Oregon State University

2018 NASA SL Team

104 Kerr Admin Bldg. # 1011

Corvallis, OR 97331

Critical Design Review

January 12, 2018

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Acronym Dictionary

9DOF Nine Degree of Freedom. 124, 130, 131

ABS Acrylonitrile Butadiene Styrene - A Common Thermoplastic Polymer. 32, 112, 122

AGL Above Ground Level. 21, 57, 61, 62, 176, 198

AIAA American Institute of Aeronautics and Astronautics. 13, 20, 223, 227

ANSI American National Standards Institute. 118

APCP Ammonium Perchlorate Composite Propellant. 200

ARM Advanced Reduced Instruction Set Computing (RISC) Machine - a family of RISC architectures for computer processors. 123

ARRD Advanced Retention and Release Device. 79, 80, 111, 141, 146

ASL Above Sea Level. 61, 62

ATF Alcohol Tobacco Firearms. 48

ATU Avionics Telemetry Unit. 54–56, 66, 73, 74, 155

AVID Advancement Via Individual Determination. 223

AWG American Wire Gauge. 134

BJT Bipolar Junction Transistor. 12, 128

CAD Computer-aided design. 112, 121, 141

CAR Canadian Association of Rocketry. 200

CDR Critical Design Review. 194, 195, 200, 201

CFR Code of Federal Regulations. 197

CPU Central Processing Unit. 123

DC Direct Current. 128

EIT Electronic and Information Technology. 197

EMI Electromagnetic Interference. 205

FAA Federal Aviation Administration. 211

FMEA Failure Mode Effects Analysis. 3, 86, 105, 194

FN Foreign National. 195

FRR Flight Readiness Review. 196, 198, 202, 204, 207

GND The Ground Reference of an Electrical Circuit. 128, 150

GPIO General Purpose Inputs and Outputs. 123, 124, 133

GPS Global Positioning System. 43, 49–51, 56, 66, 73, 74, 128

GPU Graphics Processing Unit. 123

HDPE High-density polyethylene. 32, 110, 113, 114, 143

HPR High Powered Rocketry. 15, 47, 80, 174

I/O Inputs and Outputs. 138

I2C Inter-Integrated Circuit. 131

IC Integrated Circuit. 131, 137

ICE Innovative Composite Engineering. 22, 36

ID Internal Diameter. 21, 36, 114, 115

IMU Inertial Measurement Unit. 18, 111, 130, 131, 138, 140, 190, 207

ISM Industrial, Scientific, and Medical. 50

JST Japan Solderless Terminal. 138

KE Kinetic Energy. 45

LDO Low Drop Out Regulators. 56

LED Light Emitting Diode. 73, 74, 82, 149, 182, 192

LIDAR Light Detection and Ranging. 126

LiPo Lithium Polymer. 9, 35, 54, 55, 73, 74, 111, 137, 192

LRR Launch Readiness Review. 207

MLCC Multi-Layer Ceramic Capacitor. 150

MPRL Machine Product and Realization Laboratory. 193

MSDS Material Safety Data Sheet. 211

MSFC Marshall Space Flight Center. 15

NAR National Association of Rocketry. 15, 71, 77, 81, 83, 194, 198, 200, 211

NASA National Aeronautics and Space Administration. 71, 77, 81, 83, 176, 186, 195, 200, 204, 211, 227, 228

NFPA National Fire Protection Agency. 16

OD Outer Diameter. 21

OSR Teams Oregon State Rocket Teams. 228

OSRT Oregon State Rocket Team. 13, 18, 19, 23, 47, 48, 187, 188

OSU Oregon State University. 26, 40, 227

PCB Printed Circuit Board. 50, 52, 66, 124, 138, 193

PDR Preliminary Design Review. 20, 22, 28, 51, 111, 132, 141, 188, 195, 196, 198

PLEC Payload Ejection Controller. 149–151

PPE Personal Protective Equipment. 80, 174, 175

PWM Pulse Width Modulation. 127, 177

ReCo Recovery Controllers. 64, 65

RF Radio-Frequency. 19, 21, 23, 26, 50–52, 56, 65, 66, 73, 74, 150

RISC Reduced Instruction Set Computing. 10, 123

ROS Robot Operating System. 111, 124, 138, 140, 141

RRC3 Rocket Recovery Controller 3. 47, 65, 72–74, 81, 82

RSO Range Safety Officer. 15, 81, 83, 84, 146, 200, 201, 204, 211

RSP Range Service Provider. 200

RX Receive. 49, 50, 128

SDRAM Synchronous Dynamic Random-Access Memory. 123

SL Student Launch. 47

SLAM Simultaneous Localization and Mapping. 139

SMA Sub-Miniature Version A Connector. 49, 50, 73, 74, 149

SPI Serial Peripheral Interface. 51, 54, 131

STEM Science, Technology, Engineering and Mathematics. 187, 196, 223, 224

ToF Time of Flight. 126

TRA Tripoli Rocketry Association, Inc.. 15, 194, 198, 200, 211

TX Transmit. 128

UART Universal Asynchronous Receiver-Transmitter. 51, 54

USLI University Student Launch Initiative. 18, 47, 71, 77, 81, 83, 187, 188, 196, 204, 223, 224, 228

VCC Common Voltage of the Collectors of a Bipolar Junction Transistor (BJT) devices. 128

1 General Information

1.1 Adult Educators

The Oregon State Rocket Team (OSRT) has one team advisor and one team mentor whose information can be found in Table 1.

Table 1: Team Organization Chart

Name	Nancy Squires	Joe Bevier
Professional Title	Senior Instructor	OROC TRA TAP
Academic Institution	Oregon State University	Oregon State University
Position Within OSRT	Team Advisor	Team Mentor
Contact	squiresn@engr.orst.edu (541) 740-9071	joebevier@gmail.com (503) 475-1589
TRA Number, Certification Level	TRA #15210 Level 3 NAR #97371 Level 3	TRA #12578 Level 3 NAR #87559 Level 3

1.2 Student Team Leadership

The OSRT has a team leader and safety officer responsible for the proper implementation of the safety plan, their information can be found in Table 2.

Table 2: Student Team Leadership Information

Name	Evan Gonnerman	Timothy Lewis
Title Within OSRT	Team Leader	Safety Officer
Contact	evangonnerman@gmail.com (503) 858-8806	lewis@oregonstate.edu (503) 453-6396
NAR Number, Certification Level	NAR #104618, N/A	NAR #104373, N/A

1.3 Team Structure and Organization

The OSRT consists of 37 members from the schools of Mechanical Engineering, Electrical Engineering, and Computer Science. The team strives to involve members of the campus American Institute of Aeronautics and Astronautics (AIAA) chapter and students of the local high school (Corvallis High School) as an effort to enhance the educational outreach.
Due to the multi-faceted nature of this project, it has been broken up into three sub-teams, according to technical design, with the following team descriptions:

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

- *Aerodynamics-Recovery* – Responsible for the electronics behind aerodynamic stability, all parachute systems for recovery systems, and design of stability measures. Key requirements are to ensure a safe landing, monitor kinetic energy requirements, and fabricate electrical and mechanical hardware to ensure aerodynamic flight.
- *Payload* – Responsible for the design, fabrication, and testing of a rover capable of traveling five ft. and deploying a set of solar panels. Key responsibilities include meeting all customer requirements, designing a payload that reliably functions, and rigorously testing prior to final launch.

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

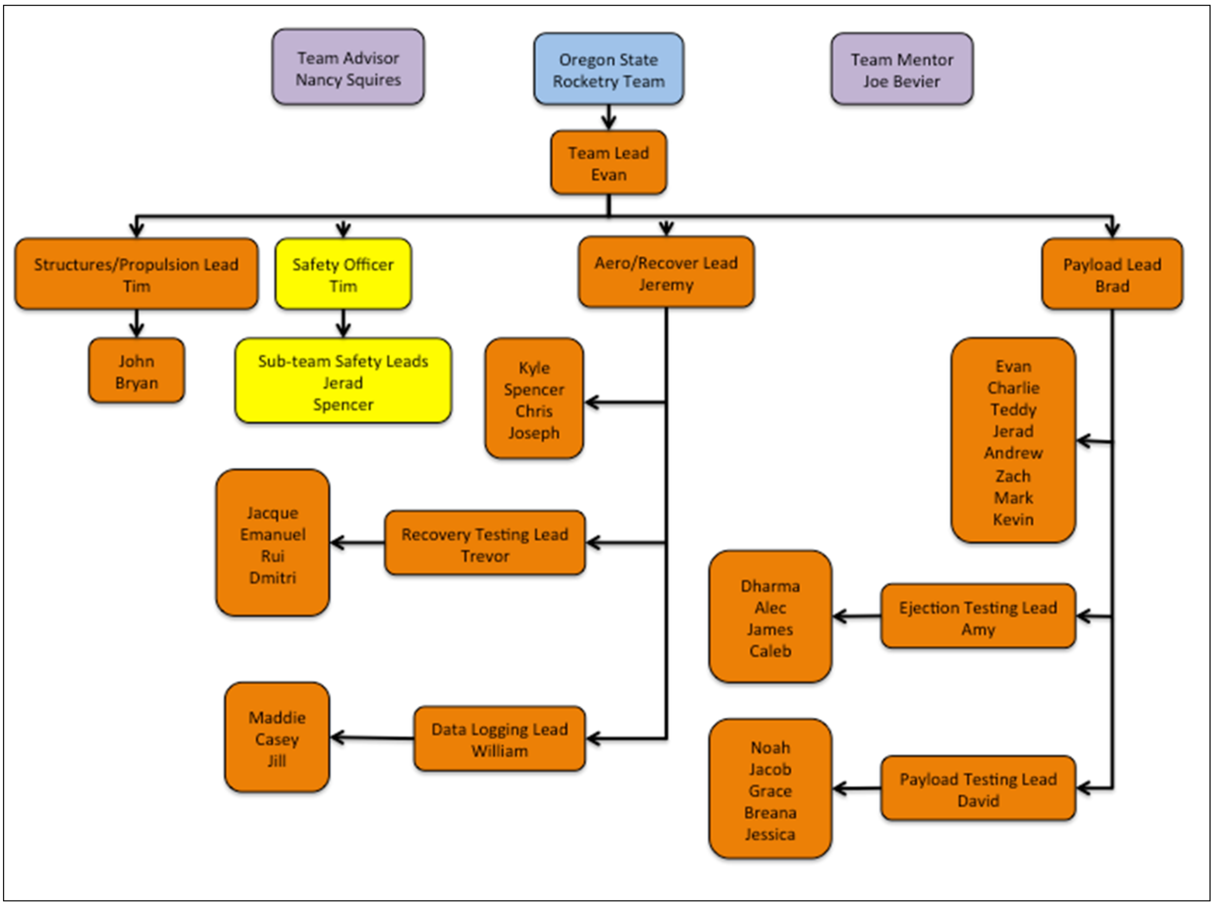


Figure 1: Team Organization Chart

1.4 NAR/TRA Sections

The team, if needed, may work with the following National Association of Rocketry (NAR)/Tripoli Rocketry Association, Inc. (TRA) groups in Table 3 for mentoring, review of designs and documentation, or launch assistance.

Table 3: NAR/TRA Groups

Organization Name	Contact	NAR/TRA
Tripoli Portland #49	Keith Packard	TRA
Eugene Rocketry (EUROC) #733	John Lyngdal	NAR
Gorge Rocket Club (GRC) #790	John Thompson	NAR
Oregon Rocketry Enthusiasts Organization (OREO) #555	George Rachor	NAR

These codes were acquired from the NAR website and have been in effect since August 2012. Timothy Lewis will be responsible for ensuring that the launch vehicle and launching procedures adhere to the requirements below in order to perform safely. The physical launch vehicle design will be in compliance with all parameters listed. All team launches will take place at an NAR/TRA certified launch site at the Marshall Space Flight Center (MSFC) where an Range Safety Officer (RSO) will have final say over any concerns. Group members will be receiving Level 1 High Powered Rocketry (HPR) certification before the final launch. In Figure 2 is a minimum distance table which outlines pre-launch area clearance based on total installed impulse. Prior to each launch, a safety meeting will be held in order to address any code issues and launch day concerns.

Certification: I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.

Materials: I will only use lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.

Motors: I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 ft of these motors.

Ignition System: I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of on-board energetics and firing circuits will be inhibited except when my rocket is in the launching position.

Misfires: If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

Launch Safety: I will use a five-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of National Fire Protection Agency (NFPA) 1127.

Launcher: I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.

Size: My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.

Flight Safety: I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

Launch Site: I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 ft, whichever is greater, or 1000 ft. for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 ft.).

Launcher Location: My launcher will be 1500 ft. from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.

Recovery System: I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

Recovery Safety: I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

MINIMUM DISTANCE TABLE

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 — 320.00	H or smaller	50	100	200
320.01 — 640.00	I	50	100	200
640.01 — 1,280.00	J	50	100	200
1,280.01 — 2,560.00	K	75	200	300
2,560.01 — 5,120.00	L	100	300	500
5,120.01 — 10,240.00	M	125	500	1000
10,240.01 — 20,480.00	N	125	1000	1500
20,480.01 — 40,960.00	O	125	1500	2000

Figure 2: Minimum Distance Table

2 Summary of CDR Report

2.1 Team Summary

Table 4: Team Summary Chart

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

2.2 Launch Vehicle Summary

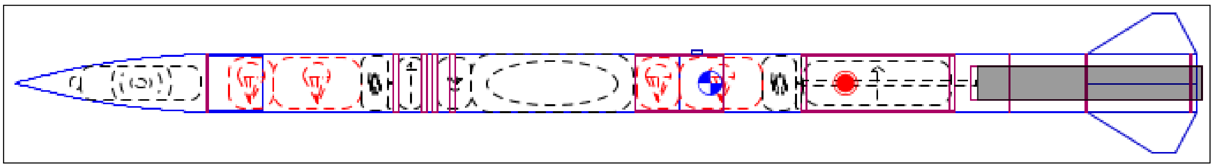


Figure 3: Open Rocket Model

The launch vehicle body is made from two sections of 5.2 in. carbon fiber tubing and uses a fiberglass nose cone. There are four trapezoidal carbon fiber fins. The launch vehicle is recovered in two independent sections: a motor section and payload section. Each section uses a single event recovery system with a drogue deployed at apogee and a main chute deployed at a lower altitude.

Table 5: Launch Vehicle Specifications

Total Length (in.)	Diameter (in.)	Loaded Weight (lbs.)	Stability (cal)
118	5.3	37.5	2.56

2.3 Payload Summary

The OSRT has chosen to complete option two for the University Student Launch Initiative (USLI) payload: a deployable rover. The rover will have two coaxial, independently driven wheels with a chassis suspended between them. A spring-loaded stabilizer arm will act as a third point of contact with the ground. A Raspberry Pi 3 will autonomously control the motors to move the rover, taking input from a sensor array including active sonar, passive sonar, and a nine-degree-of-freedom Inertial Measurement Unit (IMU). A servo-actuated solar array will be mounted on the top surface of the rover. The rover will be ejected from the airframe using black powder charges. After traveling a set distance, the solar arrays will open.

3 CHANGES MADE SINCE PDR

3.1 Launch Vehicle Criteria

The diameter of the launch vehicle has increased from 5 to 5.3 in due to constraints from our suppliers. The entire body is no longer carbon fiber. The lower section changes to fiberglass halfway up. This was done to provide a window for Radio-Frequency (RF) signals. The nosecone was also changed to meet the new body diameter size.

The drogue parachutes were changed from an elliptical shape to a cruciform shape. The required elliptical parachute would have been too small for a reliable deployment, and cruciform parachutes have a more stable descent. The parachute packing method was changed to a fold and wrap method as a deployment bag would not work with our main chute deployment method. In addition, the secondary ejection controller was changed to a Stratologger CF. This was done to add a second level of redundancy.

The motor choice has changed to the L850W. This was done as the estimated weight changed from 45.2 lb. to 37.5 lb. and the estimated altitude reached over 6000 ft.

All bulkheads on the rocket were changed from a carbon fiber and honeycomb sandwich to plywood. The switch was made because other OSRT have had problems attaching carbon fiber bulkheads and having them crumble. The bulkhead design between the payload and the upper parachutes has also been changed to provide more support and to ease the assembly process.

3.2 Payload Criteria

The wheel diameter has been increased from 4.5 in. to 4.8 in. to take advantage of the increased airframe diameter. The outer wheel surface has changed from polyurethane to memory foam for increased grip and wheel diameter expansion after deployment. The solar panel area has been reduced by 62% to 1.65 in. x 1.38 in. due to the greater availability of this panel size. Consequently, the gear size has also been reduced to 0.75 in. The solar mounts are now made of carbon fiber instead of steel and padded with foam. This has resulted in a 33% weight reduction for the solar assembly.

GPS sensors have been completely removed. Instead, a new launch vehicle detection sensor system has been added, consisting piezoelectric buzzers that are mounted in each avionics bay on-board the launch vehicle. These buzzer transmissions will be received by a dual microphone array system that is mounted on-board the rover and will allow the rover to detect the locations of the landed airframe.

The voltage regulators have been changed from TPS54383PWPR to LM2576-5.0 and LM2576-3.3 for easier soldering. The battery level indication will now be based off of the LiPo discharge curve instead of a linear one.

Design has been finalized for the payload ejection controller, and a removable bulkhead added to separate this controller from the payload bay. A Kevlar harness has been added to secure the payload throughout the flight sequence and a Nomex blanket added to protect the payload from the ejection charges. An additional retention device (an L2 Tender Descender) has been added to release kevlar harness during ejection sequence.

3.3 Project Plan

3.3.1 Budget

The local AIAA chapter donated composites manufacturing tools, removing the need for the team to buy them. Components for the sub-scale were not included in the Preliminary Design Review (PDR) budget, so all parts purchased that will not be used on the full-scale rocket were added to a separate sub-scale section. Payload testing was also separated from the rest of the payload budget to give a better breakdown of product costs vs. testing costs. Parts were added or removed to express changes in the design since PDR. Expenses and donations to date, and projected expenses and donations were added to the budget.

3.3.2 Timeline

The timeline has been broken into three sections: structures, aerodynamics, and payload. The structures timeline has been accelerated to include a first full-scale launch on February 17th and a second full-scale launch between March 3rd and March 10th. This change allows for an increase in troubleshooting efforts before the Launch Readiness Review. The payload unit testing has been pushed back until after manufacturing in January 22nd. Many testing procedures have been done through simulation and the physical tests will be done between January 22nd and February 9th. There are minimal changes to the aerodynamic timeline as the scope of this section has been kept constant through the project lifecycle.

4 Launch Vehicle Criteria

4.1 Launch Vehicle Design

4.1.1 Mission Statement and Success Criteria

The launch vehicle shall be reusable. It shall deliver the rover payload to an altitude of one mile Above Ground Level (AGL), successfully deploy recovery systems at apogee, and return the airframe to the ground within the allowable kinetic energy requirements. The mission shall be considered a success when the following has been completed:

- The launch vehicle launches in a stable configuration toward apogee
- The launch vehicle has reached the target altitude of one mile
- The launch vehicle has a successful separation into two recovery sections
- The drogue chutes deploy successfully
- The main chutes deploy successfully
- Each section lands safely and within kinetic energy requirements in target area

4.1.2 Selected Design Components from PDR and Reasoning

4.1.2.1 Rocket Body Material

The airframe will be split into two sections: an upper and a lower. The upper section will be a 0.05 in. thick carbon fiber weave with an Internal Diameter (ID) of 5.2 in. and an Outer Diameter (OD) of 5.3 in. Carbon fiber was used as it has a higher Young's Modulus than fiberglass and will be able to perform more reliably when placed under high compressive stresses. The lower section will be a carbon fiber and fiberglass mixture. At the coupling between the between the upper and lower sections will be a fiberglass material with similar thicknesses and diameters to the carbon fiber in the upper section. Halfway down the lower section the fiberglass transitions to carbon fiber. The decision to make this change resulted from the necessity to maintain RF transparency for telemetry purposes. The airframe tubes can be seen in Figure 4.

Figure 4: Airframe Tubes

4.1.2.2 Rocket Body Size

The main body tubes of the launch vehicle have a 5.2 in. inner diameter. The fiberglass section of the lower body tube has a larger outer diameter than the carbon fiber section, but the space constraints are only on internal dimension and therefore the diameter difference has no effect. The diameter of the tubes was increased from the 5 in. size planned in the PDR to 5.2 in. because the vendor, Innovative Composite Engineering (ICE), did not have a spindle that was able to roll the initial requested size. The increase in size proved advantageous because it allowed for an increase in the size of some critical components and allowed for more room to work inside the launch vehicle during construction.

4.1.2.3 Nose Cone Shape

The nose cone follows a 4:1 ogive profile. This was chosen over a cone and a Von Karman profile. The ogive profile was chosen because of its performance in the subsonic region of flight. In addition, the ogive nose cone is available from many manufacturers which helps to prevent the chance of manufacturing errors or lagging lead times affecting the mission.

The change in the diameter of the launch vehicle means that the nose cone can no longer be purchased off the shelf. Instead, a 5.5 in. nose cone will be purchased and cut down to fit the body of the launch vehicle. A custom adapter will then be used to attach the nose cone to the body. The aerodynamic impact of cutting down the nose cone should not be significant due to the low speed of the launch vehicle, and the nose cone will still be close to tangent to the body.

4.1.2.4 Nose Cone Material

As the team has settled on the ogive nose cone design and has opted to purchase the nose cone rather than manufacturing (to negate manufacturing errors common to OSRT that have tried to create their own nosecone in the past), the nose cone will be comprised of fiberglass. The high compressive strength of fiberglass and its toughness makes it ideal for the constant forces present during launch. The nose cone houses avionics and will be transmitting radio frequencies so that the team can track the position of the launch vehicle. Fiberglass is RF transparent, unlike carbon fiber. Based on the engineering requirements set for the nose cone (weight, cost, strength, ease of manufacturability, RF transparency), the decision was made to use fiberglass.

The nose cone will be under constant loading and may experience deformation. Fiberglass and carbon fiber have different failure modes. Fiberglass will deform until ultimately breaking and carbon fiber will suddenly break. Having a functional nose cone is critical and while it is unlikely either material will fail, the failure mode of fiberglass is preferred since it is less likely to damage the components that it houses if failure does occur. Lastly, carbon fiber lacks RF transparency making it difficult for the avionics to work. Because of RF transparency and failure modes of fiberglass it was chosen as a material for the nose cone.

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

4.1.2.5 Fin Shape

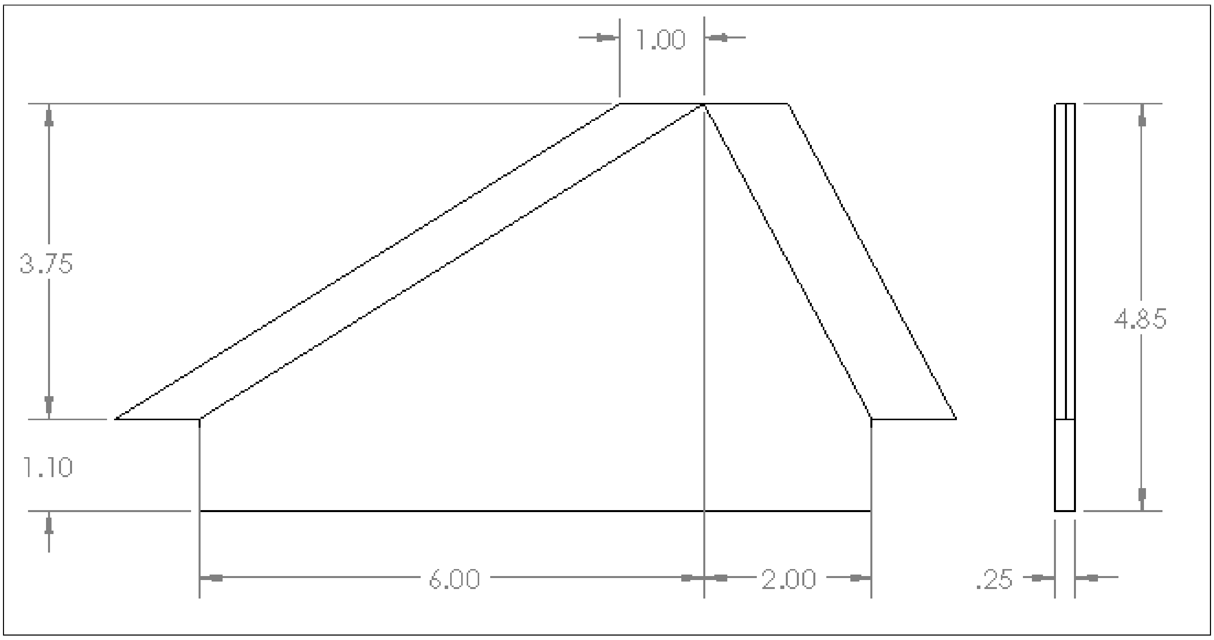


Figure 5: Mechanical Drawing of the Fin Design

The fins follow a trapezoidal profile. This profile was chosen for its aerodynamic performance, and its ease of manufacturing. The other profiles considered were the elliptical and delta shaped fins. The trapezoidal fin will be swept back as well. This was done to lower the center of pressure without extending the fins to far from the body of the launch vehicle. The thickness of the fins was selected to be 0.25 in. This was chosen in order to increase the durability and ease of manufacturing of the fins. The increased thickness will not drastically decrease the altitude of the launch vehicle.

The size of the fin was used to drive the stability of the launch vehicle. The fin size was chosen to set a stability of 2.3 calibers. Figure 5 shows the size of the fin. This fin is shorter than the diameter of the launch vehicle meaning that it does not stick out significantly.

4.1.2.6 Fin Material

As fins are essential to the stability of the launch vehicle and its aerodynamics, design decision addressed multiple factors including the durability of the fins, the lift to drag ratio, and the ease of manufacturing. Additionally, the shape must be considered to its manufacturability and thus the fin material converged on carbon fiber Nomex honeycomb structure with fiberglass edges for shape. The carbon fiber aligns with structural integrity of the rocket body while the Nomex honeycomb interior helps retain a lightweight structure leaving the fiberglass to create the aerodynamic shape required.

Carbon fiber and fiberglass ensures the durability of the fin design while the Nomex honeycomb sandwich core ensures the strength to weight ratio needed and the fiberglass ensures the shape will provide the lift to drag ratio required of the fins. While carbon fiber is not inherently flexible, the Nomex honeycomb core has an over expanded cell structure that allows it to be more flexible and perfect for use in tight radius curves. The combination of the three materials ensures the fins will function properly to the overall design of the rocket and its construction.

4.1.2.7 Bulkhead Material

The launch vehicle will utilize seven bulkheads for mounting and safety purposes. One bulkhead will be in the nose cone, four will be in the upper section, and two will be in the lower section. There will be three threaded steel rods running through each of the three sections of the launch vehicle: nose cone, upper section, and lower section. In the nose cone, the aluminum tip will be used to mount the rod to the other bulkhead. Due to the payload and recovery systems needing both ends of the upper section able to open, there will be multiple bulkheads used for increased rigidity. There will be a bulkhead located above the motor tube and another one slightly below the coupler. All the locations of the bulkheads are denoted with arrows and the threaded steel rods are bold lines found in Figure 6 below.

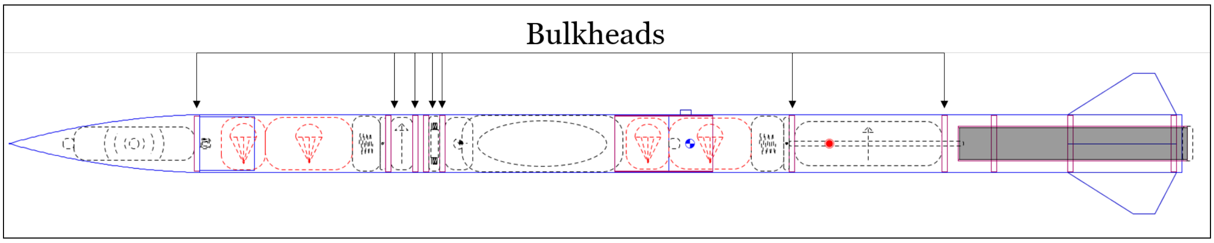


Figure 6: Rocket Mountings

The bulkheads need to be lightweight, rigid, low cost, and easy to manufacture, so the team has decided to make the bulkheads out of 1/2 in. thick, 9-ply plywood. The plywood will be able to withstand axial, bending, and torsion forces experienced from launch to recovery. If there are any issues with plywood in use or mistakes made during manufacturing, then more plywood is readily available. The use of plywood will also make is easy to make the necessary mounting holes for the threaded rod.

The shape of the bulkhead is a circle with a diameter of 5.2 in. The circle will be made with a laser cutter for precision and repeatability. After the shape is made, the necessary installation mounting holes will be drilled into it. To secure the bulkhead to the launch vehicle, RocketPoxy will be used.

4.1.2.8 Centering Ring Material

The bulkheads and centering rings will be made of the same material, a 1/2 in. thick plywood. Like the bulkheads, the centering rings will be able to withstand axial, bending, and torsion forces experienced from launch to recovery. Plywood allows for the flexibility to replace, mount, and secure the centering rings into the rocket. It is vastly easier to manufacture than carbon fiber or fiberglass. Both bulkheads and centering rings can be made from the same material because they provide a structural function with similar parameters. If the different elements are of the same material format then the manufacturing process for the two will be the same, reducing the needed material and time. The parameters that were used for making the final decision on these components were the structural strength of the component, weight, manufacturing difficulty, and cost to which plywood offers the greatest combination.

4.1.2.9 Coupler Material

With the rocket body comprised of carbon fiber, the couplers need to hold the structural integrity of the rocket during flight. As fiberglass inherently withstands bending better than carbon fiber while also retaining many of the same material characteristics in strength it makes an ideal coupler material. The couplers will thus be made from pre-impregnated fiberglass manufactured to fit inside of the carbon fiber. The manufacturing must be precise to the get the desired fit without damaging either the couplers or rocket body during assembly. Pre-impregnated fiberglass was chosen after considering the structural strength, ability to manufacture and modify, and lightweight requirements of what the couplers need to be.

A comparison of these factors between wet layup fiberglass, pre-impregnated fiberglass, and carbon fiber (pre-impregnated carbon fiber or wet layup having similar characteristics in this case) led to the conclusion that pre-impregnated fiberglass would be the best material for couplers. It is only marginally better than the carbon fiber, but the final decision has the advantage that the rocket teams at Oregon State University (OSU) have had experience working with fiberglass couplers and this makes the manufacturing process simpler. There is also the advantage that the fiberglass is RF transparent allowing for transmission if any avionics or recovery components are placed in the couplers in later designs.

4.1.3 Airframe Design

4.1.3.1 CAD Drawings of Launch Vehicle

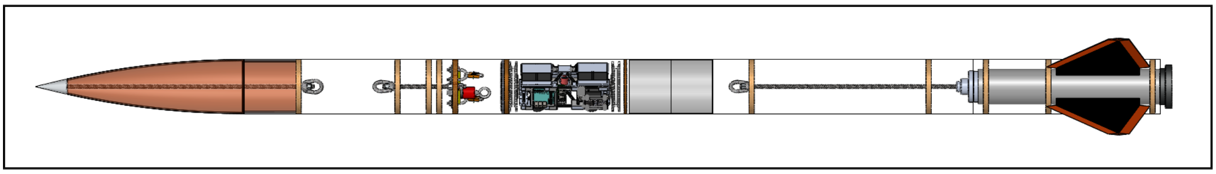


Figure 7: Launch Vehicle CAD

4.1.3.2 Diagrams of Launch Vehicle Layout

The rocket is split into two recoverable sections. These are the motor section and the payload section. The reason for recovering these sections independently is to reduce the mass of each recovered section and to limit the kinetic energy. The sections split at apogee. Both sections are recovered using the same ejection system. Figure 8 below shows the payload section and the nose cone where the split. Figure 9 shows the motor section.

The nose cone contains the tracking system for the upper section of the rocket. It is attached to the payload section through a coupler and shear pins. During the recovery phase the nose cone is ejected to allow the parachutes to deploy. The nose cone is held on by the parachute tether.

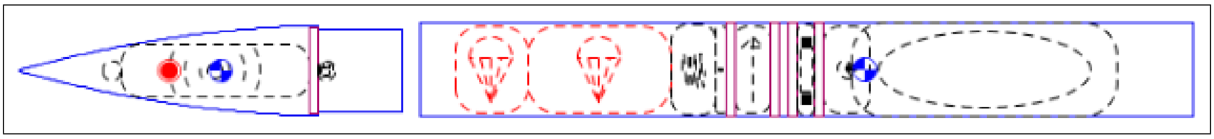


Figure 8: Diagram of the Payload Section and Nose Cone

The payload section contains the payload on the lower end and recovery section at the top. In addition, the nose cone is recovered as part of the payload section. The rover is inserted into the rocket as one assembly containing both the rover and the rover ejection controller. This assembly has a threaded rod on it that allows the assembly to be fastened down to the bulkhead in the payload section. The recovery ejection controller is then slid onto the threaded rod and the threaded rod is used to fasten down the recovery harness.

The lower section contains only the motor and its own recovery system. The motor is held in by the motor tube and a threaded retention system. The end of the motor is tapped and contains a threaded rod which connects to the recovery system. The ejection controller and tracking system is in a bay that is slid on to the

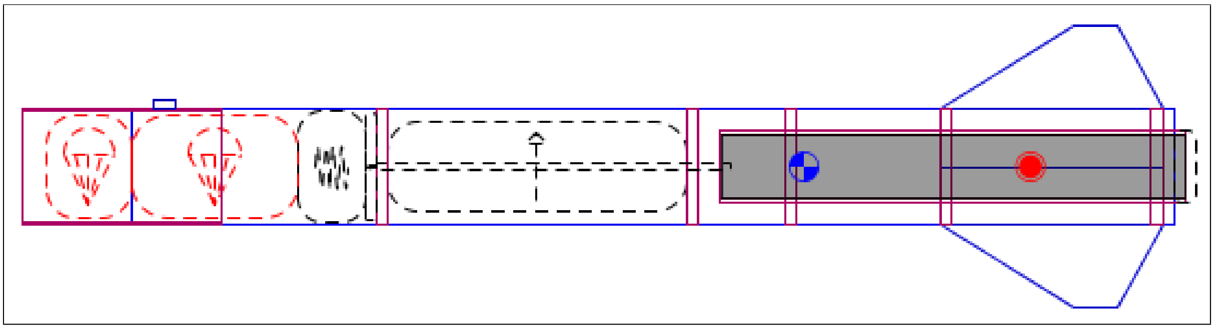


Figure 9: Diagram of the Motor Section of the Launch Vehicle

threaded rod and fastened down. This allows for all recovery forces to transfer directly from the parachutes to the motor and reduces the number of failure points.

4.1.3.3 Motor Selection

The motor that will be used for the launch vehicle is the L850W motor from Aerotech. The final decision was reached based primarily on the target apogee for the launch. The motor that was originally planned in PDR provided too much thrust for the weight of the launch vehicle, and put the projected altitude higher than was deemed acceptable even when planning for increased weight based on the waiver at the launch site. The L850W was found to provide a very close altitude to the target altitude.

4.1.3.4 Motor Attachment Method

The motor will be mounted in a 3 in. fiberglass motor mounting tube. The motor mounting tube will be secured using three 0.5 in. plywood centering rings. The motor mount tube provides the anchor point of the entire system. It serves as the housing for the reloadable motor casing. Without a separate housing the motor casing would need to be an integral part of the launch vehicle, precluding any repeat launches without significant work removing the motor between each use. The mounting tube also takes most of the forces from the motor and transfers them to the airframe. To prevent failure during launch it must be securely attached to the body tube; this is done using the centering rings.

The centering rings will be attached using epoxy to both the motor mounting tube and the main body of the launch vehicle. One ring will be placed at the rear of the mounting tube, the next just fore of the fin mounting, and the final ring near the top of the mounting tube as shown in Figure 10.

The rings will keep the motor centered during flight and will take the force from the motor during flight once they are transferred to the motor mounting tube. Three centering rings are being used to ensure that

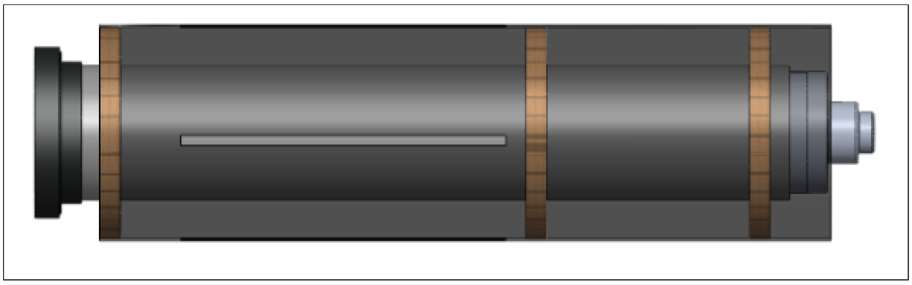


Figure 10: Layout of Motor Mount System

the motor remains centered and attached even if one ring fails, because if a two-ring system is used then the motor mount could bend around the one remaining point.

