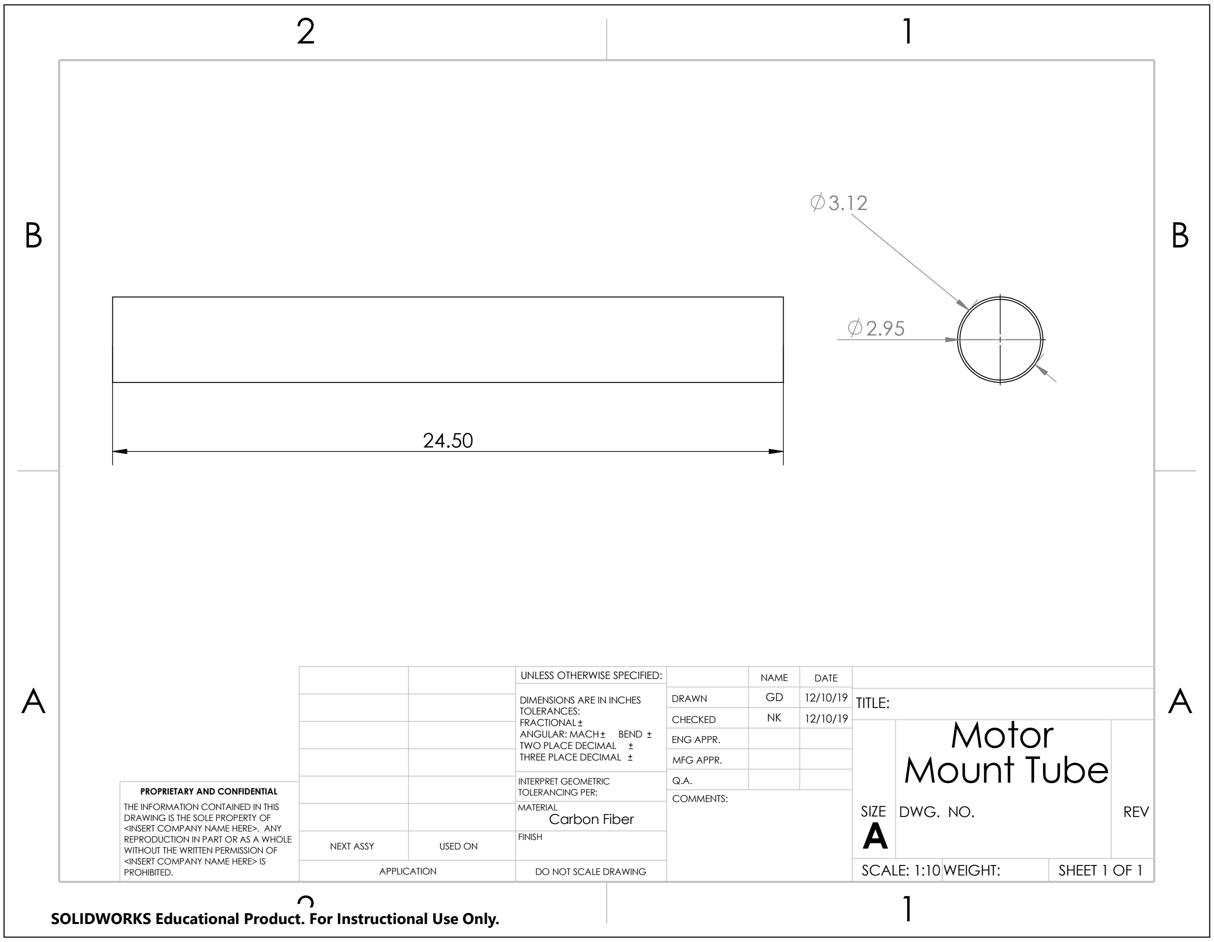


Figure 96: Motor Tube

9.2 Aerodynamics and Recovery

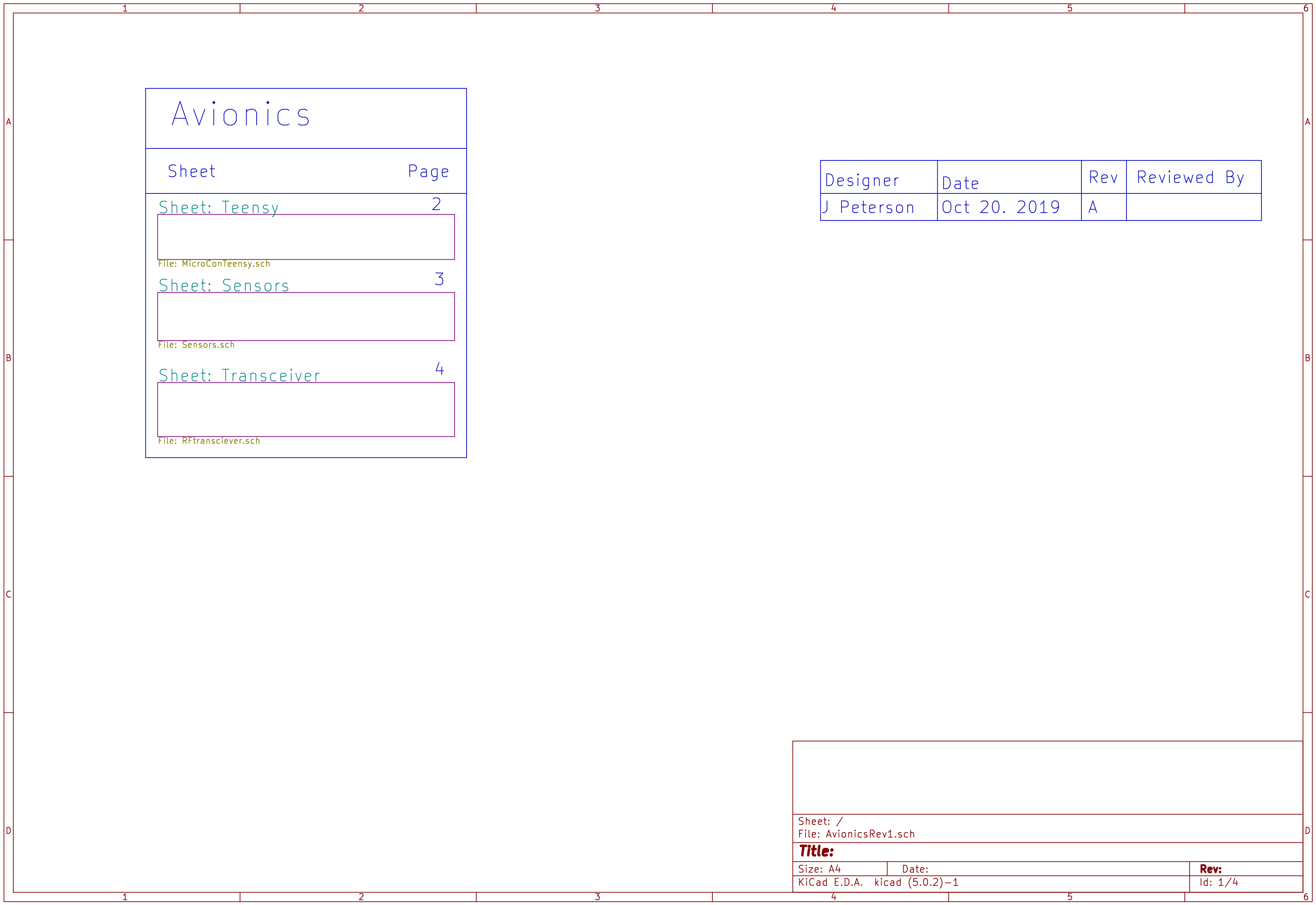


Figure 97: Avionics Schematics Page 1

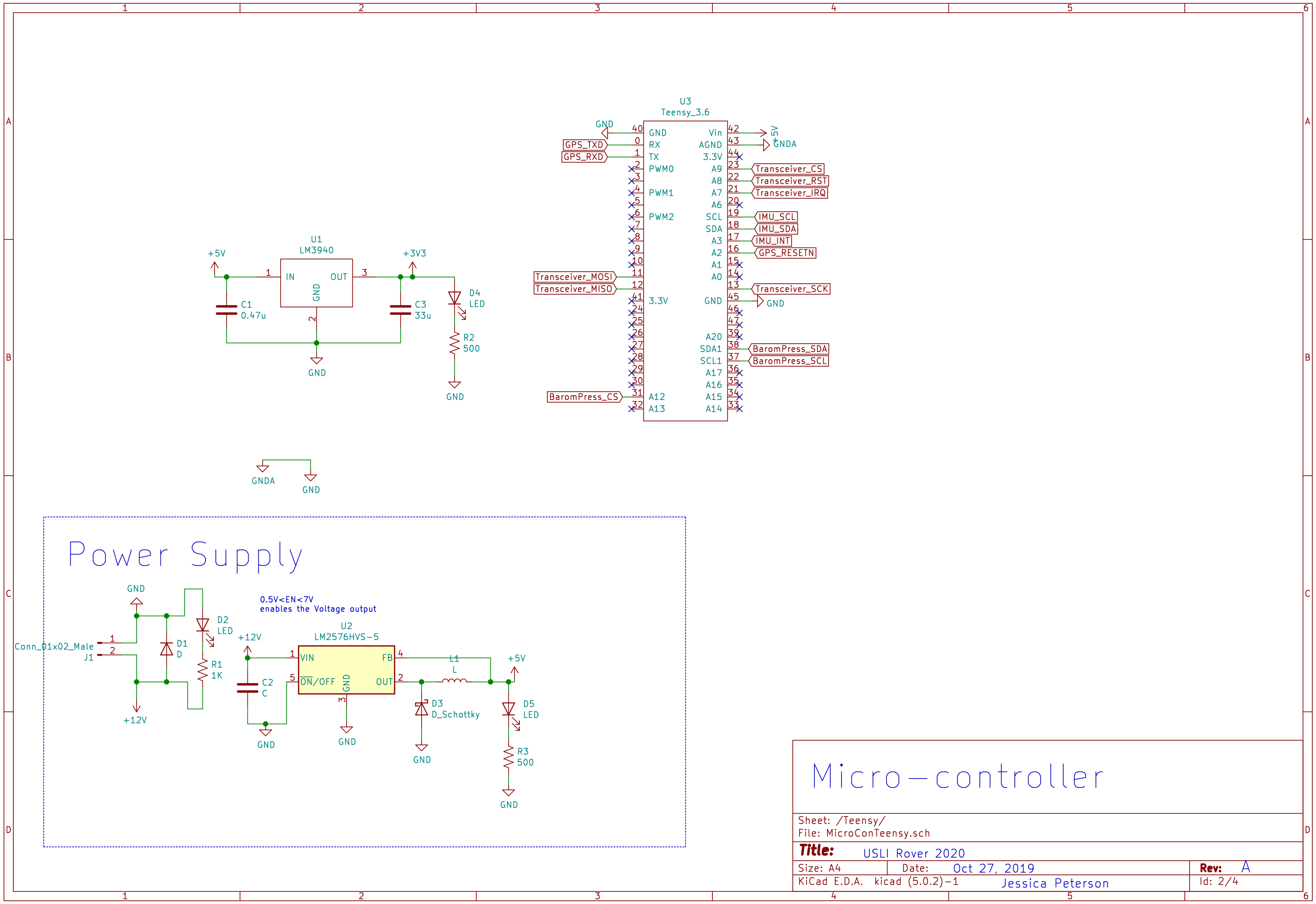


Figure 98: Avionics Schematics Page 2

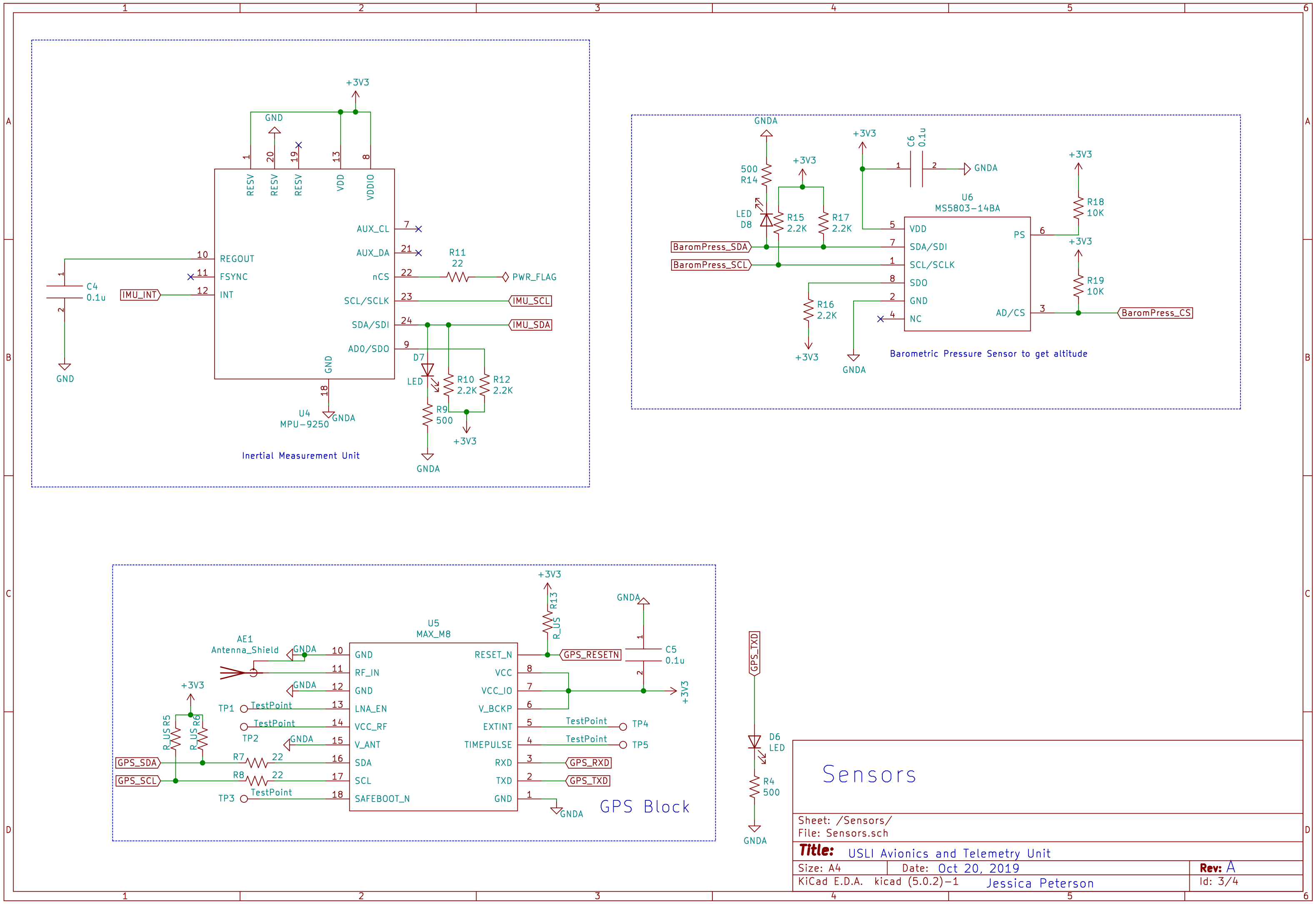


Figure 99: Avionics Schematics Page 3

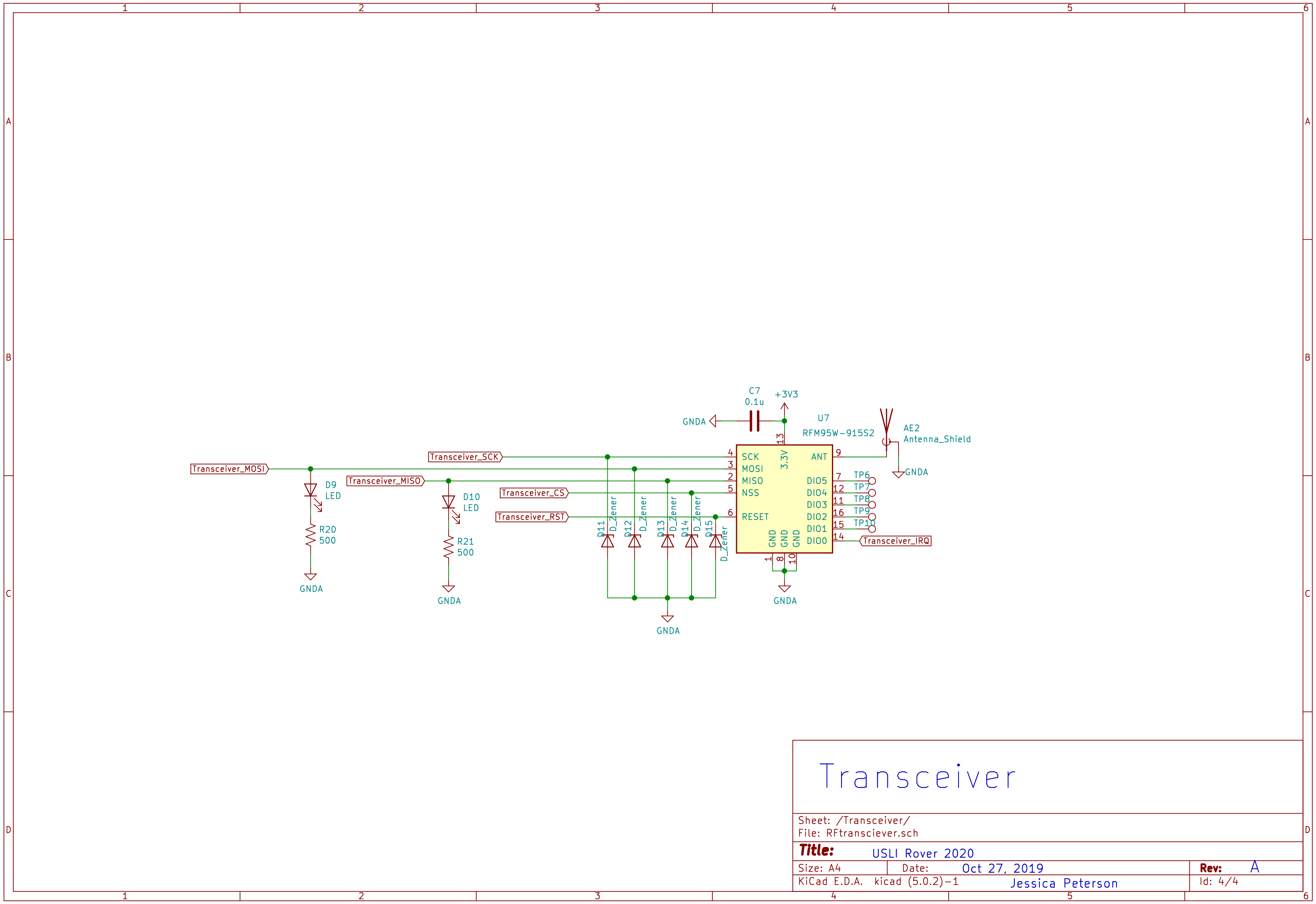
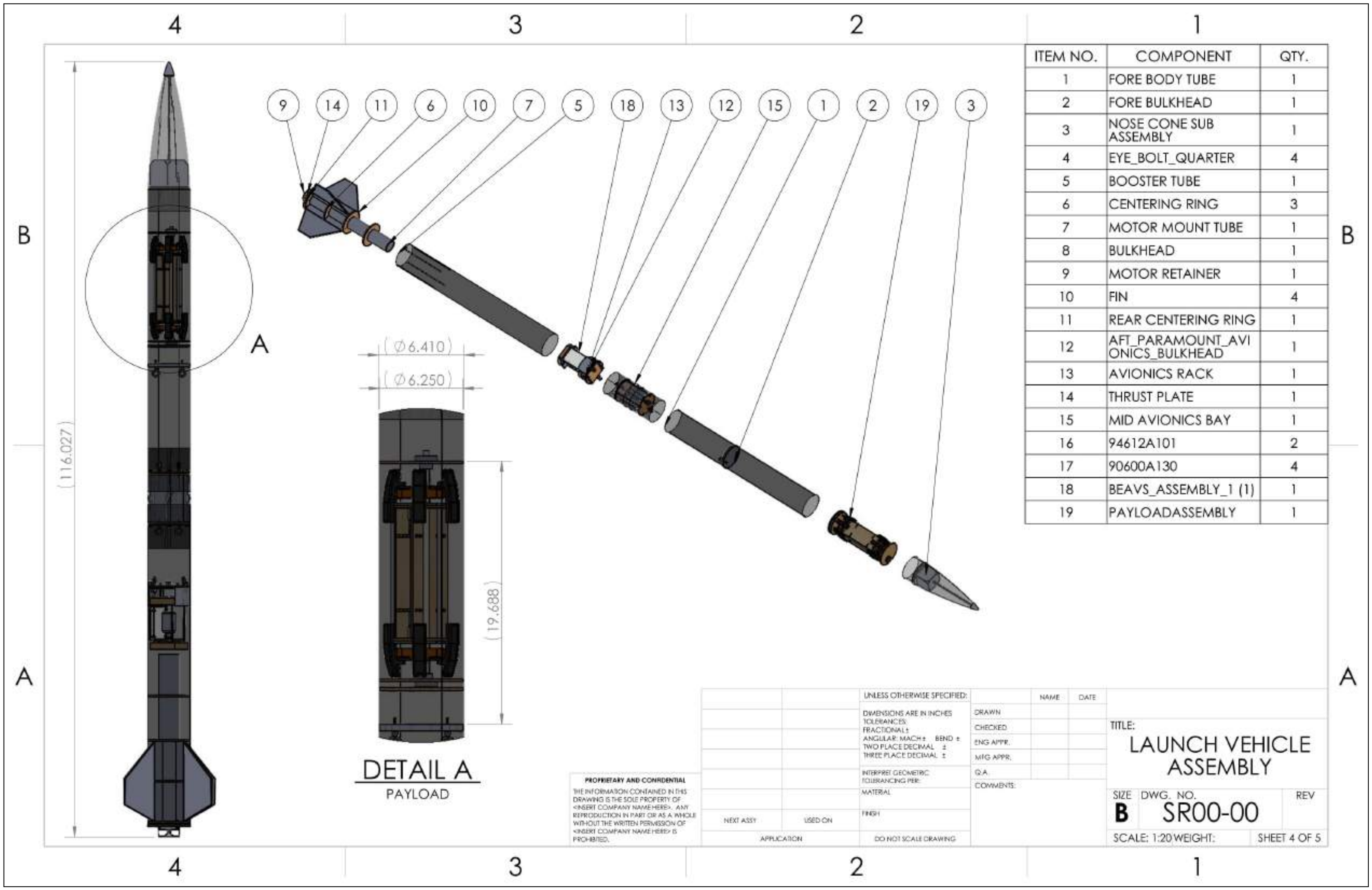


Figure 100: Avionics Schematics Page 4

9.3 Payload



ITEM NO.	COMPONENT	QTY.
1	FORE BODY TUBE	1
2	FORE BULKHEAD	1
3	NOSE CONE SUB ASSEMBLY	1
4	EYE_BOLT_QUARTER	4
5	BOOSTER TUBE	1
6	CENTERING RING	3
7	MOTOR MOUNT TUBE	1
8	BULKHEAD	1
9	MOTOR RETAINER	1
10	FIN	4
11	REAR CENTERING RING	1
12	AFT_PARAMOUNT_AVIONICS_BULKHEAD	1
13	AVIONICS RACK	1
14	THRUST PLATE	1
15	MID AVIONICS BAY	1
16	94612A101	2
17	90600A130	4
18	BEAVS_ASSEMBLY_1 (1)	1
19	PAYLOADASSEMBLY	1