To keep the motor inside the mounting tube both before and during flight a commercial screw retainer will be used. One section of the retainer will be epoxied onto the end of the motor mount tube, with the other being screwed over the motor once it has been inserted. The screw retainer will provide sufficient strength to keep the motor inside the launch vehicle, while allowing for easy insertion or removal of the motor.

4.1.3.5 Threaded Rod, Eye Bolts Attachment Method

There are three threaded rods that provide mounting points for hardware in the launch vehicle. Each threaded rod is set into a hard-point of the section. These hard-points give the threaded rods places to dissipate force into other sections of the launch vehicle and to keep the internal components of the launch vehicle secured during flight. These threaded rods also allow for simplified assembly of the launch vehicle because electronic systems and the payload can be designed to slide onto and be secured to the threaded rods.

The forward threaded rod runs through the nosecone section of the launch vehicle. It is secured to the aluminum nose cone tip as the hardpoint. This hardpoint is created by drilling and threading a hole in the base of the tip, applying a threadlocker to the rod, and screwing the pieces together. On the other end of the nose cone rod is a recovery eye nut assembly. This assembly is a removable system that allows for attachment of the nose cone to the parachutes and payload bay. It is comprised of a washer, eye nut and a locknut screwed on the threaded rod just beyond a bulkhead as seen in Figure 11.

The eye nut holds one of the parachute quick-links and a locknut holds the assembly in place while under loading. Without the locknut the forces on the eye nut could unscrew the component or pull it from the end of the threaded rod. The entire assembly can be removed to allow components below the bulkhead to be accessed, but takes the loading of recovery when fully assembled. The aft threaded rod runs from one end of the motor casing to a recovery eye nut assembly above the aft ejection controller. The casing that will be used has a threaded forward closure that allows for the creation of a hardpoint in the aft section. The threaded rod will be threadlocked into the forward closure, giving a solid connection to the well secured motor. This threaded rod will terminate in another recovery assembly the same in design and layout as the one in Figure 11.

The threaded rod assembly in the payload section is the most complicated. The nose cone and motor can both have a secure point to attach the threaded rod to. For the payload section a hardpoint to secure the threaded rod needed to be created. To create this hardpoint two bulkheads will be epoxied into the center of the payload section with an aluminum spacer to provide better placement of the threaded rod through the bulkheads. This two-bulkhead system will create a greater amount of surface area to transfer force to the body tube.

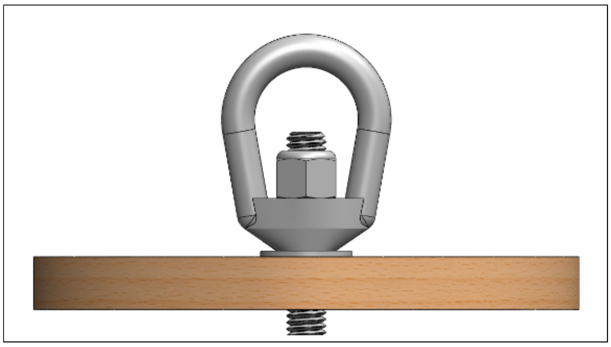


Figure 11: Layout of Recovery Eye Nut Assembly

The other difference in the payload threaded rod is that components need to be secured to both ends of the rod. To give the rod the needed anchor a heavy nut will be thread locked to the center of the rod. This nut will press against one side of the bulkhead hardpoint, and a locknut will be fastened to the other side of the bulkhead assembly. The payload end of the threaded rod will be secured with a locknut/washer assembly, like the recovery assembly sans eye nut. The other end of the threaded rod will use the same recovery assembly attached to the free ends of the other two threaded rods.

The threaded rods for the system are all 0.375 in., 16 threads per in. rods. To determine if this size was sufficient two forms of analysis where preformed. First a safety factor analysis based on the expected force applied to the rod. The expected force on the rod is 1000 lbf. based on maximum recovery loads. This is applied to an area of 0.0775 in.^{2}, which is the tensile stress area of the bolt. Using Equation 1, the following is achieved:

$$\sigma = \frac{F}{A} = \frac{1000 \text{ lbf}}{0.0775 \text{ in}^2} = 12900 \text{ psi} \tag{1}$$

$$\text{Safety Factor} = \frac{\text{Tensile Strength}}{\text{Expected Stress}} = \frac{150000 \text{ psi}}{12900 \text{ psi}} = 11.625 \tag{2}$$

Using a 0.375 in. threaded rod, with a tensile strength of 150,000 psi, a safety factor of 11.625 is achieved for the system, seen in Equation 2. This factor of safety is well above the team minimal requirement of a safety factor of 2. The other piece of analysis is to determine whether the thread will strip out of the nut before the threaded rod fails. Most hardware is designed such that the threaded rod or bolt will fail before the nut strips, but the analysis was preformed as a back-up check. Using Equation 3, the minimum thread engagement length can be found:

$$Le = \frac{2Af}{0.5\pi(D - 0.64952p)} = \frac{2 * 0.0775 \text{ in}}{0.5\pi(0.3750 \text{ in} - 0.64952 * {}^{1}\!/_{16} \text{ in})} = 0.295 \text{ in} \tag{3}$$

Where Le is the minimum engagement length of the threads, Af is the tensile strength area, D is the mean diameter, and p is the thread pitch. The minimum length of engagement for the 0.375 in. rod is 0.295 in. This is less than the thread length of the nuts that are being used, 0.453 in., and thus the threaded rod would be the part that would fail before the nut would strip.

4.1.3.6 Avionics Bay/Removable Bulkhead Design

An avionics bay is necessary to affix all the necessary electronics into the launch vehicle body. There will be two very similar but possibly differently sized avionics bays assembled inside the rocket housing. The altimeters, ejection controllers, batteries, and other necessary electronics including the locating antenna will be affixed to this component. The avionics bays must be able to survive the launch conditions while remaining lightweight. The avionics bay must be rigidly fixture inside the body and cannot be free-moving. Such movement could result in strain on cables, damage to the electronics, and could cause dangerous vibrations. The avionics bay must be removable as well, so that components can be inspected and replaced if necessary. A steel threaded rod runs through the center of the rocket body and will provide the main structural support for the avionics bay. There are no other mounting features on the inside of the cylindrical rocket tube and there is very little space available to epoxy mounting features onto the inside. As a result of this, a design decision was reached to use the main threaded rod as the primary mounting feature. The avionics bay will fit tightly inside the body tube as well, so any motion the threaded rod undergoes during flight will be mitigated by the reactionary force of the inner tube wall against the avionics bay.

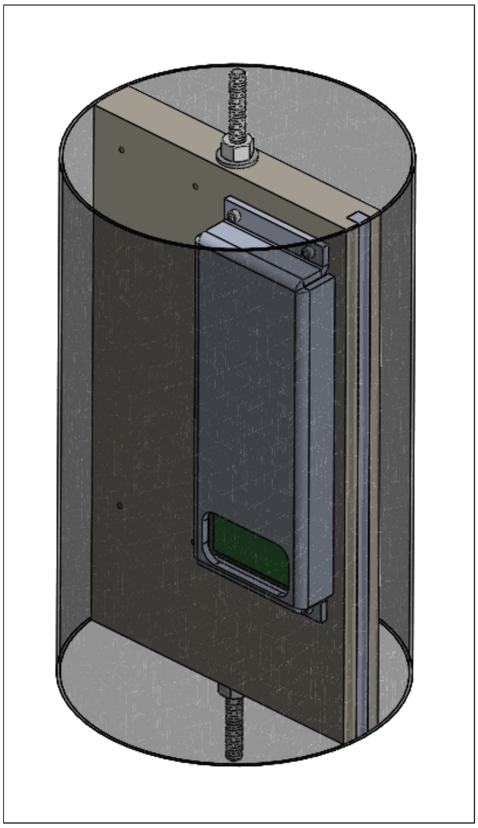


Figure 12: Avionics Bay

Material choice was quite simple, as the forces on the avionics bay will be small. None of the forces of launch or recovery will act through the avionics bay, only the mass itself will create a force that acts on the bay. High-density polyethylene (HDPE) was chosen for its non-metallic makeup, low price, its ease of machining, and its relative high strength to weight ratio. The team considered 3-D printing a structure using Acrylonitrile Butadiene Styrene - A Common Thermoplastic Polymer (ABS) initially, but the cost, low strength, and the difficulty of machining while maintaining structural integrity resulted in HDPE being chosen.

The avionics bay consists of a HDPE plate, the sides of which have been machined to the profile of the body tube. An in-plane hole runs through the center of the plate where the main threaded rod is inserted. To prevent the plate from sliding, a nut and washer below the avionics bay has already been pre-threaded and is epoxied in place to prevent it from backing out. The avionics bay rests against this washer and another washer and nut is tightened onto the other side to prevent movement axially. To prevent the entire avionics bay from rotating about the central axis, a key will be epoxied on the inside of the body tube. A receiving slot on the avionics bay will prevent such rotational motion and constrains the plate fully.

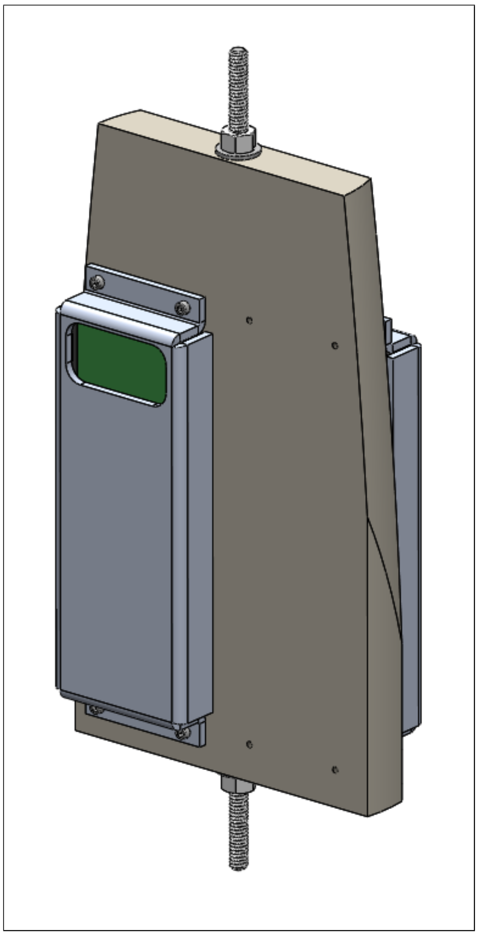


Figure 13: Tracking Slide

To accommodate the two batteries, slots will be milled into the faces of the plate. These slots are symmetrical about the central axis to ensure that the centroid is along the main threaded rod. The battery will be placed into this slot on top of a silicone rubber pad. A clamp lined with silicone rubber will then be bolted on top of the battery to prevent motion in all directions. Silicone rubber will dampen all vibrations inside the avionics bay in an attempt to minimize vibrational damage. All the other electronics will be attached via nylon bolts and spacers through their board mounting holes. See Figure 12 for a render of the design.

There will be two more compositions of these bays, one to fit in the nose cone (Figure 13) and another for ejection controllers (Figure 14). These contain the same basic principle in terms of functionality: they provide a mounting platform for the necessary electronics. The ejection controller bay will be attached to a bulkhead to allow ease of attaching the e-matches to the ejection controllers themselves through a port covered by a large washer and O-ring seal.

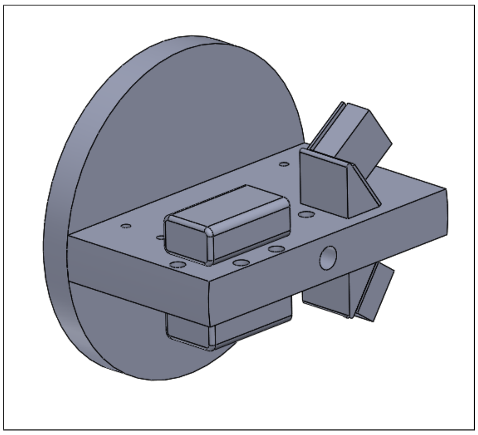


Figure 14: Ejection Slide

At each rocket interface, a bulkhead is used to create a seal for ejection charges and create a reaction force for the threaded rod and eye-bolts. A reaction ring below where the bulkhead is to be mounted is affixed to the body tube using epoxy. The bulkhead, which is comprised of a circular disc of laminated plywood, is tightened onto this reaction ring over an O-ring for a tight seal. The material choice of plywood will provide excellent strength while remaining as lightweight as possible. Plywood is inexpensive, easily machined, and was used for the sub-scale launch. It has proven to function as needed, so it has been chosen over the previous and more expensive deign of carbon fiber and honeycomb. The bolt used to tighten the bulkhead is the eye bolt that connects the tether to the other sections.

In order to contain the explosive and destructive gases from black powder ejection charges and prevent damage to avionics systems and to allow pressure buildup for ejection, a seal must be created behind each bulkhead. Rubber O-rings will be fitted into the sides and bottom side of the bulkhead, the latter of which will be tightened down on to the reaction ring. If needed, poster putty, which was used to great effect during the sub-scale launch to create a seal, will be inserted into the corner of the bulkhead and body tube.

4.1.3.7 Summary of Masses of All Sub-Systems

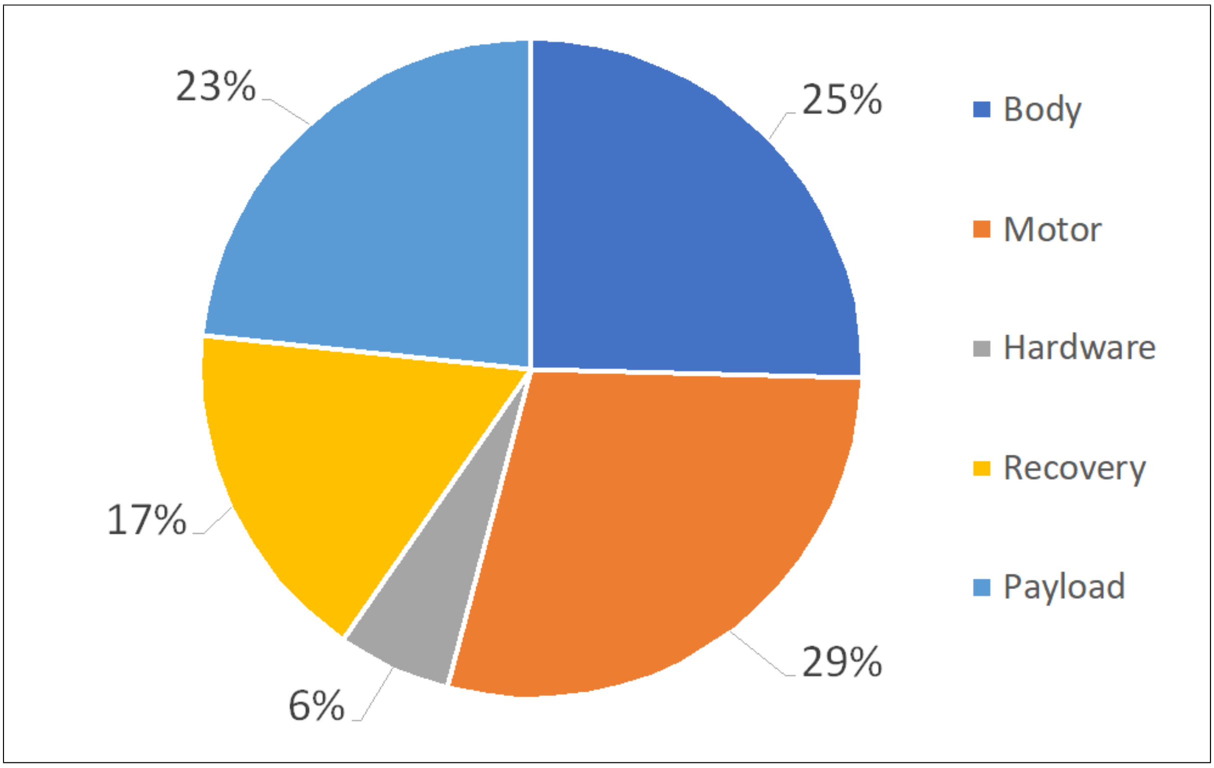


Figure 15: Final Weight

Table 6: Masses of All Sub-Systems

		Count	Weight (lb.)	Weight (oz.)
Body			9.336875	149.39
	Upper Body Tube	1	2.225	35.6
	Lower Body Tube	1	2.49375	39.9
	Coupler	2	1.925	30.8
	Bulkhead	7	1.693125	27.09
	Fins	4	1	16
Motor			10.54075	168.652
	Centering Ring	3	0.45	7.2
	Motor Mount Tube	1	1.69375	27.1
	Motor Casing	1	3.63	58.08
	Propellant	1	4.62	73.92
	Retainer	1	0.147	2.352
Hardware			2.081	33.296
	Washer	3	0.03	0.48
	Nut	14	0.308	4.928
	Eye nut	3	0.423	6.768
	Threaded Rod (8in)	5.75	1.15	18.4
	Nosecone Tip	1	0.17	2.72
Recovery			6.2425	99.88
	Drogue Parachute	2	0.0875	1.4
	Main Parachute	2	0.2625	4.2
	Nylon Harness	1	1.275	20.4
	Quick-links	7	0.5075	8.12
	Nomex Blankets	2	0.48	7.68
	Swivel	4	0.425	6.8
	Stratologger CF	2	0.0475	0.76
	RRC3	2	0.0075	0.12
	Chute Release	4	0.15	2.4
	LiPo Batteries	3	1.8	28.8
	Sled	4	1.2	19.2
	9 volts	4	0.4	6.4
Payload			8.6	137.6
	Drivetrain	1	2.9	46.4
	Batteries	1	0.14	2.24
	Chassis	1	0.71	11.36
	Stabilizer	1	0.02	0.32
	Raspberry Pi and Motor Driver	1	0.11	1.76
	Solar Assembly	1	0.35	5.6
	Sensors	1	0.2	3.2
	Misc. Rover Electronics	1	0.1	1.6
	Ejection Mechanics	1	3.63	58.08
	Payload Ejection Controller	1	0.44	7.04
Total			**36.801125**	**588.818**

4.1.4 Manufacturing Plan

4.1.4.1 Bulkheads

The shape of the bulkhead is a circle with a diameter of 5.2 in. The circle will be made with a laser cutter for precision and repeatability. After the shape is made, the necessary installation mounting holes will be drilled into it. To secure the bulkhead to the rocket, an epoxy with 1:1 weight ratio of resin and curing agent will be used. The epoxy will be generously applied to the edges of the bulkhead, where the surfaces come into contact.

4.1.4.2 Fins

The fins will be made from a carbon fiber/Nomex honeycomb sandwich material as described above. To create this material a layer of pre-impregnated carbon fiber will be adhered to each side of a Nomex honeycomb sheet. This will create a large plate with carbon fiber on each side and the honeycomb in the middle. The sheet will then be cured. After curing is complete the sheet is cut on a composite cutting table. The fins will be cut with a tab on the edge that will be set into holes cut in the side of the body tube for ease of mounting. The next step is creation of the fiberglass leading and trailing edges of the fins. The fiberglass is created as overlarge chucks and is then epoxied to the leading and trailing edges of the sandwich section of the fin. The final process for each of the fins is to machine down the edges to the desired size using a specialty bit.

4.1.4.3 Nose Cone

The nose cone will be a 5.5 in. fiberglass 4:1 Ogive Nose Cone purchased from Apogee Rockets. The team will cut away enough material so that the ID of the nose cone matches the ID of the launch vehicle body. The nose cone will be secured by clamps to minimize error. The fiberglass will be cut with a powerful fiberglass power trimmer. To ensure an accurate measurement, the location of the cut will be calculated using the equation for the shape of the Ogive Nose Cone. To reduce the likelihood of cutting too much material away or the surface is not flat, the location of the cut will be slightly above where calculated. The remaining material needed to be removed will be done so by sanding. Only when the nose cone ID reaches a constant 5.2 in. ID is it ready for assembly.

4.1.4.4 Assembly

The main tubes were a donation from ICE. These tubes will be cut to the needed size for the final launch vehicle. Once they are cut the final dimensions, holes will be machined into the sides for the fins. A rest is currently being designed to make the machining easier and to ensure that the holes are at 90° angles from each other. The final remaining step in preparation for the upper section is to epoxy the fixed bulkheads into place. These bulkheads are the ones that create the hardpoint in the payload section. They will be epoxied in using the one to one epoxy used throughout the launch vehicle. These bulkheads will be aligned with a square edge around the rim and denatured alcohol to create a nice fillet around the edges of the bulkhead.

With the bulkheads installed, the upper section is complete for permanent assembly, but the aft section needs more pieces. The next step is to place the upper centering rings around the motor mounting tube, applying epoxy to the centering rings and aligning them in the body tube. It is important to leave about an inch of the mounting tube extending from the body tube for the motor retainer. The fins are then inserted into the holes in the body tube and epoxied in place, taking extra care to get good fillets on both the inside and outside of the body tubes. When the epoxy on the fins is dry the final centering ring is placed into the body tube to hold the motor mount secure. The final steps for the motor can are to insert the secured bulkhead above the motor mount and to epoxy on the motor retainer. The bulkhead works in the same form as the previous bulkheads. For the retainer the inner section is epoxied to the outside of the motor mount tube. With all of these components epoxied and allowed to dry, the overall assembly of permanent components is complete.

4.2 Sub-Scale Flight

Overall, the sub-scale launch was a major success. Every system worked as intended, despite a few minor hiccups. During the launch, the drogue chute did not deploy, but not as a result of a system failure. Instead, the team used temporary tape to hold the parachutes in the correct packing orientation until they were inserted into the launch vehicle tube. The tape on the drogue was not removed and the parachute did not unfurl when deployed by the ejection system. Additionally, the total altitude was lower than expected. It is believed this is as a result of the launch lug location. The upper launch lug was set too high and caused the launch vehicle to become unstable on the launch rail more quickly than anticipated. As a result, the launch vehicle had an angled path and did not reach the expected altitude. Other than these mistakes, which did not create critical failures, the launch was a success. The motor worked as intended, the engine mount transferred the forces into the launch vehicle body, the ejection system separated the sections and ejected the parachutes, and the main parachute deployed at the correct moment.

While the sub-scale launch was a success, there are clear areas with room for improvement. The launch checklists must become more comprehensive to prevent simple mistakes such as leaving temporary tape on the parachutes, a mistake that cannot be duplicated. Several design changes, such as the location of the launch-lugs and the orientation of the altimeter switches, will be changed for full-scale using lessons learned in sub-scale.

4.2.1 Subscale Design

The sub-scale launch vehicle was designed to be based off of the 4 in Mad Dog DD rocket. This was done to lower the time and cost constraints of constructing the sub-scale. The main goal of this launch was to test the recovery system as well as to test the accuracy of our simulations. Instead of recovering this sub-scale launch vehicle in two sections like the full-scale, the sub-scale was recovered as one section. In addition, the sub-scale contains a tracking bay that provided flight data. Figure 16 below shows the OpenRocket layout of the sub-scale.

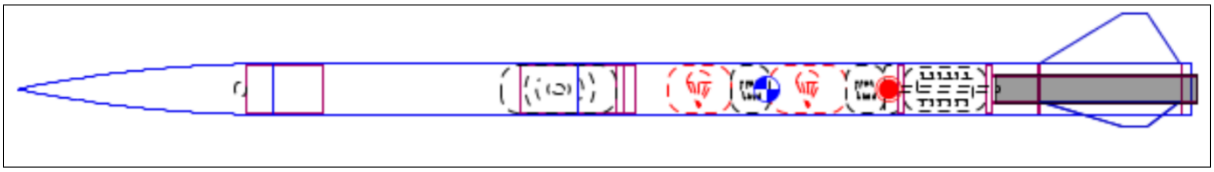


Figure 16: Sub-Scale OpenRocket Diagram

The sub-scale launch vehicle was sized to be 4/5 the size of the full scale rocket. This was chosen due to the availability of the 4 in frame. The motor used was a K1103X. This motor was selected because it simulated close to one mile and it was necesary to test the recovery system from the full altitude. The weight of the launch vehicle was 16.5 lb which is 40% of the full scale weight. Figure 17 shows the full assembled sub-scale rocket.

Figure 17: Sub-Scale Rocket Launch

The recovery harness was taken from a previous team at OSU and adapted to fit with this rocket. The main chute is a toroidal chute 60 in across, while the drogue chute is a toroidal chute that is 32 in across.

4.2.2 Launch Day Conditions

Figure 18: Launch Day Conditions

The launch was performed in Brothers, Oregon at a latitude and longitude of 43.80° N, 120.65° W. The altitude at the launch site was 4540 ft. At the location the temperature was 47 degrees Fahrenheit with 58% relative humidity. There was very little wind with a wind direction from the north-east and a speed of 4 mph. There was no precipitation with partially cloudy skies. There was at least 10 mile visibility with calm conditions throughout the day as can be seen in Figure 18.

4.2.3 Sub-Scale Analysis

4.2.3.1 Pre-Flight Simulations

The sub-scale was simulated using OpenRocket before the launch using a standard atmosphere and the launch site altitude of 4,600 ft. in Brothers, Oregon. These simulations ranged from 0 to 20 mph cross-wind velocities in 5 mph increments. The apogee ranged from 5,652–5707 ft. The flight time was expected to be 204 seconds with a ground hit velocity of 14.2–15.4 ft./s. For all the flights the launch vehicle was expected to be traveling 107 ft./s at rail exit. The stability of the sub-scale rocket was simulated as 2.39 calibers.

The launch vehicle was also analyzed using our MATLAB decent velocity program. Table 7 below shows the calculated descent velocities under each possible recovery configuration.

Table 7: MATLAB Descent Velocities

Descent Configuration	**Descent Velocity**
Tumbling Only	79.93 ft./s
Tumbling and Drogue	34.95 ft./s
Tumbling, Main, and Drogue	15.32 ft./s
Tumbling and Main	17.18 ft./s

4.2.3.2 Experimental Data

Altimeter data was collected using the ReCo StratoLogger CF and an on-board Jolly Logic AltimeterThree. Due to a purchasing oversight the data connector for the RRC3 was not purchased in time to read the data. Both sets of data were analyzed to obtain the rail exit velocity, both descent velocities, and the max height and velocity attained during flight. The StrattoLogger data is displayed in Figure 19, and the AltimeterThree data is displayed in Figure 20. Analysis from both datasets is summarized in Table 9.

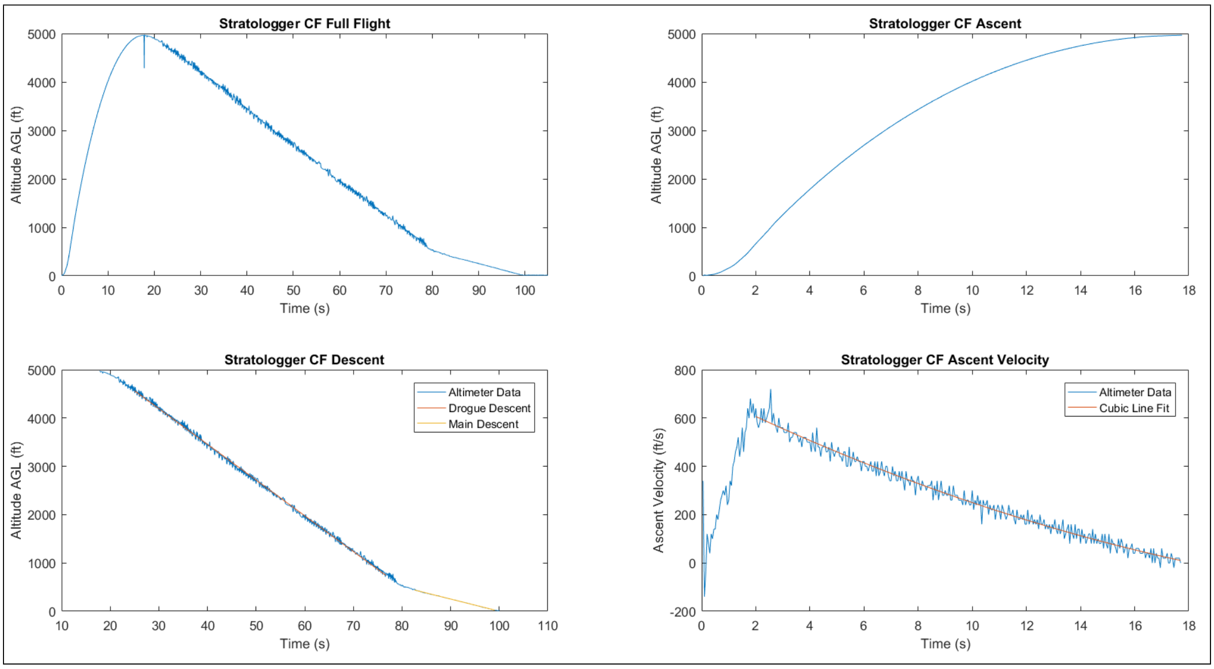


Figure 19: Acquired StratoLogger Altitude Data

The ascent was integrated to obtain the ascent velocity profile to determine the rail-exit velocity and maximum velocity. A linear fit was applied to the tumbling descent and main parachute descent to determine their terminal velocities. A summary of the event timing is provided in Table 8.

Table 8: Summary of Sub-Scale Events

Event	StratoLogger CF	AltimeterThree	OpenRocket Sim
Motor Ignition	T+ 0.00	T+ 0.00	T+ 0.00
Motor Burnout	T+ 1.85	T+ 1.90	T+ 1.90
Apogee	T+ 17.75	T+ 17.40	17.20
Main Deployment	T+ 78.80	T+ 77.85	T+ 83.50
Landing	T+ 99.65	T+ 99.95	T+ 135.00

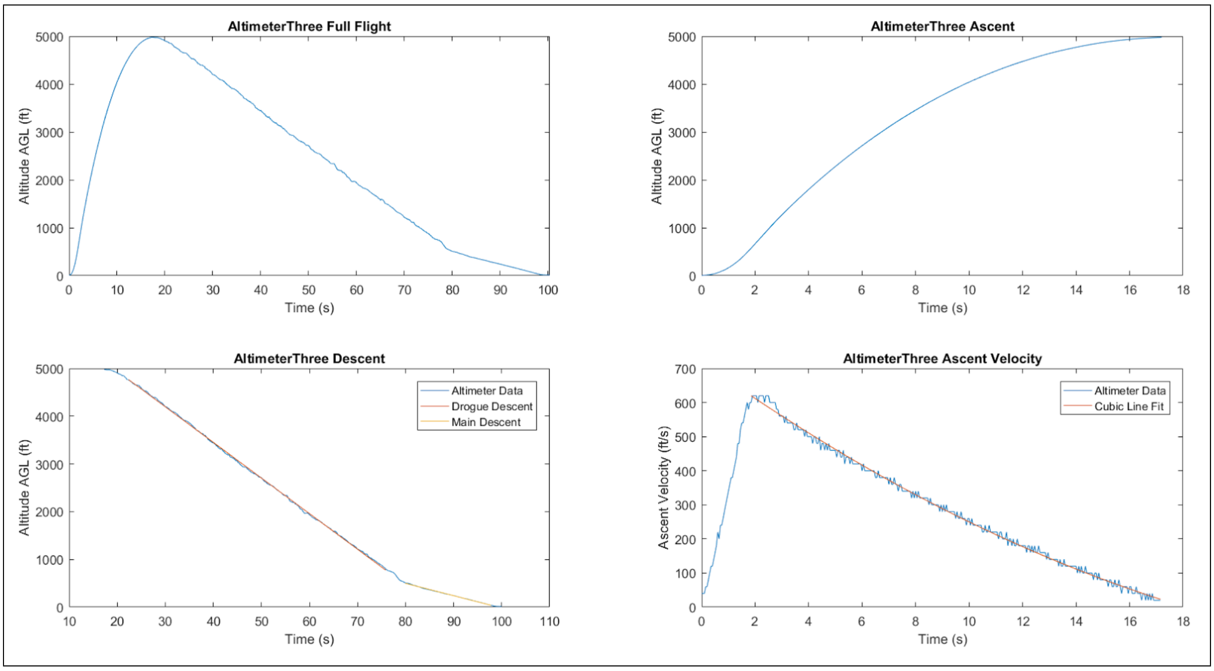


Figure 20: Acquired AltimeterThree Altitude Data

Table 9: Comparison of Experimental and Sub-Scale Data

	Apogree	Max Velocity	Rail-Exit Velocity	Tumbling Descent Velocity	Landing Velocity
StratoLoggerCF	4,976 ft.	660.0 ft./s	80-120 ft./s	73.9 ft./s	25.2 ft./s
AltimeterThree	4,977 ft.	629.9 ft./s	85 ft./s	74.6 ft./s	25.9 ft./s
OpenRocket Sim	5,332 ft.	736.0 ft./s	118 ft./s	132.0 ft./s	14.8 ft./s

Both altimeters provide similar values for all velocities and almost the same apogee height. The differences in max velocities is mainly due to noise in the altimeters and error from integrating the altitude. The differences in rail exit velocities are mainly due to the slow update time of the altimeters (20 Hz), and neither had a data point right at the rail exit.

Global Positioning System (GPS) tracking was also on board the rocket, and the drift radius from the launch pad over the flight is plotted with the altimeter data in 21. The final drift as calculated by the GPS was 1,265 ft. from the pad. There are points where the GPS data stagnates as if it is not refreshing, so more testing will be required on the tracking sled to check its accuracy.

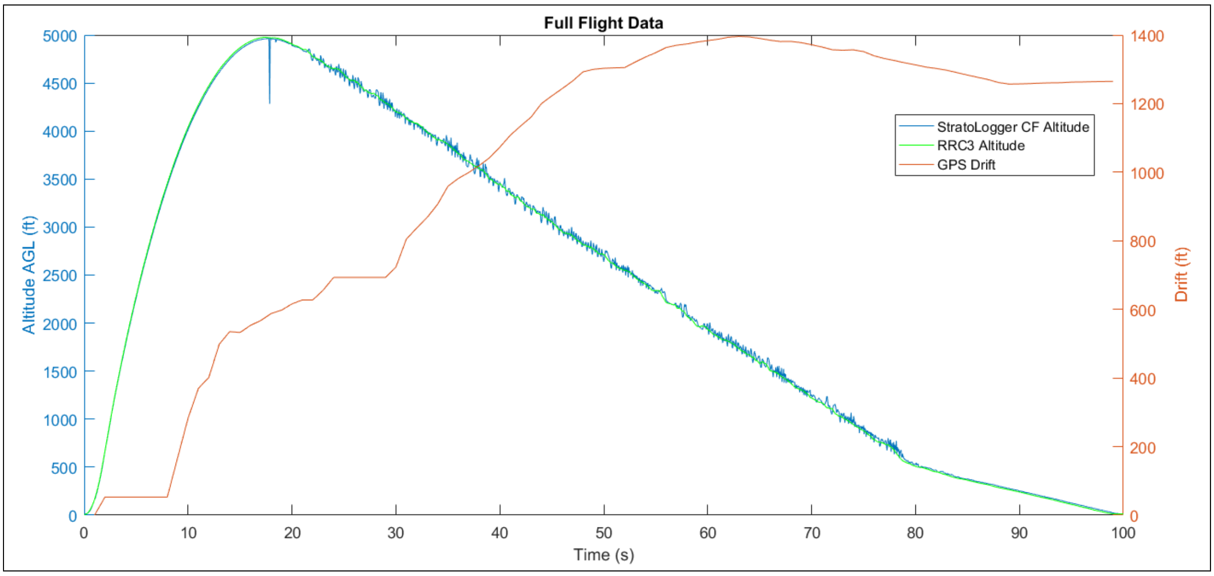


Figure 21: Sub-Scale Altimeter and GPS Data

The drift was also measured by using the GPS co-ordinates from the launch and landing position, as found by Google Maps using an iPhone. The straight-line drift from Google Maps was 1,338 ft. There discrepancy between Google GPS and onboard GPS is likely due to error in the onboard GPS, but more testing will be required to confirm.

4.2.3.3 Post-Flight Descent and Drift

The descent of the launch vehicle was simulated with tumbling, and without a drogue, shown in 22. Launch day conditions and ground pressure were used in the barometric model used to calculate parachute drag. Apogee was set to 4,977 ft. and the launch height at 4,600 ft., the altitude of the launch site. The simulated descent was 90.67 s long, which would create a drift of 531 ft. with the recorded 5.8 ft./s cross-winds. The actual descent took 81 s, which would have made a 473 ft. drift.

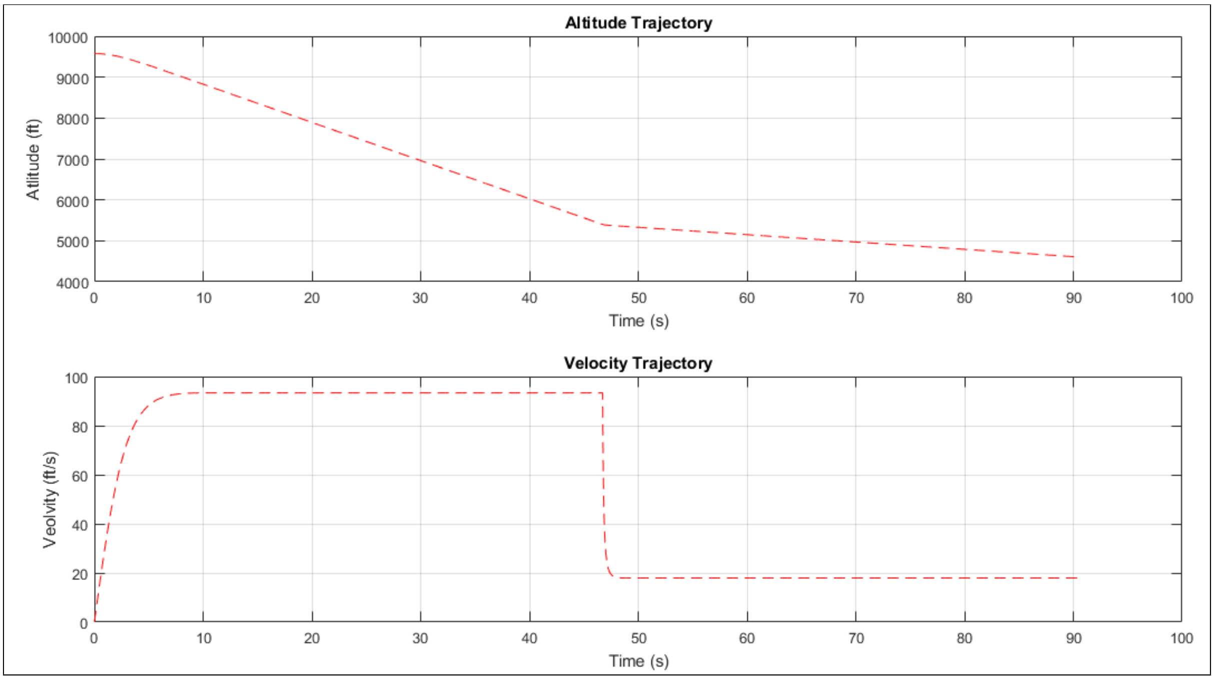


Figure 22: Simulated Descent of Sub-Scale Launch Vehicle

4.2.3.4 Differences Between Simulated and Experimental Data

The actual apogee was 355 ft. lower than predicted, and the max velocity and rail exit velocity were 80% the predicted values. The sub-scale launch vehicle had a very rough paint job on it, which would have created a lot more drag, lowering the velocity profile and decreasing the maximum altitude.

Motor burnout occurred at the same time as in the simulations, around 1.90 s, and apogee occurred within half a second of the simulated times. The actual main deployment occurred sooner than the OpenRocket simulations, but the OpenRocket simulations include a brief period where the rocket descends ballistically for 300 ft. after apogee before tumbling begins. OpenRocket simulates main deployment instantly, which would increase descent time for simulations.

The tumble velocity calculated by Open Rocket was also very far off from the actual value. Values calculated from the MATLAB script agree with both the tumbling velocity and the tumbling plus main velocity.

There was a large difference between the simulated drift distance and the actual drift distance. Simulations for drift assumed that apogee occurred directly over the launch pad, whereas the actual rocket had drifted 597 ft. by the time separation occurred, and drifted 740 ft. after apogee. That was a drift radius 50% larger than predicted after apogee.

4.3 Recovery Subsystem

4.3.1 Selected Components

4.3.1.1 Recovered Sections

The launch vehicle will be recovered in two independent and untethered sections. Since both sections will have a lower mass than the whole launch vehicle, a higher landing velocity can be used while remaining under the landing Kinetic Energy (KE) requirements. This allows smaller parachutes to be used, which can be deployed and inflated more controllably. Lower mass and higher landing velocities will also decrease the effective drift radius of both sections compared to a single, slower section. Using two sections can simplify payload ejection by putting the payload closer to an open end and by removing any obstructions in the airframe for the payload.

Two sections adds a bit more complexity to the design. Both independent sections contain their own set of ejection controllers and telemetry avionics. The airframe will also require more couplers and bulkheads. If implemented correctly, neither of these additions will affect the overall performance of the recovery system.

4.3.1.2 Recovery Compartments

A single recovery compartment per section will be used primarily for improved control over main parachute deployment and reduced recovery loads. This will protect the payload during descent by having the main parachute eject with the drogue, so it is already outside of the launch vehicle with lines stretched when the main is deployed. Fewer ejections and separations are required, which decreases the number of failure points. It will reduce the number of bulkheads and separation charges required, offsetting the additional complexity added by using two recovered sections. It will also keep the total number of sections under the maximum of four. Also, the section which houses the rover payload can have an open end with no rigging or attachments to block the rovers exit from the launch vehicle, which will further simplify the rover ejection.

Figure 23: Fruity Chutes Iris Ultra Standard

4.3.1.3 Canopy Shapes

All parachutes and rigging will be manufactured by a reputable vendor. Since the team has limited fabrics experience, this was determined to be the most reliable option.

A toroidal canopy shape was selected for the main parachutes. It has the highest coefficient of drag out of all shapes considered, which reduces the required parachute area, pack volume, and final weight. Since the main parachutes are being inflated outside of the launch vehicle with a single compartment recovery, the increased risk or entanglement during deployment which is associated with toroidal parachutes will not be a concern. Fruity Chutes Iris Ultra Standard parachutes, shown in Figure 23 will be used.

Cruciform shaped canopies will be used for the drogue parachutes. Since they have only eight shroud lines, cruciform parachutes are very resistant to tangling during ejection. The open side sections allow the parachute to quickly align itself with the incoming wind, so an ejection into a headwind or crosswind will not cause issues. Cruciform parachutes have a low coefficient of drag, but since the drogues are relatively small the effect on area and final weight is negligible. Top Flight Recovery X-Type parachutes, shown in Figure 24, will be used.

Figure 24: Top Flight Recovery X-Type

4.3.1.4 Canopy Material

1.1 oz Ripstop Nylon will be used for all the canopies. It is lighter than 1.9 oz nylon with minimal sacrifices in the strength of the gore, which will decrease the weight and packing volume. Ripstop will keep any rips or burns on the parachute from spreading, reducing the risk of damage from black powder.

4.3.1.5 Bridle Material

Tubular Nylon webbing will be used for all bridle lines for its increased elasticity and wider sizing compared to Kevlar. The elasticity will reduce impact forces on rocket components during the recovery by acting as a damped spring. The wider sizing and less abrasive material will help prevent zippering and friction damage to the airframe. This is important both drogue parachutes eject in the forward direction, increasing the risk of zippering. Nomex and Kevlar protectors will be placed over the bridle to compensate for lower thermal resistance of Nylon compared to Kevlar. A rating of 4000 lb. with 1 in. sizing was selected to provide a sufficient factor of safety, while the wider tubing will help prevent zippering.

4.3.1.6 Packing Method

All parachutes will be packed using a fold and wrap method. The parachutes will be folded around the shroud lines and rolled in a Nomex blanket so that they can be compressed easily and protected from ejection gases. A deployment bag was considered unnecessary for the drogue since at apogee there should be low wind velocities and extraction/inflation will not occur quickly. Since single recovery is being used, a deployment bag cannot be used with the main parachute since it would interfere with the main tether. The decreased pack density of fold and wrap compared to deployment bags will increase the pack volume of the parachutes and size of the recovery compartment slightly, but the bridle lines occupy the most space, so the effect is minor.

4.3.1.7 Altimeter

Both the Rocket Recovery Controller 3 (RRC3) and StrattoLogger altimeters were the selected alternatives to control the ejection charges for their excellent reliability records and proven design. Many past OSRT and USLI teams have used both with very few issues. Both altimeters calculate apogee using only a barometric sensor, which has a reduced chance of detecting false positives compared to using an accelerometer. The RRC3 can send data to the other avionics units to log data and send it to the ground station in real time. Both can verify the maximum recorded altitude via a series of beeps to fulfill the scoring altimeter requirements. Two different altimeters were selected for redundancy if there is a manufacturing or design defect in one which might affect the entire batch or product.

4.3.1.8 Main Parachute Retainer

A single compartment recovery requires a retainer to keep the main parachute reefed until it is deployed at a lower altitude to meet the Student Launch (SL) requirement for a dual deployment recovery. The Jolly Logic Chute Release has been selected for its reputation as a reliable product and easy to use design. It will be tied around the main parachute bundle and ejected out with the main parachute during apogee, then open at the programmed altitude. Past USLI teams and HPR enthusiasts have successfully used the Chute Release with few problems and great results. Unlike devices such as the Tender Descender, the Chute Release does not require any interface with the avionics or modifications to the existing airframe design. For redundancy, two Chute Releases will be tied together so that if either is activated the main parachute deploys.

4.3.1.9 Arming Switch

The FingerTech Mini Power switch was selected due to its robust design over the magnetic switches. It can be stored within the airframe, reducing aerodynamic effects compared to other mechanical switches. The FingerTech is armed by screwing a $^{3}/_{32}$. in hex screw three full turns where it tightens down in the on position. The switches will be positioned so that the hex wrench can be slotted through the existing static ports and pressure relief holes, therefore no other modifications to the airframe are required.

4.3.1.10 E-Matches

Firewire Initiators were selected mainly due to Alcohol Tobacco Firearms (ATF) restrictions on other e-matches. They also have a very good reputation and have been used successfully by many past OSRT teams. The solid core wire is not ideal for the mechanical stress in the wires, but there are no commercial e-matches available with stranded wire. Rather than crimp stranded wire to the leads and introduce another failure point, the solid core leads will be secured to relieve as much mechanical stress as possible.

4.3.1.11 Ejection Method

The decision to use black powder ejection charges was based on engineering judgment and research. Black powder charges will be loaded into small sections of surgical tubing with an e-match to trigger the explosives. The ends will be stuffed with Nomex wadding and secured with zip-ties to prevent leakage out the sides during liftoff. These charges will be affixed to the bulkhead using additional zip-ties and tape. The decision to move forward with this specific design is a result of the successful experience Oregon State University, other universities, and amateur rocketry enthusiasts have with this design. The main focus of this system is reliability, not ingenuity. See Figure 25 for an example of what an ejection charge will look like, except that this team used hot glue to seal the ends instead of Nomex and zip-ties.

Figure 25: Ejection Charge

The sub-scale launch was invaluable at revealing a major failure mode of this system. It relies on a sealed environment created between the bulkheads. This seal was not present for very first ejection tests, which caused a significant loss of ejection pressure. A seal was created using silicone rubber around the outside of the bulkhead, as well as applying poster putty to the inside of the bulkhead after installation. This secondary putty layer provided the seal needed to ensure no gases were lost. Additionally, explosive gases could cause serious damage to the ejection controllers, a situation in which the sub-scale testing came dangerously close to experiencing. Another important insight from sub-scale pertains to the charge size. The methods used to calculate charge size in a theoretical setting are not accurate. There are far too many deciding factors that determine whether a charge is large enough; the force from the strength of the shear pins is only one. The charge size needed to be roughly triple the calculated amounts. While testing was always going to be the deciding factor on charge size, it is important to understand how inaccurate those models are.

4.3.1.12 GPS Module

The GPS design considerations and design decisions cover the two primary components that comprise this system, the receiver chip itself, and the antenna used in receiving the signal. GPS operates on the L1C 1.575 GHz civilian GPS band. Key performance indicators for the GPS unit include the Receive (RX) sensitivity, power consumption, time to first fix, and position update frequency. RX sensitivity ensures that a signal can be found even in densely populated areas where severe signal attenuation and noise may be present. The more sensitive the receiver is, the greater the likelihood of quickly locking on to a signal and determining the exact coordinates of the device. Power consumption during tracking and acquisition are important parameters as it will define the power requirements for the system and influence the choice of power delivery system. Time to first fix defines the amount of time under a variety of conditions including cold start, warm start, and hot start in which the GPS will acquire a signal with a good degree of accuracy. The lower the time to first fix, the longer the GPS unit can be kept in sleep mode prior to launch thereby saving power and ensuring all systems are functional for any length of time that the launch vehicle may be on the launch pad, in the air, or on the ground. Additionally, if the signal is lost, the time to first fix defines the time necessary to reacquire a signal and continue to transmit data. Position update frequency is the final requirement that governs the selection for a GPS module. During flight, the launch vehicle will be traveling very quickly; to accurately track its position, a high refresh rate on the position will be necessary. This will allow for greater the ground but also creates a buffer in which the GPS has increased probability of successfully transmitting correct positioning coordinates for a fixed period. Calculations of positioning may be incorrect or packets may be dropped during wireless communication. Having greater packet density over a period, provided that the transceiver can handle the data throughput, results in a higher probability of at least one successful transmission for the fixed period.

The Global Top PA6H, Trimble Copernicus II, UBlox MAX-M8Q-0, and SparkFunVenus GPS were considered as options for the GPS module. The SparkFunVenus GPS will be used due to its high sensitivity receiver architecture capable of capturing signals down to -165 dBm, 1-second time to first fix hot start, 29-second time to first fix cold start, and the inclusion of an on board Sub-Miniature Version A Connector (SMA) connector. The sensitivity off the Global Top and Trimble modules is good but sacrifices performance to produce a lower cost device. Time to first fix for the Global Top and Trimble models is also higher due to the lower cost components and fewer includes GPS channels. The UBlox and SparkFun modules have very similar performance characteristics with 18Hz and 20Hz maximum update rates respectively, and -165 dBm RX sensitivity. Ease of use is a factor that encompasses the form factor, amount of documentation and support available, and the difficulty of system integration. This is the deciding factor between the UBlox and SparkFun modules due to the nearly identical electrical performance characteristics. The SparkFun module is a thru-hole mounted breakout board with a SMA connector pre-soldered onto the board. The UBlox module comes in either a surface mount or land grid array package. In addition to the increased difficulty of soldering into the system, an RF Printed Circuit Board (PCB) trace would need to be designed to allow for connection of an external antenna. RF PCB traces require a high level of knowledge and skill to implement correctly and are outside of the scope of this teams' knowledge. The SparkFun module provides a similar feature set in an easier to use form factor which is why it will be used.

4.3.1.13 GPS Antenna

The second primary component within the GPS block is the antenna. Due to the distance over which GPS satellites must transmit timing and positioning data, the signal seen by the GPS receiver is very weak and can reach down into the -160 dBm range. While the Rx chain built into most GPS receivers can achieve a similar level of sensitivity, maximum performance can only be achieved through a high gain active antenna. For this reason, a high gain antenna capable of achieving 30 dB of gain on the RF signal prior to baseband down conversion will be used. This additional gain will ensure that a greater number of GPS signals are captured and used which will increase the time to first fix and steady state signal retention.

4.3.1.14 RF Transceiver

The RF transceiver chosen for this application on board the launch vehicle is critical to the success of the flight and recovery of the launch vehicle. The transceiver will be responsible for facilitating the communication between the launch vehicle and the base station. As a result, the choice must support data throughput capable of handling 20 Hz GPS update signals as well as any other data that may be relayed back to the base station such as altitude and temperature. Key performance indicators for the RF transceiver include the transmitter power, current consumption, maximum data rate throughput, range, and ease of implementation. The importance of the data throughput, transmitter power, and range are paramount to the success of the communication with the launch vehicle for the duration of the flight. These parameters were given the highest weighting in the design matrix. The choice to use 900 MHz falls under the ease of use consideration as it is an unlicensed Industrial, Scientific, and Medical (ISM) band so no radio license is necessary to operate within this band. Additionally, communication channels using this frequency are mature and very reliable, which help to satisfy the durability of the engineering component choice.

The alternative options to 900 MHz would be either 433 MHz or 2.4 GHz. While it provides greater range and the option for a higher power transceiver, the 433 MHz band requires a radio operator license and sacrifices data throughput due to the lower frequency and smaller frequency band available. These drawbacks make it potentially unsuitable for the anticipated data throughput. 2.4 GHz 802.11 communication protocols provide high data throughput on the scale of hundreds of megabytes per second. The 2.4 GHz band suffers from range limitations due to the high frequency, however, and has a maximum range of 105 ft. The range limitations eliminate the 2.4 GHz band from use in this application. The 900 MHz band provides sufficient range of up to 9 miles (line of sight) for a 250 mW transceiver with high gain antennas. Given that the primary type of data transmitted is GPS coordinates, calculating the packet size and necessary throughput needed for reliable data transfer was included in the design decision and can be seen below in Equation 4. The 900 MHz band satisfies these requirements. The second primary deciding factor for the RF transceiver was the output power of the transmitter. This directly determines the possible range of the system and due to the importance of launch vehicle recovery to the success of the mission, there must be no doubt or possibility of this system failing to operate due to extended range.

$$1500 \text{ bits} * \frac{20 \text{ packets}}{1 \text{ second}} = 30,000 \text{ bits} \tag{4}$$

Since the PDR the choice to use the DigiXbeePro SX has changed to accommodate new restrictions implemented during the PDR. The design change has been prompted by restrictions implemented during the PDR presentation meeting. A transmit power limit of 200 mW as defined by competition restrictions updated during the PDR. The XbeePro SX is a 1W transceiver which exceeds the limits of the competition and resulted in the need to change the transceiver choice. The XbeePro 900HP has a software selectable power output range of 5 mW to 250 mW allowing for adjustable transmit power based on launch conditions and staying within competition restrictions.

The DigiXbeePro 900HP satisfies all the requirements of this application and provides the best performance out of all of the options considered. With a maximum transmitter output power of 250 mW, the range provided and software selectable steps provide superior performance over competitor models such as the Murata DNT90MCA, and Adafruit RF M96W. The maximum data throughput of 200 kbps far exceeds the data throughput necessary to facilitate the transmission of telemetry data which has an estimated demand of 30 kbps. The detailed documentation and reliable communication protocol provided by the Xbee series which utilize the Digi-mesh communication protocol, make the Xbee a clear choice to ensure reliable and consistent data transfer given a distributed mesh network that requires remote control of endpoint devices. With support for both Universal Asynchronous Receiver-Transmitter (UART) and Serial Peripheral Interface (SPI), serial communication with the XBee transceiver provides the widest selection for communication interfaces. RX sensitivity of -110 dBm will ensure that even the weakest signals will be received by the intended device.

4.3.1.15 RF Launch Vehicle Antenna

The RF antenna on the launch vehicle has similar performance requirements to the antenna on the base station. Gain, position of the antenna, and size constraints are the primary governing factors for the on-board launch vehicle antenna. During flight, the orientation of the launch vehicle and antenna relative to the base station will be unknown. It is for this reason that a wide radiation pattern is necessary to broadcast towards the base station regardless of the orientation of the launch vehicle. This removes both the Yagi and dish antenna as options for this application. The monopole whip antenna, most commonly seen on wireless access points and routers offers 360° radiation and reasonable gain. For applications where size constraints are an issue, a wire cut based on the wavelength of the signal can be used however it does suffer from low gain due to the inaccuracy of the impedance matching into the antenna. Alternatively, the most space conscious solution, the PCB antenna can provide high gain, 360-degree radiation as seen in the Figure 26, and a very small form factor.

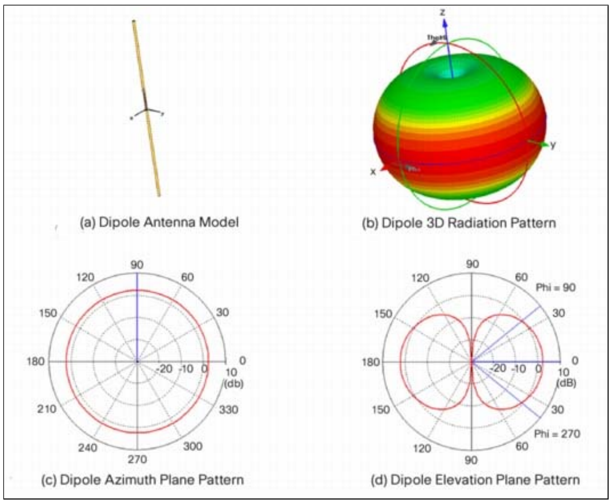


Figure 26: Dipole Antenna Radiation Pattern

The knowledge and time to design such an antenna is beyond the scope and capacity of this team. Due to these limitations, the monopole whip antenna is presented as the best solution for this application providing high gain in a low cost small package with a radiation pattern suitable for use on board a rocket. The Digi International 7 in., 900 MHz whip antenna was chosen to satisfy all requirements of the launch vehicle antenna. With 2.1 dBi of gain, small form factor, and omni directional radiation pattern, the A09-HSM-7 provides all necessary performance at a low cost.

4.3.1.16 RF Ground Antenna

The design of the base station antenna was determined by the gain and antenna position relative to the launch vehicle. The three primary antenna designs that were considered covered a spectrum of radiation patterns suitable for almost any application. Since the base station will not move for the duration of the flight and the path of the launch vehicle requires only a narrow incident angle relative to the base station, the Yagi antenna is best suited for this task. Dipole antennas provide a 360° radiation pattern, which is excellent if the direction of the receiver is unknown however since the approximate path of the launch vehicle is known, a full 360° radiation pattern is unnecessary and sacrifices antenna gain due to the omnidirectional radiation. Dish antennas provide excellent directionalization and gain characteristics for two stationary transceivers. The radiation pattern for dish antennas is typically less than 10°; however, this will not provide the desired spread to ensure that the base station receives the signal transmitted by the launch vehicle. The Yagi antenna allows for a wider radiation spread to better accommodate the path of the launch vehicle while still maintaining excellent directionalization and gain relative to a dipole antenna. The construction and radiation pattern for Yagi antennas can be seen in Figure 27.

Yagi antennas can be dual polarized, thereby increasing the radiation angle while maintaining the same level of directionalization. By using a dual polarization configuration, the antenna now transmits signals on horizontal and vertical axes giving the signal a much wider radiation pattern increasing the ability for the antenna to transmit or receive signals. The Terrawave T09150Y11206T Yagi Antenna was chosen to provide high gain and a highly directional signal to ensure maximum performance in the direction of the launch vehicle flight path. With 15 dBi of gain, the antenna will ensure that transceivers are utilized to their maximum potentials given the constraints of the competition which limit the transceiver power to a maximum of 200 mW.

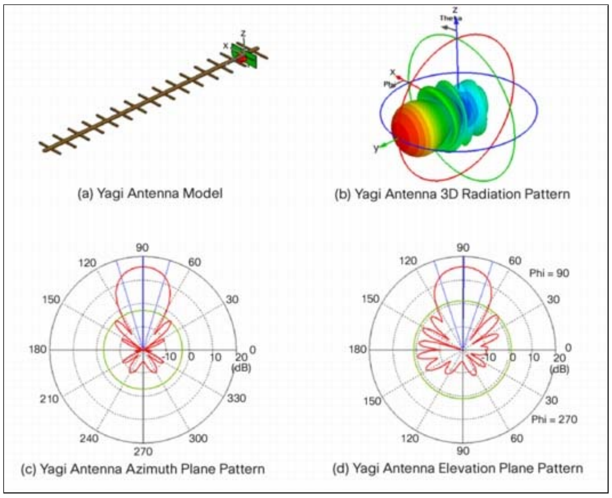


Figure 27: Yagi Antenna Radiation Pattern

4.3.1.17 Controllers

The Avionics Telemetry Unit (ATU) system requires on vehicle data manipulation in order to log the data and parse it for necessary information, while also saving data bandwidth on the wireless communication channel. A small low power microcontroller capable of basic data manipulation, text parsing, and serial communication is required to provide this functionality. The Teensy 3.6 utilizing the ARM Cortex-M4 processor will provide all functionality for the ATU and give headroom necessary for expansion of measurement devices in the future. Capable of SPI and UART providing 3 buses of each, the Teensy 3.6 will enable each component to maintain an individually addressable UART bus in order to mitigate delays created by shared bus bandwidth. Digital logic levels of 3.3 V are compliant with all devices within the system and ensure that no component will be overdriven under any circumstances. The onboard microSD card slot allows for onboard datalogging as a redundant backup to the transmitted data as well as saving all data that does not need to be sent in real-time to the ground station. The feature set as well as the documentation, small form factor, low cost, support for Arduino libraries, and high frequency 32 bit 180 MHz processor make the Teensy 3.6 the optimal option for application in the ATU module. The breakout board that will be utilized can be seen in the Figure 28 below.

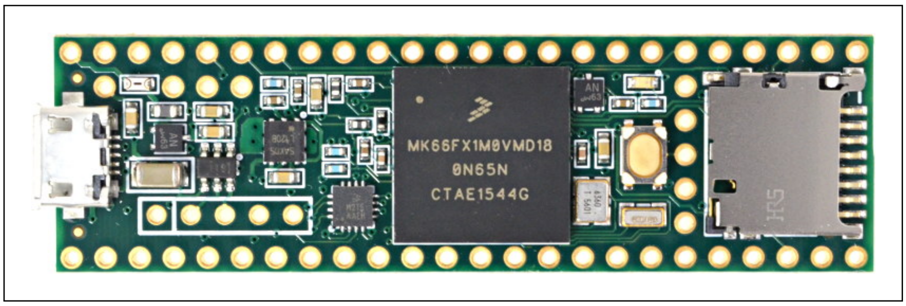


Figure 28: Teensy

4.3.1.18 Batteries

The design decision for the power supply system was based on the voltage that can be supplied reliably, the durability of the battery cells, max current output, energy density, and size constraints of the avionics bay. While 9 V alkaline batteries offer the best reliability and durability, they suffer from low energy density and current output which increases the weight and size of the power supply significantly. Alternatively, LiPo 18650 cells offer the highest energy density but sacrifice safety as they are very volatile and may explode if punctured. Lithium cells packed into prismatic packs offer slightly lower energy density than LiPo 18650 cells but offer much higher safety as they are less likely to explode in the event of a failure. Prismatic packs provide similar weight and size flexibility found in LiPos as well as rechargeability and high current output. The combination of these factors makes prismatic lithium cells the best option balancing safety and

Table 10: Power Consumption of Various Components

Component	Max Current Consumption [mA]	Supply Voltage V]	Power Consumption [mW]
Xbee Pro 900hp	290	3.3	957
Vdd to 3.3V LDO	10	7.4	74
Vdd to 5V LDO	3.2	7.4	23.68
GPS Module	100	3.3	330
Active GPS antenna	10.3	3.3	33.99
Teensy 3.6	100	5	500
		Total	1918.67

performance of the system to ensure that it is the least likely solution to fail. The need for high capacity batteries is due to the potential for the launch vehicle to remain on the launch pad with all systems on for an extended period. This disqualifies Alkaline 9 V batteries as an option due to the low energy density and high weight relative to the lithium polymer and lithium ion alternatives. Additionally, 9 V batteries may not be able to supply the desired maximum current that the system needs to operate. Alkaline batteries are only capable of outputting close to 1 A for a period of half an hour which is insufficient for this application. Calculations for battery capacity can be seen below in Table 10 and Equations 5 and 6. 18650 LiPo cells are standardized for use in many mobile electronics due to their ability to be recharged thousands of times and high energy density 18650 LiPo cells are notoriously volatile and can ignite if punctured. This creates a severe safety concern due to the extreme forces that components within the launch vehicle are anticipated to encounter and eliminates the 18650 LiPo cell as a potential option. Lithium prismatic cells offer similar energy density to 18650 LiPo cells and provide similar current output. However, when punctured, lithium prismatic cells are not prone to ignition and normally inflate to contain the expanding gas. This feature makes lithium prismatic cells a much safer option over the LiPo alternative.

The ATU will use Turnigy 2200 mAh 2S 25C LiPo prismatic cell batteries. Turnigy LiPo batteries are known for high reliability and providing current within a small margin of the rated value. The maximum power consumption has been calculated in Table 10 to represent corner cases and worst case scenarios. The capacity of 2200 mAh is chosen with the target of 4 hours continuous runtime at full power. At this capacity, the expected runtime under critical operating conditions is calculated below in Equation 6 to be 8.48 hours of runtime at an estimated maximum 1918.67 mW of power consumption continuously.

$$\text{Battery Capacity [mAh]} = \text{Power Consumption [mW]} * \frac{\text{Hours Active}}{\text{Battery Voltage [V]}} \tag{5}$$

$$1918.67 \text{ mW} * \frac{8 \text{ hours}}{7.4 \text{ V}} = 2074 \text{ mAh} \tag{6}$$

4.3.1.19 Voltage Regulators

The 7.4 V batteries chosen to supply the avionics system with power will need to be regulated down to the voltages required for each of the components within the subsystem. The transceiver and GPS receiver require 3.3 V supplies with very low noise. The battery supply voltage will be regulated down to 3.3 V and then conditioned using Low Drop Out Regulators (LDO) to ensure that the supply has consistently low noise. Any noise on the input supply to any of these components could lead to a severe reduction in RF performance. Using high performance regulators prevents this issue from happening. The microcontroller signal processor will require a 5 V DC supply. Noise is not as large of a concern; however, lower noise on the supply is always a desirable feature. As a result, an LDO will also be used for this application. Texas Instruments LM1085 Fixed output LDOs will be used to regulate and step the voltage of the batteries down to the ideal voltage for each component within the ATU subsystem. LM1085 linear low dropout regulators provide low noise, high precision fixed supply voltages for the required 3.3 V and 5 V rails within the ATU. Additionally, 10 uF capacitors will be added near the supply terminal points at both the input and output in order to reduce the ripple further on the load even under fast changing conditions.

4.3.2 Final Recovery Design

4.3.2.1 Recovery Layout

The major events of the recovery system are shown in Figure 29. The rocket is split into two independent sections: the aft section holds the motor case and fin can, and the fore section contains the payload and nose cone. The payload bay is open ended with minimal distance between the payload and opening to make payload ejection easier.

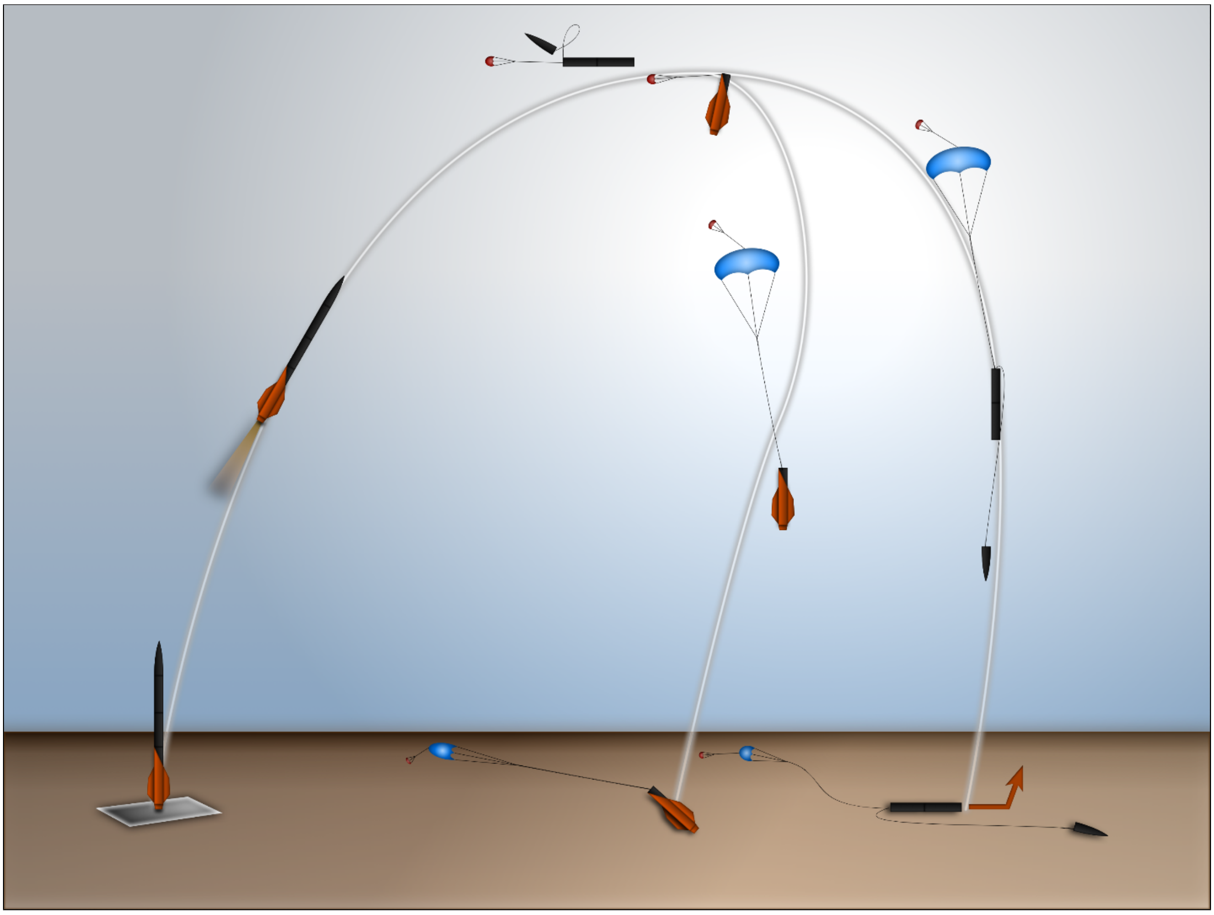


Figure 29: Recovery System Timing and Events Diagram

At apogee, the fore and aft sections are separated by ejection charges controlled by the aft section ejection altimeters, which are located above the motor bulkhead. This deploys the aft drogue parachute while the fore section remains intact, which allows the two sections to drift apart and avoid collisions.

At one second past apogee the fore section is separated by ejection charges controlled by the fore ejection altimeters, which deploys the fore drogue parachute. Both the fore and aft ejection altimeters have a set of secondary back-up charges and altimeters, which provide redundancy in case the first set of charges fails. Both secondary charges are fired one second after the respective primary charges.

Both sections fall under the drogue until they reach a height of 800 ft. AGL, where the Jolly Logic Chute Releases activate the main parachutes. This height was selected to give the main parachutes enough time to open, while still being low enough that the sections do not drift too far under the mains. Both sets of parachutes are tethered using two Chute Releases in series, so that if one opens the main will deploy. Since there is no black powder used, both the primary and secondary Chute Releases for both mains will open at the same altitude. A summary of timing events is provided in Table 11.

Table 11: Recovery Controller Timing

Time/Altitude	Event	Controller
+0 s	Launch Vehicle Separation/Aft Drogue (Primary)	Aft RRC3
+1 s	Launch Vehicle Separation/Aft Drogue (Secondary)	Aft StratoLogger
+1 s	Fore Drogue (Primary)	Fore RRC3
+2 s	Fore Drogue (Secondary)	Fore StratoLogger
800′ AGL	Mains Deploy (Primary and Secondary)	Jolly Logic Chute Releases

Fore Section The fore section recovery system layout is shown in Figure 30.