Figure 101: Payload Rocket Assembly

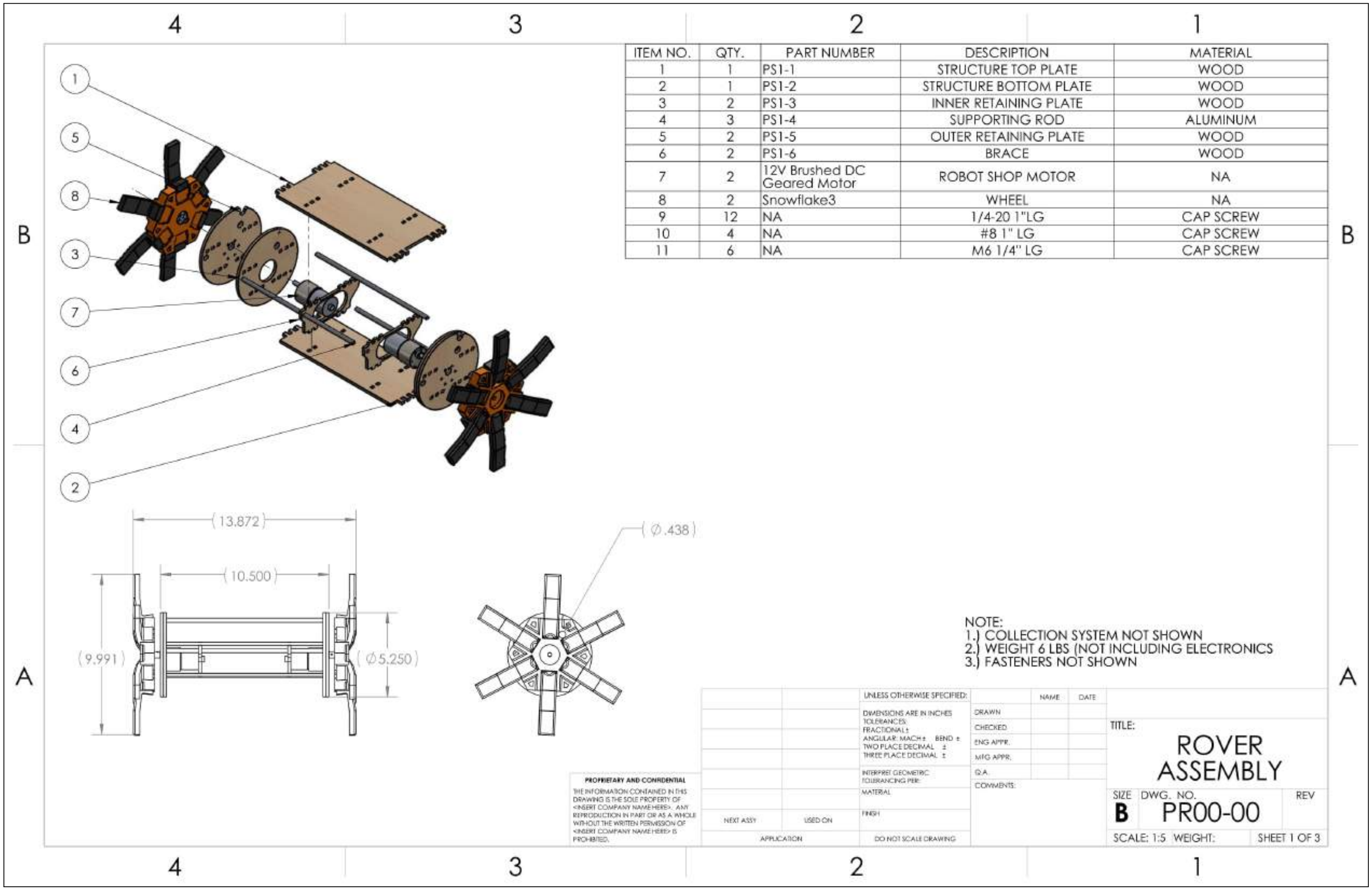


Figure 102: Payload Assembly

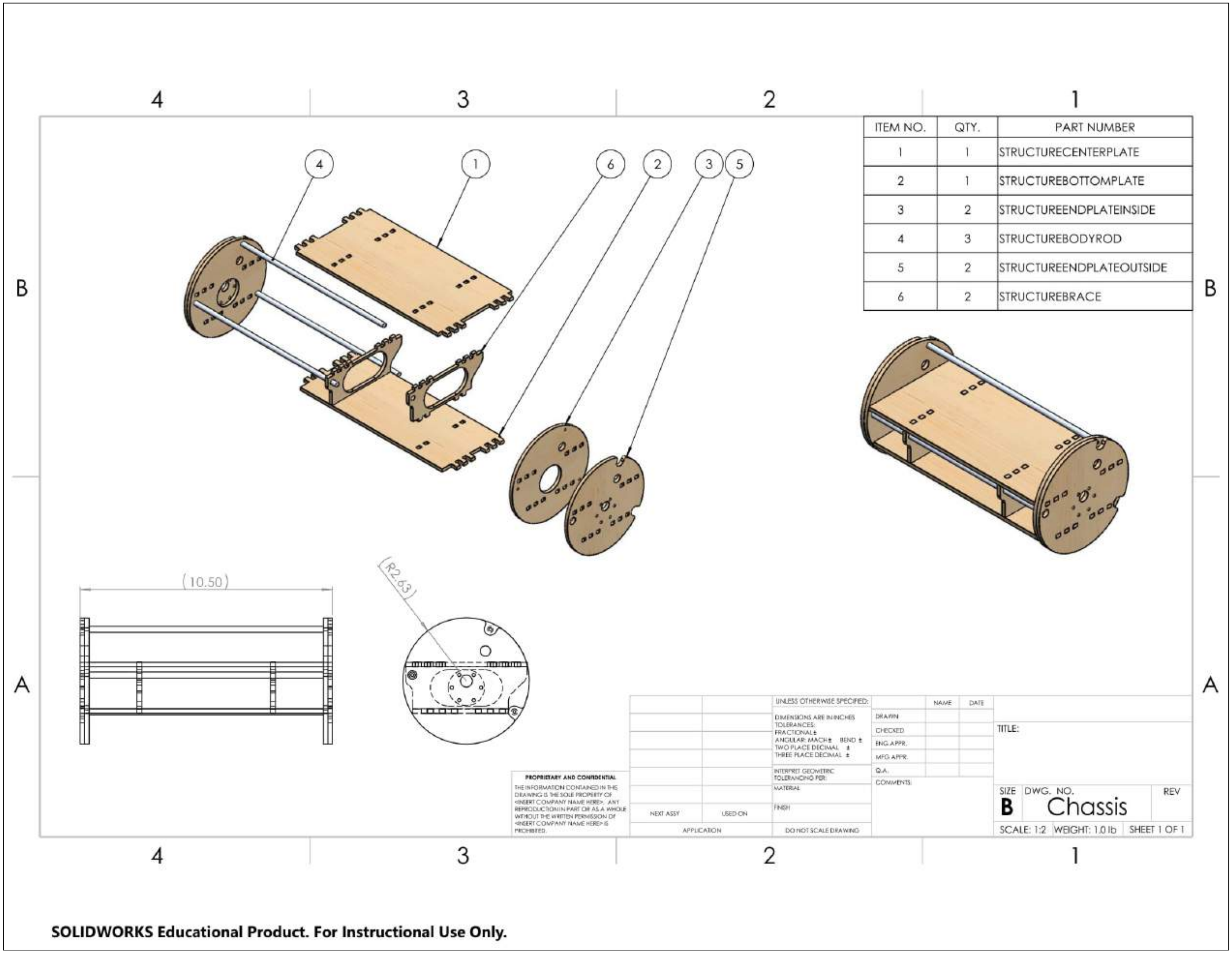


Figure 103: Payload Chassis Assembly

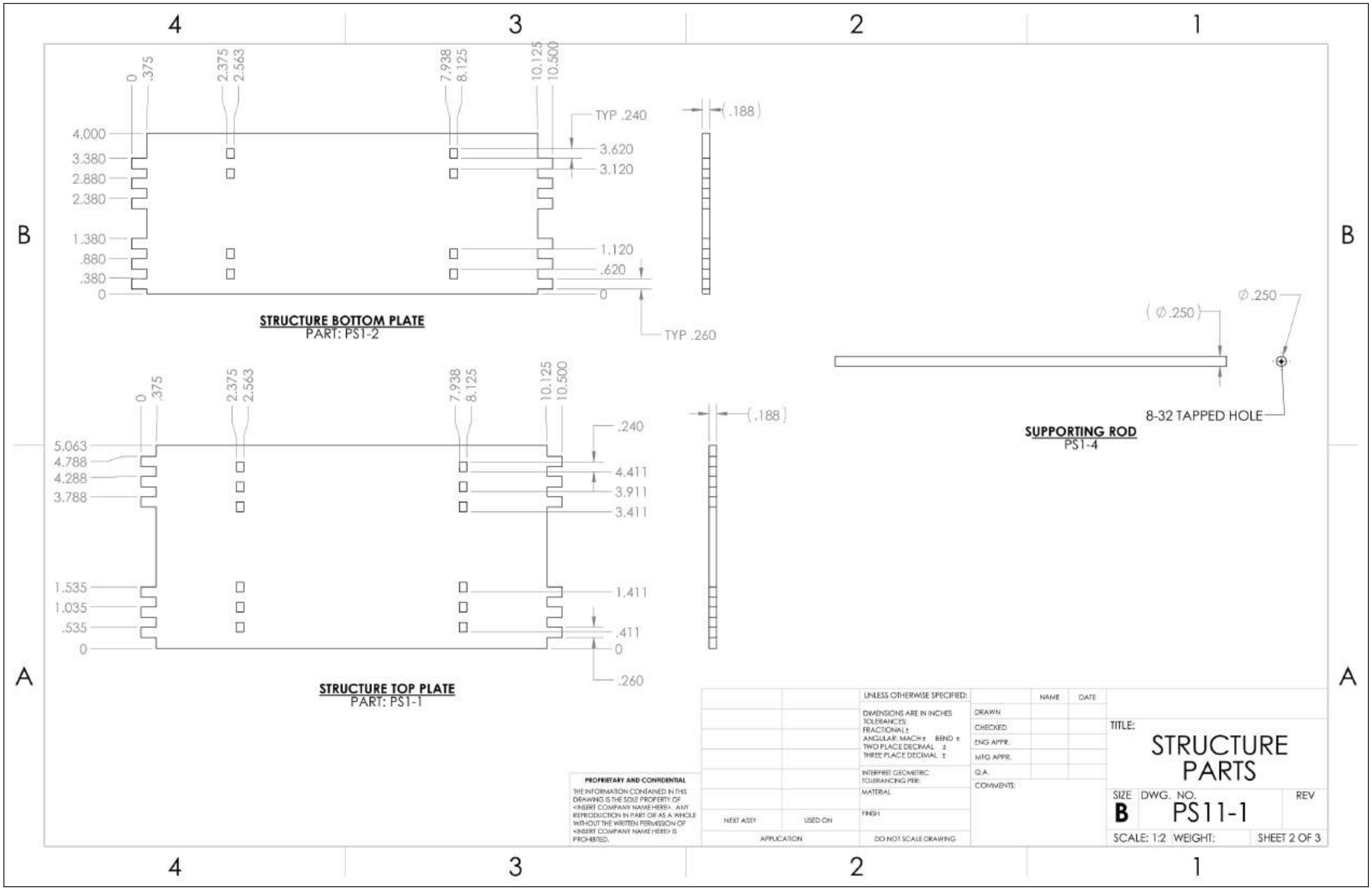


Figure 104: Payload Chassis Parts 1

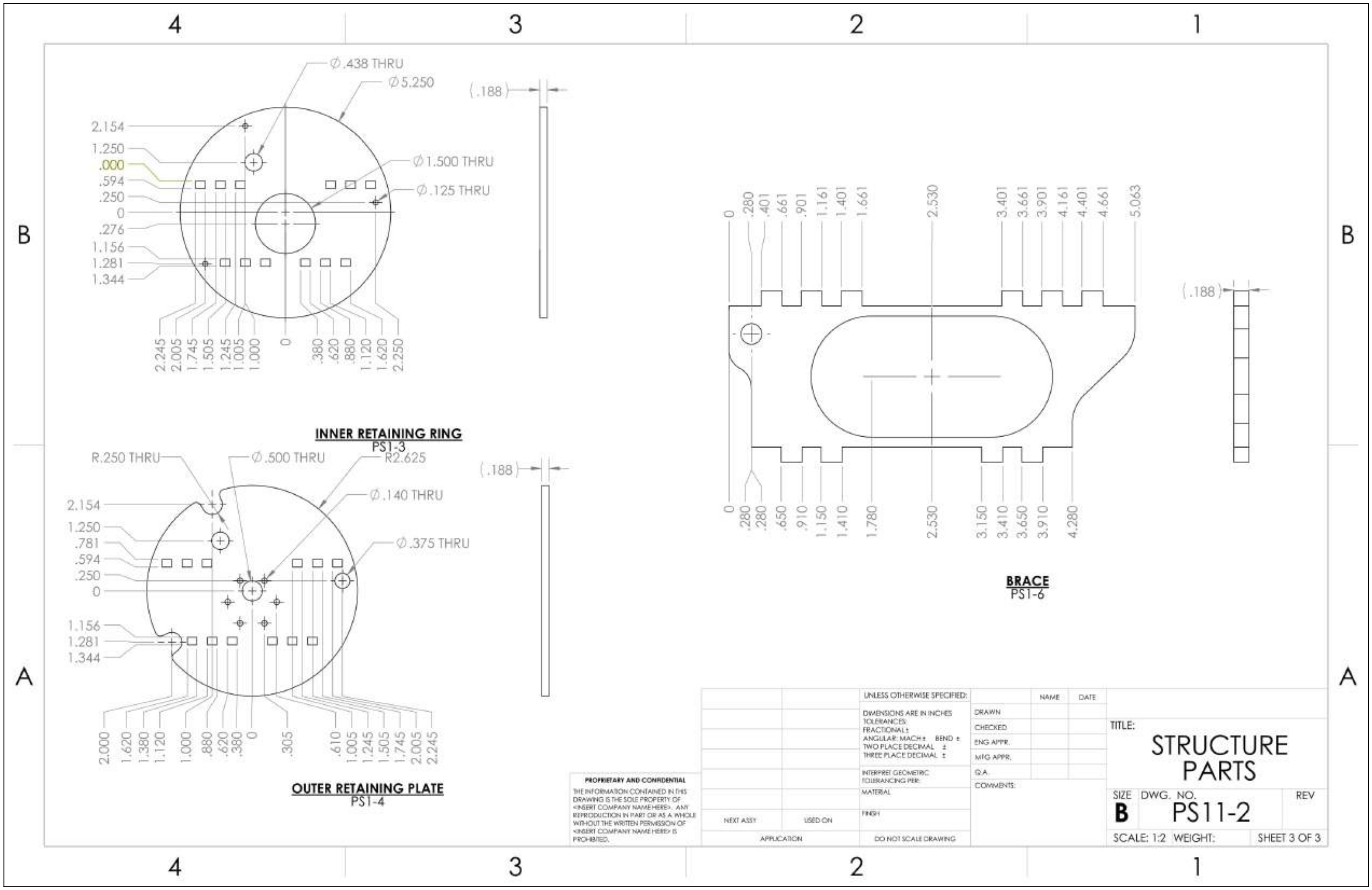
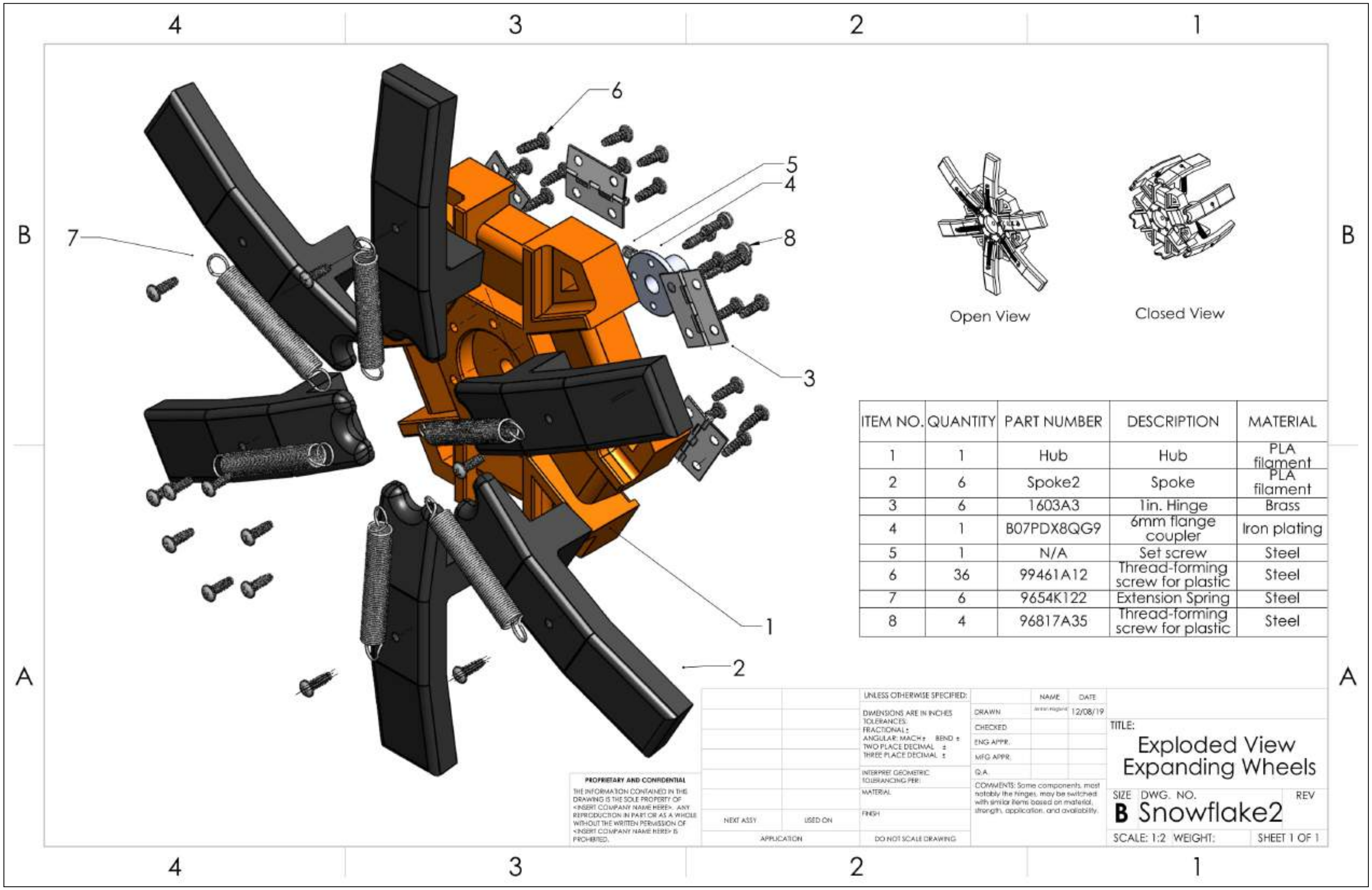


Figure 105: Payload Chassis Parts 2



ITEM NO.	QUANTITY	PART NUMBER	DESCRIPTION	MATERIAL
1	1	Hub	Hub	PLA filament
2	6	Spoke2	Spoke	PLA filament
3	6	1603A3	1in. Hinge	Brass
4	1	B07PDX8QG9	6mm flange coupler	Iron plating
5	1	N/A	Set screw	Steel
6	36	99461A12	Thread-forming screw for plastic	Steel
7	6	9654K122	Extension Spring	Steel
8	4	96817A35	Thread-forming screw for plastic	Steel