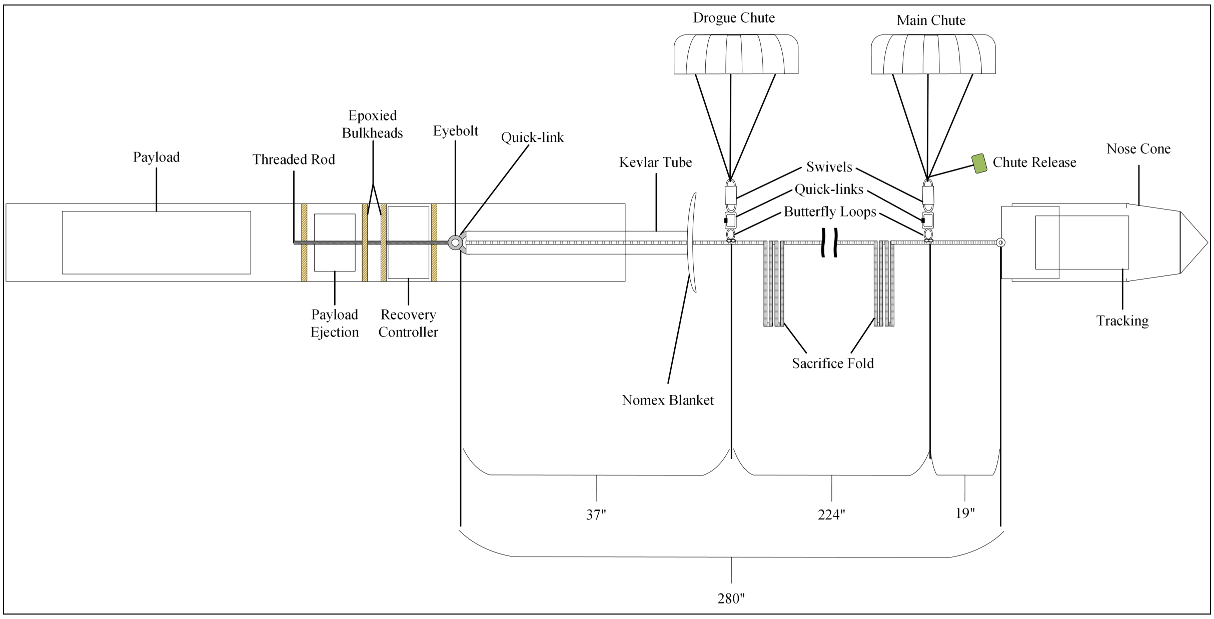


Figure 30: Fore Section Recovery System Layout (Not Shown to Scale)

The harness is connected to both the nose cone and payload sections by closed eyebolts attached to threaded rods. The nose cone rod is secured to the aluminum tip, and the payload rod is attached to a set of two bulkheads attached to the payload section. 1 in. thick tubular Nylon bridle, 280 in. in length, with sewn end-loops is attached to each eyebolt by 1/4 in. quick-links. The main parachute is attached to the bridle 12 in. away from the open end of the nose cone, and the drogue parachute is attached 12 in. away from open end of the payload section. The shrouds of both parachutes secured to a 3000# swivel on a 1/4 in. quick-link which is attached to the bridle through a butterfly loop.

By attaching the main parachute further from the payload, the main will continue to drift away from the rocket after the payload section lands, reducing the chances of the payload section getting covered by either the parachutes or the rigging.

Aft Section

The aft section recovery system layout is shown in Figure 31.

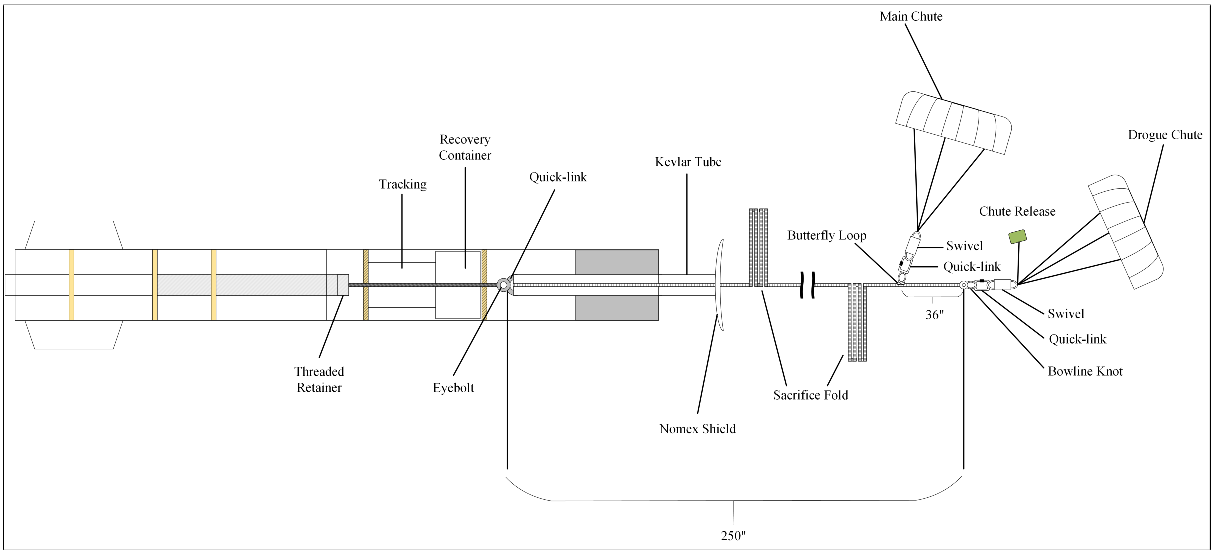


Figure 31: Aft Section Recovery System Layout (Not Shown to Scale)

The aft harness consists of a single eye nut attached to a 1 in. thick Tubular Nylon bridle, 250 in. in length, with sewn end loops, which attach to an eye with a 1/4 in. quick-link. The eye nut is secured to a threaded rod which mounts to the forward motor retainer. The drogue parachute is attached to the far end of the harness with the main parachute mounted 36 in. down from that. This will also place the main below the drogue before it is deployed, which will keep it in consistent air flow for a more reliable inflation.

Additional Hardware

To provide protection from the black powder charges, the lower 3 feet of both Nylon harnesses closest to the ejection gases will be covered with a thermal resistant Nomex sleeve. A Nomex blanket will also be placed between the ejection charges and the other recovery components, and a Nomex cover placed on every Chute Release. To mitigate the chance of any of the parachutes becoming tangled during descent due to twisting, all parachutes will be mounted with a swivel between the bridle lines and suspension lines.

Two sacrificial z-folds will be placed on each harness consisting of six folds of 10 in. long sections taped with blue masking tape. Upon separation some of the energy will be dissipated in breaking the tape, protecting the rocket components and payload.

Redundancy

Redundancy is provided by using duplicates of all ejection controllers. Two altimeters will be used in each section, and each will be powered off independent batteries with separate switches. The altimeters will be electrically and magnetically isolated from each other and from any other on-board electronics. The primary altimeter will be connected to the primary ejection charges and will operate normally. The back-up altimeter will be set for a short time delay, and will be connected to the secondary set of ejection charges, which are larger than the primary. If the primary altimeter or charges fail, the pressure from the second charges will be greater than the primary, making it more likely to separate properly at the risk of damaging interior components. If the primary system operates as intended, the compartment will be open when the secondary charges fire and over-pressure will not be an issue. Two different brands of altimeters will be used for the main and primary charges, in case there is a manufacturing or design defect in one of the altimeters. To add redundancy to the Chute Releases, two units will be used on each main parachute. They will be attached to one another so that if either controller activates, the loop is opened, and the main parachute can unfurl. Since there are no risks associated with both controllers activating at the same time, they will be programed identically.

4.3.2.2 Parachute Sizes and Velocities

Main Parachute Size

Toroidal shaped Fruity Chutes Iris Ultras will be used for both main parachutes, with a manufacture provided drag coefficient of 2.2.

The empty motor weight of the fore and aft sections are 19.0 lb. and 14.88 lb., respectively. The terminal velocity of the main parachute is determined by the landing KE requirements. To get the maximum landing velocity, it was assumed that the landing velocity is equal to the terminal velocity of the main: These results can be seen in Equation 7 and Equation 8

$$\frac{1}{2}mv_{main}^2 \leq KE_{max} \tag{7}$$

$$v_{main} \leq \sqrt{\frac{2KE_{max}}{m}} \tag{8}$$

The main parachute terminal velocity must be lower than 15.94 ft./s for the fore section and lower than 18.01 ft./s for the aft section. Since these figures do not account for the drag of the drogue or rocket body, the terminal velocity of the mains could be slightly higher than what was calculated, but in the interest of safety these are used as the maximum limits for the main velocities.

The inner spill hole of a toroidal parachute is 1/5th the outer diameter, and the cross-sectional area can be calculated by Equation 9.

$$A = \frac{6}{25}\pi d^2 \tag{9}$$

Tumbling was added to the simulation using Equation 10.

$$C_{d,t}A_{ref} = C_{d,f}A_f + C_{d,bt}A_{bt} \tag{10}$$

Where $C_{d,t}A_{ref}$ is the equivalent drag coefficient multiplied by the reference area from the tumbling body, $C_{d,f}$ is the equivalent drag of the fins, $C_{d,bt}$ is the equivalent drag of the body tube, A_f is the area of a single fin multiplied by the fin factor, and A_{bt} is the side area of the body tube. Values of $C_{d,bt} = 0.56$, $C_{d,f} = 1.42$, and a fin factor of 1.42 for four fins were used.

The tumbling velocity of the fore section without the nosecone separating is 121.3 ft./s. The tumbling velocity for the aft section including the fins is 107.3 ft./s.

The terminal velocities for available Iris Ultra sizes are plotted for both sections in 32. The average altitude of Marshal Space Flight Center, 1,900 ft., is used for the ground altitude. The terminal velocities of the mains are calculated at the deployment altitude of 800 ft. AGL, or 2,700 ft. Above Sea Level (ASL). Since the rocket will land in air denser than used in calculation, the actual landing velocity will be slightly lower than predicted.

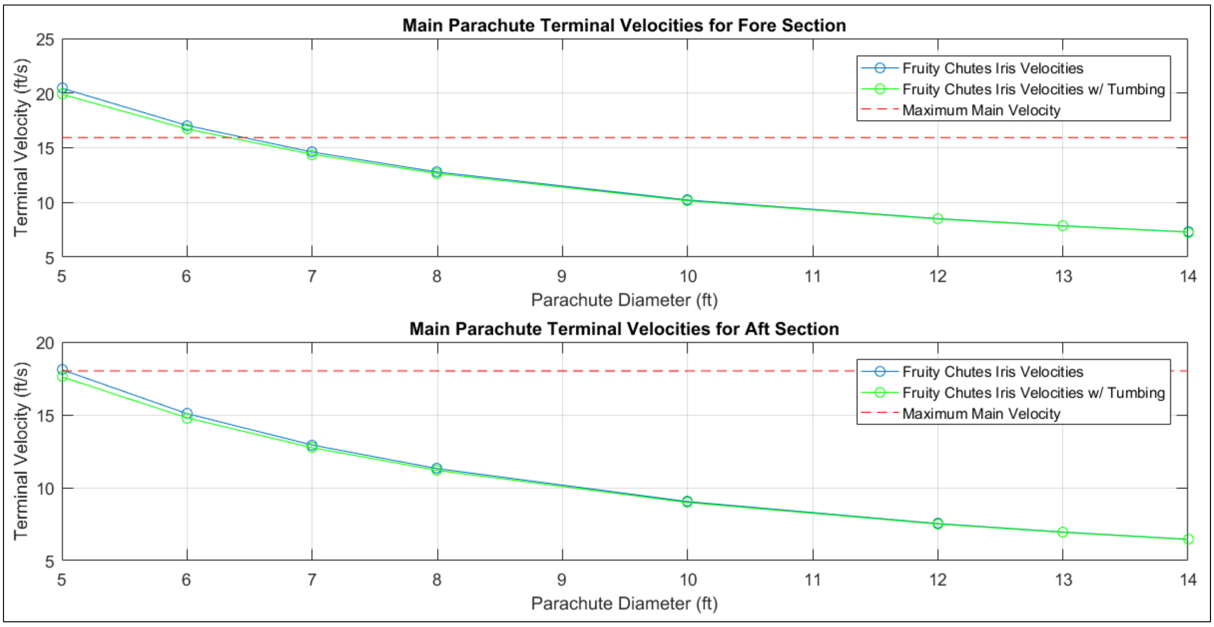


Figure 32: Terminal Velocities of Available Fruity Chutes Iris Ultra Parachutes

A 7 ft. main will be used for the the fore and and a 6 ft. main used for the aft section, which will have terminal velocities of 14.5 ft./s and 14.9 ft./s, respectively, with tumbling.

Drogue Parachute Size

Cruciform shaped Top Flight X-Type parachutes will be used for the drogue parachutes, which has a drag coefficient of 0.98.

Assuming the mains deploy instantly at 800 ft. and descend at 14.5 ft./s, the drift under the mains in 20 ft./s crosswinds would be 1103 ft. The drift under the drogue must be less than 1,396 ft. The descent time for the drogues in 20 ft./s cross winds should be less than 69 s, or a terminal velocity greater than 64 ft./s.

The area of a cruciform parachute can be found by Equation 11:

$$A = 2lw - w^2 \tag{11}$$

The terminal velocity for available Top Flight X-Type sizes are plotted for both sections in 33. The terminal velocities of the drogues are calculated at the deployment altitude of 5,280 ft. AGL, or 7,980 ft. ASL.

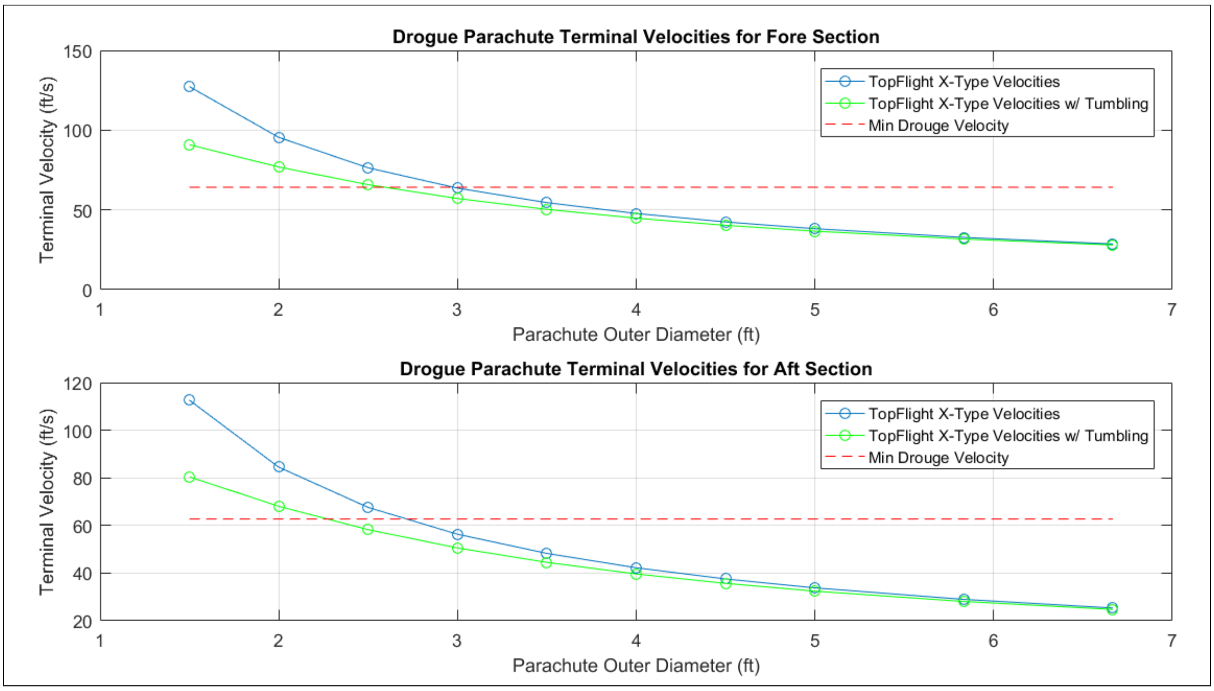


Figure 33: Terminal Velocities of Available Top Flight X-Type Parachutes

A 2 ft. parachute will be used for the fore sections and a 1.5 ft. parachute will be used for the aft section, which will give the fore and aft drogue parachutes terminal velocities of 76.9 ft./s and 80.4 ft./s, respectively, with tumbling. A summary of the calculated velocities is provided in Table 12.

Table 12: Summary of Fore Section and Aft Section Velocities

	Velocity (ft./s			
Section	**Tumbling**	**Drogue**	**Main**	**Landing**
Fore	121.26	76.88	14.50	14.14
Aft	107.31	80.40	14.93	14.61

4.3.2.3 Ejection Charge Sizing

To determine the charge size, the pressure between the bulkheads is needed. A shear stress analysis was performed using three nylon #2–56 shear pins. The cross-sectional area of the free volume was used to calculate the force on the bulkheads using Equation 12. The resultant pressure required to shear the pins is 8.2 psi. Including an approximation for friction and applying a factor of safety of 1.33 results in a minimum pressure of 12 psi. The target of 15 psi is reached using a factor of safety of 1.67. These factors of safety are tentative and will be refined during actual testing to determine the required pressure to cause separation. Equation 13 is used to calculate the required amount of black powder. The factor of safety should include external forces such as acceleration, wind, or unexpected weight.

$$P = \frac{\tau_{y,\text{pin}} A_{\text{pin}} n_{\text{pin}}}{A_{\text{inside}}} \tag{12}$$

$$W_p = \frac{PV}{R^* T} \tag{13}$$

Rouse-Tech, a manufacturer of rocketry parts, uses Equation 14 to approximate the weight of black powder required to achieve separation using the dimensions of the free volume.

$$m_b = 0.006 d_c^2 L_c^2 \tag{14}$$

There are two separate recovery sizes that will be using the same essential design, one for a sub-scale launch and the other for full-scale. Using the geometries from the rocket model, the amount of black powder required can be calculated using each method in Table 13. After reviewing the results, the higher values for sub-scale were used as a starting point for testing as they are more conservative.

Table 13: Black Powder Charge Size Calculations

Recovery Section	Length (in.)	Diameter (in.)	Charge Size (oz.)	
			Eq. 1	Eq. 2
Full-Scale	12	5.2	0.0557	0.0507
Sub-Scale	15	3.8	0.0372	0.0507

During the first six tests, pressure was lost through gas escaping through the bulkhead seal. To counteract this, poster putty was used as a temporary one-time sealant. Its effects was immediate and incredible. Combustion gasses were trapped inside the free volume and a much greater percentage of forces were applied to separation and ejection. The summary of the different weights of black powder charges used for separation testing and their outcome are listed in Table 14.

Table 14: Sub-scale Black Powder Test Charge Sizes

Charge Size (oz.)	Pass/Fail
0.052911	Fail
0.070548	Fail
0.088185	Fail
0.141096	Pass

Clearly, the actual weight of black powder varies quite significantly from the calculated amounts. Testing is the only verifiable way to confirm whether the charge size is significant enough. Further testing will be conducted on the full scale launch vehicle to ensure that the charge size is adequate.

4.3.2.4 Recovery Controller Design

The fore and aft recovery systems are controlled by two identical Recovery Controllers (ReCo), which are both made from commercially available altimeters. A block diagram of the system is shown in Figure 34.

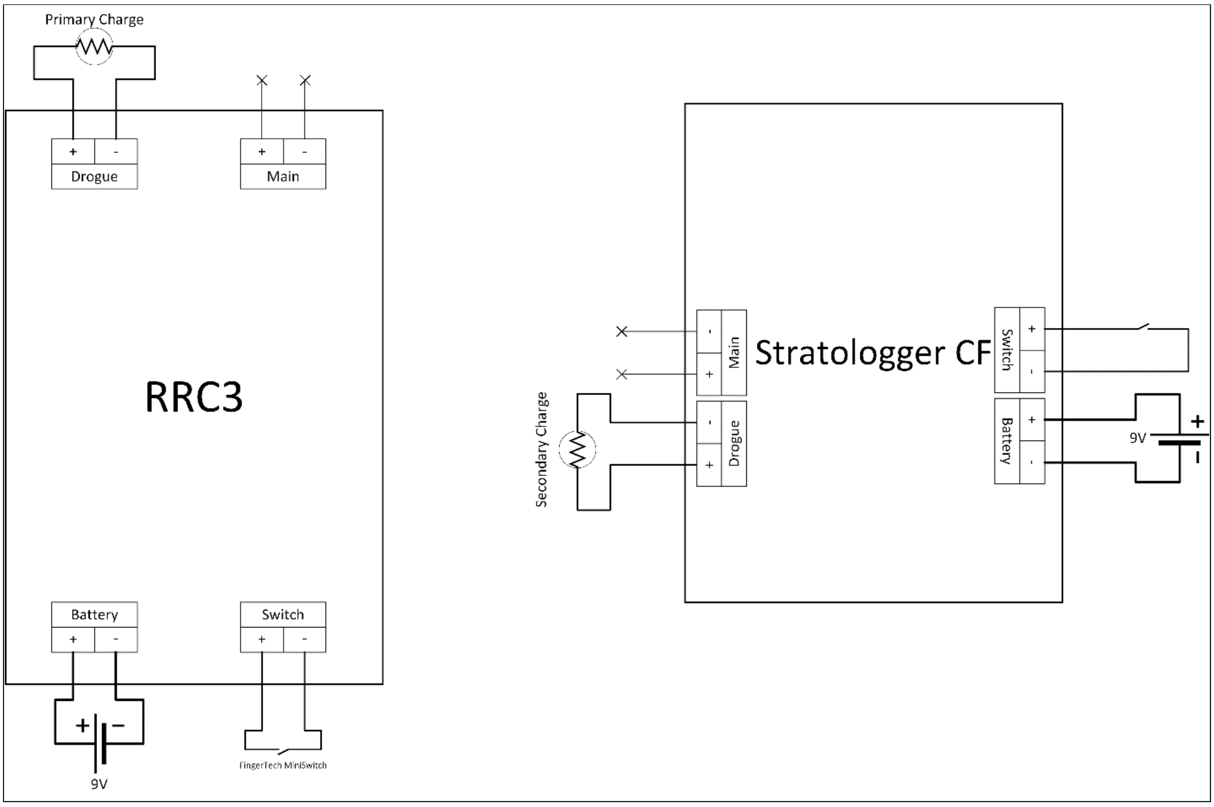


Figure 34: Recovery Controller Block Diagram

Each ReCo uses a MissileWorks RRC3 altimeter to ignite the primary drogue charge, and a PerfectFlite StratoLoggerCF to ignite the secondary drogue charge. The aft primary charge, which ejects the aft parachutes and separates the launch vehicle sections, is ignited at apogee. The fore primary charge, which ejects the fore parachutes, is ignited one second past apogee. Both secondary charges ignite one second after their respective primary charges.

Each altimeter is powered by an individual commercially available Duracell 9V battery. Each altimeter is armed by an individual FingerTech Mini Power Switch, which uses a hex key to turn the power switch from the exterior of the rocket, and which can be screwed down into the on position. There are no electrical connections between any of the altimeters or any of their components. None of the altimeters selected contain any large magnetic components.

Switch leads, battery leads, and e-match leads are secured to the altimeters with screw clamps, allowing for fast field maintenance. E-match leads will be twisted and covered in braided shielding to prevent unintentional ignition from RF interference.

Both ReCos, each containing two altimeters, two switches, two batteries, and two ejection charges, are housed in a separate bay which is covered in magnetic shielding to prevent RF interference. The ReCo bay and the airframe it sits in will have four 1/4 in. static ports through them to ensure a proper pressure reading for the altimeters.

4.3.2.5 ATU/Ground Station design

The ATU will have an approximate weight of 0.6 lb. including the voltage regulators, four layer PCB, microcontroller, GPS module, RF module, and active GPS antenna. The size of the ATU will be determined by the size of the PCB which is specified to have dimentions of 3 in. width, 4 in. length, and 2 in. thickness. The ground station will have an approximate weight of 10 lb. including the computer required to control the system, Yagi antenna, and RF transceiver components that will be included on the base station. There are no size constraints on the base station due to the location on the ground having no impact on the launch vehicle.

4.4 Mission Performance Predictions

4.4.1 Simulated Flight Profile

The OpenRocket simulation of the launch vehicle shows an apogee between 4981 ft. and 5199 ft. Figure 35 is a graph of the 10 mph simulation. This simulation shows that the launch vehicle takes 18.8 seconds to reach apogee. The data from this simulation also states that the velocity off the rod is 65 ft./s and the maximum velocity is 576 ft./s.

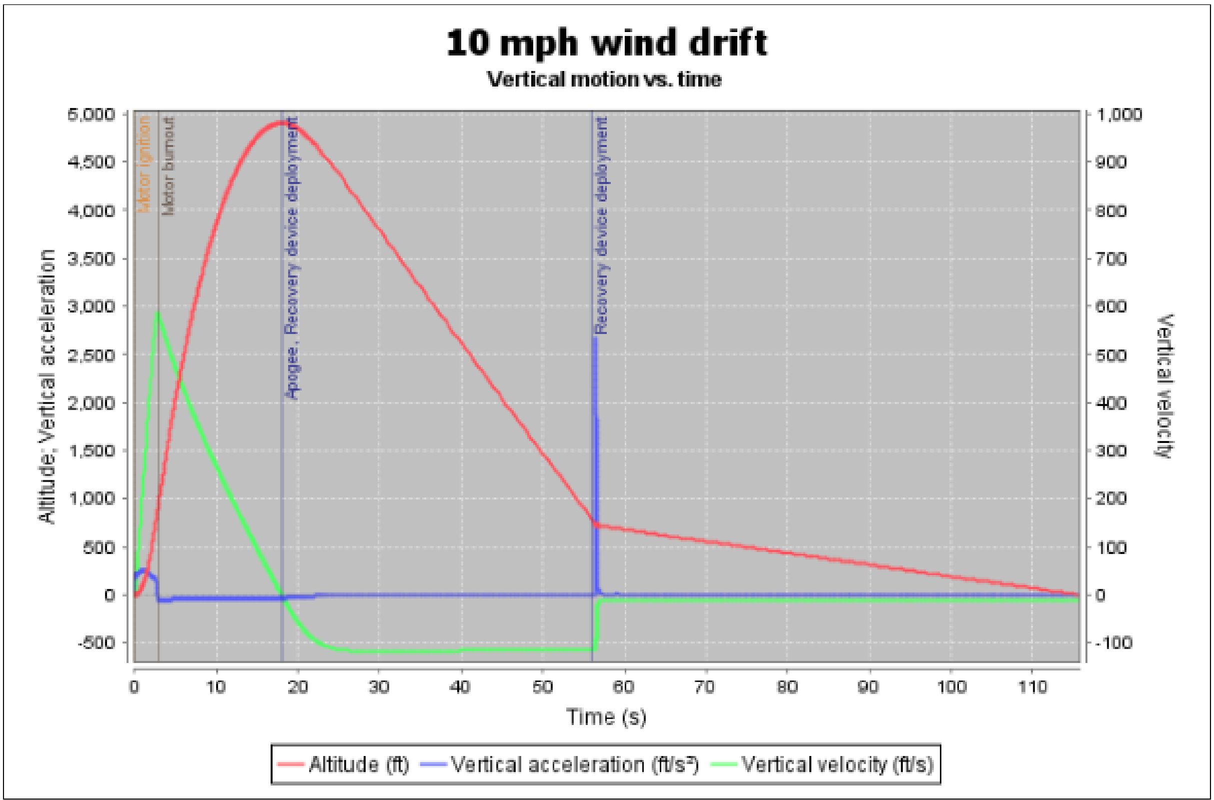


Figure 35: OpenRocket Simulation of 10 mph Wind Drift

A Rocksim analysis of the launch vehicle showed an altitude of 5552.79 ft. In this simulation the launch vehicle took 19.45 seconds to reach apogee. Finally the simulation showed a velocity off the rod of 65 ft./s and a maximum velocity of 586.5 ft./s.

The differences in flight profile are likely due to differences in the way that the center of pressure is calculated. The drag on the launch vehicle could cause the launch vehicle to slow less on its way to apogee. Both of these altitudes are within the acceptable range, and neither simulation is high enough to threaten going over the waiver limit at the launch site.

4.4.2 Stability Margin, CP, CG

The stability margin was calculated using OpenRocket and Rocksim simulations. Both of the models used for these simulations are shown below. The models are based from the measured weights or simulated weights of each section. The stability of the models were 2.56 calibers and 2.56 calibers from OpenRocket and Rocksim respectively with the models seen in Figure 36 and Figure 37.

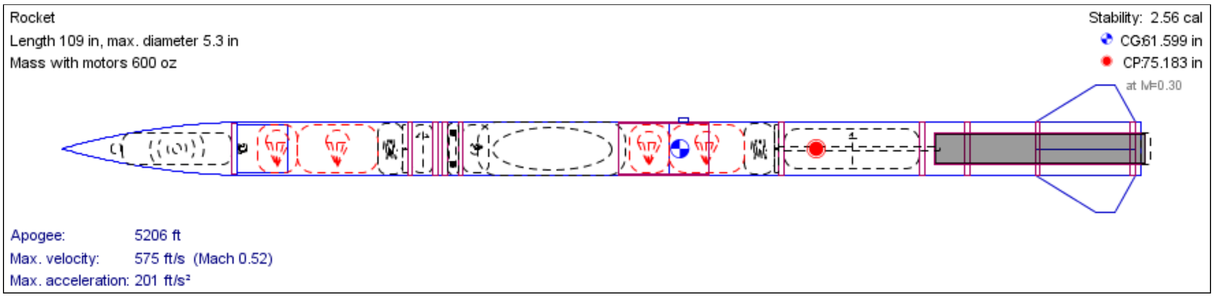


Figure 36: OpenRocket Simulation of Launch Vehicle Stability

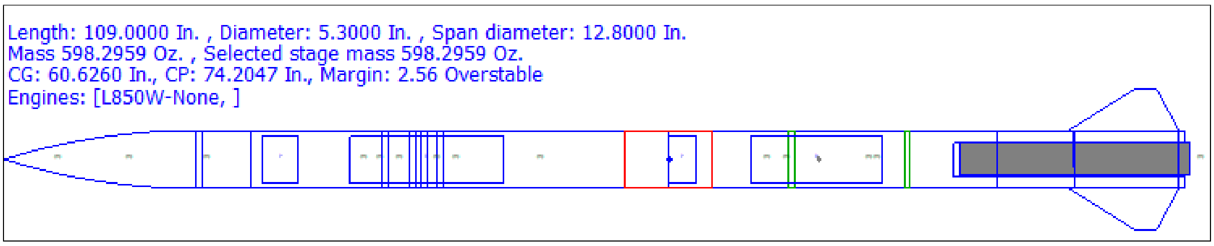


Figure 37: Rocksim Simulation of Launch Vehicle Stability

These stabilities are the same which gives us a high confidence in the simulations. These stability models are highly dependent on the weight of the components in the launch vehicle. During the construction of the launch vehicle it will be important to keep track of the component weights.

4.4.3 Kinetic Energy for Each Section

The selected parachutes, their terminal velocities, and landing energies are listed in Table 15. Landing velocity accounts for the drag from both parachutes, and all velocities include tumbling.

Table 15: Kinetic Energies of Each Section

Section	Weight (lb.)	Main Size (ft.)	Drogue Size (ft.)	Main Velocity (ft./s)	Drogue Velocity (ft./s)	Landing Velocity (ft./s)	Drogue Kinetic Energy (ft.-lbf)	Landing Kinetic Energy (ft.-lbf)
Nose Cone	4.4	7	2	14.50	76.88	14.14	403	13.66
Payload	15.0						1,376	46.57
Aft	14.9	6	1.5	14.93	80.40	14.61	1,495	49.38

4.4.4 Drift

A MATLAB script was used to calculate the descent trajectory using the barometric formula to account for changing air density. Accelerations and decelerations are accounted for assuming deployment occurs instantaneously. The resulting trajectory is plotted in Figure 38.

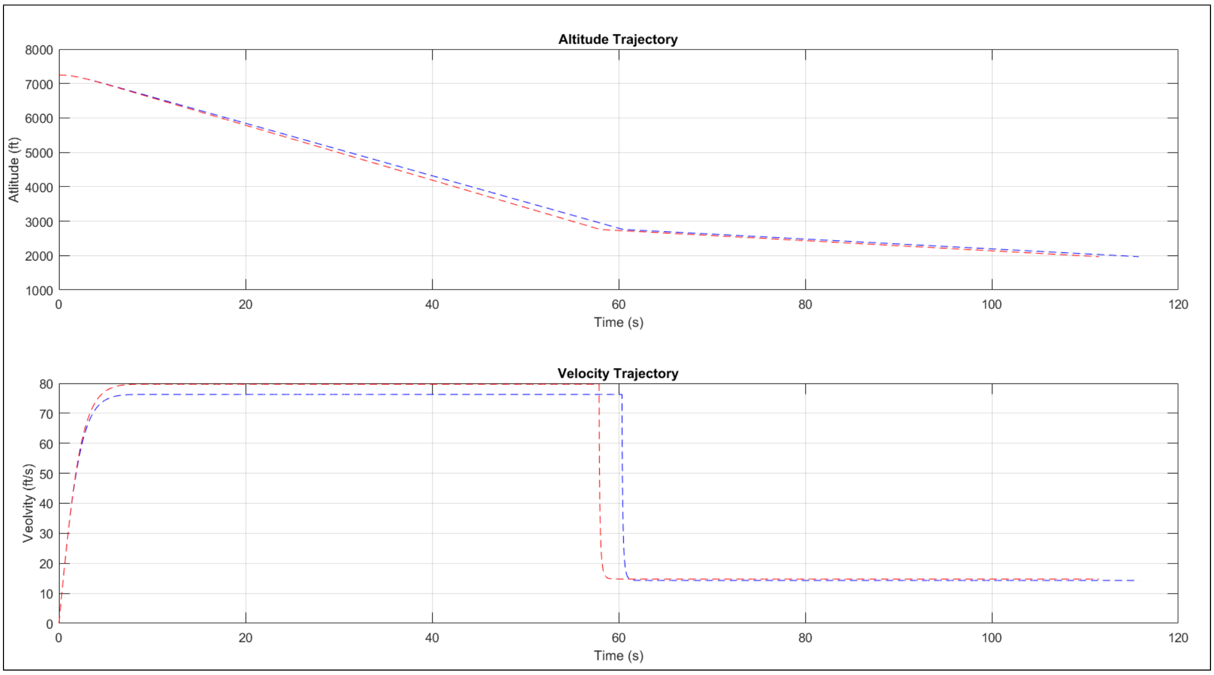


Figure 38: Descent Trajectory for Fore and Aft Sections

Drift distances were calculated using the descent times from each simulation, assuming cross wind speeds are an average over the entire descent and do not affect the vertical trajectory. Weather-cocking was not included in the MATLAB model, so apogee is assumed to happen directly over the launch pad for all calculations. The drift distances from MATLAB and Open Rocket simulations are summarized in Table 16.

Table 16: Summary of Simulated Drift Distances

Simulation			**Cross Wind Velocity (ft./s**				
Section	**Program**	**Descent Time (s)**	0	5	10	15	20
Fore	MATLAB	115.7	0	579	1,157	1,735	2,314
	OpenRocket	100.2	0	501	1,002	1,503	2,004
Aft	MATLAB	111.5	0	558	1,115	1,672	2,230
	OpenRocket	100.2	0	501	1,002	1,503	2,004

The projected drift for both sections in maximum cross-wind conditions remains within the SL required radius of 2500 ft. With 20 ft./s winds, the rocket will drift to a calculated maximum of 2,314 ft, which is 92% of the radius requirement.

5 Safety

5.1 Launch Concerns and Operation Procedures

5.1.1 Recovery Preparation

USLI Recovery Preparation Checklist

Paperwork Needed

- Open launch vehicle flysheet
- Motor datasheet
- National Aeronautics and Space Administration (NASA) flysheet
- Proof of NAR certification

Assembly in Preparation Area

Launch Vehicle Motor

- **All motor assembly must be done by team mentor**
- **Joe Bevier will assemble the motor**
- Assemble Aerotech L850W motor in 75/3840 case based on Motor Assembly Checklist
  - See Motor Assembly Checklist (Section 5.1.2)

Lower Recovery Harness

- **Ensure all sharp objects and flammable materials are removed from workspace**
- **Failure to follow all steps will result in complete mission failure due to recovery failure**
- **Kyle O'Brien will ensure all steps have been properly followed**
- Inspect drogue parachute
- Inspect main parachute
- Roll drogue chute and shroud lines
- Cover drogue chute with Nomex blanket and tie off with temporary tape
- Wrap main chute in Nomex blanket
- **Failure to wrap main parachute in Nomex may result in fire damage**
- Secure main chute with two Jolly Logic chute releases
  - Use two short rubber bands
  - Tether Jolly Logic controllers at parachute swivel
- Turn on Jolly Logic controllers
- **Failure to turn on Jolly Logic controllers will result in no main parachute release**
- Set Jolly Logic controllers to 800 ft.

- Add sacrifice folds between the main parachute link and the main connection as well as between the main parachute and the drogue parachute.

Upper Recovery Harness

- **Ensure all sharp objects and flammable materials are removed from workspace**
- **Failure to follow all steps will result in complete mission failure due to recovery failure**
- **Kyle O'Brien will ensure all steps have been properly followed**
- Inspect drogue parachute
- Inspect main parachute
- Roll drogue chute and shroud lines
- Cover drogue chute with Nomex blanket and tie off with temporary tape
- Wrap main chute in Nomex blanket
- **Failure to wrap main parachute in Nomex may result in fire damage**
- Secure main chute with two Jolly Logic chute releases
  - Use two short rubber bands
  - Tether Jolly Logic controllers at parachute swivel
- Turn on Jolly Logic controllers
- **Failure to turn on Jolly Logic controllers will result in no main parachute release**
- Set Jolly Logic controllers to 800 ft.
- Add sacrifice folds between the main parachute link and the main connection as well as between the main parachute and the drogue parachute.
- Add a third sacrifice fold between the drogue and the nosecone quicklink

Lower Ejection Unit

- **Use safety glasses for each step of Ejection Unit assembly**
- **Jeremy Goodrich will ensure all steps have been properly followed**
- Check voltage of both 9V batteries (acceptable range: 9.0 V - 9.4 V)
- Connect 9V batteries to both StratoLogger and RRC3
- Turn on RRC3, listen for beep sequence, and turn off
  - 5 second long beep, 10 second pause
  - 5 second long beep
- Turn on StratoLoggers, listen for beep sequence, and turn off
  - 1 long beep, 9 fast beeps
  - 2 second pause
  - 1 long beep, 4 single beeps
  - 5 second long beep
  - 2 second pause

  - Series of beeps (last recorded altitude)
  - No beeps should follow
- **Ensure multimeter is set to resistance and no power is pushed to e-match**
- **E-matches can fire if exposed to a current source causing harm to any participants near components**
- Check e-match resistances (acceptable range: 1.3-1.6 ohm)
- Secure ejection charges to bulkhead and put lead wires through hole, tighten washer over hole
- Attach primary charge leads to RRC3 drogue port, attach secondary charge leads to Stratologger drogue port
- Tighten down sealing washer
  - **Failure to include putty will result in a potential ejection failure**
  - Ensure putty is placed in each e-match holes

Lower Tracking Unit

- **Ensure LiPo has been charged in fire resistant bag**
- **Serious injury can be caused from an over charger LiPo battery**
- **Chris Snyder ensures all components of this Unit have been correctly assembled**
- **Check LiPo battery voltage on balance charger to ensure full capacity**
- Connect RF antenna to Xbee SMA connector
- Connect GPS antenna to GPS SMA connector
- Connect battery to Avionics Tracking Unit (ATU) leads to power on the system
- Ensure system is powered on, indicated by Light Emitting Diode (LED) on teensy microcontroller and power LED located on GPS module.

Upper Ejection Unit

- **Use safety glasses for each step of Ejection Unit assembly**
- **Jeremy Goodrich will ensure all steps have been properly followed**
- Check voltage of both 9V batteries (acceptable range: 9.0 V - 9.4 V)
- Connect 9 V batteries to both Strattologger and RRC3
- Turn on RRC3, listen for beep sequence, and turn off
  - 5 second long beep, 10 second pause
  - 5 second long beep
- Turn on Strattologgers, listen for beep sequence, and turn off
  - 1 long beep, 9 fast beeps
  - 2 second pause
  - 1 long beep, 4 single beeps
  - 5 second long beep
  - 2 second pause

  - Series of beeps (last recorded altitude)
  - No beeps should follow
- **Ensure multimeter is set to resistance and no power is pushed to e-match**
- **E-matches can fire if exposed to a current source causing harm to any participants near components**
- Check e-match resistances (acceptable range: 1.3-1.6 ohm)
- Secure ejection charges to bulkhead and put lead wires through hole, tighten washer over hole
- Attach primary charge leads to RRC3 drogue port, attach secondary charge leads to Stratologger drogue port
- Tighten down sealing washer
  - Ensure putty is placed in each e-match holes

Upper Tracking Unit

- **Ensure LiPo has been charged in fire resistant bag**
- **Serious injury can be caused from an over charger LiPo battery**
- **Chris Snyder ensures all components of this Unit have been correctly assembled**
- Check LiPo battery voltage on balance charger to ensure full capacity
- Connect RF antenna to Xbee SMA connector
- Connect GPS antenna to GPS SMA connector
- Connect battery to Avionics Tracking Unit (ATU) leads to power on the system
- Ensure system is powered on, indicated by LED on teensy microcontroller and power LED located on GPS module.

Lower Section

- **Wear gloves for all steps associated with the Lower Section**
- **Ensure dust cap is attached to nozzle of motor**
- **Make sure there are no flammable materials near motor**
- **Motor can explode and cause harm to personnel and objects in area**
- **Jeremy Goodrich ensures all steps have been precisely followed**
- Insert motor into motor tube
- Secure motor with Aero Pack retainer
- Slide ejection sled onto lower threaded rod
  - Ensure the alignment has been made during assembly
- **Failure to see single thread of eye nut may result in recovery failure**
- Put on washer, eye nut, and locknut with a single thread of eye nut visible
- Putty bulkhead using poster putty
- Attached recovery harness using quicklink
- Fill tube with cellulose insulation

- **Kyle O'Brien ensures parachutes have been packed correctly**
- Remove all tape from main and drogue parachute
- **Failure to remove tape will result in unideal recovery performance**
- Pack down parachutes
- Take first sacrifice fold next to main parachute and line next sacrifice fold and fold (forms a bundle)
- Place bundle into tube
- The second sacrifice fold will be placed next to folder (forms second bundle)
- Place second bundle into tube

Nose Cone Assembly

- **Jeremy Goodrich will ensure all steps are followed for Nose Cone Assembly**
- **Safety glasses and gloves should be used for all parts of Nose Cone Assembly**
- Slide the upper tracking bay onto threaded rod
- Tighten down using a locknut and washer
- Slide bulkhead onto threaded rod
- **Failure to see single thread of eye nut may result in recovery failure**
- Put on washer, eyenut, and locknut with a single thread of eye nut visible
- **Failure to apply putty will result in a potential ejection failure**
- Putty bulkhead using poster putty

Upper Section

- **Jeremy Goodrich and Charlie Sandford will ensure steps are followed**
- **Safety glasses and gloves should be used for all parts of Upper Section**
- Slide payload section into payload bay
- Use nut to attach payload to backside using nylock and washer
- Slide upper ejection bay into tube
- **Failure to see single thread of eye nut may result in recovery failure**
- Put on washer, eye nut, and locknut with a single thread of eye nut visible
- Putty bulkhead using poster putty
- Attached recovery harness using quicklink
- Fill tube with cellulose insulation
- **Kyle O'Brien ensures parachutes have been packed correctly**
- **Remove all tape from main and drogue parachute**
- **Failure to remove tape will result in unideal recovery performance**
- **Pack down parachutes**
- Take first sacrifice fold next to main parachute and line next sacrifice fold and fold (forms a bundle)
- Place bundle into tube

- The second sacrifice fold will be placed next to folder (forms second bundle)
- Place second bundle into tube
- Add a third sacrifice fold between the drogue and the nosecone
- Attach nose cone with a quicklink
- Press nose cone with 3x 2-56 nylon shear screws for attachment

Final Assembly

- **Safety glasses and gloves are required for all steps for Final Assembly**
- **Jeremy Goodrich is in charge of verifying all steps are followed**
- Slide upper section into lower section
- **Failure to attach nylon screws may result in premature separation**
- Attached with 3x 2-56 nylon screws

5.1.2 Motor Preparation

USLI Motor Preparation Checklist

Paperwork Needed

- Open launch vehicle flysheet
- Motor datasheet
- NASA flysheet
- Proof of NAR certification

Assembly in Prep Area

Motor Preparation

- **Joe Bevier will do all assembly of the motor**
- **Tim Lewis will ensure all safety steps will be followed**
- **Safety concerns includes ammonium perchlorate composite propellant, therefore avoid moisture and combustion sources**
- **Failure to closely follow all steps will result in mission failure and no launch**
- Remove forward and aft closures
- Remove forward seal disk
- Open reload kit bag
- Grease all O-rings
- Grease sides and bottom delay charge
- Place O-ring on seal disk
- Place seal disk on top of powder grains
- Place delay charge into forward closure
- Place O-ring on forward closure
- Screw in forward closure
- Place O-ring on aft closure
- Insert nozzle
- Screw in aft closure
- Tighten both enclosures
- Cut hole in motor cap
- Insert motor cap

5.1.3 Payload Preparation

L2 Tender Descender Assembly Steps:

Materials:

1) Quick Links
2) Housing
3) Link Retainer Assembly (connected to housing by Kevlar lanyard)
4) Sheath
5) U-Bolt Assembly (fixed to bulkhead)

Each of these materials can be seen in Figure 39.

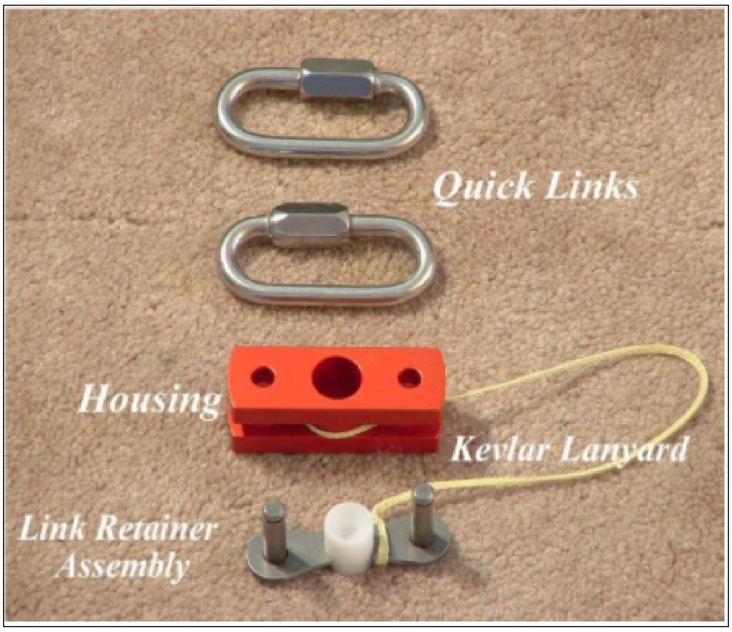


Figure 39: L2 Tender Descender Components

Assembly:

1) Thread the kevlar shock cord through one of the attachment quick links
2) Install e-match into housing ejection canister
3) Pour 0.2 g of 3F or 4F black powder into the ejection canister
4) Fix tape over ejection canister to hold black powder and e-match in place
5) Install the quick link with the shock cord tethered through to the U-bolt which is fixed within the airframe. This ensures the device remains within the airframe during ejection
6) Fix alternate quick link to payload ejection harness

7) Re-install the quick links to the housin
8) Thread wiring through forward bulkhead to microcontroller within the nose cone
9) Place sheath over descender to minimize damage due to freed components following ejection

Advanced Retention and Release Device (ARRD) Assembly Steps:

Materials:

1) Nut and washer
2) Toggle
3) Ejection charge canister
4) Ejection charge cap
5) Ball bearings
6) Spring assembly
7) Red body aluminum housing
8) Adhesive disk

Each of these materials can be seen in Figure 40.

Figure 40: ARRD Components

Assembly:

1) Unscrew base and remove toggle

2) Place ball bearings in red body aluminum housing
3) Place toggle assembly into red body, push piston into body securing toggle
4) Place pyrodex and e-match into cartridge
5) Place adhesive disk over cartridge
6) Screw assembly base and red body housing together

Payload bay assembly steps:

1) Attach one end of both kevlar shock cord loops to aft housing endplate U-bolt using quick links
2) Secure rover between plywood end plates
3) Insert soft foam sections surrounding rover chassis
4) Place loose kevlar shock cord onto spring assisted release mechanism in end plate slot
5) Wrap carbon fiber sheet around rover

STOP: Hold carbon fiber sheet in place and prepare fixed bulkhead

1) Secure Tender Descenders to fixed bulkhead U-Bolts
2) Attach ARRD through tapped hole

STOP: Personal Protective Equipment (PPE) Required. HPR level 1 certification required to handle black powder charges.

3) Fix black powder charges to fixed bulkhead using duct tape
4) Wire ARRD, Tender Descender and ejection charge e-matches to PLEC activation controller
5) Attach both kevlar loops of the harness to individual Tender Descenders
6) Attach backup retention ties to the ARRD

STOP: Run through Inspection and troubleshooting checklist

7) Thread rod of payload section into the launch vehicle and secure on alternate side of the structural bulkhead

Inspection and troubleshooting:

- Were both Tender Descenders and the ARRD connected as described within the assembly steps?
- Were the retention devices wired to the activation controller?
- Was the rover activated prior to placement in the launch vehicle? Confirm audible buzzer.
- Pull on the rover housing from inside the airframe. Does it move from its vertical location? If so, repeat the entire assembly.

5.1.4 Setup on Launcher

USLI Setup on Launcher Checklist

Paperwork Needed

- Open rocket flysheet
- Motor datasheet
- NASA flysheet
- Proof of NAR certification

Load for Transport to Launch Pad

- **Tim Lewis will ensure all steps have been properly followed**
- Parts box with the following parts for final assembly
  - Multimeter
  - 3/32 Allen wrench
  - Extra igniter
  - Rocket assembly screwdrivers
  - Sandpaper for clips
- Step stool

Preparation at Launch Pad

- **Tim Lewis will ensure all steps have been properly followed**
- **Failure to wait for approval can result in injury from alternative launch vehicles**
- Wait for RSO approval to approach launch pad
- Slide launch vehicle onto launch rail
- **Failure to raise launch rail will result in complete mission failure**
- Raise launch rail
- Angle launch rail as directed by RSO

Final Launch Preparation

- **Tim Lewis will ensure all steps have been properly followed**
- **Kyle O'Brien will ensure all beep sequences are properly met**
- **Failure to arm any ejection & tracking units may results in failed recovery**
- Arm lower RRC3s
  - Using 3/32 in. Allen wrench, power up the altimeter
  - Listen for proper beep sequence
    - 5 second long beep, 10 second pause
    - 5 second long beep

    * 1 short beep (if no short beep, check primary drogue charge e-match)

- Arm upper RRC3s
  - Using 3/32 Allen wrench, power up the altimeter
  - Listen for proper beep sequence
    * 5 second long beep, 10 second pause
    * 5 second long beep
    * 1 short beep (if no short beep, check primary drogue charge e-match)
- Arm lower StratoLoggers
  - Using 3/32 Allen wrench, power up the altimeter
  - Listen for proper beep sequence
    * 1 long beep, 9 fast beeps
    * 2 second pause
    * 1 long beep, 4 single beeps
    * 5 second long beep
    * 2 second pause
    * series of beeps (last recorded altitude)
    * 1 beep (if 0, check secondary drouge charge e-match)
- Arm upper Strataloggers
  - Using 3/32 Allen wrench, power up the altimeter
  - Listen for proper beep sequence
    * 1 long beep, 9 fast beeps
    * 2 second pause
    * 1 long beep, 4 single beeps
    * 5 second long beep
    * 2 second pause
    * series of beeps (last recorded altitude)
    * 1 beep (if 0, check secondary drouge charge e-match)
- Arm payload
  - Using 3/32 Allen wrench, power up the altimeter
  - LED sequence with a half second on and half second off
- Remove step stool from launch area
- Move all non-essential personnel back to launch control box

5.1.5 Igniter Installation

USLI Igniter Installation Checklist

Paperwork Needed

- Open rocket flysheet
- Motor datasheet
- NASA flysheet
- Proof of NAR certification

Igniter Installation

- **All non-essential team members to clear the launch area**
- **Igniter insertion to be carried out under supervision of RSO**
- **All team members must be wearing safety glasses**
- Check continuity of igniter
- Ensure launch system disarmed
- Insert long end of igniter all the way into the hole in the motor cap
- Attach wire ends of igniter to launch system
- Clear launch area of all personnel

5.1.6 Troubleshooting

Arming switches cannot be reached through static ports

- Disarm all active charges
- Pull rocket and return to assembly area
- Realign altimeter that cannot be reached

One of the altimeters does not arm

- Disarm all active charges
- Pull rocket and return to assembly area
- Check voltage on 9 V battery
- Create new ejection charge with a new igniter
- Check new igniter resistance

Payload doesn't arm

- Disarm all active charges
- Pull rocket and return to assembly area
- Check voltage on 9 V battery
- Create new ejection charge with a new igniter
- Check new igniter resistance

Igniter continuity failure

- Use back up igniter
- If this one fails
  - Disarm all active charges
  - Pull rocket and return to assembly area

Rocket doesn't fire on button press

- Wait for RSO
- Follow RSO directions for dealing with misfire

RSO calls off launch for safety violation

- Disarm all active charges
- Pull rocket and return to assembly area

Structural failure in frame noticed on pad

- Disarm all active charges

- Pull rocket and return to assembly area
- Determine if failure leads to scrapping the launch

5.1.7 Post-flight Inspection

- Turn off all altimeters
- Check for non-discharged deployment charges
- Remove any charges and safe them by shorting the leads
- Recover all components and return to assembly area
- Remove parachute harnesses from each section
- Detach eyenut assembly from lower section
- Remove lower av-sled and lower ejection bay
- Remove motor and place in sealed compartment
- Remove upper ejection controller
- Remove payload section
- Remove upper av-sled
- Inspect body tube for damage
- Inspect nosecone for damage
- Inspect parachutes for damage
- Pull altimeters and avionics from launch vehicle
- Scrub inside of airframe and bulkheads clean to
- remove any black powder residue
- Clean motor case between 1-3 hours after launch

5.2 FMEA

Payload FMEA								
Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Rover Chassis	Chassis Structural Failure	Ejection failure (getting stuck), damage to other rover components, mission failure	8	CF rod comes out of joint	1	2	16	Inspect rover prior to launch. Epoxy rods firmly in place.
				Rod fails under stress	1	3	24	Purchase rod from known, reputable manufacturer. Test chassis under full loads.
Rover Stabilizer	Stabilizer doesn't deploy	Inability to drive	7	Spring arm slips	3	3	63	Firmly secure spring arm
				Hinge binds	2	4	56	Ensure holes are aligned, stabilizer doesn't bend in transit.
				Debris prevents opening	4	2	56	Eject rover away from parachutes. Ensure springs are strong enough to clear debris.
Payload Rover Drivetrain	The wheel falls off the driveshaft	Damage to airframe, improper functionality of rover, potential projectile	7	Set screw loose and not properly tightened	5	4	140	Use torque wrench to tighten screws to 9.5 pound-inches. Use blue Loctite to fasten final components
				Severe tension forces on rover	1	7	49	Orient rover so that main forces during recovery are compressive. Use accelerometers during full-scale tests to ensure correct compressive accelerations
	Binding of material when shaft rotates	Improper rotation of driveshaft, injury to human fingers/hands, mission damage to manufactured components	6	Human interface with rover during operation	6	1	36	Ensure component is in testing fixture during operation. Comply with checklist verifying proper usage or rover
				Strings/twine near rover during operation	4	3	72	Utilize large wheel diameters that will not grip string/twine. Eject rover from airframe and travel away from airframe
	Bearings are removed from housing	Driveshaft does not rotate properly, rover does not travel as intended	4	Machined housing hole diameter incorrect	6	5	120	Have a member that has not manufactured the housing measure the hole diameters using a set of calipers. Diameter should be at least 0.005" less than OD of bearing
				Driveshaft pulls bearings from housing	1	8	32	Ensure high forces on rover are compressive to verify driveshaft functionality
	Driveshaft expands due to temperature increase	Driveshaft does not rotate properly, components fails from radial expansion	3	Bearings hold driveshaft tightly	3	6	54	Ensure bearing ID greater than driveshaft OD by at least 0.010"
				Aluminum coupler holds driveshaft tightly	5	6	90	Ensure coupler ID greater than driveshaft OD by at least 0.010"
Payload Rover Motor Driver & Overcurrent Protection	Wires supplying power and receiving power catch on fire	Fire damage to rover and potential loss of control of motors	8	Diameter of wire used to connect motor driver subsystem to motors and power supply is unable handle 8.2 Amps of current	2	3	48	Use 18 gauge wire for wiring the motor driver which is rated for 10 Amps of current
	Wiring for subsystem detaches or disconnects	Motor(s) will no longer receive control signals for movement	10	Vibrational forces crack or tear out solder joints/screw terminals	4	3	120	Joints are reinforced with epoxy and wire screw terminals are tightened with power tool to 9.5 pound-inches
	Motor(s) burn out from stalling	Motor(s) will not be reusable for multiple missions and will need replacement, power supply will waste excessive energy	6	No feedback implemented to protect motor(s)	5	5	150	Implement a current sensor for feedback to prevent long term stalling of motor(s)

Payload FMEA								
Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Payload Rover Batteries	Short circuit between power and ground leads of batteries	Sparks, battery swelling, and release of heat and hydrogen gas	6	Mishandling batteries while installing them into the rover	4	3	72	A formal procedure will be written with instructions explaining how to safely install the batteries into the rover.
				Battery lead becomes disconnected and makes contact with other lead	3	5	90	Research will be conducted to find wire connectors will the least likelihood of becoming disconnected.
	Over-charging of batteries	Battery swelling, and release of heat and hydrogen gas	4	Charging batteries without smart charger	2	1	8	The team will agree to only buy smart chargers, so that non-smart chargers are never used for charging the batteries.
				Personnel using wrong charge settings for battery type	5	4	80	A formal procedure will be written with instructions explaining how to properly charge the type selected for this project.
	Battery puncture	Sudden combustion of batteries, rover systems, or nearby vegetation	9	Batteries are punctured by pinching of the frame during a collision	3	1	27	1. Inspect rover prior to launch. Epoxy rods firmly in place. 2. Purchase rod from known, reputable manufacturer. Test chassis under full loads.
Payload Rover Voltage Regulator	Voltage regulator supplying over voltage	Many or all electrical systems connected to the power rail get fried	4	Voltage regulator over heats and supplies irregular output voltage	5	4	80	The voltage regulator will be thoroughly tested at nominal and peak values and make use of a heat sink to insure it will be able to properly dissipate heat.
	Voltage regulator supplying under voltage	All electrical systems connected to power rail turn off	1	Battery lead becomes disconnected with voltage regulator	3	2	6	Research will be conducted to find wire connectors will the least likelihood of becoming disconnected.
				Voltage regulator can not supply power necessary for the rover to operate	6	4	24	The voltage regulator will be thoroughly tested at nominal and peak values and make use of heat sink to insure it will be able to provide the necessary power to operate the rover.
Payload Ejection Controller	RF Antenna Signal Disconnected	Ejection controller will not ignite retention and deployment charges: partial mission failure	6	Assembly connector becomes dislodged	2	6	72	Assembly connector physically latches
				Excessive interference	2	8	96	Range organizes operating frequencies and wire is shielded on inside of body tube
	Ejection Controller Assembly Connector Becomes Disconnected	Deployment charges will not arm, rover will not deploy: partial mission failure	6	Excessive vibration from launch vehicle	2	10	120	Assembly connector physically latches
				Error or carelessness in vehicle assembly	4	4	96	Assembly checklist contains warnings to double check connections and to pay special attention to loading orientation
	Battery Becomes Dislodged or Disconnected	Deployment charges will not arm, controller will not function, rover will not deploy: partial mission failure	6	Excessive vibration from launch vehicle	3	10	180	Batteries are zip tied in multiple orientations and slip-checked upon assembly
				Error or carelessness in vehicle assembly	4	4	96	Assembly checklist contains warnings to double check connections and to pay special attention to loading orientation
	Control Electronic Malfunction	E-match relays will not activate, rover will not deploy: partial mission failure	6	Manufacturing error	1	8	48	Microcontroller will be tested before assembly
	One Relay Electronic Malfunction	Corresponding e-match relays will not activate, rover will not deploy, rover may be damaged: partial mission failure	5	Manufacturing error	2	10	100	Relays will be tested before assembly. Relays have pull down resistors to sink leakage current and filter capacitors to mitigate RF noise on e-match leads

Payload FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Payload Ejection Controller	Two Relay Electronic Malfunctions in Series	Corresponding e-match relays will not activate or may activate after arming. Rover will not deploy or rover will be damaged within body tube. Damage to launch vehicle: partial to total mission failure.	10	Manufacturing error	1.5	10	150	Relays will be tested before assembly. Relays have pull down resistors to sink leakage current and filter capacitors to mitigate RF noise on e-match leads. Two relays in series must be activated in order for each e-match to ignite. The relays are different models to avoid batch manufacturing errors
	E-Match Connection Becomes Dislodged	Corresponding e-match relays will not activate. Rover will not deploy or rover will be damaged within body tube. Damage to launch vehicle: partial to total mission failure.	6	Excessive vibration from launch vehicle	2	10	120	Screwed spring terminal blocks are used to fasten e-match leads
				Error or carelessness in vehicle assembly	4	4	96	Assembly checklist contains warnings to double check connections and to pay special attention to loading orientation
	Rover Pull-Pin Becomes Dislodged Upon Vehicle Assembly	Rover batteries will be partially depleted upon deployment. Rover may not have battery to avoid obstacles and travel minimum requirement or not deploy solar panels: possible partial mission failure	4	Excessive vibration from launch vehicle	5	10	200	Ejection testing will be used to determine tightness of pull-pin connection. If necessary, connector will be switched or tape will be added.
				Error or carelessness in vehicle assembly	7	4	112	Assembly checklist contains warnings to double check connections and to pay special attention to loading orientation
	Rover Pull-Pin or Maintenance Connector Becomes Dislodged Upon Vehicle Ascent or Descent	Rover batteries will be partially depleted upon deployment. Rover may not have battery to recover from being stuck and travel minimum requirement or not deploy solar panels: possible partial mission failure	4	Excessive vibration from launch vehicle	4	10	160	Ejection testing will be used to determine tightness of pull-pin connection. If necessary, connector will be switched or tape will be added. Assembly checklist contains warnings to double check connections and to pay special attention to loading orientation

Payload FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Rover Solar Panel	Failure to Deploy	Partial mission failure, no other effect	6	Power system becomes disconnected	3	5	90	Use locking connectors and secure wires with zip ties
				Obstruction blocking full deployment (See next entry)	2.5	5.5	82.5	(See mitigations for linked causes)
	Obstruction blocking full deployment	Partial mission failure, no other effect	6	Fastener or other part within ejection housing comes loose	3	3	54	Use thread lock for all threaded components; use spring clamps for all non threaded connectors
				Rover, housing, or forward section becomes stuck in ground upon landing	2	8	96	Test rover ejection to determine sufficient black powder charges to randomize deployment location. Use spring loaded rover housing plate with large surface area to act as landing pad for rover.
	Panels Crack or Break	Partial mission failure, no known competition failure	3	Excessive vibration from launch vehicle	4	7	84	Panels are shielded in carbon fiber and held tightly with carbon fiber trays and foam padding
				Excessive shock from rover deployment	5	8	120	Panels are shielded in carbon fiber and held tightly with carbon fiber trays and foam padding
Sonar	Sonar DC Input Voltage higher/lower than required	Sensor disabled or damage to sensor and other rover electronics	8	Rover voltage regulator not operating correctly	5	4	160	Extensive testing of 5V voltage regulator and sensor DC power input properties
				Improper Manufacture	1	9	72	Purchase sensor, voltage regulator, and batteries from known, reputable manufacturer
	Sonar current draw larger than stated	Rover batteries drained	8	Improper Manufacture	1	9	72	Purchase sensor from known, reputable manufacturer
	Sonar distance to object calculation longer than actual distance	Rover collides with object in path	9	Object is within 12 inches of sensor front face	8	5	360	Navigation algorithm method
				Sensor not operating correctly	4	6	216	Extensive testing of sensor distance to object accuracy prior to mission
	Sonar distance to object calculation shorter than actual distance	Rover corrects current navigation path unnecessarily	5	Sensor not operating correctly	4	6	120	Extensive testing of sensor distance to object accuracy prior to mission
	Sonar reports no distance to object calculation	Rover collides with object in path	9	Sensor not operating correctly	3	2	54	Extensive testing of sensor distance to object accuracy and reliability prior to mission
Payload Retention	Tender Descender release	Payload is subject to success of backup device (ARRD), payload could prematurely eject from airframe	8	Early ignition of e-match	2	2	32	Test e-match resistance prior to any launch. Ensure reliability of activation electronics.
				Mechanical system failure	3	3	72	Implement Descender sheath. Test load capabilities.
	ARRD release	Payload is subject to success of primary device (Tender Descender), payload could prematurely eject from airframe	8	Early ignition of e-match	2	3	48	Test e-match resistance prior to any launch. Ensure reliability of activation electronics.
				Mechanical system failure	1	4	32	Test load capabilities. Practice assembling ARRD.
				Kevlar cord failure	1	2	16	Ensure Kevlar cord is rated for adequate tension expected during flight. Inspect for fracture prior to launch.
Payload Housing	Harness fracture	Payload prematurely ejects from launch vehicle	9	Kevlar harness material fractures during mission	2	3	54	Ensure Kevlar harness is rated for adequate tension expected during flight. Inspect of fracture prior to launch.

Payload FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Payload Release	Rover is unable to release from housing following ejection	Payload is unable to traverse environment and complete ground mission	7	Payload damage from flight forces	4	4	112	Use minimal black powder charges as possible. Protect payload from powder dust and forces of pressure from ejection.
				Payload caught on harness	4	2	56	Implement springs which push harness out of payload path following release from airframe.
				Carbon fiber doesn't release	2	2	28	Manufacture thin carbon fiber sheet which is rolled into place. Test ability to unfurl correctly.
Rocket Detection Sensors	Microphone and/or Piezoelectric buzzer DC Input Voltage higher/lower than required	Sensor disabled or damage to sensor and other rover/rocket electronics	8	Rover voltage regulator not operating correctly	5	4	160	Extensive testing of 3.3V voltage regulator and sensor DC power input properties
				Improper Manufacture	1	9	72	Purchase sensor, voltage regulator, and batteries from known, reputable manufacturer
	Microphone current draw larger than stated	Rover batteries drained	8	Improper Manufacture	1	9	72	Purchase microphone and batteries from known, reputable manufacturer
	Piezoelectric buzzer current draw larger than stated	Piezoelectric buzzer battery supply on-board rocket drained	8	Improper Manufacture	1	9	72	Purchase piezoelectric buzzers and batteries from known, reputable manufacturer
	Dual microphone array system reported angle to piezoelectric buzzer source transmission larger than actual angle localization	Rover does not navigate away from all pieces of the rocket casing	7	Sound localization algorithm not operating correctly or extensive noise/interference	6	5	210	Extensive testing of algorithm accuracy in the presence of noise/interference
				Dual microphone array hardware not operating correctly	4	4	112	Extensive testing of dual microphone array detection and accuracy capabilities
	Dual microphone array system reported angle to piezoelectric buzzer source transmission smaller than actual angle localization	Rover does not navigate away from all pieces of the rocket casing	7	Sound localization algorithm not operating correctly or extensive noise/interference	6	5	210	Extensive testing of algorithm accuracy in the presence of noise/interference
				Dual microphone array hardware not operating correctly	4	4	112	Extensive testing of dual microphone array detection and accuracy capabilities
	Dual microphone array system reports no angle to piezoelectric buzzer source transmission	Rover collides with object in path	9	Dual microphone array hardware and/or sound localization algorithm not operating correctly	3	2	54	Extensive testing of sound localization algorithm reliability and accuracy

Recovery FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Parachutes	Attachment points fail	Complete System Failure	9	Quick links come undone	2	5	90	Visually inspect all quick links prior to launch
				Bridle Comes Loose	3	4	108	Check all knots prior to launch; use sewn loops wherever possible
				Hardware Failure	2	4	72	Use welded, closed eyebolts; ensure sufficient force rating on all hardware
	Parachute failure	Increased peak loads, damage to rocket components, causes long-term damage; lowers strength of lines, damage to airframe and components	9	Uncontrolled Inflation	3	4	72	Test packing method and record method for consistency, consider packing volume when selecting parachute sizes, use better packing methods where required
				Flame damage to components	2	4	72	Protect all components close to ejection gasses with flame retardant material
				Self-Impact	3	3	81	Final rigging layout will be inspected by HPR mentor; bridles sized long enough to prevent the possibility of collision
Electronics	Charges fail to ignite	Complete system failure	8	Loss of power	3	5	120	Check and replace batteries prior to every flight; redundant systems used
				Wiring disconnects	4	4	128	Insulate all wires to protect physically, use spring clamps or screw terminals for all connections; redundant systems used

Recovery FMEA								
Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Electronics	Premature Ejection	Damage to airframe and components, reduced altitude	8	Unexpected excitation of e-matches from RF interference	2	6	92	Recovery altimeters EMI shielded, shielding used on all wires
				Inaccurate altitude sensing	2	5	80	Reliable altimeters will be used; altimeters will have static ports for better accuracy
	Electronics damaged by charges	Failure to operate properly, loss of electronics	7	Lack of seals between charges and electronics	6	4	168	Sealing putty will be placed around edges of all non-fixed bulkhead, all fixed bulkheads will be properly sealed
Black Powder Ejection Charges	Launch vehicle sections fail to separate	Loss of launch vehicle, mission failure	9	Insufficient black powder	1	3	27	Several ejection test will be preformed to find sufficient charge size, backup charges of larger size will be used
				Lacking seal	5	4	180	Sealing putty will be placed around edges of all non-fixed bulkhead, all fixed bulkheads will be properly sealed
				Insufficient wading	3	2	54	Wading will be added and forced into the empty spaces
	Damage to internal components	Damage to parachutes, damage to internal components	7	Incomplete burn	6	4	168	Charges will be packed tightly and sealed at each end
				Excess black powder	2	4	56	Several ejection test will be preformed to find sufficient charge size, charges will not be sized

Propulsion FMEA								
Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Motor	Catastrophic failure at take off	Injury to nearby people, Damage or destruction of rocket, damage to launch equipment	10	Damage to Motor or Casing during storage or transport	3	4	120	Inspect motor carefully before use, handle with care and properly package for transport
				Improper Manufacture	1	9	90	Purchase motor from known, reputable manufacturer
	Motor fails ignite	Mission failure, replace motor	6	Damage to Motor or Casing during storage or transport	3	4	72	Inspect motor carefully before use, handle with care and properly package for transport
				Improper Manufacture	1	9	54	Purchase motor from known, reputable manufacturer
				Igniter Failure	5	5	300	Have extra igniter on hand, igniters installed by RSO
Retainer	Retainer falls off	Loss of motor	8	Improperly attached	3	4	96	Inspect epoxy attachment
				Comes unscrewed	4	4	128	Screw down retainer tightly on motor insertion and check tightness just before launch
	Retainer Breaks	Loss of motor, damage to motor	8	Manufacturing defect	2	2	32	Inspect all parts on delivery

Propulsion FMEA

Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Centering Rings	Centering rings break	Loss of motor, damage to airframe, loss of motor control	8	Manufacturing defect	3	5	120	Manufacture extra centering rings
				Excessive force	2	7	112	Put extra centering rings in system to absorb additional loads
				Improperly aligned	4	3	96	Put in each centering ring in with a small square, then brace and apply epoxy
	Improper Alignment	Loss of motor control	6	Improper installation	3	3	54	Put extra centering rings in system to keep system centered after failure

Structures FMEA								
Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Rocket Body	Tear caused from fin ripping off	New dangerous trajectory, unrecoverable launch vehicle, motor failure	8	Improper fin installation	2	3	48	Use correct mixture of epoxy, ensure all fins are filleted
				Improper Manufacture	1	8	64	Manufacture tubes rolled from a reputable manufacturer
	Buckling	Recovery system failure, unrecoverable launch vehicle	8	Improper Manufacture	1	8	64	Manufacture tubes rolled from a reputable manufacturer
				Improper Storage	1	8	64	Store in an appropriate location and handle with care
	Thermal Shock	Recovery system failure, unrecoverable launch vehicle	8	Improper Manufacture	1	8	64	Manufacture tubes rolled from a reputable manufacturer
				Extreme temperature difference	1	5	40	Only launch under optimal conditions
	Zippering	Severe damage to launch vehicle	6	Recovery lines pulling across edge of tube	5	6	180	Apply additional reinforcing composite layers at recovery ends of body tubes
Bulkhead	Adhesive fails	Payload damage, recovery system failure, catastrophic rocket failure	8	Incorrect epoxy mixture applied	3	3	72	Follow all instruction for mixing epoxy
				Insufficient amount of epoxy applied	3	4	96	Generously apply all epoxy with fillets
	Cross-Grain Failure	Payload damage, recovery system failure, catastrophic rocket failure	8	Plywood stored improperly	3	6	144	Store plywood in cool, dry areas and handle with care
				Low quality plywood	3	8	192	Select plywood from reputable sources, select best looking plywood
	Fracture	Internal components damaged damage, internal components displaced	6	Threaded rod bending moment	1	3	18	Use washers large enough to reduce stress created from bending
				Threaded rod compression on plywood	2	3	36	Only use necessary tension to secure threaded rod to plywood

Structures FMEA								
Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Nosecone	Improper shape	Non-uniform flight path, increased drag	5	Damage in testing	5	4	100	Metal nosecone tip to absorb direct force, careful inspection after use
				Improper Manufacture	2	3	30	Purchase nose cone and fit to airframe, carefully edge nosecone so it meshes with tube neatly
	Loss of nosecone	Unable to launch, no housing for avionics	8	Not attached to main tube	3	4	96	Follow installation checklists, do final inspection of launch vehicle before sealing
				Destroyed in testing	2	4	64	Metal nosecone tip to absorb direct force, careful inspection after use
Fins	Fins misaligned	Erratic flight profile, loss of launch vehicle	7	Damage to fins	3	4	84	Handle fin section carefully, do not put weight on fins, inspect and repair fins after launch
				Improper alignment of fins	5	3	105	Build a fin jig for aligning the fins during the build
	Fins fall off	Erratic flight profile, loss of launch vehicle, damage to surroundings	8	Damage to fins	3	4	96	Handle fin section carefully, do not put weight on fins, inspect and repair fins after launch
				Epoxy failure	1	9	54	Carefully apply epoxy and inspect after drying, properly fillet all edges
Coupler	Shear	Loss of launch vehicle, failure of recovery system	8	Excess bending moment	3	5	120	Have couplers extend about one caliber in each direction
				Improper Manufacture	4	3	96	Apply several layers of fiberglass in different directions
Eye nut recovery assembly	Breaking	Loss of recovery system, loss of launch vehicle	9	Excessive force	2	4	72	Model forces and increase size of eye nut to account for forces in system
	Threads stripping	Loss of recovery system, loss of launch vehicle	9	Excessive force	2	4	72	Model forces and increase size of eye nut to account for forces in system based on calculation of minimum thread engagement
				Improper attachment	5	2	90	Inspect all attachment points to ensure the threads all line up and a solid connection is created

Structures FMEA								
Function	Failure Mode	Effects of Failure	Severity	Failure Causes	Occurrence	Detection	RPN	Mitigation
Threaded Rod	Fails under tension	Loss of recovery system, loss of launch vehicle	9	Excessive force	4	5	180	Model forces and increase size of threaded rod to have a safety factor of at least 2 for the entire system
	Strips hardpoints	Loss of recovery system, loss of launch vehicle	9	Excessive force	2	4	72	Design the hole depth in hardpoints to be higher than the minimum thread engagement length
Shear pins	Shear pins fail to break	Recovery system does not deploy, loss of launch vehicle, launch vehicle becomes projectile	10	Insufficient pressure on shear pins	3	5	120	Have backup black powder ejection charges larger than primaries, test all charges with ejection test before launch

5.3 Personnel Hazard Analysis

During manufacturing and testing phase of the project there will be many safety hazards to the individuals taking part. These personal hazards need to be fully understood and addressed to ensure the safety of all team members. By working on mitigation plans and verification of those plans being put in place all working members will operate in a safer environment. It will also allow for a team member who undertakes a new task to be properly briefed on the hazards related to the task.