Figure 106: Payload Wheel Assembly

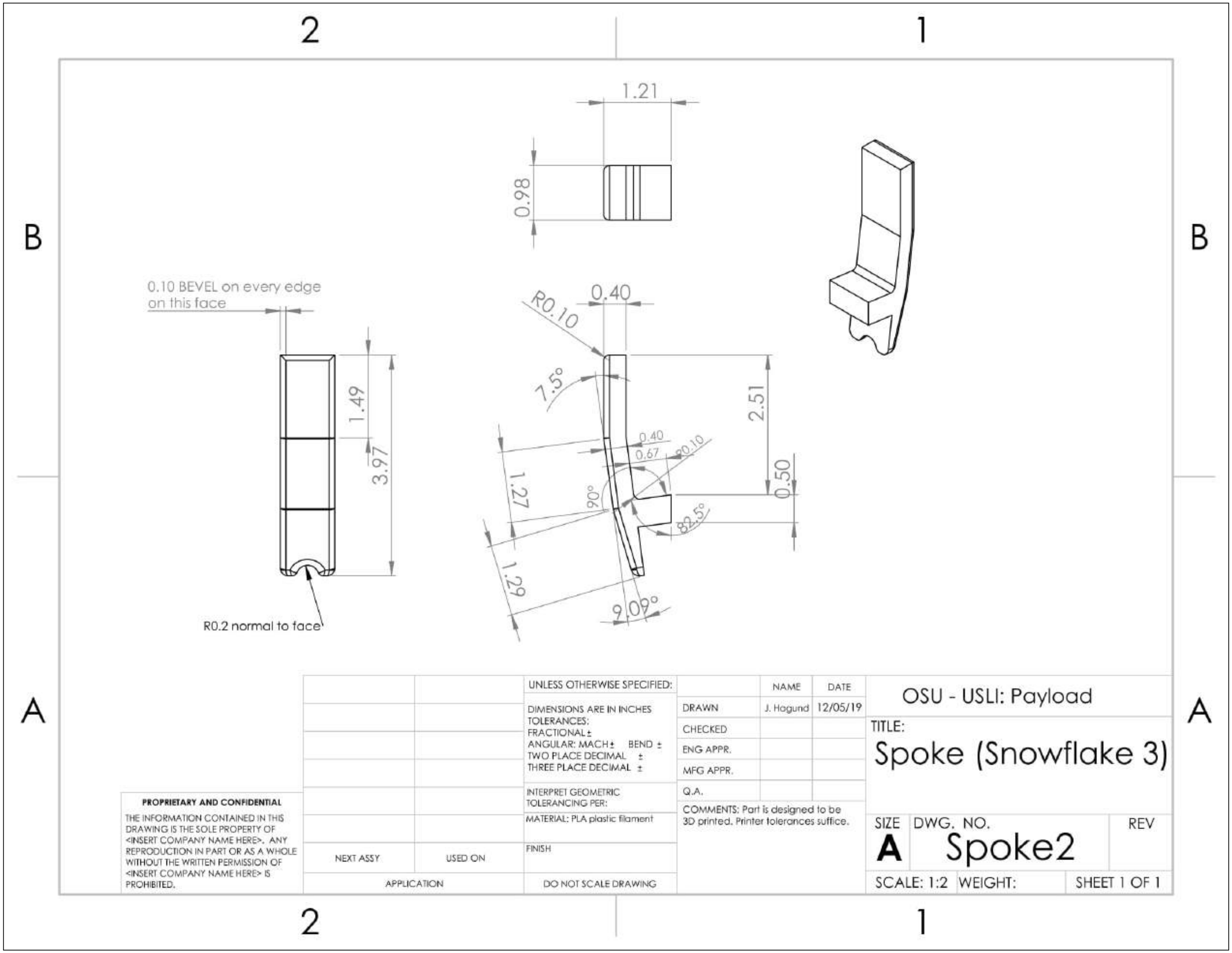


Figure 107: Payload Wheel Spoke

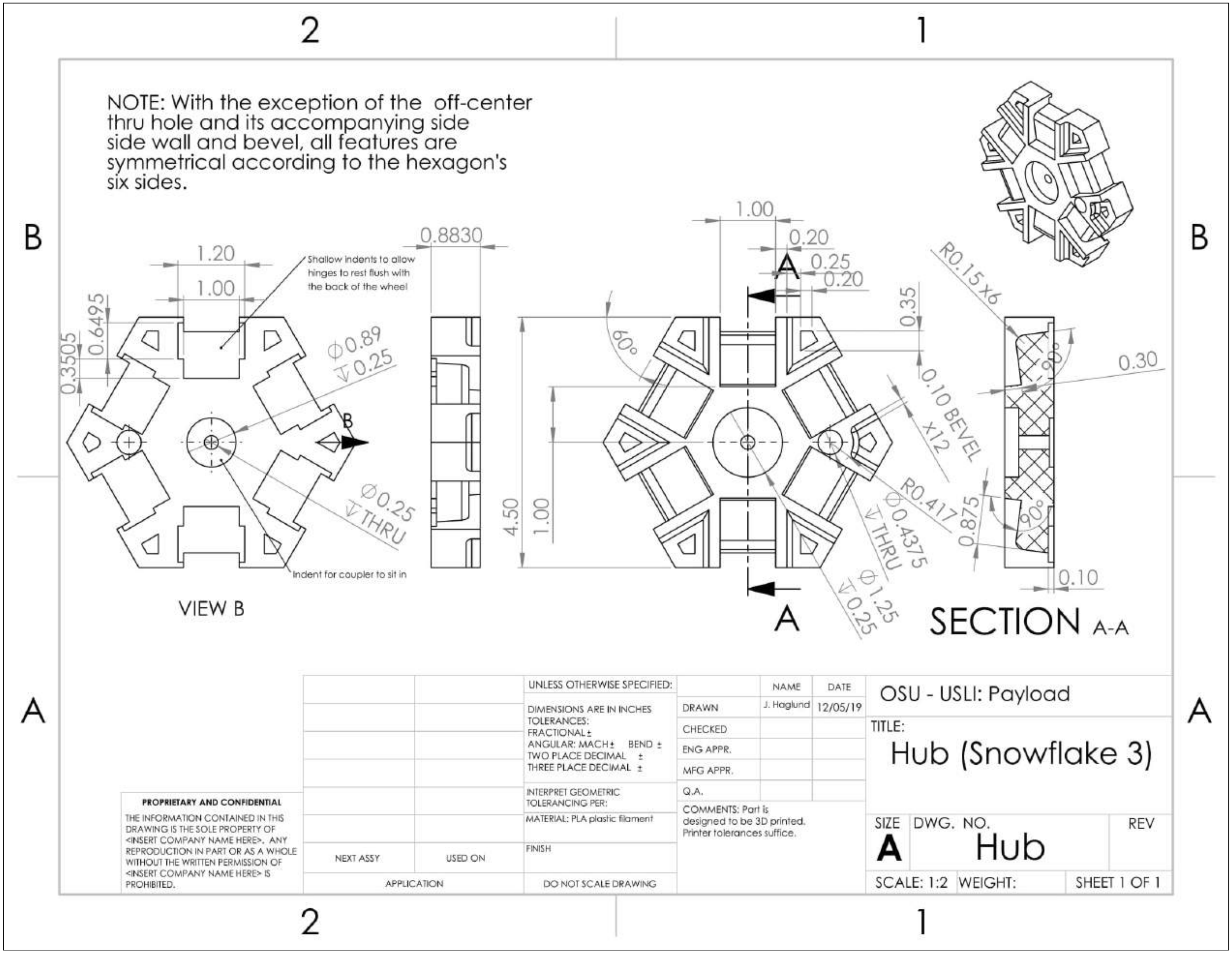
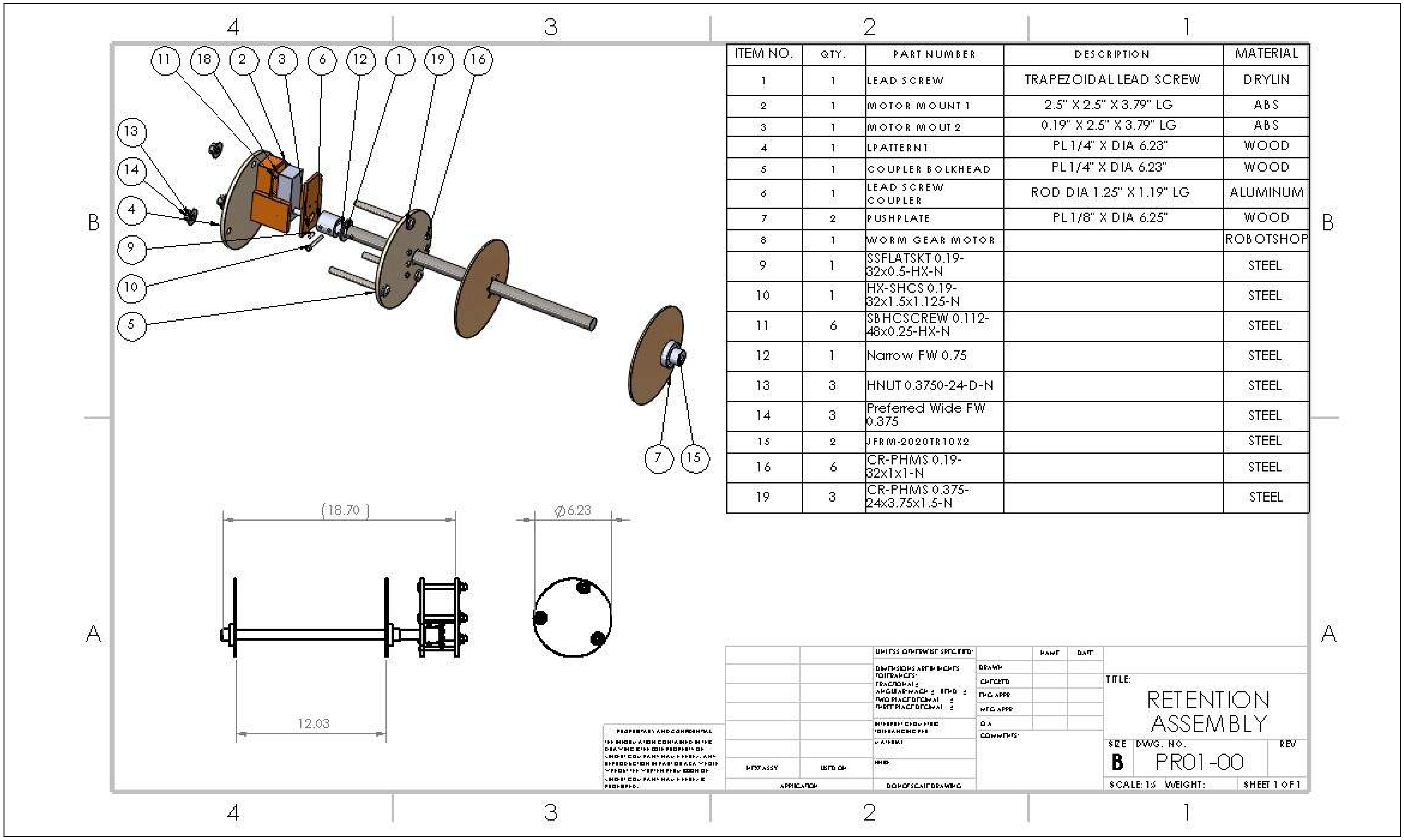


Figure 108: Payload Wheel Hub



ITEM NO.	QTY.	PART NUMBER	DESCRIPTION	MATERIAL
1	1	LEAD SCREW	TRAPEZOIDAL LEAD SCREW	DRYLIN
2	1	MOTOR MOUNT 1	2.5" X 2.5" X 3.79" LG	ABS
3	1	MOTOR MOUT 2	0.19" X 2.5" X 3.79" LG	ABS
4	1	LPATTERN1	PL 1/4" X DIA 6.23"	WOOD
5	1	COUPLER BOLKHEAD	PL 1/4" X DIA 6.23"	WOOD
6	1	LEAD SCREW COUPLER	ROD DIA 1.25" X 1.19" LG	ALUMINUM
7	2	PUSHPLATE	PL 1/8" X DIA 6.25"	WOOD
8	1	WORM GEAR MOTOR		ROBOTSHOP
9	1	SSFLATSKT 0.19-32x0.5-HX-N		STEEL
10	1	HX-SHCS 0.19-32x1.5x1.125-N		STEEL
11	6	SBHCSCREW 0.112-48x0.25-HX-N		STEEL
12	1	Narrow FW 0.75		STEEL
13	3	HNUT 0.3750-24-D-N		STEEL
14	3	Preferred Wide FW 0.375		STEEL
15	2	JFRM-2020TR10X2		STEEL
16	6	CR-PHMS 0.19-32x1x1-N		STEEL
19	3	CR-PHMS 0.375-24x3.75x1.5-N		STEEL