The creation of the personal hazard analysis was undertaken as a team effort both to collect the largest array of possible hazards and to ensure that all team members understand the risks involved. This also allowed collective brainstorming to determine the best ways to mitigate the hazards.

To maintain continuity for the analysis and to make it easily understandable for all involved teams the hazard analysis tool is the one presented in the competition handbook. This made it both easier to coordinate internally and make our findings more useful for other teams. The method of analysis is laid out in detail below.

	Severity			
Probability	1 Catastrophic	2 Critical	3 Marginal	4 Negligible
A - Frequent	1A	2A	3A	4A
B - Probable	1B	2B	3B	4B
C - Occasional	1C	2C	3C	4C
D - Remote	1D	2D	3D	4D
E - Improbable	1E	2E	3E	4E

Figure 41: Risk Assessment

The red combinations are high risk events. These events must be noted and additional efforts to form mitigation plans and support must be placed underway immediately. The yellow events are medium risk. These events are undesirable, but sometimes unavoidable due to the nature of the task. When they cannot be further mitigated extreme care must be taken when preforming them. The green is low risk and includes tasks that must be done with care, but either through mitigations or the default risk of the task the overall danger of the task is low. The uncolored events are for minimal risk events. Some of these events can be extremely dangerous, but with extremely unlikely probability, meaning that it is important to understand the risk, but additional safety precautions tend to be minimal unless the task increases the likelihood of the event occurring.

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

Figure 42: Severity Definition Table

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

Figure 43: Probability Definition Table

Personal Hazard						
Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Injury to Extremities	Improper use of power tools	Laceration	2C	All parts secured before drilling operation, use proper drill speed, wear heavy gloves when using hand drill	Check with other team members before drilling to verify procedure, wear heavy gloves as PPE	2D
	Improper use of manual mill	Laceration	2B	All users of heavy machinery must complete a shop safety and tool usage course, all shop clothing rules shall be followed, parts not to be touched while machine is running	All students using heavy machinery wear machine shop certification, routine checks of all users during tool use to insure shop rules followed	2D
	Improper use of manual lathe	Laceration	2B	All users of heavy machinery must complete a shop safety and tool usage course, all shop clothing rules shall be followed, parts not to be touched while machine is running	All students using heavy machinery wear machine shop certification, routine checks of all users during tool use to insure shop rules followed	2D
	Improper use of bandsaw	Loss of fingers, laceration	2B	All users of heavy machinery must complete a shop safety and tool usage course, all shop clothing rules shall be followed	All students using heavy machinery wear machine shop certification, routine checks of all users during tool use to insure shop rules followed	2D

Personal Hazard						
Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Injury to Extremities	Improper use of soldering iron	Burns	3B	All parts secrured before soldering operations, soldering irons unplugged after use	All soldering irons used in deignated space with appropriate equipment, all soldering irons unplugged immediately after use	3D
	Detonation of motor	Laceration, severe damage to exposed body, burns	1D	Motor reloads stored in proper magazine, only moved when preparing for use, direct handling preformed only by NAR level 2 certified mentor	Motor reloads are stored in specific container designed for that purpose, motor moved under supervision of safety officer and given to mentor upon arrival at launch site	1E
	Detonation of black powder	Loss of fingers, laceration, burns	2C	All work with black powder preformed by certified individuals, packing of charges carried out away from any ignition sources, black powder stored in cool, dry environment	Specific individuals tasked with preparation of ejection charges, specific storage location for black powder in lab	2E
Injury to Eyes	Chips from machining	Loss of vision, damage to eyes	3B	Wear eye protection, use proper feeds and speeds, secure all parts before use	Eye protection worn, proper speeds and feeds on posted by each machine, methods for securing all parts available and checked	3D
	Dust from machining	Irritation of eyes	3B	Wear eye protection, check MSDS for material before machining it	Eye protection worn, MSDS made available and read for each material in manufacturing phase	3D

Personal Hazard						
Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Injury to Respiratory System	Dust from Composites machining	Irritation of the respiratory system, long term damage to respiratory system	3B	Wear respiratory protection, preform machining in well ventilated area away from other work spaces	Dust masks worn during machining or while in machining area, section of workspace with increased ventilation designated composites area	3E
	Fumes from chemical agents	Irritation of the respiratory system, long term damage to respiratory system	2B	Wear respiratory protection, preform work with vaporous chemicals in well ventilated area away from other work spaces, check MSDS of all chemicals being used	Dust masks or respirators worn as dictated by MSDS, work preformed in ventilated area of workspace and all fumes allowed to clear before any other work preformed	2E
	Paint fumes	Irritation of respiratory system	4C	Painting preformed in well ventilated areas	Painting preformed in designated painting area, painting preformed in small sections to allow fumes to dissipate	4E
	Fumes from solder	Irritation of resperatory system, long term damage to resperatory system	2B	Preform all soldering opperations in well ventilated areas	All soldering irons used in deignated space with additional ventilation devices	2E
Injury to Skin	Contact with epoxy	Irritation of skin	4B	Gloves worn during work, access to water to clean affected areas	Nitrite gloves worn during all epoxy operations, wash basin in workspace	4D
	Contact with chemical agents	Irritation of skin, discoloration of skin	2C	Gloves worn during work, check MSDS for cleaning procedures and additional hazards	Nitrite or neoprene gloves worn based on chemical, wash basin in workspace for applicable materials	2E

5.4 Environmental Hazard Analysis

When creating a project of this magnitude it is important to understand how it will affect the environment and how the environment will affect the final product. The FMEAs consider how any specific section of the launch vehicle or rover payload might fail internally, but not how random external factors may affect the functions. These external factors are covered in the Environmental Hazard Analysis.

This analysis covers all possible ways that the environment can cause damage to hardware, cause regulation violation or otherwise hinder mission success. These hazards are categorized to cover environmental effects to the launch vehicle, to the rover, and to electronic systems. These hazards are important to consider because they will be directly affecting the system during the mission. In addition, many of these hazards can cause a loss of the launch vehicle, and therefore must be carefully monitored and mitigated as much as possible.

The environmental hazards are analyzed using the same methods as the personal hazard and use the same scale and measurement system.

Enviromental Hazards						
Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Damage to Launch Vehicle	Wind	Loss of launch vehicle, launch vehicle moving beyond recovery range	1C	Preform drift analysis, monitor weather conditions for launch	Drift analysis preformed for wind speeds up to 20 mph, launches rescheduled if weather conditions do not permit effective launch and recovery	1E
	Trees	Launch vehicle stuck in trees, airframe damaged on impact	2C	Launches preformed in areas with minimal trees	Test launches carried out in treeless environment, when launching near trees launcher angled away from trees	2E
	Powerlines	Launch vehicle stuck in powerlines, loss of launch vehicle	2C	Launch away from powerlines	All launches will take into account powerlines that could possible interfere with recovery and adjust launch angle accordingly	2E
	Standing/Open Water	Launch vehicle submerged, loss of launch vehicle	1D	Launches preformed in areas with no water	Test launches carried out in waterless environment, when launching near water launcher angled away from water	1E
	Humidity	Motor or black powder charges fail to ignite	3C	All combustibles need to be stored in dry environment	Combustible storage is low humidity, combustible only out of storage for short time immediately before launch	3E

Enviromental Hazards						
Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Damage to Launch Vehicle	Inclement Weather	Loss of launch vehicle, damage to components, cancelation of launch	3C	Check weather report, be vigilant while at launch site	Before all launches weather reports will be continually monitored and launch cancelled/delayed if weather does not permit safe launch	3E
	Fall during transport	Damage to launch vehicle, bending of fins	3C	Secure launch vehicle during transport, pad transport method	The launch vehicle will be transported in a padded storage container to prevent fall damage.	3E
Damage to Rover	Uneven terrain	Rover stuck	3B	High ground clearance for rover	Rover wheels designed to give chassis large ground clearance, rover tested on uneven terrain	3D
	Mud	Rover stuck	3B	High torque drive system	Rover drive train designed with high torque system, rover tested in muddy conditions	3D
	Large objects on ground	Rover unable to progress	3A	Collision avoidance system	Rover designed with redundant object avoidance systems, rover detection routines tested	3D
	Rover deployment collision	Rover incapacitated by impact, rover stuck in object	2B	Enclosure for rover to absorb impact	Rover casing is spring loaded and has large surface area to absorb impact an allow for ease of deployment	2D
	Grass/foliage winds around drive system	Rover becomes stuck and unable to move	3D	Cover axles, increased power	Motors designed to increase power to stall torque if rover becomes stuck	3E

Enviromental Hazards						
Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Damage to electronic systems	Humidity	Electrical systems become unresponsive or defective	2C	Electronics kept in dry conditions	All electronic systems stored in dry container, all systems tested before use to verify integrity, backups for components kept on hand	2D
	Temperature	Electrical systems become unresponsive or defective	2C	Electronics kept in cool conditions, design systems for high temperatures	All electronic systems stored in cool container, all systems tested before use to verify integrity, backups for components kept on hand, systems deigned for extended periods of time in high temperatures	2E
	Signal Interference	Premature firing of e-match, premature start of other internal electronics	2C	Shielding of the electronics	All sections are individually shielded and all wires twisted to avoid interference	2E
Damage to environment	Chemical residue from spent motor	Toxifying ground water and soil	3B	Clean motors in controlled environments	Motor are cleaned into a sealable container that can be disposed of as needed	3E
	Chemical release during motor usage	Toxic chemical release in air and large area dispersal	3B	Minimal motor usage	Only the motors to be used for needed test flights will be formed	3C
	Acid or chemical leakage from batteries	Toxifying ground water and soil	3C	Check batteries, dispose of appropriately	All batteries will be placed in a specific box to be carried to all events and is available in the workspace, this box will then be disposed of properly	3E

Enviromental Hazards						
Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Damage to environment	Manufacturing waste	Increased build up of non-degradable materials	4A	Recycle all possible material, dispose of appropriately	All waste and excess material will be disposed off based on machine shop specifications and kept as extra stock if possible	4C
	Launch vehicle landing	Damage to trees, grass, shrubs, small animals	4C	Reduce landing kinetic energy	The landing kinetic energy is being minimized in all designs to reduce damage to launch vehicle and environment	4D
	Material ejected from launch vehicle	Debris on field, contamination of ground	3C	Make ejected material have low enviromental impact	The wading for the launch vehicle is cellulose inslation, which is largely recycled product and does not off gas	4C

6 Payload Criteria

6.1 Payload Overview

The payload shall be an autonomous rover. The rover will complete a specific mission: to travel 5 ft. on the ground followed by deployment of solar panels. The rover will be carried in the payload bay of the launch vehicle throughout the flight. After the launch vehicle is determined to have landed safely, a signal will be transmitted to the section of the launch vehicle containing the payload to eject the rover. The rover will exit the open end of the payload bay, still contained in a carbon fiber housing. Once the housing is clear of the airframe, it will spring open out of the carbon fiber housing, releasing the rover. The rover will drive at least 5 ft. away from all parts of the airframe, navigating away from the launch vehicle and around any obstacles by using data from on-board sensors. Once the rover has reached a sufficiently clear location, the solar array will open, completing the mission.

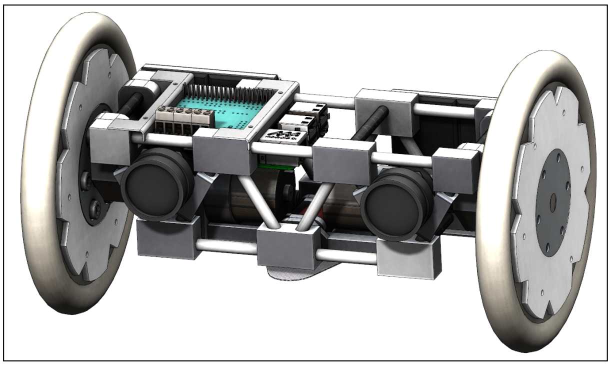


Figure 44: Rover, Pre-Deployment

The rover, shown in Figure 44, has two coaxial, independently driven wheels, made of HDPE with a rim of expandable foam. Each wheel is connected to a gearmotor by a stepped steel shaft. A set of roller and thrust bearings transmit the wheel force into the chassis rather than into the gearmotor, to protect the gears from damage. The chassis itself is an aluminum and carbon fiber truss riding between the wheels. The motors each sit inside this truss, attached with shock-absorbing foam. Mounted in the center rear of the chassis is a stabilizer to keep the entire rover from simply spinning. The stabilizer is on a spring loaded hinge so it will only protrude after rover deployment, as seen in Figure 45.

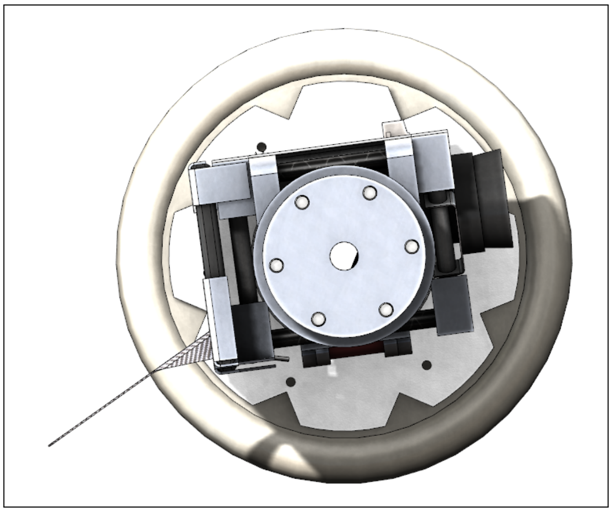


Figure 45: Deployed Rover Side View

The rover is controlled by a Raspberry Pi 3B microcontroller. A brushless metal-geared servo unfolds a pair of solar panels attached to the top of the rover. Four single-cell LiPo batteries are mounted to the back. Data is inputted to the control system through dual sonar sensors mounted to the front of the rover, as well as an IMU unit, contained internally. Additionally, an array of microphones will detect signals emitted from the airframe sections in order to direct the rover away from any piece of the launch vehicle. These inputs will be used by an autonomous control algorithm using Robot Operating System (ROS) and running on the Raspberry Pi, which will direct the rover to its final location 5 ft. away from the launch vehicle. During flight, the entire rover will be encased in a flexible sheet of carbon fiber, capped at the end with aircraft-grade plywood, similar to the bulkheads used in the airframe. An ARRD will retain this whole assembly with Kevlar straps until ejection, when black powder charges will drive the payload from the airframe.

6.2 Rover Mechanical Systems

6.2.1 Chassis

The chassis is the assembly at the core of the rover, providing the structure to which each component is attached. Since it interfaces with all of the other components, there are several strong requirements the design must fulfill. The chassis must be robust enough to withstand significant forces on launch and on landing, but it also must be small enough to fit within the airframe and include space for the internal rover systems, while allowing sufficient ground clearance when driving. In addition, it must be possible to manufacture and relatively light.

Several chassis designs were presented and considered as part of the PDR. Each was evaluated to see how well it fulfilled the requirements. A carbon fiber truss-like design with aluminum joints was chosen for its high strength and low mass, as well as simplicity of mounting for the drivetrain and other systems. A Computer-aided design (CAD) render of this design can be seen in Figure 46.

Each member is a 0.25 in. diameter carbon fiber rod. These are connected by aluminum joints. The joints are aluminum blocks 0.5 in. wide, with 0.375 in. deep holes into which the rods are inserted and then epoxied in place. These blocks are shown in Figure 47. Some of these holes are drilled at 60 degree angles so that each side of the truss is composed of equilateral triangles. Strictly speaking, this frame is not a truss, since the members are not simply pinned at the end. In practice, however, this adds strength, as a significant portion of the rods are held within the aluminum blocks.

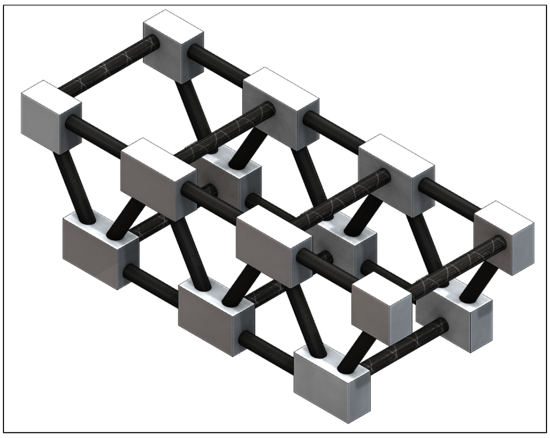


Figure 46: Truss Design

6.2.1.1 Chassis Prototype

Since manufacturing the aluminum joints is a highly time-intensive process, a prototype of this chassis has been assembled, seen in Figure 48. The joints have been made of ABS using additive manufacturing. Oak dowels of the appropriate size are used in place of the carbon fiber. This prototype allows preliminary assembly and testing for fit and mounting of all of the sub-assemblies.

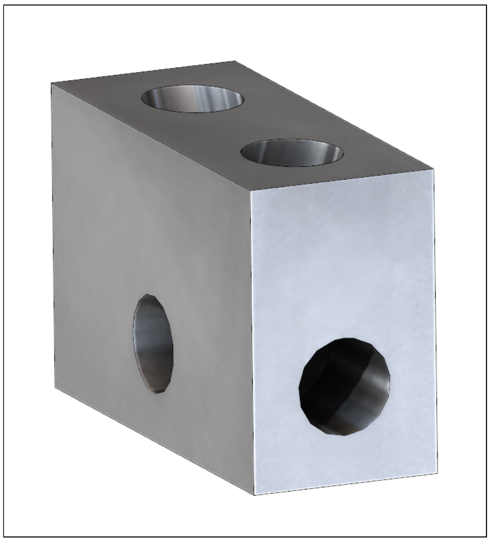


Figure 47: One of the Aluminum Blocks

6.2.1.2 Integration

Several components, including the drivetrain and the stabilizer, are permanently integrated to the chassis by having the carbon-fiber rods pass through clearance-fit holes. This allows them to rotate as designed. Other components, mainly electronics, will have mounts which screw directly into tapped holes in the aluminum joints. This allows for a high degree of customization - the prototype is used for experimentation with precise hole locations in order to determine the ideal mounting points.

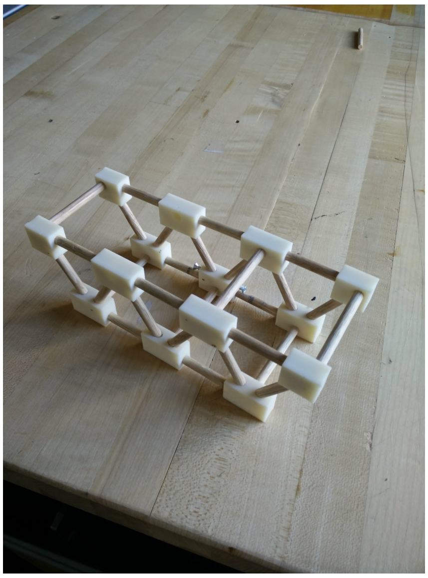


Figure 48: Chassis Prototype

6.2.2 Drivetrain

The drivetrain is central to the success of a mobile rover. Without a robust system that can withstand the immense forces of flight, the large stresses upon landing, and the variability of ejection, the mission cannot succeed. Components of the drivetrain that are essential to the functionality are the motors, the motor drivers, and the wheels. The integration of the motor with the chassis and the design specifications of this complete assembly will be detailed while the exploded view can be seen in Figure 49.

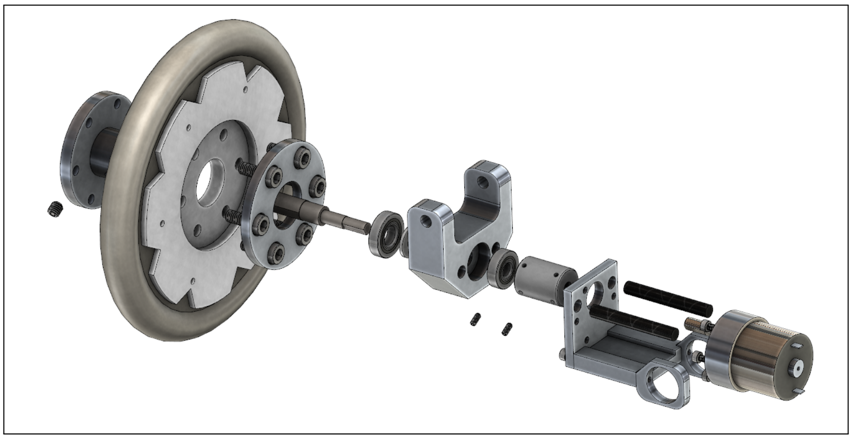


Figure 49: Drivetrain Exploded View

The design of the wheel structure of the rover included extendable, closed, and open structures. The decision was made to use a closed structure to ensure reliability in ground traversal while maximizing surface points of contact. The main material of the wheel will be HDPE. This material is known for its high strength-to-weight ratio and can be used up to temperatures of 130° C without excessive thermal expansion. The wheel frame will be fastened using a sandwich method between a stainless steel hub and an aluminum plate. This sandwiching method creates a planar stress across the center of the wheel rather than point stresses around the six bolt holes. By choosing a high strength, low weight material and reducing the torsional stresses, the wheels will be able to traverse the tilled field conditions at the launch field. Because ground clearance is a significant engineering specification that must be met and one that will be tested throughout manufacturing and assembly, a pseudo expandable structure will be implemented. By installing a memory foam insert into a milled out center slot in the wheel, it is possible to introduce a larger wheel diameter upon ejection from the airframe. As seen in Figure 50, the compressed wheel diameter will fit within the 4.9 in. carbon fiber casing, while the extended wheel diameter will allow for a radial increase of 0.625 in. when traveling.

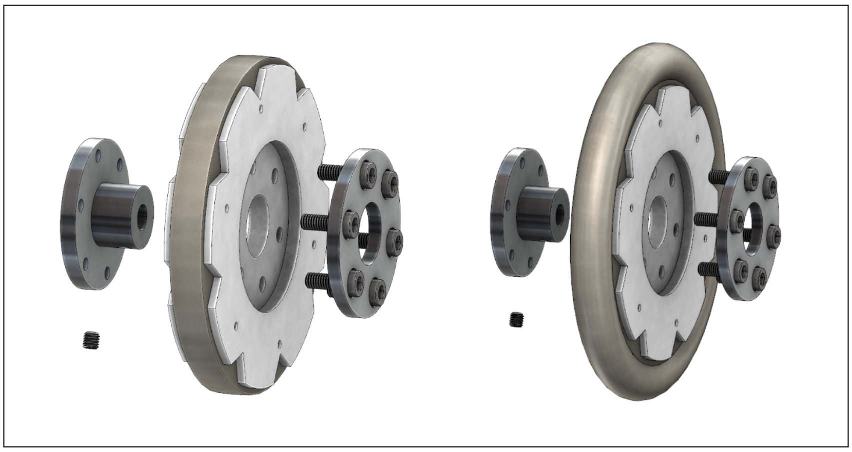


Figure 50: Memory Foam Wheel Expansion

This wheel configuration allows for more points of contact during travel as the memory foam will compress to match the contour of the terrain it travels on. Finally, the memory foam will allow for a higher coefficient of friction between smooth terrain and the wheel when compared to an HDPE structure. The design specifications of the wheel frame assembly are as follows:

- Wheel Closed Diameter: 4.8 in.
- Wheel Expanded Diameter: 6.05 in.
- Wheel Thickness: 0.75 in.
- Wheel Structure Material: HDPE
- Wheel Grip Material: 3.5 lb. Memory Foam
- Hub ID: 0.393 in.
- Wheel Assembly Weight = 0.81 lb.

The driveshaft is supported and interfaces with the chassis via a U-shaped bearing block. Inside this housing are two radial bearings with a radial load rating of 320 lb. for the outer bearing and a radial load rating of 200 lb. for the inner bearing. Inside the bearing block will be a high-load thrust bearing with an axial load rating of 980 lb. The outer and inner bearings will be press fits in the bearing block with a slip fitting with the driveshaft. Figure 51 shows the bearing block configuration. The driveshaft has four steps in it to accommodate bearings and couplers. The driveshaft has an outer diameter of 0.390 in. with a D-shape for the M3 set screw in the wheel hub. The shaft steps down to 0.370 in. to slip fit through the outer bearing and then drop down to 0.245 in. to slip fit through the thrust and inner bearings. Finally, there will be a step to 0.230 in. with a D-shape to accommodate the aluminum flex coupler.

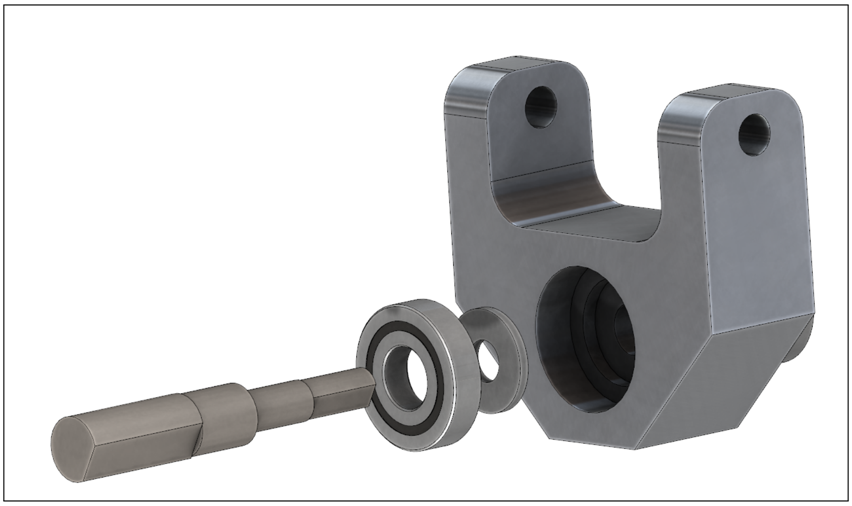


Figure 51: Bearing Block Assembly Setup

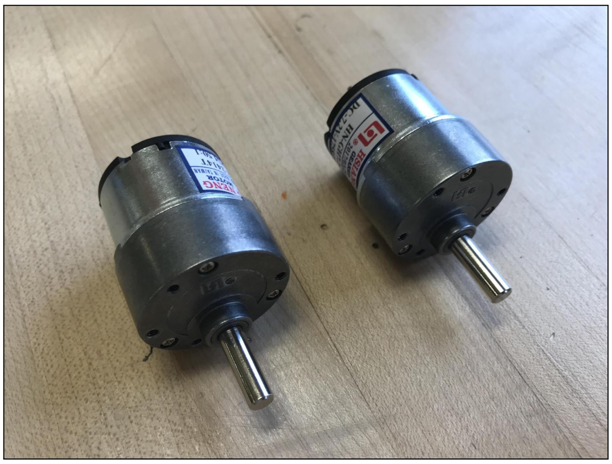
The bearing block assembly allows for compressive forces to be transferred to the chassis through the U-block while allowing rotation of the driveshaft. The design specifications of the bearing block assembly are as follows:

- Outer Bearing ID: 0.375 in.
- Outer Bearing Radial Load Rating: 320 lb.
- Thrust Bearing ID: 0.25 in.
- Thrust Bearing Axial Load Rating: 980 lb.
- Inner Bearing ID: 0.25 in.
- Inner Bearing Radial Load Rating: 200 lb.
- U-Block Material: 6063-O Aluminum

Options included in the motor design were brushed motors with high rpm capabilities, brushed motors with high torque capabilities, and brushless motors with mid-level rpm and torque capabilities. A decision matrix was used to verify that a high-torque motor would be best suited for this design as it allowed for a compact housing with precise documentation and impressive performance characteristics. The selected motor is a GHM-04 brushed motor which can be seen in Figure 52 and has the following design specifications:

- Operating Voltage: 7.2 V
- Continuous Operating Current: 500 mA
- Escape Current: 2450 mA
- Stall Current: 2450 mA
- Operating Rotations: 146 rpm
- Operating Torque: 0.89 lb. - in.
- Stall Torque: 7.81 lb. - in.
- Motor Weight: 0.27 lb.

The motors will interface with the U-block and a rubber cylinder mounted around a center axel on the chassis. This interface will allow for vibration dampening characteristics when the rover is placed under high compressive stresses of over 30 g's of acceleration during recovery. The motor mounts will ensure that all forces are transferred into the axels of the chassis while allowing the motors to experience no external forces. The motor mount assembly interface is shown in Figure 53.



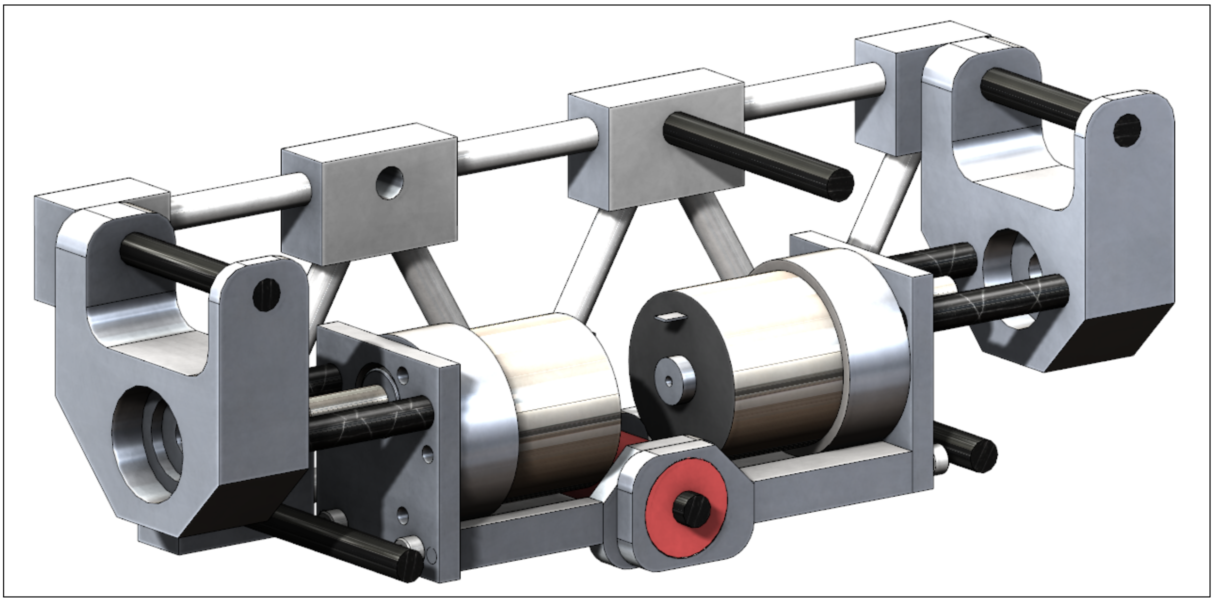


Figure 53: Motor Mount Interface

6.2.3 Solar

6.2.3.1 Cell Selection

The solar assembly consists of two commercially available solar cells. The solar cells were chosen based on power density and size. Eight solar cells were selected for comparison based on the following criteria:

- Power density (W/in^2)
- Surface Area (in^2)
- Relative Sizing Compared to Rover

Power density was originally the primary factor in cell selection, but rover volume constraints dictated that the next smallest cell with high power density be used. The cells chosen are the SLMD960 by IXYS, as seen in Figure 54.

These cells produce up to 6.1 V and can supply up to 35 mA of current. They are monocrystalline and feature high mechanical robustness.

Figure 54: SLMD960 Solar Cells

6.2.3.2 Housing

The cells have no mechanical features to fasten them to a mount, so a carbon fiber tray was designed with assembly and protection in mind, as seen in Figure 55. This will be manufactured around an aluminum blank and cured with countersunk screws to form the space necessary for mounting.

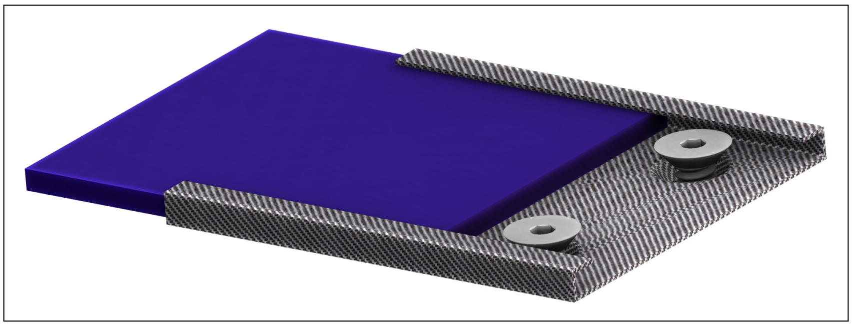


Figure 55: Solar Cell Within Casing

Figure 56 shows that this tray is bolted to a set of flanges which couple the panels to the axles. Screws were used as opposed to epoxy to keep assembly of the panels modular, which aids in vibrational and destructive stress testing of the panels.

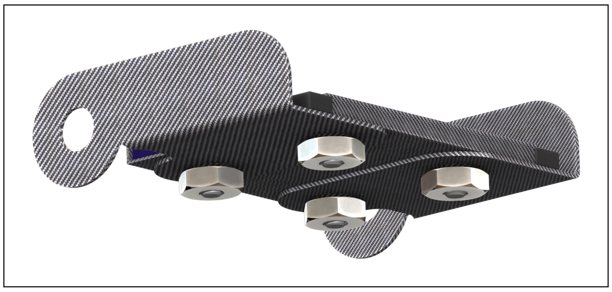


Figure 56: Solar Tray Mounts to Pivoting Flanges

Vibrational protection is also provided by foam pads pressed against the open ends of the tray, which are the black strips as seen in Figure 57.

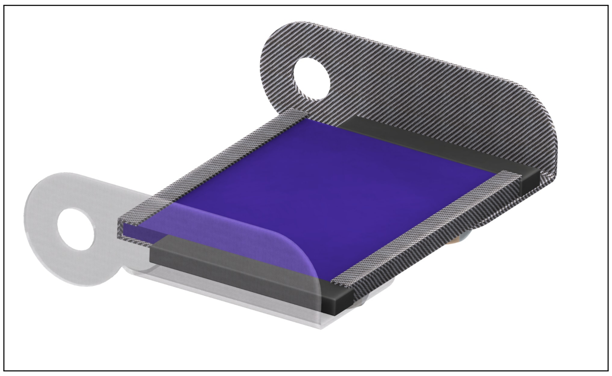


Figure 57: Foam Strips Protect Solar Cells

6.2.3.3 Deployment

The deployment system is a two panel design with one stationary panels and one actuated panel. The actuation is driven by a standard size servo, and is discussed further in 6.3.3.2. The servo has a 25T sprocket connection, which interfaces with a mounting servo horn. The servo horn is a stock part with M3 tapped holes, but American National Standards Institute (ANSI) 4-40 holes must be added to connect a gear because of the clearance available on the gear. This mounting configuration is shown in Figure 58.

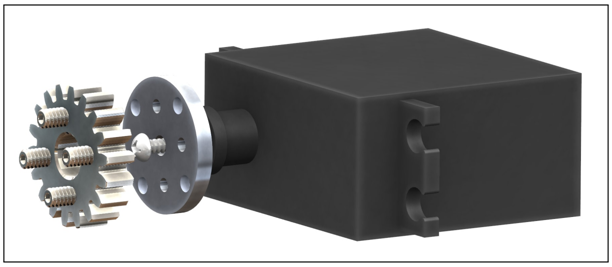


Figure 58: Servo Horn Mounting Configuration

A set of 0.75 in steel gears are used to allow the servo to sit beneath the panels. The pinion attaches to the panel shaft with a standard keyway, as seen in Figure 59. Retaining clips hold the axles in place, as well as offer vibrational resistance, shown in Figures 59 and 60. A number of washers are used for spacing and rotational rigidity.

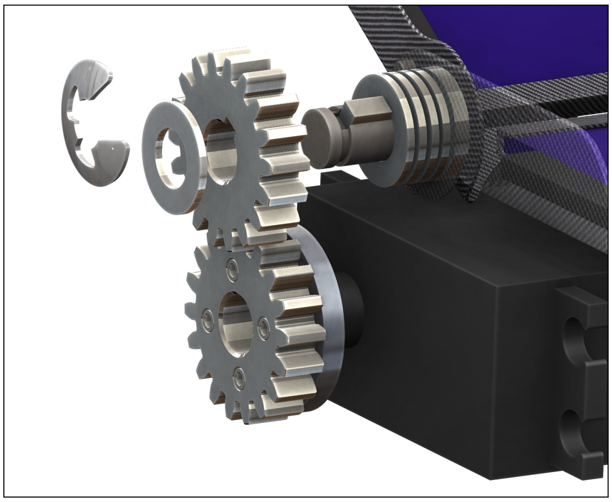


Figure 59: Cutaway View of Keyway and Spacers

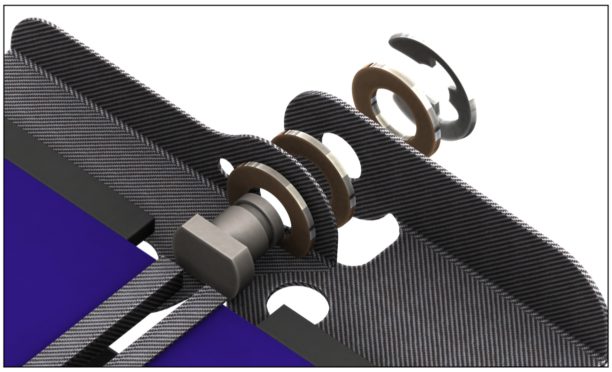


Figure 60: Passive Axle Connection

The panel is actuated from the axle with a standard press-fit dowel pin that will be fastened with thread locker, shown in Figure 61.

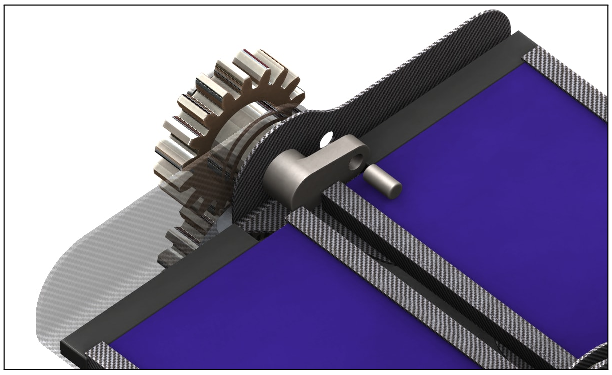


Figure 61: Driven Axle Connection

The washers shown in Figure 59 also located a set of sheet metal casings that serve multiple purposes:

- Maintain proper gear mesh distance
- Provide structure for particle protection enclosure
- Protect moving gears from interfering with wiring

This view also demonstrates that the panels are well protected until deployment. Figure 63 shows a full assembly of the panels in their deployed position.

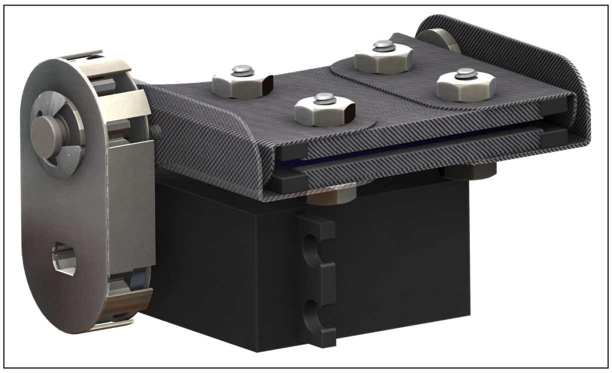


Figure 62: Protected View of Solar Assembly

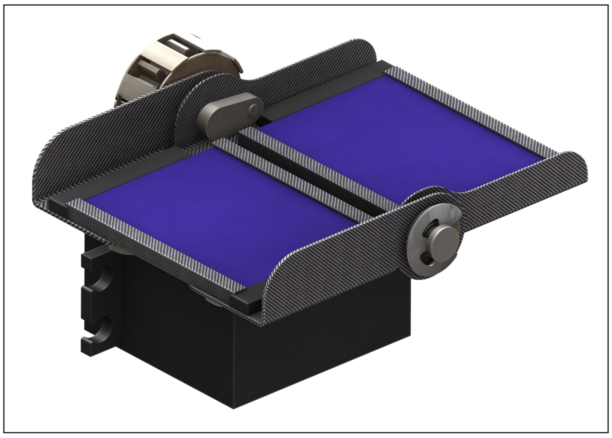


Figure 63: Deployed View of Solar Assembly

6.2.4 Stabilizer

Since the rover only has two wheels, a third point of contact with the ground is necessary for stable driving. Without some kind of stabilizer, the rover would simply spin in place when the motors attempt to drive, leaving the entire rover stationary. Additionally, it is necessary that this stabilizer contacts the ground some distance away from the wheels, in order to prevent the rover from flipping. However, when contained in the launch vehicle, it obviously must not extend beyond the 4.8 inch diameter of the wheels. These constraints necessitated the development of a folding stabilizer design. Several designs were evaluated for their robustness, simplicity and suitability for the application. A single-fold design was chosen, rotating in a parallel axis to the rotation of the wheels. Because it rotates in this direction, rotating the wheels at the same time the stabilizer is unfolding will assist in the deployment of the stabilizer. CAD renders of this design can be seen in Figures 64 and 65.

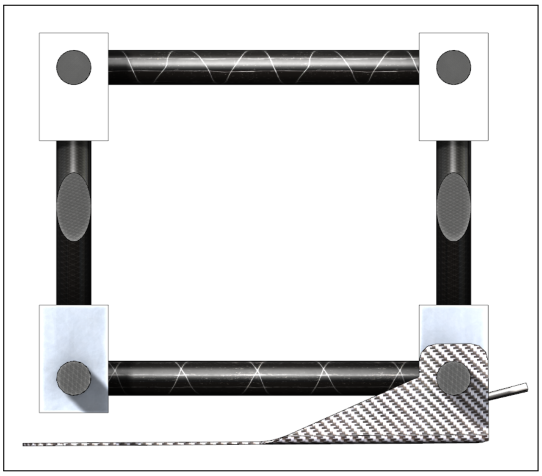


Figure 64: Section View of Chassis and Stabilizer

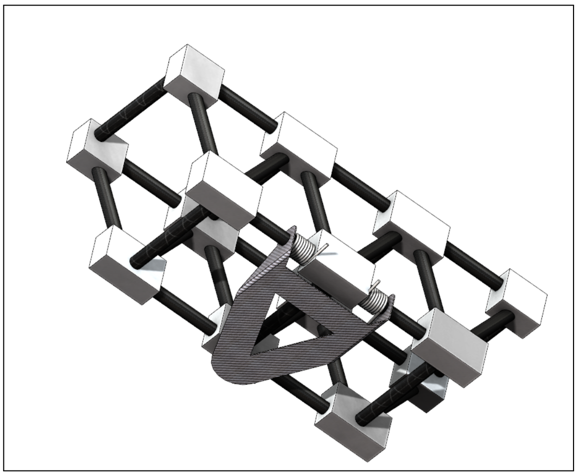


Figure 65: View of chassis and Stabilizer from Below

The stabilizer itself is made of carbon fiber, with holes through which the carbon-fiber rods of the chassis pass. The stabilizer rotates around these rods. Torsion springs are compressed when the stabilizer is folded below the chassis, and drive the stabilizer open when the rover housing opens.

6.2.4.1 Stabilizer Prototype

In combination with the ABS and oak chassis prototype, a preliminary prototype of the stabilizer has been developed. Made of sheet aluminum and using the same springs as the final design, this prototype allows examination of how the stabilizer actually operates in practice and how the springs will be connected to the chassis. The prototype can be seen in Figures 66 and 67.

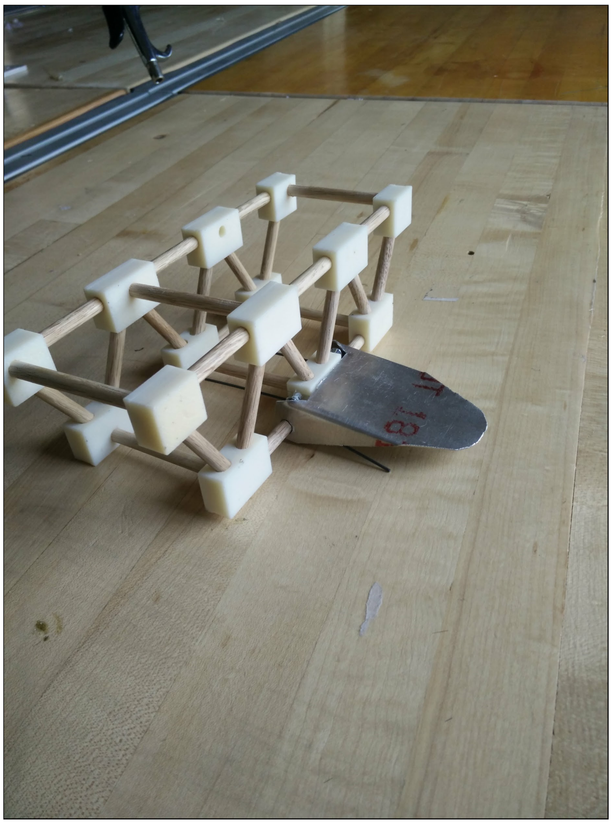


Figure 66: The Deployed Prototype Stabilizer

Figure 67: Detail View of Prototype Stabilizer

6.3 Rover Electronics

6.3.1 Controls

6.3.1.1 Raspberry Pi

In order to complete the mission of travelling 5 ft. away from any piece of the launch vehicle casing after landing and deploying solar panels, many electronic systems have been implemented on the payload rover system. These systems include object avoidance sensors, waypoint localization sensors, inertial localization sensors, motors, overcurrent protection, solar panel actuation, and a battery power system. Each of these electronic and mechanical systems need a central microprocessor to connect to, that can manage the data that is being observed and produced. The Raspberry Pi 3 was the chosen microprocessor to act as this central computation unit on-board the payload rover.

The Raspberry Pi 3 has a quad-core Advanced RISC Machine - a family of RISC architectures for computer processors (ARM) Cortex A53 Central Processing Unit (CPU) that is clocked at 1.2 GHz, Graphics Processing Unit (GPU) clocked at 400 MHz, a 1 GB Synchronous Dynamic Random-Access Memory (SDRAM), and 40 General Purpose Inputs and Outputs (GPIO) pins. The Raspberry Pi 3 was chosen to be the best alternative due to its extensive processing capabilities and ability to handle many different electrical systems that will need to be connected to it. The microprocessor will be running ROS in order to give the rover all of the data it needs to decide where to navigate to and deploy its solar panels. For navigation purposes, the Raspberry Pi will receive a distance-to-object calculation from the object avoidance sensors and an angle to the launch vehicle casings from the waypoint localization sensors. It will process these signals and send them to ROS which can then use its navigation algorithm to travel the correct path. In terms of mechanical navigation methods, the motors and over current protection module will be connected to the Raspberry Pi so that the motors can be told when to initiate forward or reverse action, and increase or decrease speed depending on the terrain. Finally, a Nine Degree of Freedom (9DOF) inertial localization sensor will be interfaced to the Raspberry Pi. This sensor will provide data to the rovers operating system, ROS, in terms of accelerometer, gyroscope, and magnetometer data.

Each of these sensors and electrical systems will be interfaced to the central microprocessor and a PCB. The systems will connect to the PCB via screw terminal connections for power and ground traces. Connections made from electrical systems to the Raspberry Pi will use wires soldered into the Raspberry Pi's GPIO pins and soldered to the sensors connection points. This is detailed in the payload electrical schematic in Figure 68. This schematic contains the battery system, voltage regulators, and screw terminal connections for ground and power traces of all electrical components that will interface with the Raspberry Pi and the PCB.

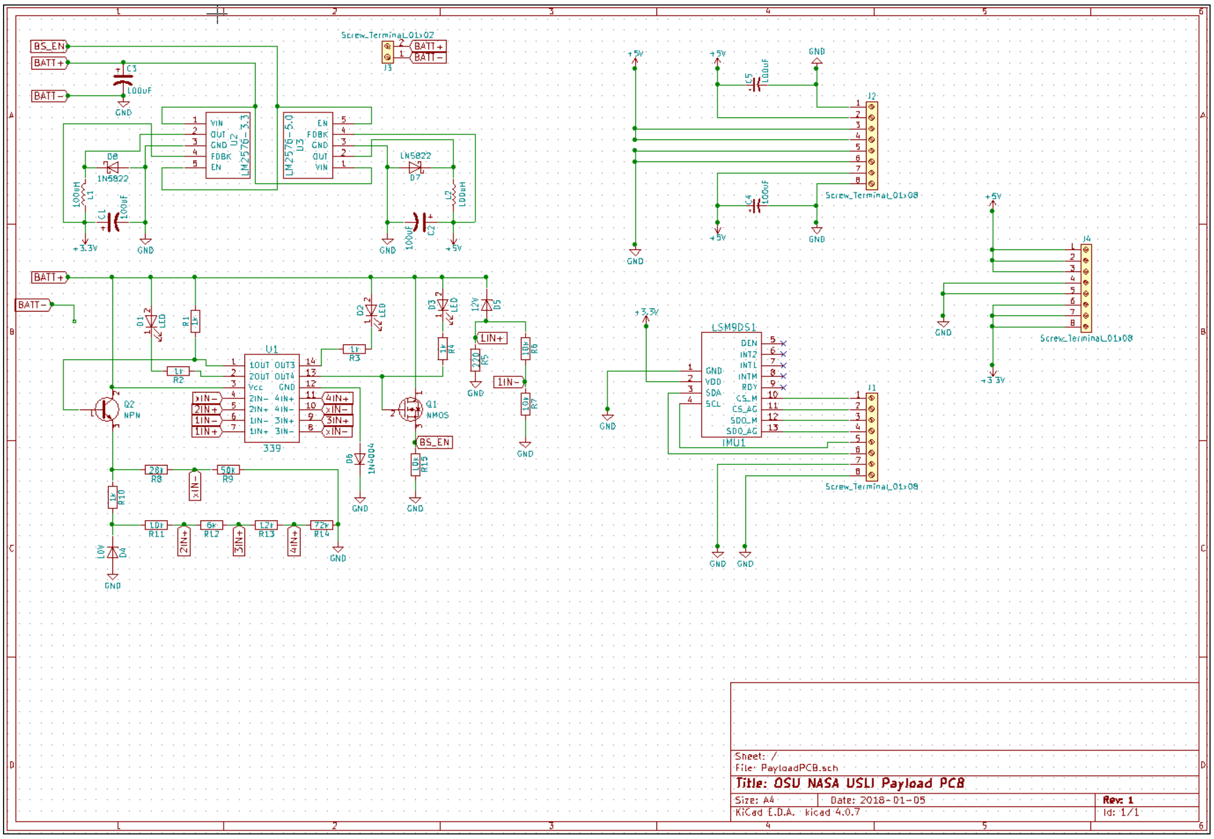


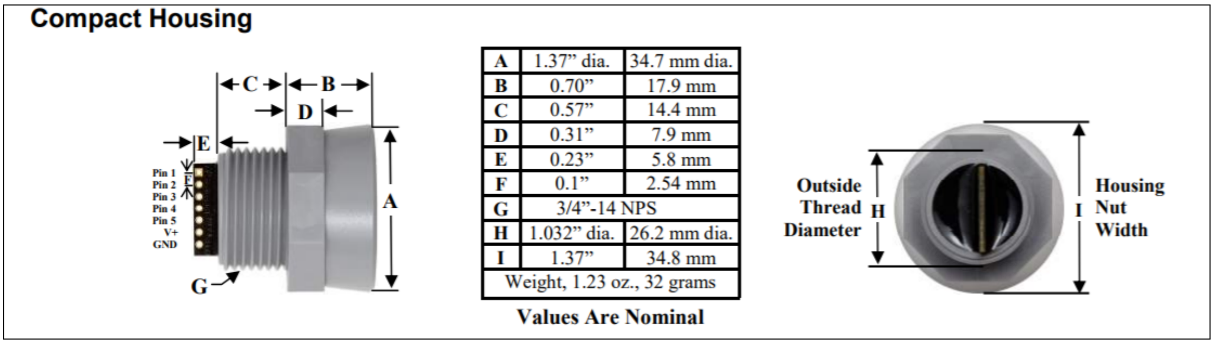
Figure 68: Payload Rover Schematic

6.3.2 Sensors

Upon safe recovery of the launch vehicle, the payload rover must be able to autonomously navigate at least 5 ft. in any direction away from all pieces of the launch vehicle housing. In order to accomplish this task, multiple sensors on board the rover will be used for basic object detection and autonomous navigation purposes. The sensors must be capable of withstanding up to 60 g's of force as well as heavy vibration forces from the launch and recovery. Due to these high demands, the chosen sensors must have a high durability rating. Size and weight are also limiting factors in the design and selection of sensors for the rover, as there is a minuscule amount of space on board for components to be mounted. Battery selection also falls under this size and weight restriction which in turn places a restriction on the current that each sensor can draw. A highly sophisticated sensor tends to draw a large amount of current which would not be suitable due to the limited amount of charge capacity available on the payload batteries. Detection range of the sensors is not as critical of a factor as those previously listed since the rover is not traveling an extensive distance. A detection range of 5 ft. or less is suitable for the demands of the rover navigation in this competition.

6.3.2.1 Object Avoidance

The object detection alternatives for the rover sensors include Light Detection and Ranging (LIDAR), sonar, radar, and Time of Flight (ToF) cameras. LIDAR components have the longest detection range and provide reliable readings; however, they lack durability, have larger current draws, and are very large in dimensions and weight. LIDAR modules also typically spin 360 degrees in order to map out the surrounding environment. In this high stress environment that requires protection against large forces, any component with critical moving parts would not be suitable. ToF cameras provide an accurate object detection method and are very small in size and weight. They also require a low nominal current to operate. The downside to the ToF cameras is that they do not operate well under conditions with lots of light, such as in direct sunlight. The rover could be operating in direct sunlight after landing depending on the weather come launch day; this makes ToF cameras not a suitable alternative for the rover. Radar and sonar methods are similar in that they are small in size, have low current draw, and provide the detection range required. Sonar proved to be the more viable alternative due to the wide availability of sonar modules, and extensive documentation on detection techniques using sonar devices. The MB7360 HRXL-MaxSonar-WR component was chosen over the other sonar modules mainly due to its high durability and IP67 environmental protection rating. See Figure 69. The IP rating stands for the Ingress Protection rating, where the first digit represents the protection rating against solid objects and the second digit represents the protection from liquids. The IP67 rating denotes that the component is protected from dust and is water resistant in water levels ranging from 15 cm to 1 m. The compact outer housing adds a slight amount of mass to the component but also provides a vast amount of protection both against weather and outside forces acting on the electronics contained inside. See Figure figure:MB7360 HRXL-MaxSonar-WR with Datasheet. Despite the increase in weight on the MB7360, it was a justifiable decision due to the extra protection that is provides to the delicate sensor housed inside. The MB7360 has a detection range of up to 5 m which is sufficient for the needs of the rover in this competition. The component operates at a frequency of 42 kHz, a supply voltage of 5 V, and has a low nominal current draw of 3.1 mA. The range reading from this sonar sensor can be sent to the microprocessor on board the rover in an analog, pulse width modulation, or serial format. Pulse width modulation was the chosen technique on which to transmit the range data to the on-board micro-controller.



A	1.37" dia.	34.7 mm dia.
B	0.70"	17.9 mm
C	0.57"	14.4 mm
D	0.31"	7.9 mm
E	0.23"	5.8 mm
F	0.1"	2.54 mm
G	3/4"-14 NPS	
H	1.032" dia.	26.2 mm dia.
I	1.37"	34.8 mm
Weight, 1.23 oz., 32 grams		

Figure 69: MB7360 HRXL-MaxSonar-WR with Datasheet

The object detection system consists of two sonar modules, filtering capacitors for the signal, and an object detection algorithm capable of outputting the distance to objects. The sonar modules output and receive an ultrasonic 42 kHz signal that is used to detect objects in their line of site. The ultrasonic sonar sensors measure the time of flight of the transmitted sound signal that has reflected off an object to calculate the distance to the object. Each module will use a pulse width modulation format that displays the distance to detected objects from its varying duty cycle. The sensors are capable of detecting objects within 1 ft and 5 ft away. Two 100 uF capacitors will be used between power and ground to filter out any electrical noise from the power signal. See system schematic in Appendix A. Each of the components in this system must be capable of withstanding large vibrational forces during launch, high g-forces up to 60 g's during flight, and up to 75 ft.-lb. of kinetic energy upon recovery and landing. Due to these demanding durability constraints, the chosen sensor type has a protective outer casing that is IP67 rated and can withstand large forces, dust, debris, and water. Power consumption is also a significant concern for the rover since it is powered solely from on-board batteries and must navigate to its destination successfully without running the batteries down too quickly. Due to this power constraint, the selected sonar sensors have a low nominal current draw of roughly 3.1 mA and a peak current draw of roughly 98 mA. This low nominal current draw will ensure that the sonar system does not draw power too quickly from the on-board battery supply.

The chosen form of communication for the sonar modules to send the calculated distance to object values is a pulse width modulation format. The pulse has a logic level of 5 V due to the component being powered from a 5 V supply. The distance to an object in the path of a sensor is converted into a pulse width representation which has a scale factor of 1 uS/mm. To illustrate this scale factor, if an object is 500 mm away from the front of a sensor face, a high pulse at 5 V with a width of 500 μs could be seen on an oscilloscope connected to the PWM pin of the sonar module. Once this pulse width representation is created it is sent to the central microprocessor on the rover which will use the calculated distance measurement in it's internal navigation algorithm to avoid any objects in its path and decide the necessary course of action. From viewing the sonar system schematic in Appendix A, the MB7360 sonar modules connect PIN 2 (Pulse Width Modulation (PWM)) to the digital input pin of the microprocessor that is capable of using pulse width modulation. PIN

7 (The Ground Reference of an Electrical Circuit (GND)) is connected to the ground of the circuit, while PIN 6 (Common Voltage of the Collectors of a BJT devices (VCC)) is connected to a Direct Current (DC) power source of 5.0 V. A filtering capacitor with a value of 100 μF is connected in between ground and Vcc in order to filter out unwanted electrical noise. In order to not have the two sonar modules taking range readings at the same time and interfering, the sensors will take readings sequentially. One sensor will take a range reading and once it is completely finished the second sonar module will begin to capture a range reading. The modules will alternate in this fashion continually to detect objects in the rover's path. In order to accomplish this, PIN 4 (RX) of the right sonar module is connected to a digital input pin on the microprocessor. The microprocessor will be able to send the triggering signal for the sonar to take a reading via this PIN 4 (RX). Per the MB7360 datasheet, PIN 5 (Transmit (TX)) of the right sonar will be connected to PIN 4 (RX) of the left sonar. This will allow the two sonar modules to take sequential readings upon receiving the signal from the microprocessor via PIN 4 (RX) on the right sonar. See the sonar schematic in Appendix A for the detailed wiring diagram.

6.3.2.2 Waypoint Localization

Rocket Detection Sensors

Upon landing, the payload rover needs to be able to navigate at least 5 ft. away from any of the two-three pieces of the rocket housing lying in the landing zone. The rocket detection system is the electrical system that will play the crucial role in giving the payload rover the tools necessary to identify each piece of the rocket casing so its internal navigation algorithm can deceiver where the rocket casing pieces are and avoid them.

The methods researched for this rocket detection system include GPS, ultrasonic transducers, and piezoelectric buzzers. The GPS module is very small in dimensions, lightweight, and has low power draw; however, it was chosen to not be a viable option as the accuracy of GPS is not precise enough for the navigation distance of 5 ft. in this mission. The piezoelectric buzzers and ultrasonic transducer options both have low current draw, minimal mass, and small dimensions. The ultrasonic transducers proved to not be a viable option as their operational frequency was too similar to the operational frequency of 42 kHz that the sonar object detection system is running at. After further research, the piezoelectric buzzers proved to be the best alternative for the mission requirements.

The CPE-2202A Piezoelectric buzzer with an included internal driving circuit, seen in 70, was selected to be the best alternative for this system. The CPE-2202A transmits a loud signal at a rated frequency of 3000 Hz in all directions. The buzzer has a minimal weight of 5.0 g, height of 16 mm, and diameter of 24.2 mm. The buzzer operates at 12 V and has a very low current draw of 11 mA to ensure that it can transmit for a substantial amount of time.

Figure 70: CPE-2202A Piezoelectric Buzzer

Figure 71: CMC-9745-130T Electric Condenser Microphones

Transmitter System Setup

There will be a piezoelectric buzzer mounted on each separated piece of the rocket casing. These piezoelectric buzzers will continuously transmit a loud tone in order to "label" the rocket as a specific object for the payload rover to avoid. The piezoelectric buzzers are small, light components that will not contribute significantly to the weight of the rocket system, as weight is an area that must be reduced as much as possible to maintain desirable flight characteristics. The components also have a low nominal current draw and will be powered by standalone power supplies on-board the rocket system. Each buzzer module will be mounted in the avionics bay and will be initially off during launch. Upon recovery and landing, each of the two avionic bays on the rocket will send a signal to the buzzers that will activate them to begin transmitting. The buzzers will output a frequency of 3000 Hz in a loud, continuous tone with a sound pressure level of 85 dB at 30 cm away. The buzzers each contain an internal driving circuit that enables them to simply be connected to the nominal supply voltage and a tone will begin being produced. On-board the rover there will be a dual microphone array that will use a sound localization technique to identify the transmitted tones from each of the buzzers, localize the tone, and navigate away from the sound.

Receiver System Setup

On the receiving end, a dual microphone array will be constructed with two CMC-9745-130T electric condenser microphones. The microphone component can be seen in 71. This receiver array will be mounted on the payload rover. The microphones operate with a nominal voltage of 5 V and low nominal current draw of 0.5 mA. They also are minimal in size with a height of 4.5 mm, diameter of 9.7 mm and a weight of 0.80 g. The microphones have a sensitivity of -45 dB to -39 dB and will detect and receive the transmitted signals coming from the piezoelectric transmitters. The use of the dual microphone array is in order to use a sound localization technique to determine where the sound is coming from, i.e., where the pieces of the rocket casing are located. For example, if the microphones pick up a signal that is coming from a buzzer to the right side of the array, the right most microphone will detect this signal first whereas the leftmost microphone will "hear" the signal slightly later in time. This difference in arrival time between the two microphones and amplitudes of the received signals will be used to calculate the distance to the piezoelectric buzzer and its orientation relative to the receiving microphone array. A graphical form of the system setup can be seen in 72.

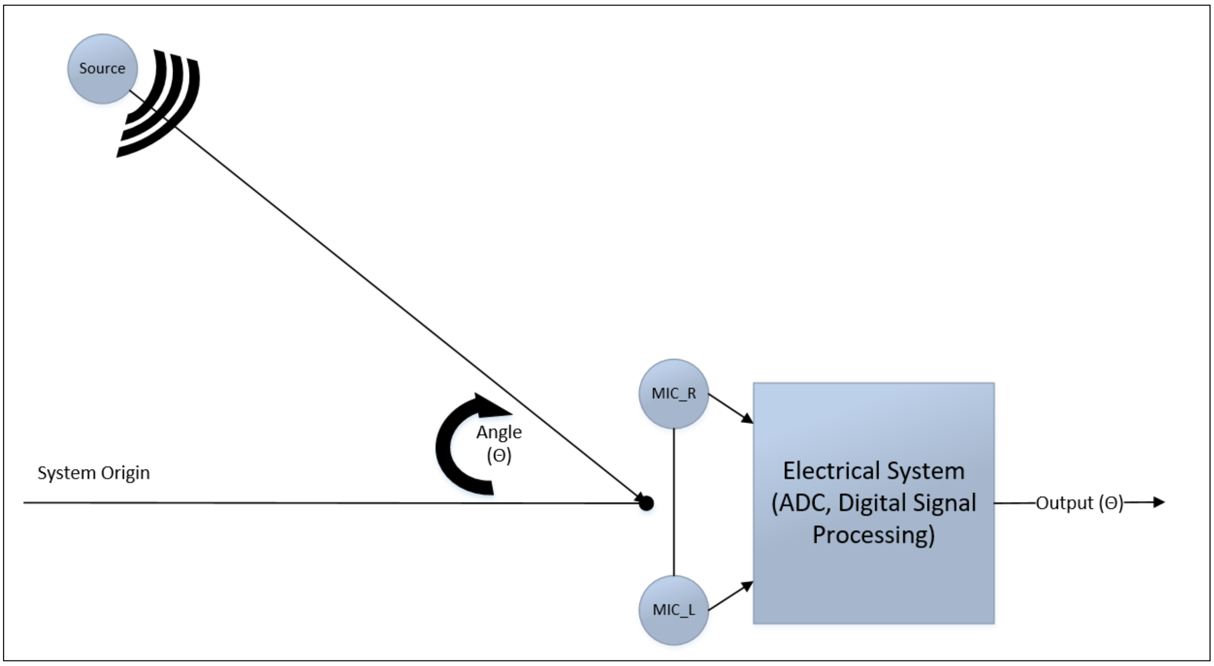


Figure 72: Differential Microphone System for Rocket Triangulation

6.3.2.3 Inertial Localization

The payload rover needs to be aware of aspects of its movement such as angular velocity, acceleration, and heading. To solve this problem, a motion-sensing 9DOF IMU will be implemented on-board the rover system. The chosen alternative for this 9DOF IMU is the LSM9DS1 Integrated Circuit (IC) which proved to be the best decision over other ICs based upon its available forms of digital communication, ease of implementation, and low current consumption.

The LSM9DS1 has a digital interface that is capable of communicating over SPI and Inter-Integrated Circuit (I2C) which will interface well with the Raspberry Pi 3 central microprocessor on the rover. The LSM9DS1 chip is equipped with three sensors; a 3-axis accelerometer, 3-axis gyroscope, and a 3-axis magnetometer, which gives it the nine degrees of freedom capabilities. The chip is able to track the rover's angular velocity, acceleration, and heading in three dimensions. The data that is produced and sent over I2C or SPI to the central microprocessor is in the form of acceleration, angular rotation, and magnetic force. This data will be used by the rover's operating system, ROS, in order to keep the system updated with useful movement data as the rover navigates the landing zone.

The LSM9DS1 requires a supply voltage of 1.9 V to 3.6 V and features a low nominal current draw of 1.9 mA. The LSM9DS1 is in the form of a breakout board which significantly eases the implementation to the rover system and can be simply wired to the Raspberry Pi central microprocessor to send its data calculations. The board can be seen in Figure 73.

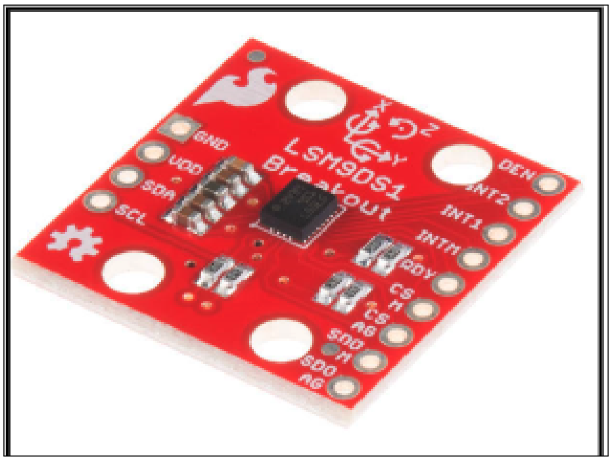


Figure 73: LSM9DS1 Breakout Board

6.3.3 Actuators

6.3.3.1 Motor Drivers & Overcurrent Protection Design

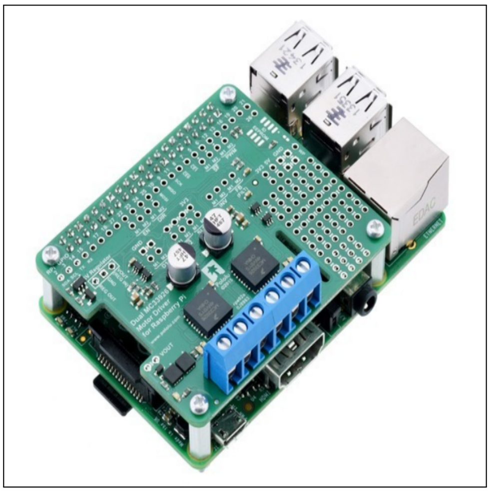


Figure 74: Dual MC 33926 Motor Driver Mounted to Raspberry Pi 3B

The selected components for the motor drivers and overcurrent protection have not changed since PDR. As discussed in the PDR, the final choice for motor drivers is the Dual MC33926 for Raspberry Pi due to better power efficiency, ease of integration, and available documentation for troubleshooting. A current sensor will be used to implement the overcurrent protection through a feedback configuration. The final choice discussed in the PDR was the INA169 Current Sensor because it had the highest output range, is easy to integrate, and took up the least amount of space. For reference, Figure 74 and Figure 75 below are the chosen motor driver and current sensor respectively.

As a system, the motor driver will mount directly to the Raspberry Pi. It is the interface between the drive train and the electronics used to control the rover.

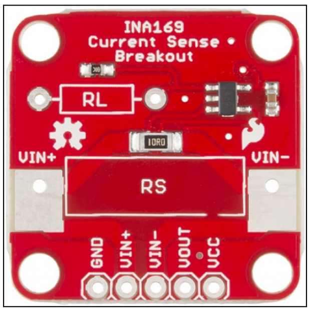


Figure 75: INA 169 Current Sensor

An unregulated voltage from the power system which ranges from 17 V to 12 V will be used as the input voltage for the motor driver. The remaining interfaces are 2 outputs per motor channel. Motor 1 will be connected to M1A and M1B of the wire terminals, while motor 2 will be connected to M2A and M2B. Between motor 1 and terminal M1A, the INA169 Current Sense board will be wired in series with the two components to measure the current draw. RS in Figure 75 is the shunt resistor that measures the current, and RL is the load resistor that determines the output voltage for any detected current. VIN+ will be connected to M1A, VIN- will be connected to one side of the motor, and the other end of the motor will be connected to M1B. VOUT of the current sensor will be connected to a GPIO pin on the Raspberry Pi and will output a max voltage of 3.3 V when stall currents are detected. The same setup will be used for motor 2 with wire terminals M2A and M2B respectively, and can be seen in block diagram below in Figure 76.

When 3.3 V are detected by the Raspberry Pi, software will read the value as a logic high and know that one of the motors are stalling. From there, software can cut power to the motors and prevent excessive current draw. Once current no longer flows through the motors, the current sensors will no longer output a logic high voltage and the algorithm on the rover can decide the next course of action to take.