Figure 109: Payload Retention Assembly

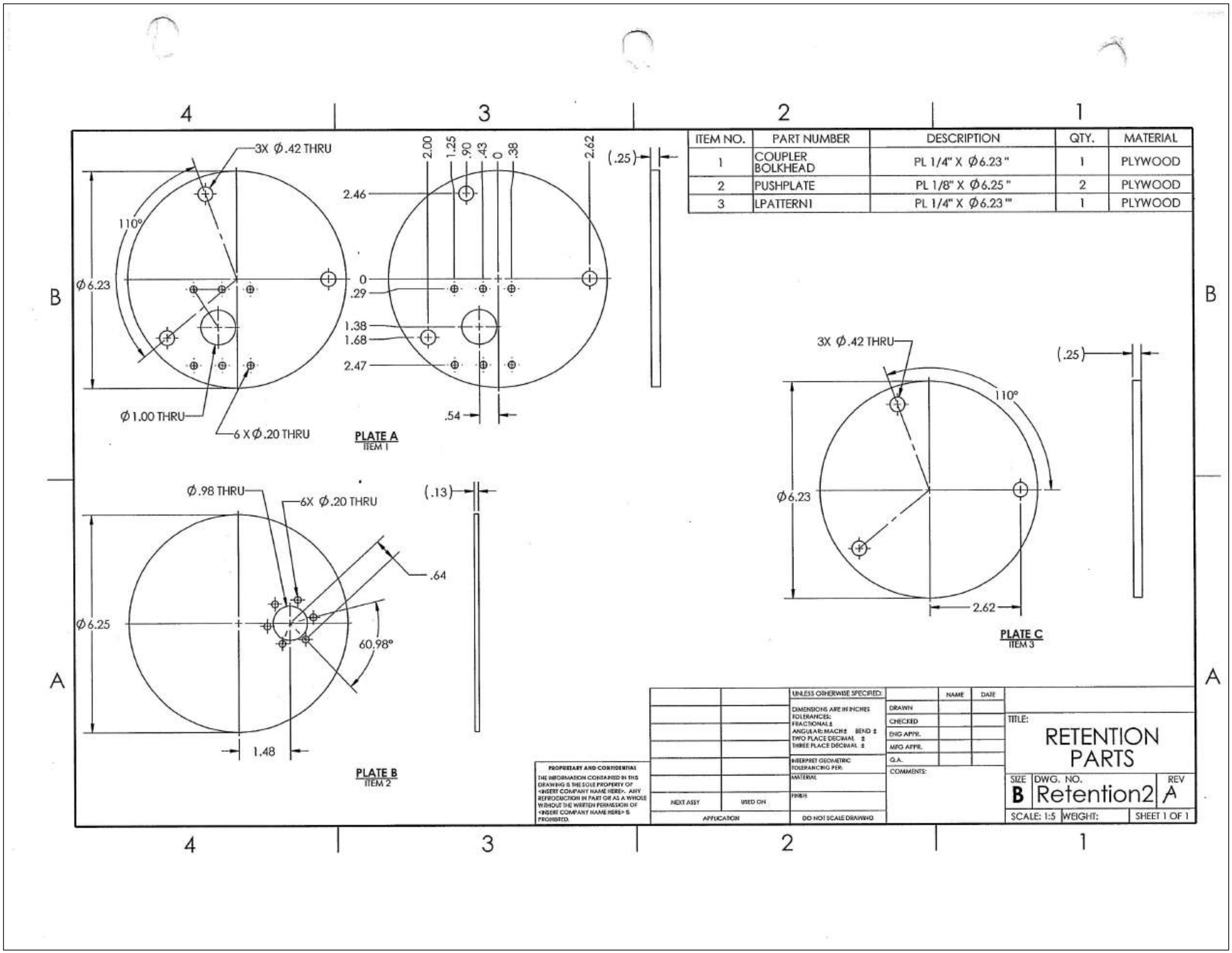


Figure 110: Payload Retention Parts 1

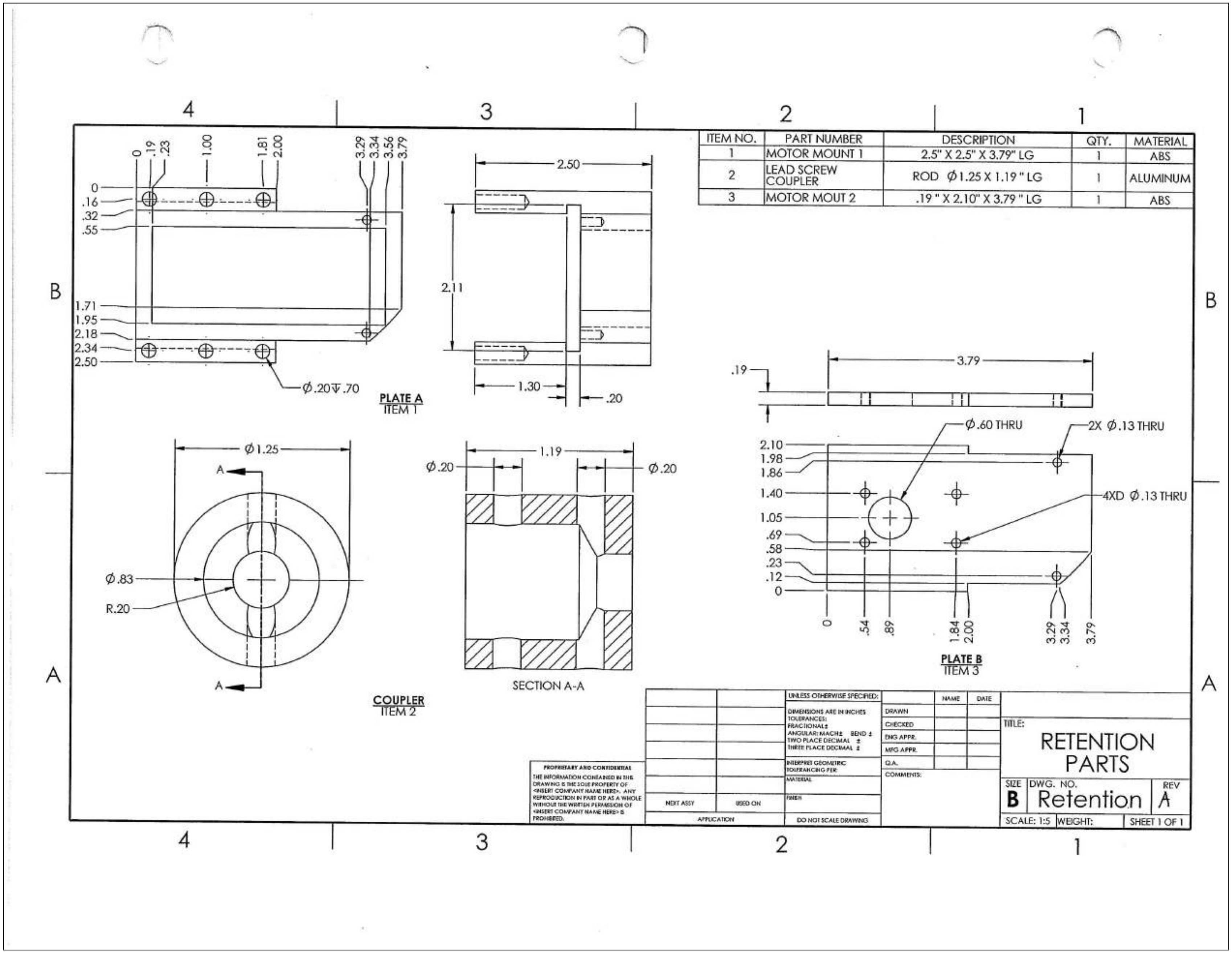
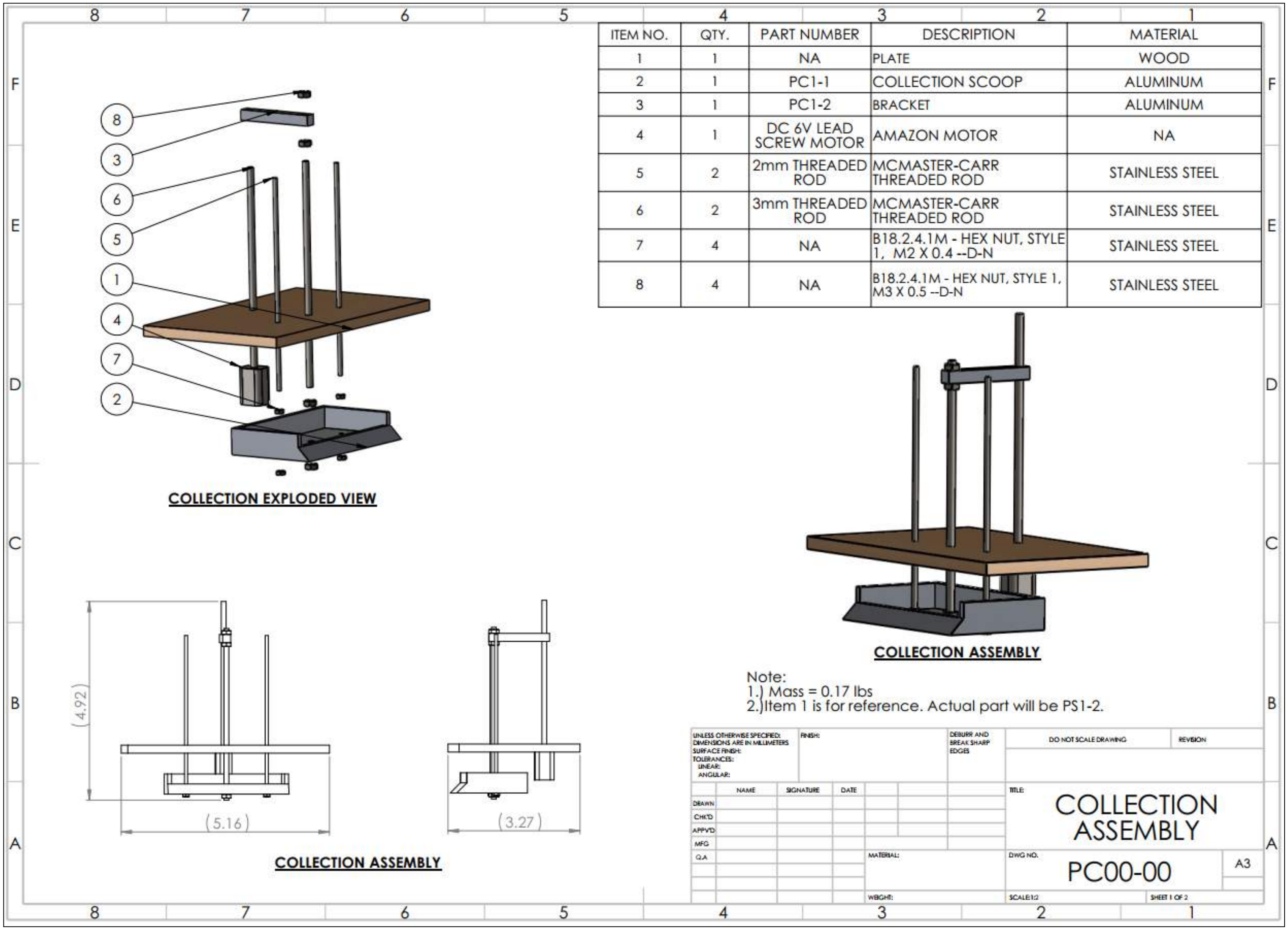


Figure 111: Payload Retention Parts 2



ITEM NO.	QTY.	PART NUMBER	DESCRIPTION	MATERIAL
1	1	NA	PLATE	WOOD
2	1	PC1-1	COLLECTION SCOOP	ALUMINUM
3	1	PC1-2	BRACKET	ALUMINUM
4	1	DC 6V LEAD SCREW MOTOR	AMAZON MOTOR	NA
5	2	2mm THREADED ROD	MCMASTER-CARR THREADED ROD	STAINLESS STEEL
6	2	3mm THREADED ROD	MCMASTER-CARR THREADED ROD	STAINLESS STEEL
7	4	NA	B18.2.4.1M - HEX NUT, STYLE 1, M2 X 0.4 --D-N	STAINLESS STEEL
8	4	NA	B18.2.4.1M - HEX NUT, STYLE 1, M3 X 0.5 --D-N	STAINLESS STEEL

Figure 112: Payload Collection Assembly

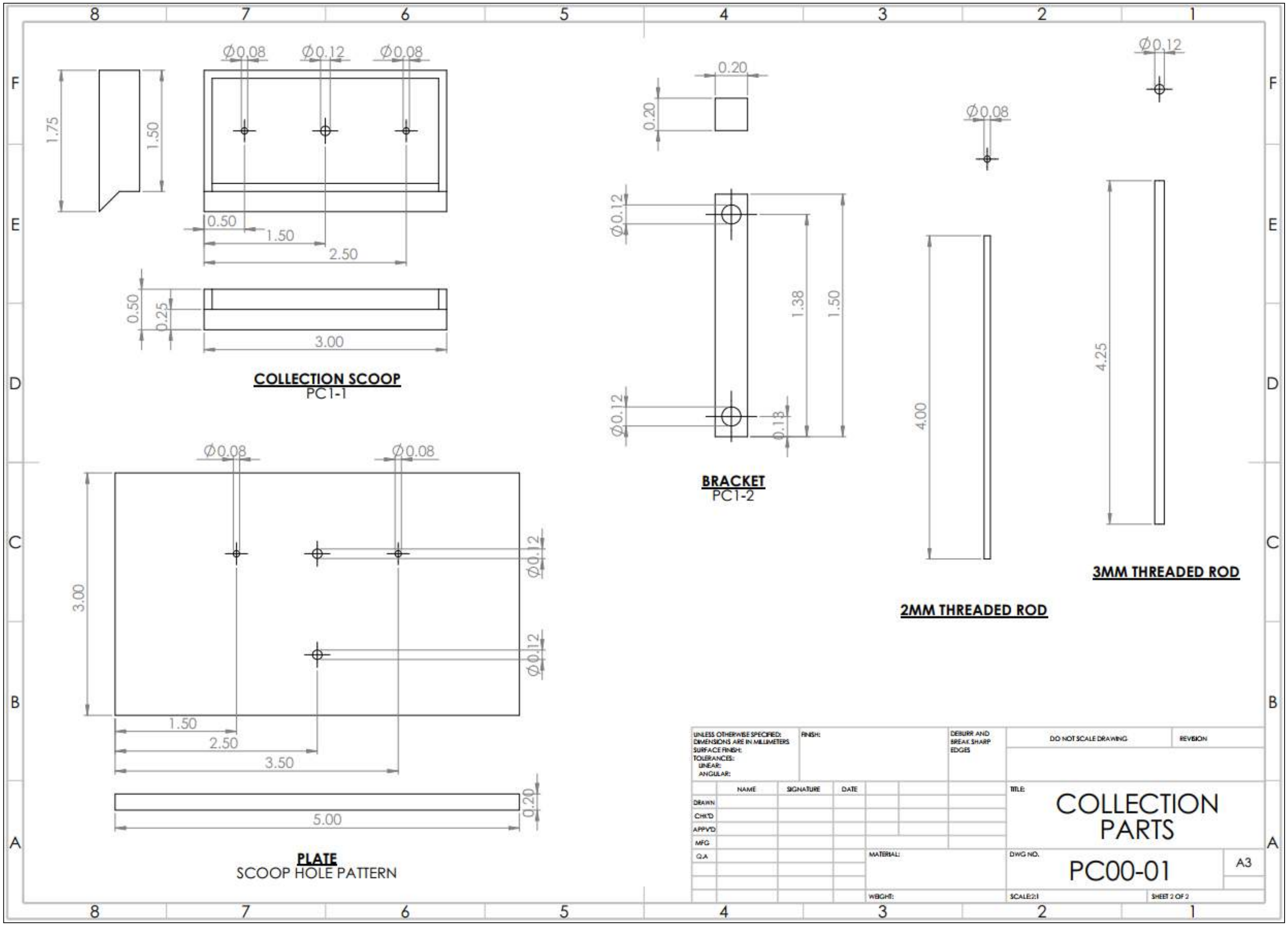


Figure 113: Payload Collection Parts

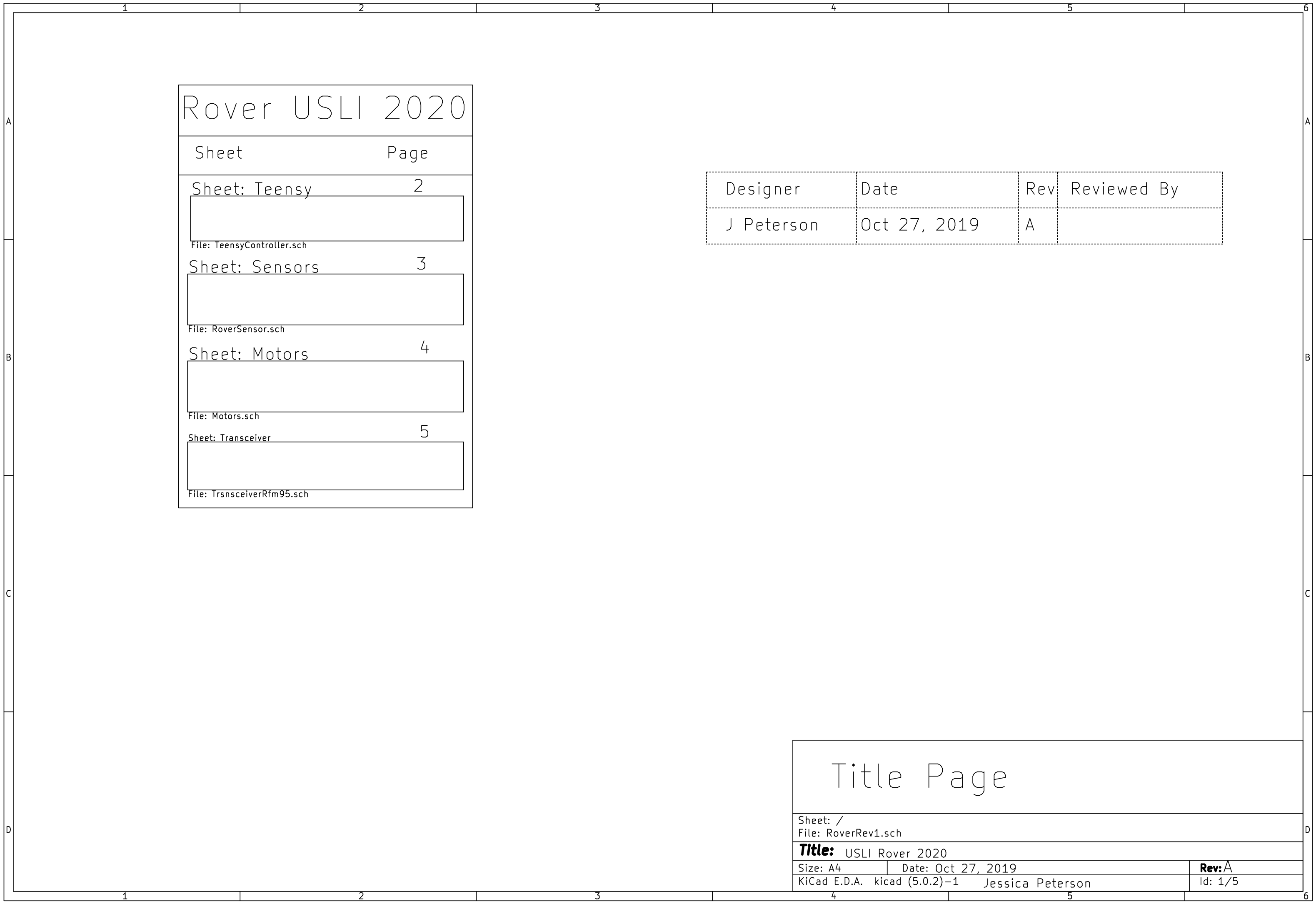


Figure 114: Payload Schematics Page 1 Title Page

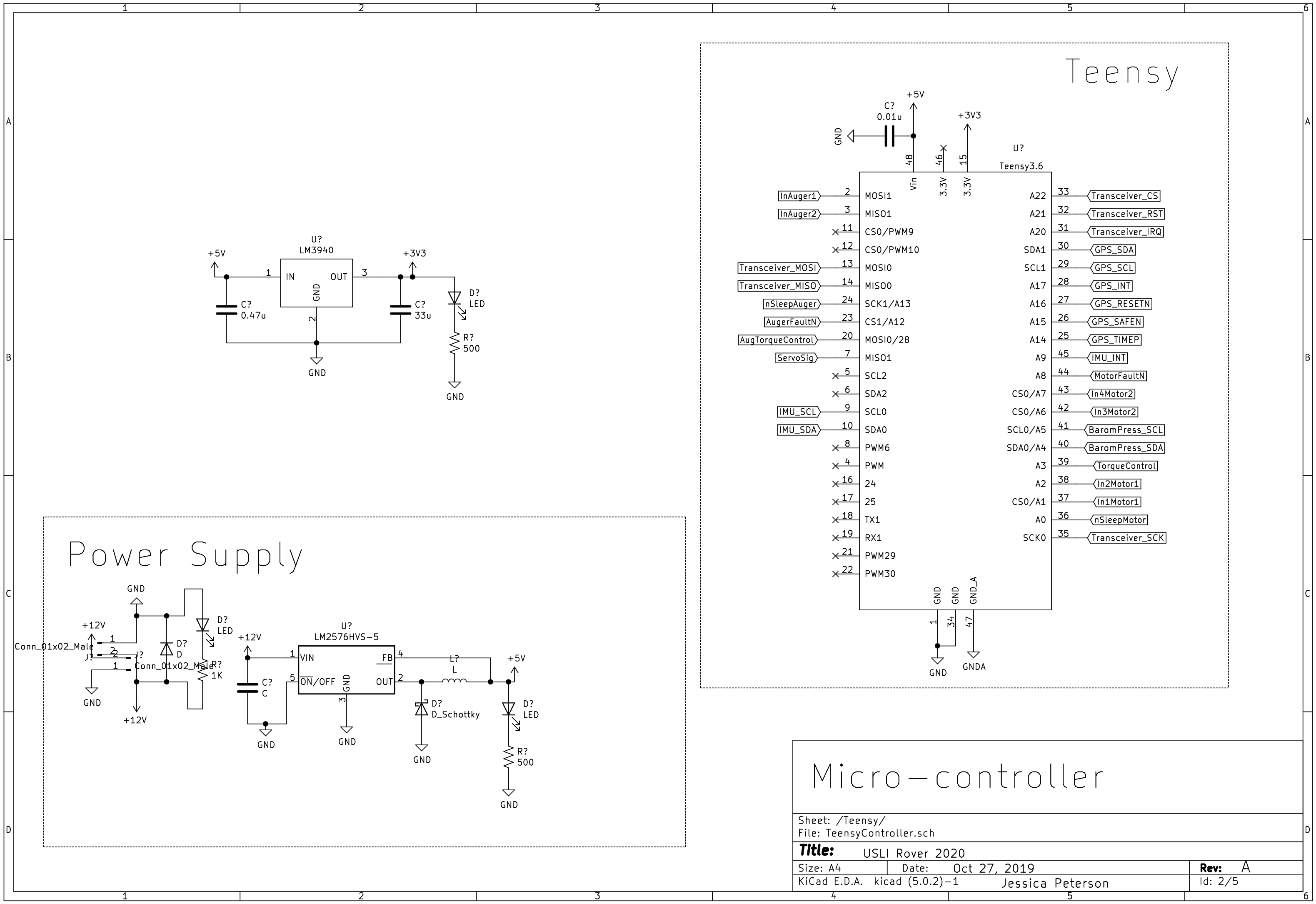


Figure 115: Payload Schematics Page 2 Microcontroller

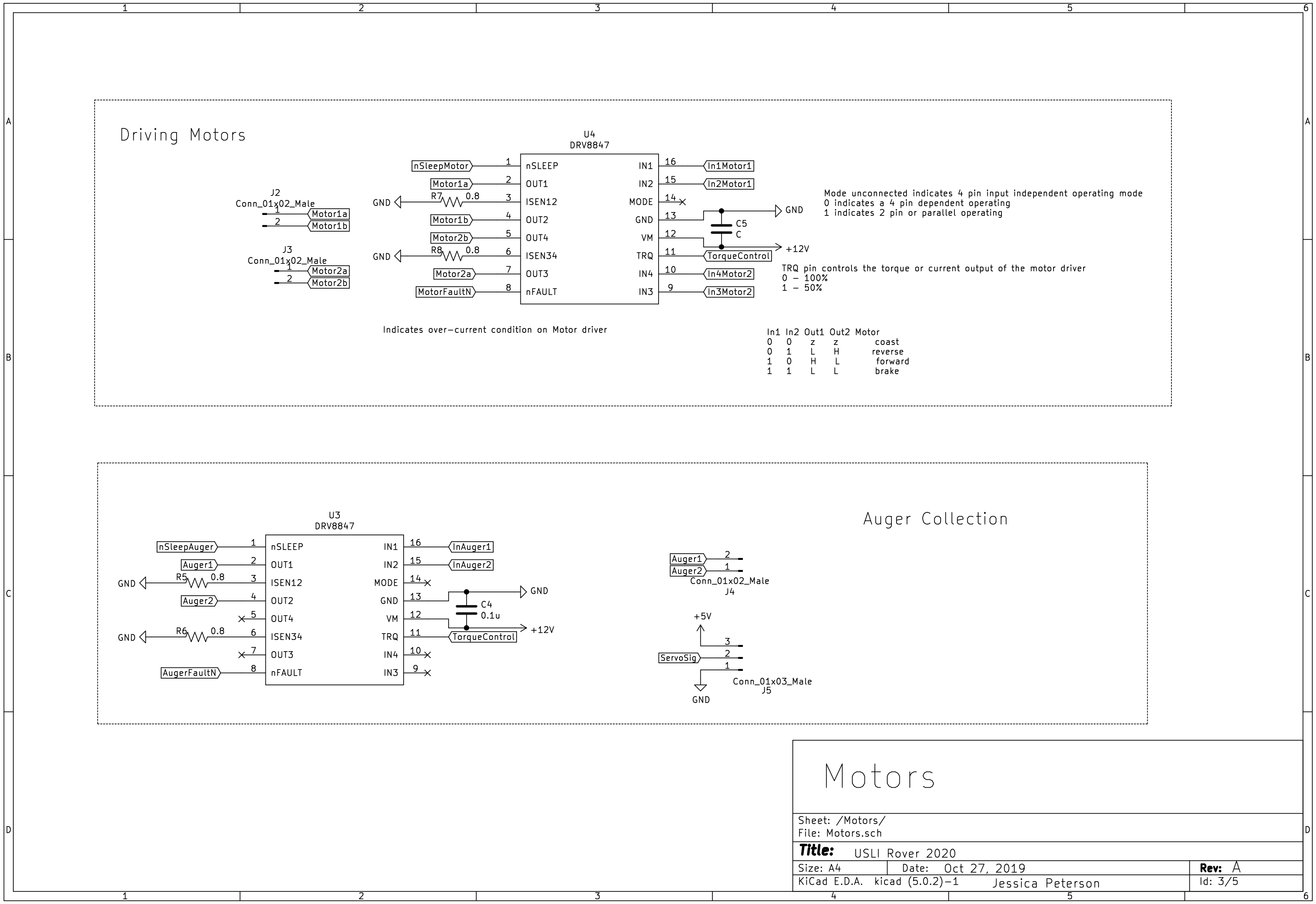


Figure 116: Payload Schematics Page 3 Sensors

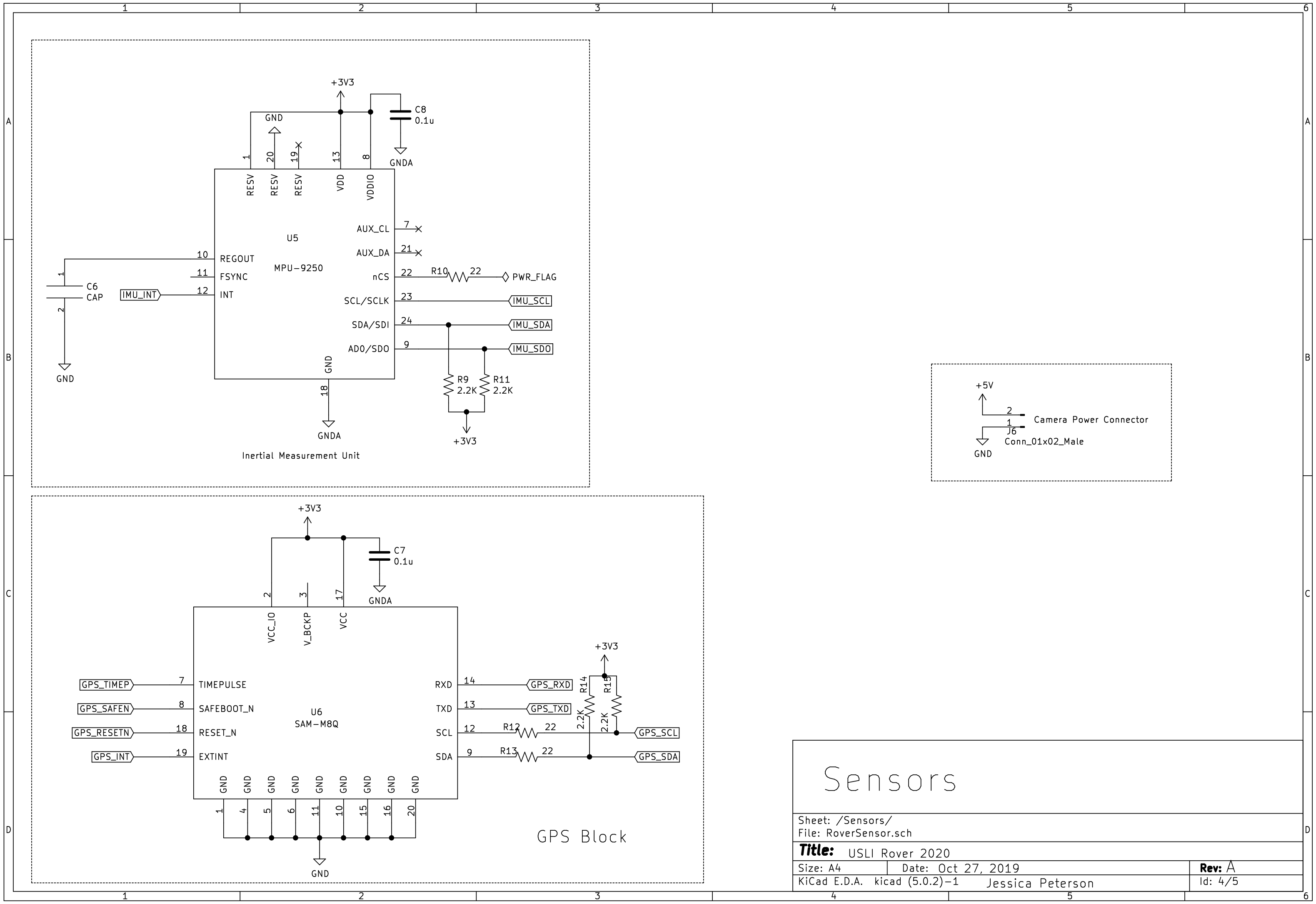


Figure 117: Payload Schematics Page 4 Motors

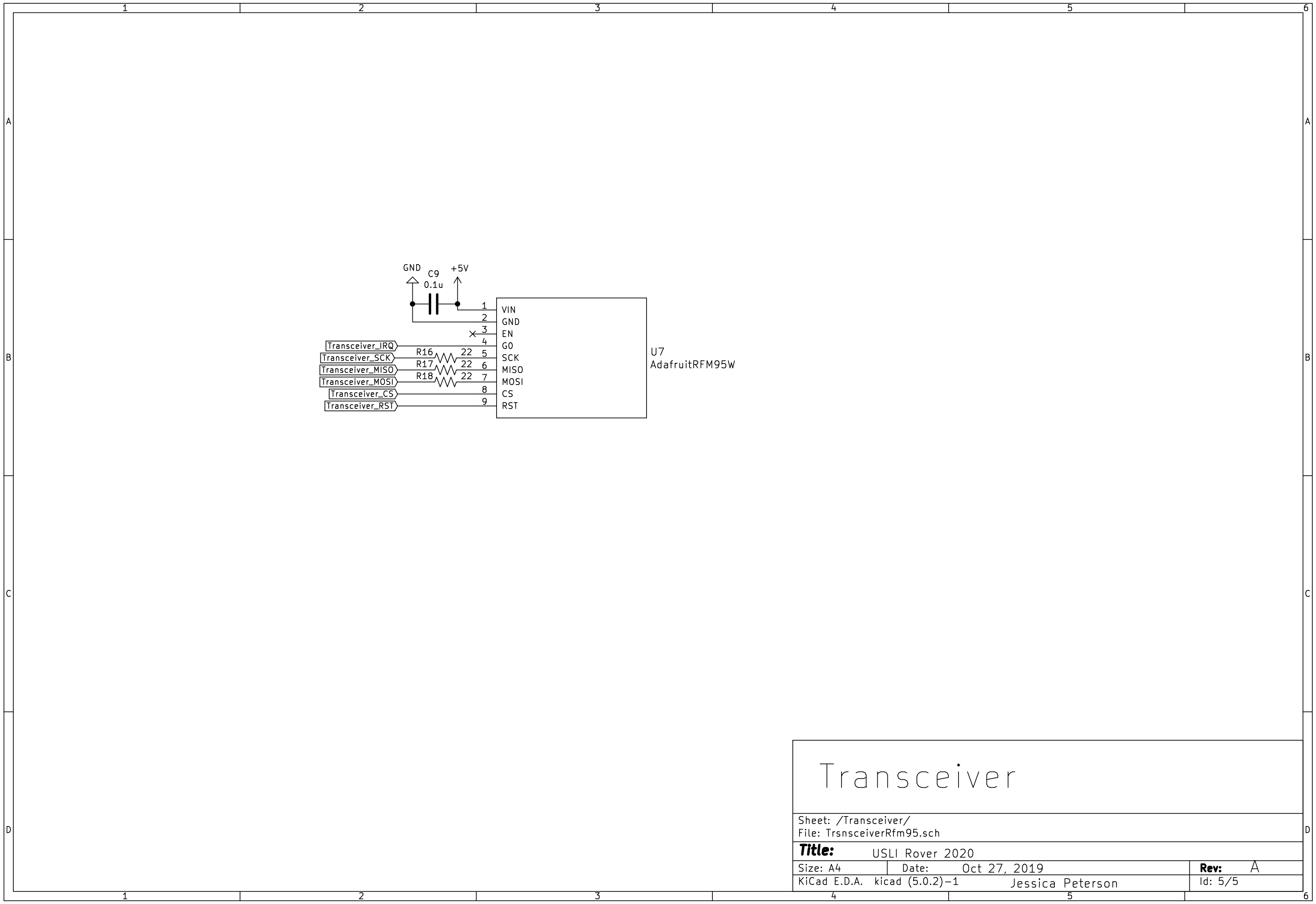


Figure 118: Payload Schematics Page 5 Transceiver

9.3.1 Hand-Written Work for Payload Drivetrain

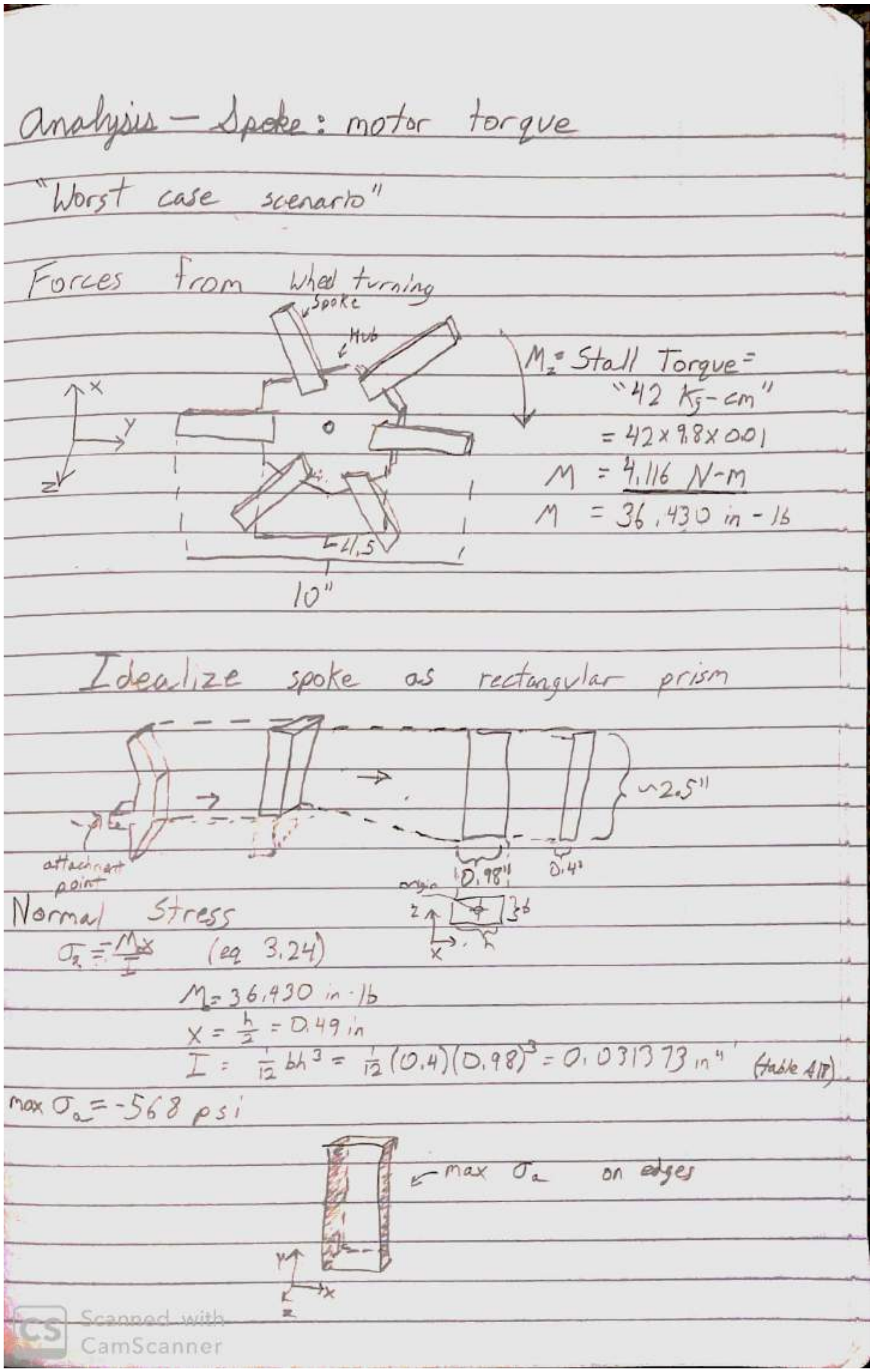


Figure 119: Analysis of Spoke Bending Stress Under Applied Motor Stall Torque

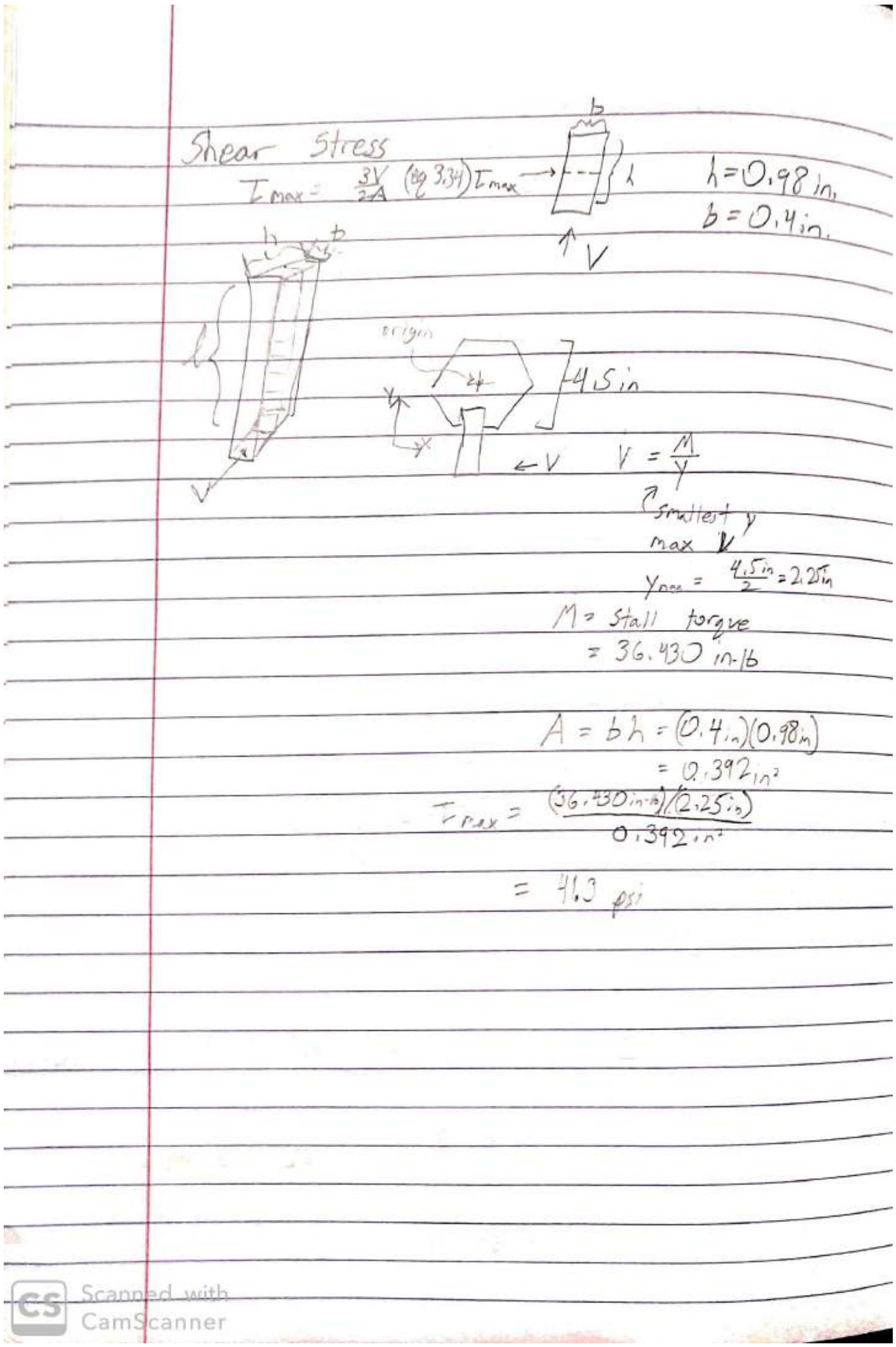


Figure 120: Analysis of Spoke Shear Stress Under Applied Motor Stall Torque

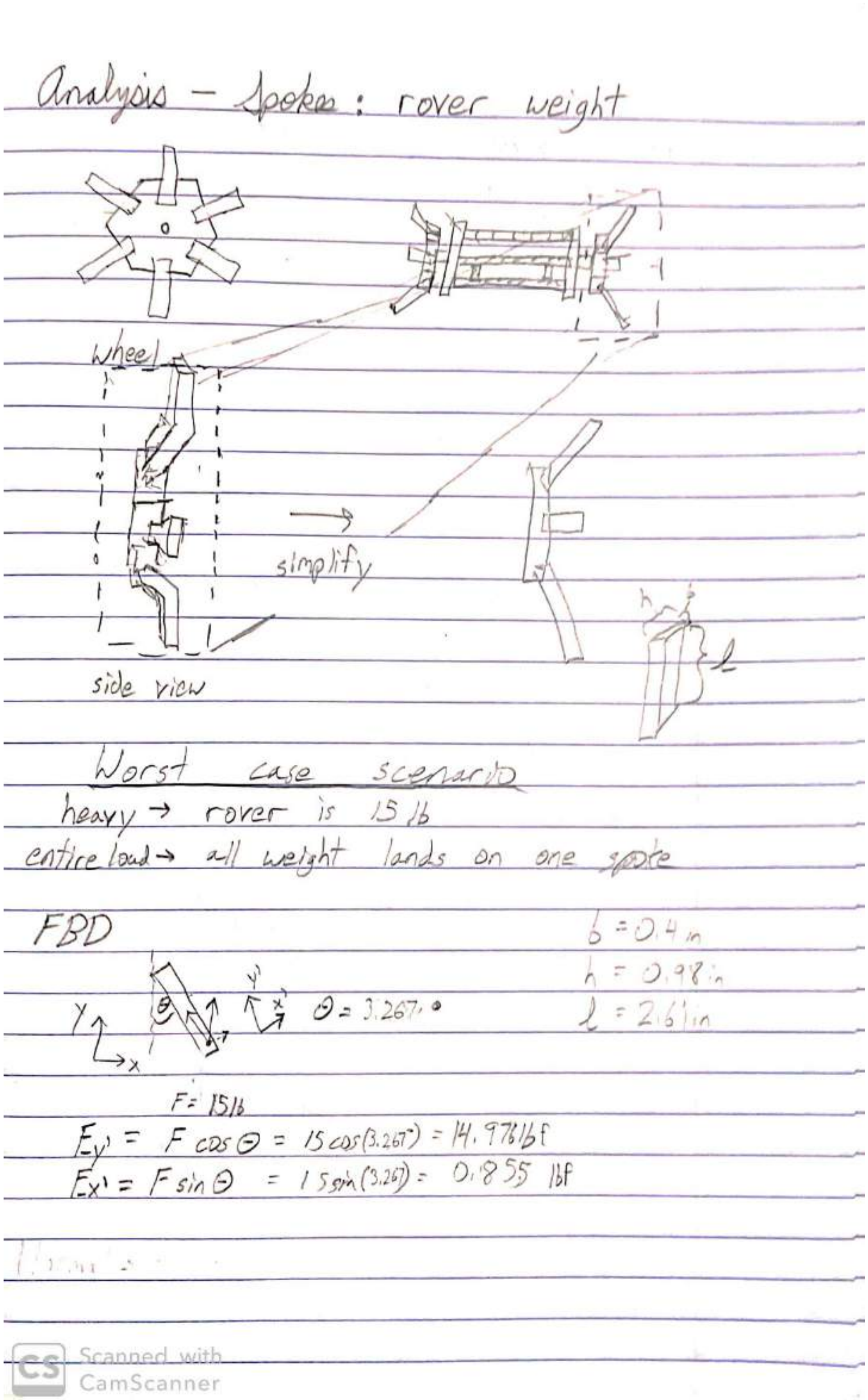
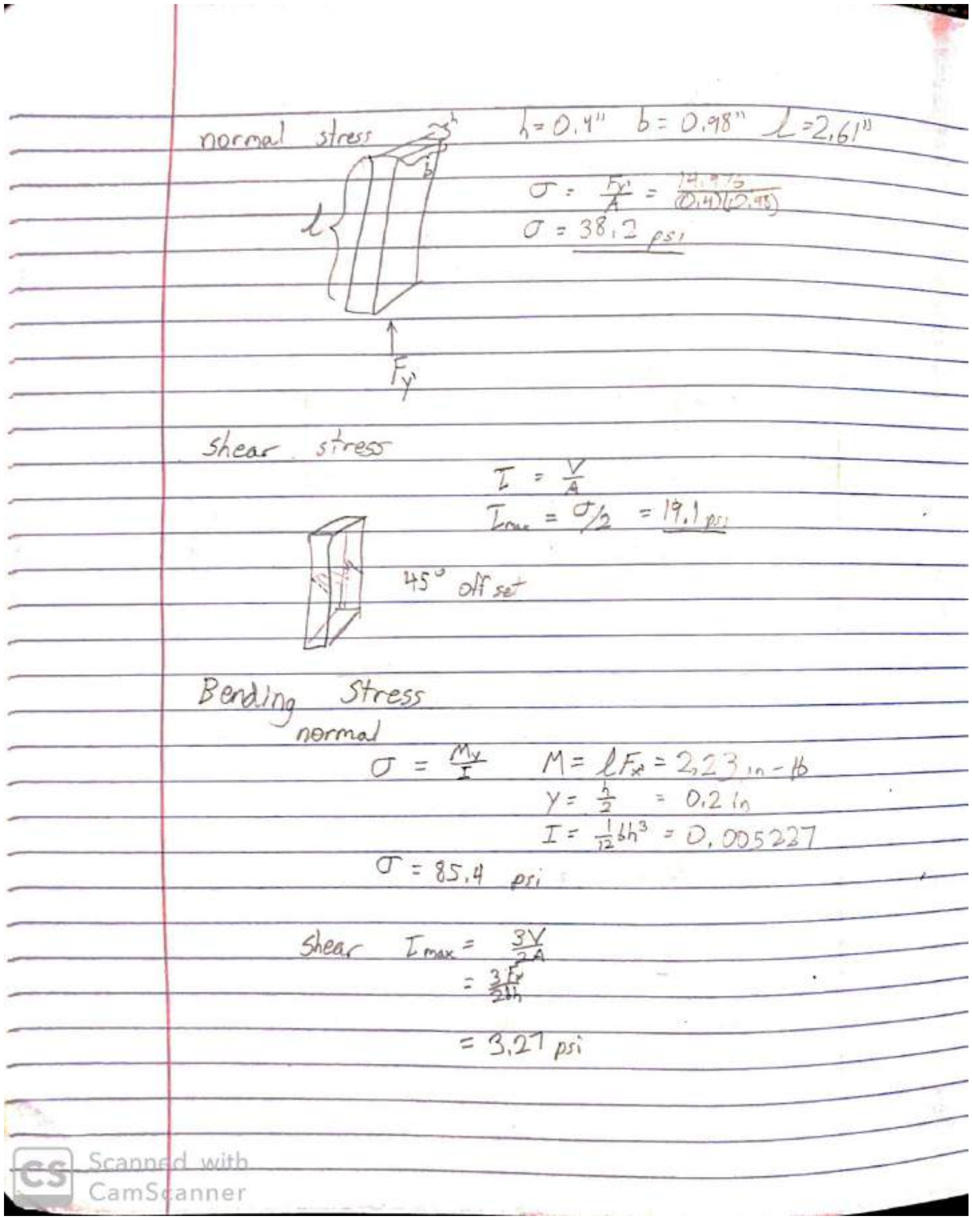


Figure 121: Analysis of Spoke Under Applied Weight of Payload Rover



normal stress

$h = 0.4''$ $b = 0.98''$ $l = 2.61''$

$\sigma = \frac{F_{y'}}{A} = \frac{14.976}{(0.4)(0.98)}$

$\sigma = \underline{38.2 \text{ psi}}$

l

b

h

$F_{y'}$

shear stress

$\tau = \frac{V}{A}$

$\tau_{max} = \sigma/2 = \underline{19.1 \text{ psi}}$

45° offset

Bending Stress

normal

$\sigma = \frac{My}{I}$ $M = lF_x = 2.23 \text{ in-lb}$

$y = \frac{h}{2} = 0.2 \text{ in}$

$I = \frac{1}{12}bh^3 = 0.005227$

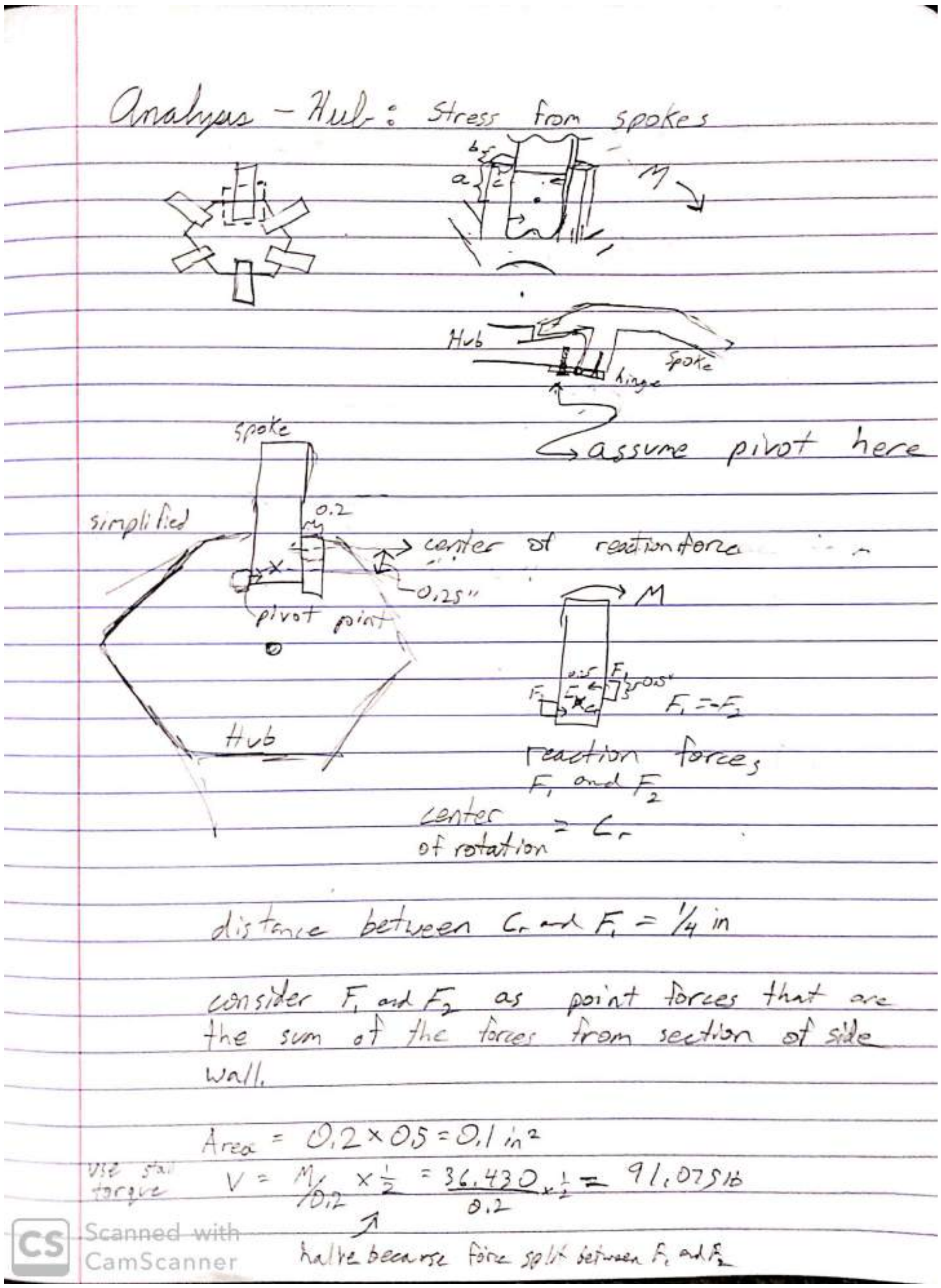
$\sigma = 85.4 \text{ psi}$

shear $\tau_{max} = \frac{3V}{2A}$

$= \frac{3F_x}{2bh}$

$= 3.27 \text{ psi}$

Figure 122: Analysis of Spoke Shear Stress Under Applied Weight of Payload Rover


Analysis – Hub: Stress from spokes

Hub
spoke
hinge
assume pivot here

spoke
simplified
0.2
center of reaction force
0.25"
pivot point
Hub

M
0.5
F_1
F_2
0.05"
$F_1 = -F_2$

reaction forces F_1 and F_2

center of rotation = C_r

distance between C_r and F_1 = 1/4 in

consider F_1 and F_2 as point forces that are the sum of the forces from section of side wall.

Area = $0.2 \times 0.5 = 0.1 \text{ in}^2$

use stall torque $V = \frac{M}{0.2} \times \frac{1}{2} = \frac{36.430}{0.2} \times \frac{1}{2} = 91.075 \text{ lb}$

halve because force split between F_1 and F_2

Figure 123: Analysis of Hub Sidewall Strength Under Applied Load

$\tau = \frac{91.075 \text{ lb}}{0.1 \text{ in}^2} = 910.8 \text{ psi}$ ← a little high

→ Try not to let spoke pivot by its hinge (in the wrong direction that is)

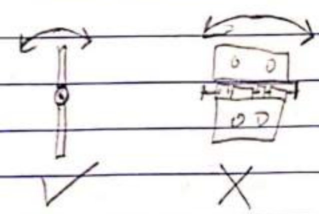


Figure 124: Analysis of Hub Sidewall Strength Under Applied Load

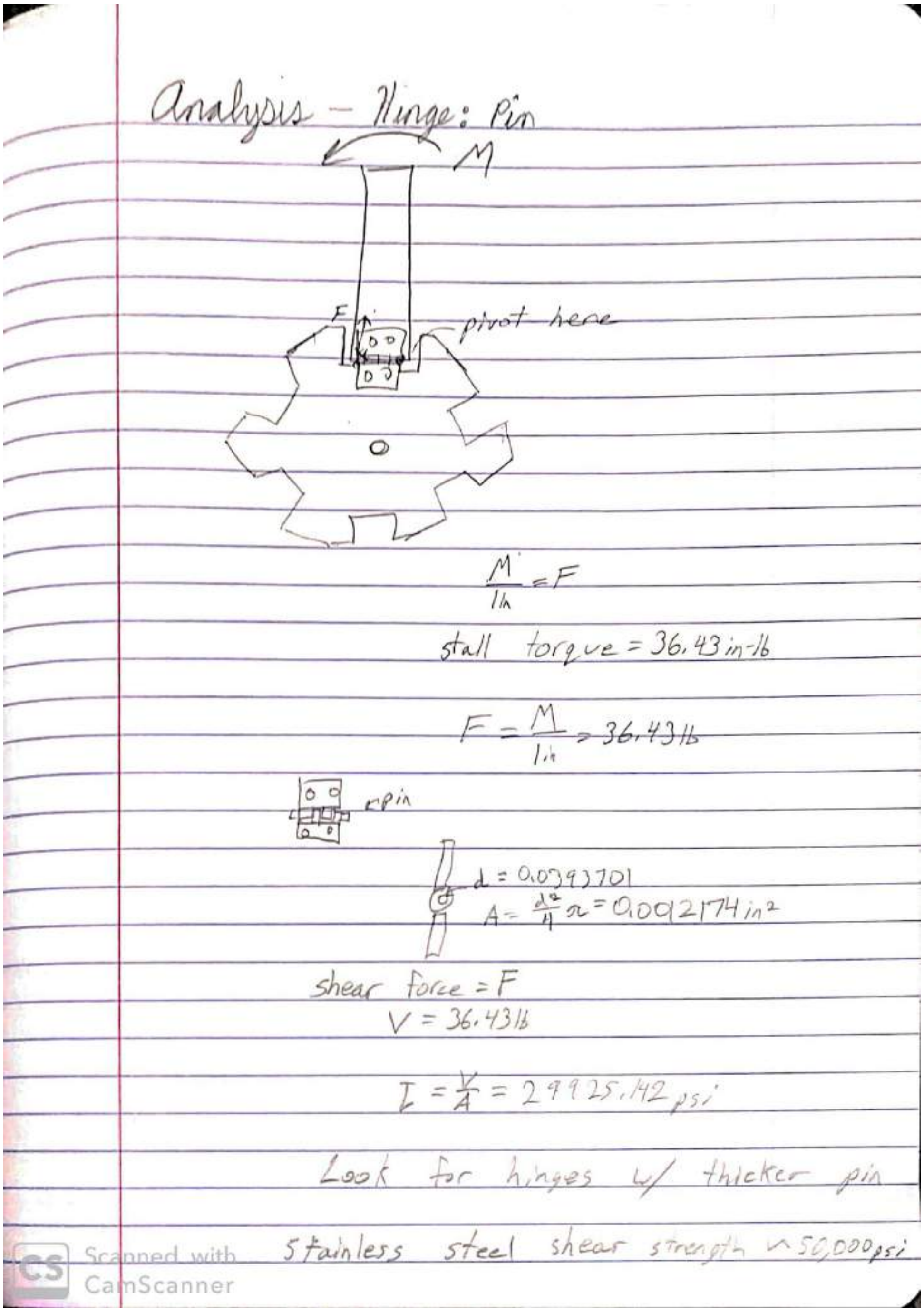


Figure 125: Analysis of Hinge Pin Shear Stress Under Applied Load