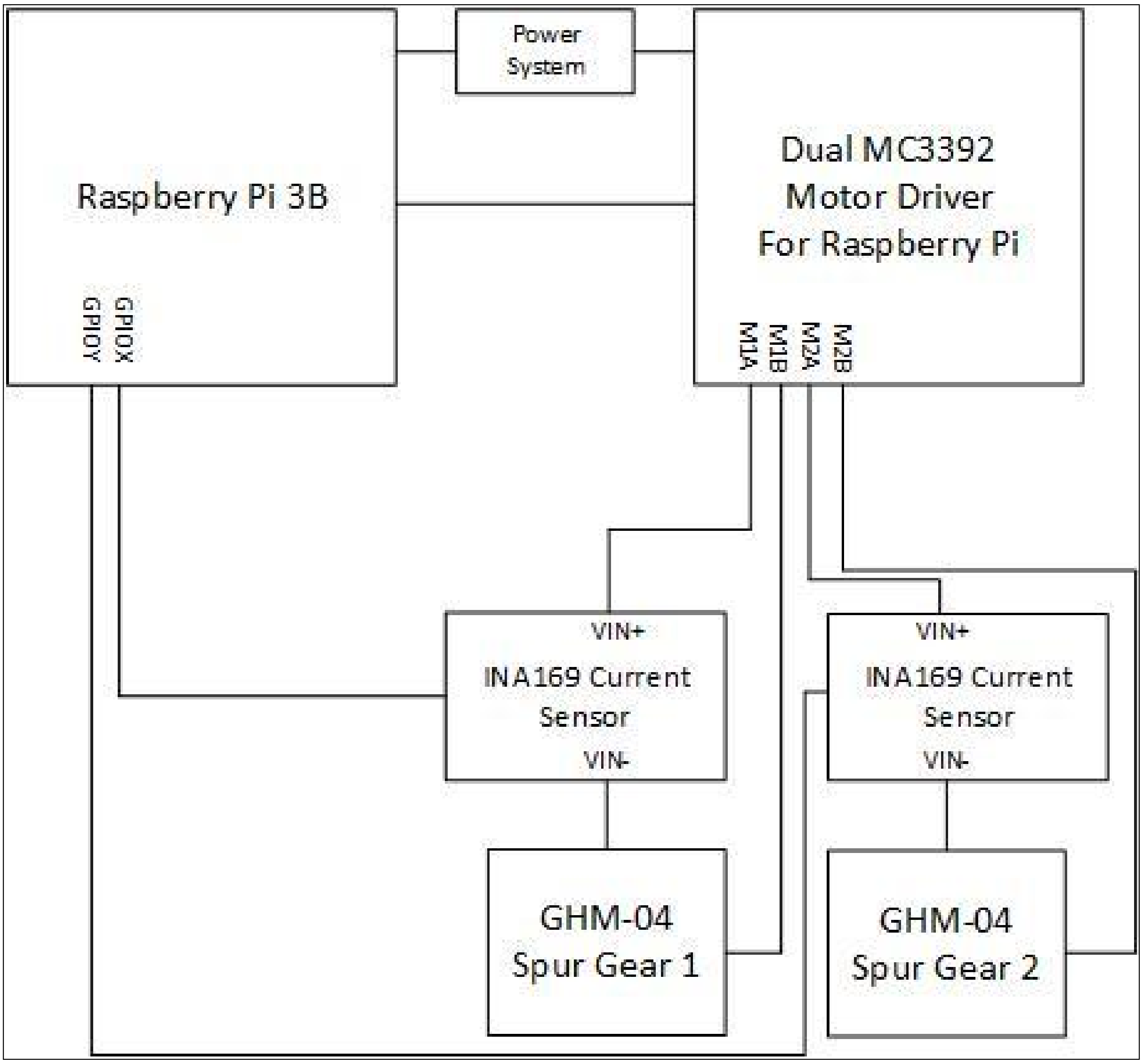


Figure 76: Motor Drivers & Overcurrent Protection Subsystem Block Diagram

Additional consideration needs to be made in terms of wire gauge. With the max current draw from each motor being 4.1 A, it is possible that total current being supplied by the power system to motor driver reaches 8.2 A. The wire used to connect the power supply to the driver must be minimum 18 American Wire Gauge (AWG), which can handle 10 A without risk of electrical fire. Final wiring of this subsystem will follow the electrical schematic shown below in Figure 76.

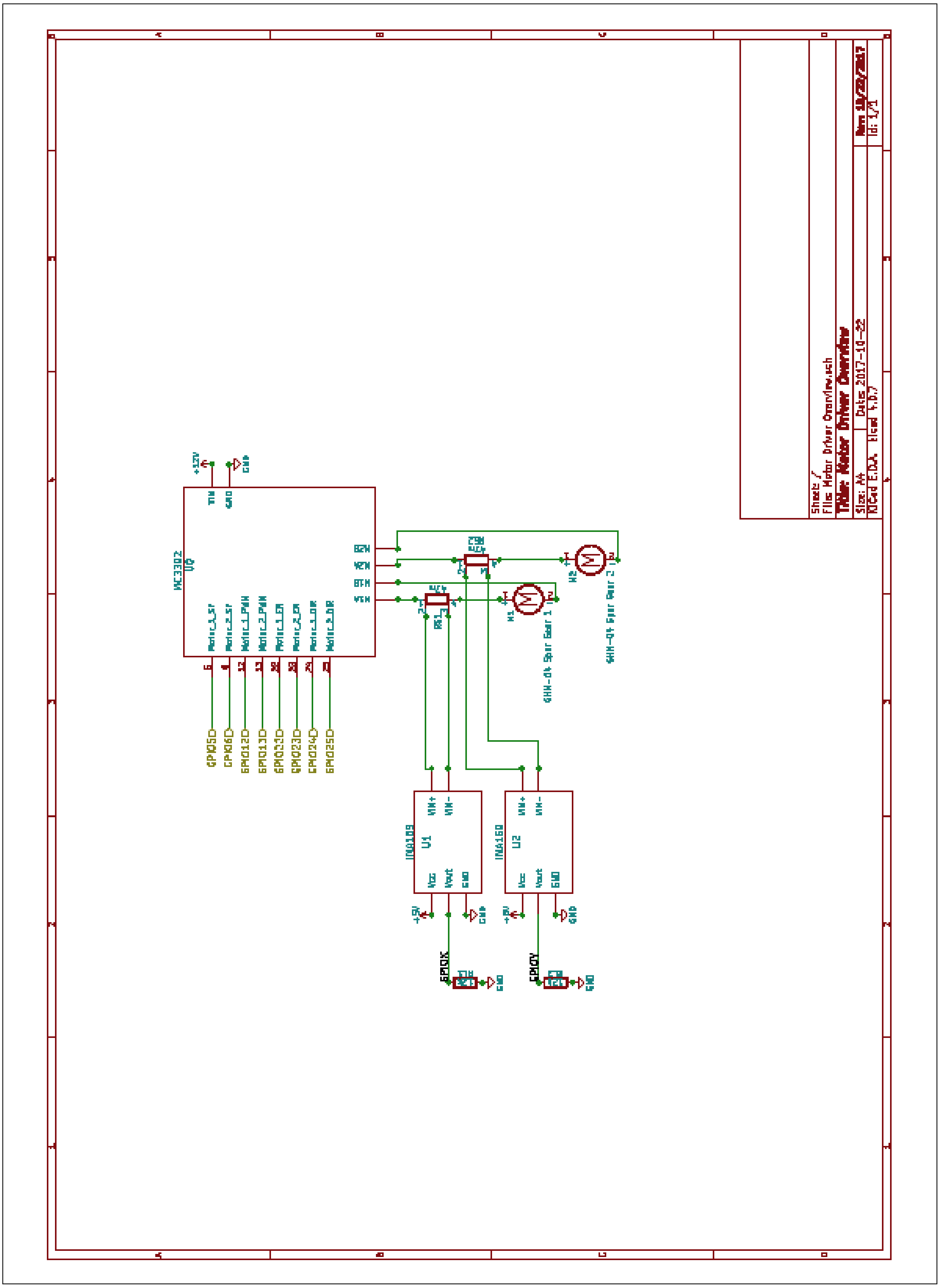


Figure 77: Motor Driver & Overcurrent Protection Schematic

6.3.3.2 Solar Actuation

Figure 58 shows how the solar gears are driven. The system is actuated with a standard size servo motor. Due to the lack of redundancy in the deployment activation, the servo selected must be as reliable as possible. There are a few variances between rotational servo motor models, the common differences being as follows:

- Plastic or Metal Internal Gears
- Plastic or Metal External Interface Sprocket
- Positional or Continuous Rotation
- Brushed, Coreless, or Brushless Motor
- Analog or Digital Internal Driver
- Ranges of Torque and Mechanical Power

Metal gear and sprocket servos are higher quality, more reliable, but slightly heavier and more expensive. The marginal weight is acceptable, **so a servo with metal gear train was prioritized.** Continuous rotation servos are much less common, so quality models are harder to source. Positional rotation models have a limited range of motion, often 180 degrees or less. 180 degrees is sufficient for this mission because the 1:1 gear ratio will allow the panels full deployment, so **a positional model is sufficient.** Brushed motors are the cheapest of motor type, and are slow and heavy. Coreless are slightly lighter and faster. However, brushless motors offer the advantage of durability, consistency, and high power. The solar deployment does not need to be fast, but it does need to be robust. **Therefore a brushless motor is necessary.** Analog drivers are less expensive, but digital drivers have much more responsive positional and holding feedback, which ensures accurate and reliable positioning. Therefore, **a digital driver is very important.** Based on these criteria, a servo motor was selected with the highest mechanical power that the budget allowed, providing the model met the aforementioned criteria. The model selected is a Futaba BLS-275SV Servo, as shown in Figure 78

Figure 78: Futaba BLS-275SV Servo

This actuator has the following features:

- Input Voltage Range: 4.0 V - 8.4 V
- Stall Torque Range: 190 oz-in - 210 oz-in (8 lbs. at Edge of Solar Panel)
- Brushless Motor
- Digital Driver
- Titanium Internal Gears
- Dual Ball Bearing Shaft Support

6.3.4 Power

The rover payload electrical systems must be completely independent of the electrical systems in the launch vehicle, so the rover must have its own power supply. The rover power supply consists of four LiPo batteries and two voltage regulators, one for 5 V and the other for 3.3 V. LiPo batteries were chosen for this project because they are reusable, and they have a high size-energy-density. The Turnigy Graphene LiPo batteries chosen for this project were specifically picked due to their form factor and charge capacity. A picture of the batteries can be seen below in Figure 79.

Figure 79: Turnigy Graphene LiPo Batteries

Each cell has a maximum charge capacity of 950 mAh and a nominal voltage of 3.7 V/cell. The four batteries will all be connected in series to provide a higher voltage for the regulators and motors. Having a higher input voltage increase the efficiency of both the regulators and the motors. At maximum charge, the batteries will be at a voltage of 4.2 V/cell, making a series voltage of 16.8 V. At minimum charge, the batteries will be at a voltage of 3.0 V/cell, making a series voltage of 12 V. The Turnigy LiPo batteries chosen for this system can provide 61 A continuously and 123 A at peak current. The rover payload will draw an estimated 1.37 A nominally, so the batteries chosen for this project are more than capable of supplying the necessary power to the rover. Initial testing of the batteries showed they were able to provide the estimated nominal current of 1.37 A for a little over 30 minutes, giving the rover 30 minutes to move away from the launch vehicle and deploy solar panels. The four batteries are friction fit into sleeves on the back of the frame. The sleeves have caps on both ends, preventing the batteries from shaking out of them.

The voltage regulators chosen for this project were the LM2576-5.0 and LM2576-3.3 made by Texas Instruments. These are identical switching voltage regulators accept for their fixed output voltages. They can handle a wide range of input voltages which is necessary due to the changing battery voltage. With the external components chosen for the IC, they will be able to provide 2.5 A at 5 V and at 3.3 V. The electrical systems connected to the regulators will draw no more than 650 mA, so the regulators will sufficiently be able to provide power to every system connected to the regulators. The regulators will be integrated into the custom PCB along with the battery level indication.

6.3.5 Wire Management

The permanent wire connections on the rover such as sensors and board to board connection are made using 20 gauge wires and through hole solder connections. Tension is taken off these connections by wire braiding and taping sections to the frame where possible. The temporary connections such as actuators and batteries are connected using screw terminals. Screw terminals provide a sturdy connection that doesn't require too much effort to connect or disconnect. The batteries will be connected to the custom PCB with the use of a wire harness, wire braiding, and screw terminals. An image of the battery wire harness can be seen below in Figure 80.

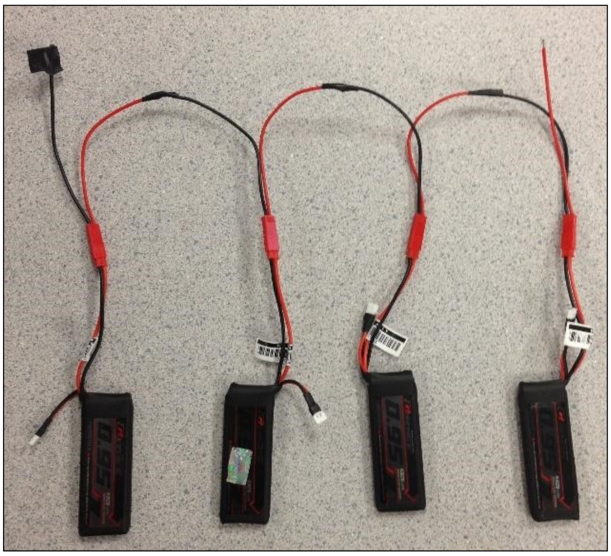


Figure 80: LiPo Battery Wire Harness

The wire harness is made of four Japan Solderless Terminal (JST) female connectors soldered together in series. The two bare leads are the leads which will be connected into the screw terminals on the PCB. Tension for the temporary connection is minimized using the same methods as the permanent connections.

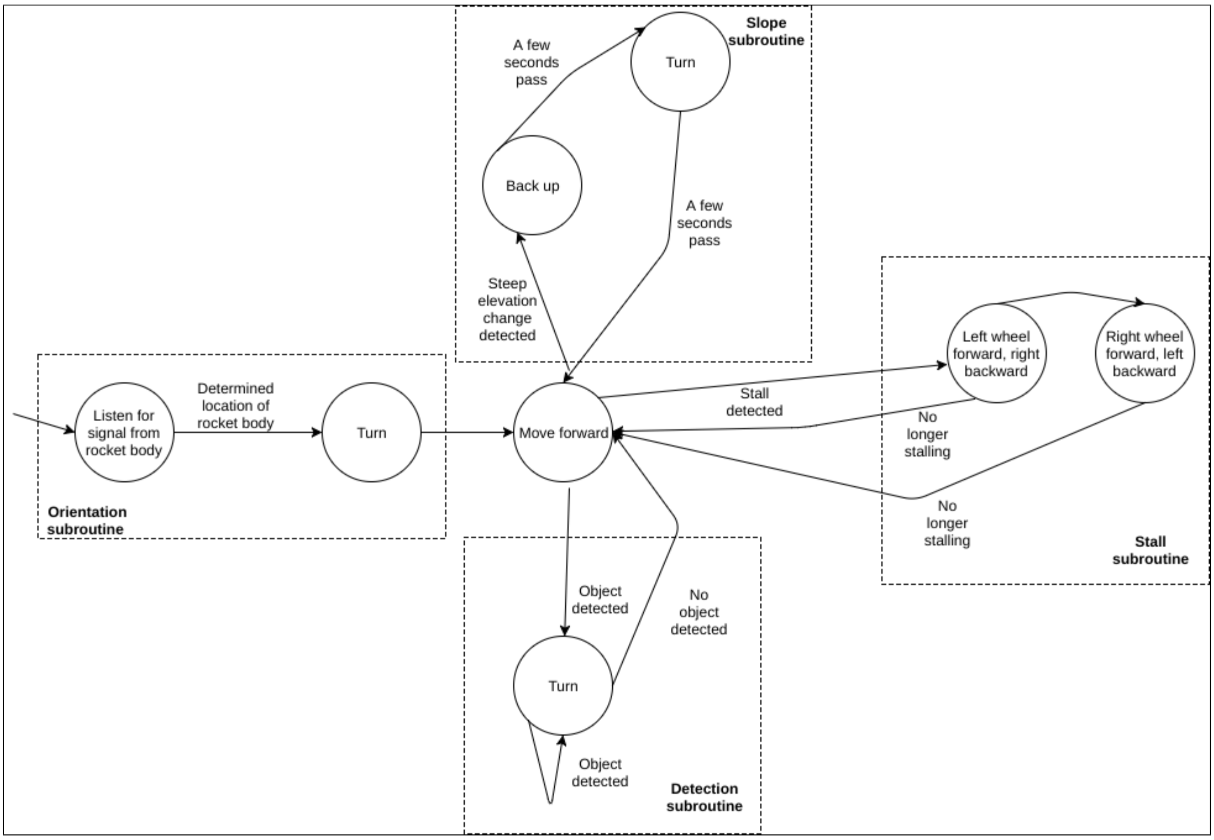
6.4 Rover Software

The software of the rover on the bottom level will be run on the Raspbian operating system (a Debian derivative), which will serve as a resource interfacing the rover software and ROS with the Raspberry Pi's hardware components. ROS will be used as the link between high level algorithmic computation and Inputs and Outputs (I/O) components, such as sonar sensors, microphones, and the IMU. ROS modules responsible for movement and path finding will subscribe to streams for these various sensors. Other ROS modules will be responsible for publishing sensor data as it arrives based on hardware interrupts to these streams. In the event of race conditions, data coming from more "vital" sensors, such as the motor driver or the IMU will take priority.

6.4.1 Movement Algorithms

Overall, the rover software will utilize three movement algorithms of varying complexity, The hardware needed by the less complex algorithms will be a strict subset of the hardware needed by their more complex counterparts, meaning that the rover can still function to some degree even if most of its sensors fail at a hardware level. Such redundancy is crucial when considering a rover than must function autonomously after experiencing extreme g forces during flight.

Figure 81: State Diagram for the Rover's Second Movement Algorithm



The three movement algorithms are as follows:

1) Simultaneous Localization and Mapping (SLAM): The rover will utilize a combination its magnetometer and its position relative to rocket frame parts (calculated by determining the phase shift because the same signals as recorded by the rover's two separate microphones) to triangulate its position. It will then utilize its front-facing sonar sensors combined with incremental scanning (via turning) to perform mapping of its surrounding area. Combined, this information will be used to determine an obstacle-free path for the rover away from the rocket frame that it will follow until it is at least five ft. away.
2) Obstacle avoidance: The rover will determine the location of any nearby rocket frame parts by listening for their signal on its dual microphones and then face away from them. From there, the rover will

move forward, avoiding obstacles detected by its sonar sensors by turning away from them. For steep declines, which front-facing sonar sensors will not detect, the IMU will alert the rover of said decline and the rover will back up, turn away from the decline, and continue moving. At regular intervals, the rover will check it absolute direction against its initial one using its magnetometer in order to ensure that turning done during obstacle avoidance has not resulted in the rover now facing the landing site which it intends to leave.

3) Basic movement: As before, the rover will face away from the rocket if the microphones are functioning. From there, it will simply move forward continuously, only changing directions if it gets stuck, at which point it will alternate turning left and right at full power in an attempt to wiggle itself out of whatever trapped it. This strategy, corresponding to the stall subroutine in Figure 81, is also employed by the other two algorithms in the event of motor stall, but the ultimate goal of the more complex algorithms is to avoid getting stuck in the first place.

Figure 81 shows a state diagram of the second movement algorithm listed above. The overall diagram is split into four distinct subroutines. The first, the orientation subroutine, is run as soon as the rover is ejected from its housing. It involves listening for the rocket's signal on its twin microphones and then turning until the phase shift of the signals corresponds to facing away from the rocket. The second, the slope subroutine, occurs the rover determines via its IMU that the angle of descent is too steep. It then backs up and turns away from the hole. The third, the stall subroutine, occurs when the motors stall. Here, the rover alternates between full power left and right turns in an attempt to wiggle out of the trap. Finally, the detection subroutine occurs when the sonar sensors indicate that there is an obstacle ahead. The rover will then turn until there is no obstacle in front and continue to move forward.

6.4.2 Sonar Sensors

The sonar sensor data for the rover will need to be formatted in such a way that is understood by ROS's gmapping libraries. The digital formatting of this module will follow the ROS navigation stack `sensor_msgs/Range.msg`. This definition will be configured to the infrared radiation type to conform with examples provided by the ROS sonar tutorials. Additionally this definition will contain max and min ranges of the module as well as the fixed range of the calculated output.

6.4.3 Inertial Measurement Unit

The IMU will utilize ROS's navigation stack as a standard for analog output to digital data types. Specifically, we will use the `sensor_msgs/Imu.msg` message definition. This message contains a header for orientation, angular velocity, and linear acceleration for the X, Y, and Z axes.

6.4.4 Motor driver

The controls for the motor itself will be abstracted away from ROS and implemented in a separate class outside of the framework. For the driver itself we will use Pololu's library for the Pololu Dual MC33926 Motor Driver, which is currently implemented in Python. If needed, we will convert this driver into a C++ implementation using the C++ version of the Wiring Pi Library.

6.5 Ejection System

As described within the mission profile, the airframe will descend in two separate sections: motor and payload. The scientific payload will be housed within the payload section which is tethered to the launch vehicle nose cone. Following separation the payload section will have one structural end fully open to the environment as the coupler will descend along with the motor section. During descent the payload will be retained within the launch vehicle by a Kevlar harness which is released upon landing. Following successful ground recovery of the payload and motor sections, a signal is initiated which will release the payload utilizing black powder charge ignition from an e-match.

Within the PDR, design alternatives were evaluated for their ability to complete the stated payload ejection requirements. Decisions were made based off of a scoring of the alternatives against engineering specifications. The results of the analysis are summarized below in Table 17.

Table 17: Ejection System Decisions

Task Solution Evaluated	**Final Decision**	**Reasoning**
Overall Ejection Method	Open end ejection	Ejecting out an exposed end of the payload section makes for a relatively simple design for the structures team. Additionally it has no structural impact on launch vehicle performance.
Retention	Primary: Tender Descender	Reliability to secure payload throughout entire flight sequence. Both release devices initiate from a small black powder charge.
	Backup: ARRD	Both release devices initiate from a small black powder charge.
Linear Motion Ejection	Black Powder charge	Black powder is extremely reliable and durable. Additionally the technology is flexible to meet the changing needs of the payload team if necessary.

A complete CAD mock-up of the payload bay can be referenced below in Figure 82. The design will be reviewed at a sub system level.

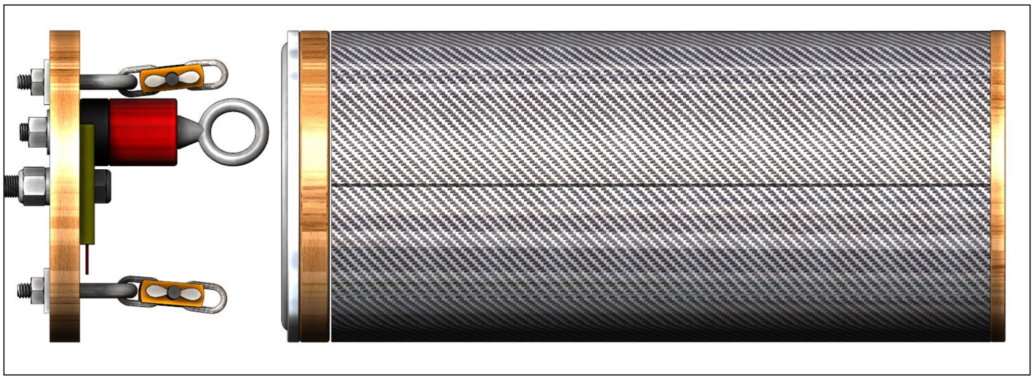


Figure 82: Ejection Bay CAD

The entire ejection system mass is estimated to be 3.6 lb. Analysis was completed using SolidWorks part volume and material density ratings sourced from vendor specification sheets. This quantity will be verified within testing procedure 17 as materials are sourced. A component wise breakdown can be referenced in Table 18.

Table 18: Payload Ejection Mass

Component	**Qty**	**Mass (lb.)**	**Total Component Mass (lb.)**
Tender Descender	2	0.11	0.22
Tender Descender Sheath	2	0.017	0.034
Advanced Retention & Release Device	1	0.55	0.55
Bulkheads	3	0.75	2.25
Black Powder ejection charges	2	0.022	0.044
Threaded rod	1	0.586	0.586
Carbon Fiber Sheet	1	0.15	0.15
Kevlar Harness	1	0.1	0.1
Assorted Fasteners	N/A	0.2	0.2
Nomex Blanket	1	0.05	0.05
		Total System Mass:	3.634

6.5.1 Housing

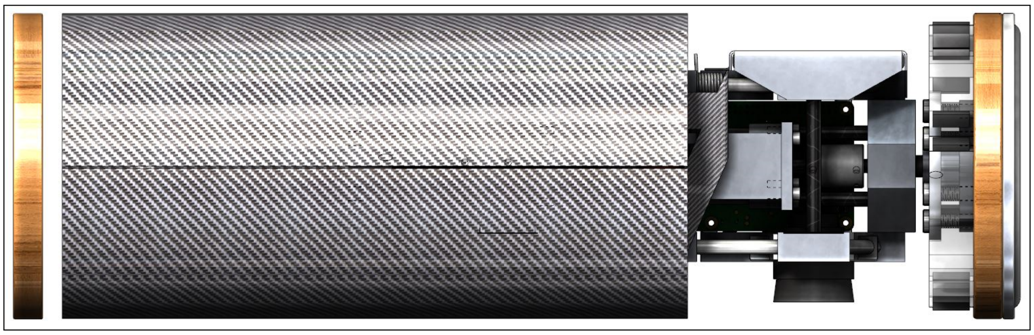


Figure 83: Payload Ejection Housing

During descent and landing of the launch vehicle, the rover will experience forces acting from parachute tension primarily. The deployable rover requires a housing while within the airframe to protect critical hardware. The housing will consist of a soft foam mold surrounding the rover chassis. Additionally a flexible carbon fiber sheet will surround the rover and foam in order to press fit the payload bay within the airframe. Release of the rover will occur following the unfurling of the carbon fiber sheet.

Figure 84: Aft Ejection Bulkhead

At each end of the rover, the HDPE wheels will contact plywood bulkheads which serve to mitigate compression forces acting on the payload during the ejection sequence. The bulkheads are notched at opposing edges where the Kevlar harness will reside. Pictured in Figure 84 is the bulkhead at the bottom of the section which will be the point at which the rover rests. The Kevlar harness will attach at pre-sewn loops to quick links fixed to a hard mounted U-bolt.

6.5.2 Retention

OpenRocket analysis estimates that the launch vehicle will experience up to 30 g's during descent. The primary safety concern regarding the payload is the secure retention of the system throughout the flight. Additionally, any retention methods require the ability to release prior to ignition of the ejection charges.

Retention of the payload will occur from two size L2 Tender Descenders which are traditionally used for high power rocket dual-deployment. The device is rated for a maximum shock load of 2,000 lb and releases upon ignition of a contained charge. Each descender will have one end hard mounted to the ejection bulkhead and the other end fixed to a pre-sewn loop in the kevlar harness. Release of the descender will free the payload harness for ejection from the airframe.

Figure 85: Tender Descenders

Figure 86: Rattworks AARD

Figure 87 displays the retention devices laid out on a fixed bulkhead. The bulkhead itself it fixed to an aluminum 3/8 in threaded rod. Ejection charges are packed as described within section 6.5.3. E-matches are wired through the bulkhead to the activation controller.

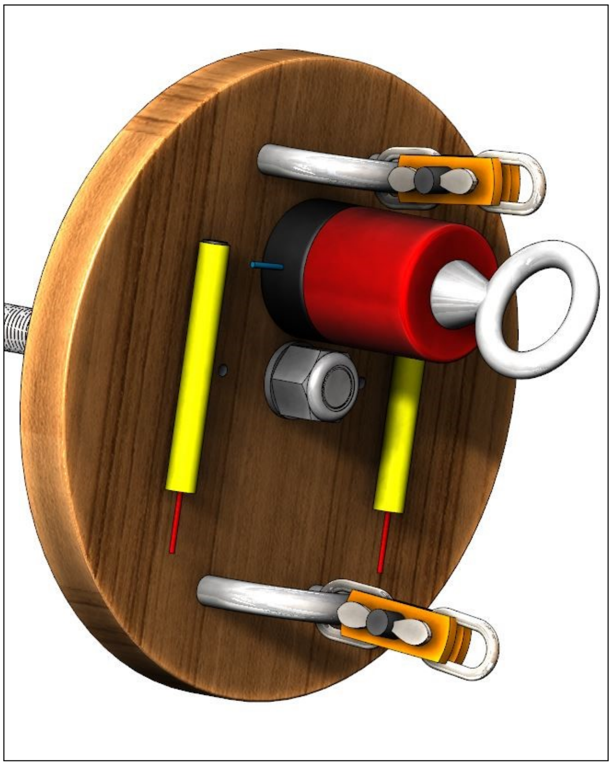


Figure 87: Fixed Retention Bulkhead

6.5.3 Ejection

Following release of the retention harness, black powder charges will be initiated, imparting a force upon the rover housing to clear it from the airframe. Equations 15, 16 and 17 are used in calculating size of black powder charges for payload ejection. Radius (r) and length (l) in equation 1 refer to the volume in which the black powder charge combusts. Temperature (T) and the gas constant (R) are known values from 4F black powder gas properties. Force (F) is estimated from a dynamic analysis modeling the payload as a point mass and using kinematic properties. Given these knowns, an estimated mass of black powder is produced to be around 6 grams. This modeled value will be tested in great length in test procedure #18.

$$V = \pi * r^2 * l \tag{15}$$

$$m = \frac{F * l}{\frac{R}{T}} \tag{16}$$

$$P = \frac{F}{\frac{\pi}{4 * d^2}} \tag{17}$$

The entire bay in which the ejection charge combusts will be filled with dog barf wadding. Additionally, the fore payload housing bulkhead will be covered by a Nomex blanket. This protects the rover from black powder dust which will affect performance of electronics and solar capabilities.

An outline of steps to perform payload ejection is as follows:

1) Successful ground recovery of the payload section
2) Clearance from the RSO to deploy
3) Signal to release ARRD and Tender Descenders simultaneously
4) Signal to ignite black powder ejection charges

Following these steps the payload will clear the airframe and traverse the environment.

6.5.4 Activation

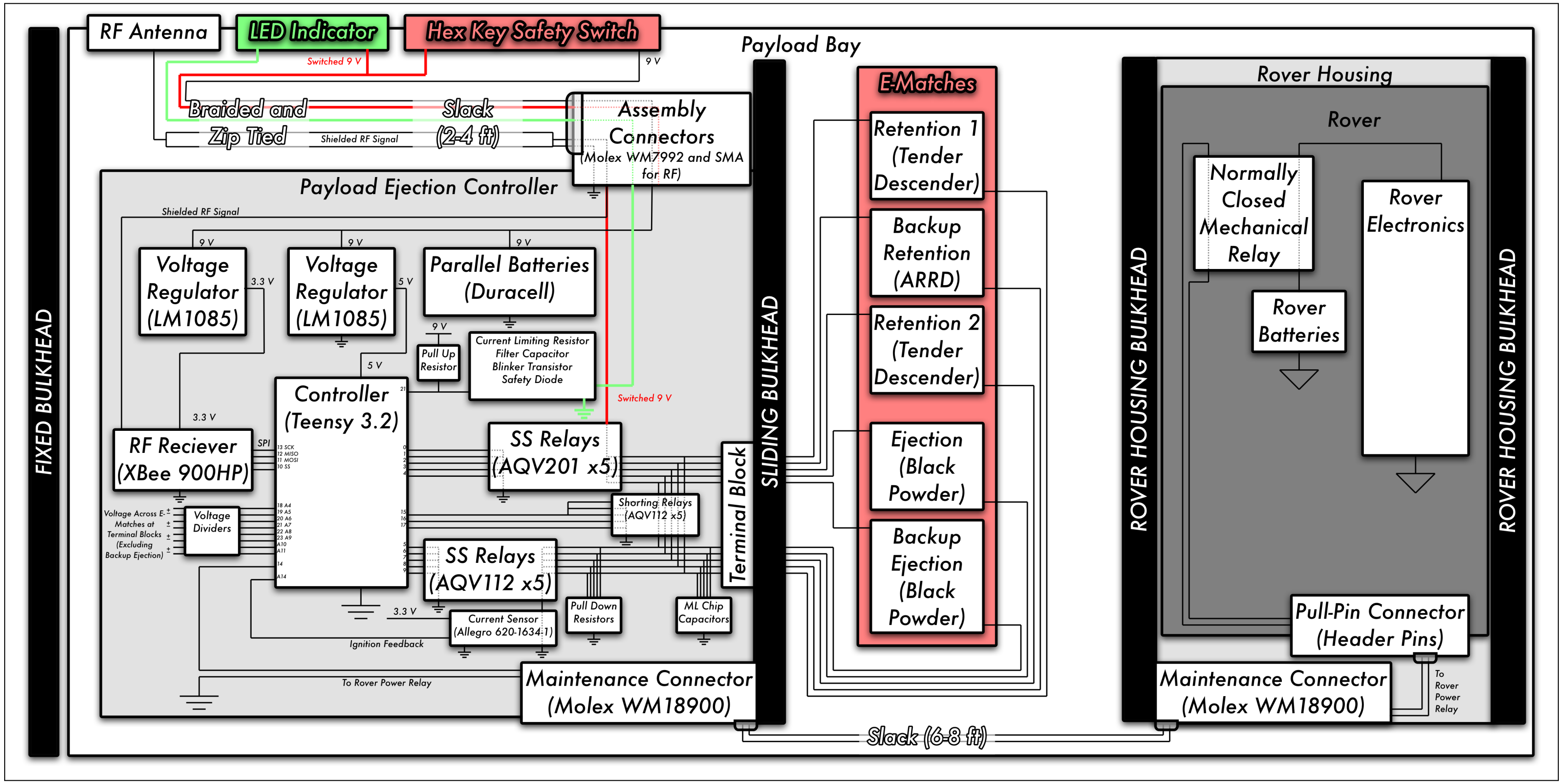


Figure 88: Block Diagram of Payload Ejection Controller

6.5.4.1 Bulkheads

A high level view of the payload ejection controller is shown in 88. The payload bay of the launch vehicle is constrained by the inside of the forward body tube and forward section fixed bulkhead.

The Payload Ejection Controller (PLEC) is mounted to the forward side of a sliding bulkhead, which is the same bulkhead to which rover retention devices are connected.

6.5.4.2 Wiring Assembly

Because the PLEC bulkhead must be coupled to the rover housing bulkhead, and the rover housing has little clearance to the body tube, the PLEC must have a connector that can be attached before the rover housing is loaded into the body tube. This function is accomplished with a locking Molex connector (DigiKey model WM7992) for the safety switch and LED, and an SMA for the antenna. This wire harness has enough wire slack that the disconnected wire harness can extend out of the body tube.

When the rover is deployed, the relay wire tether that controls rover sleep mode must have enough slack that the connectors will either not experience significant stress or that the bulkhead is out of the body tube so the wire connector can be pulled free. Adding slack to the relay control wire prevents the connector from being pinched between the body tube and rover housing bulkhead.

6.5.4.3 Safety Switch and Indicator

The switch is a hex key single pull single throw device accessed through a hole in the side of the launch vehicle. The indicator is a blinking LED. When assembled, one side of the safety switch is connected directly to the 9 V battery supply, and the other side of the switch is connected to the cathode of the LED and to the load side of the sourcing e-match relay. The anode of the LED is connected to the transistor that allows for blinking, whose gate is connected to the controller. There is also another diode in series with the anode of the LED to prevent any current from flowing from the controller, back through the LED and to the e-match relay. If for any reason the controller fails to output a blinking signal to the LED control transistor, a pull-up resistor will keep the transistor closed and the LED will still indicate that the charges are armed, though the LED will not blink.

A detailed view of the LED indicator block can be seen in the appendices, 94.

6.5.4.4 Relay Redundancy for E-Match Safety

The e-matches are activated using a triple redundancy circuit. Though e-matches are not polar devices, for the purpose of this discussion, the source lead of the e-match will be called the cathode, and the sink lead will be called the anode. One relay shorts the terminals of each e-match together so that no voltage can be generated across them. A source relay blocks the switched 9 V node from energizing the e-match, and a sink relay blocks the GND node from closing the e-match circuit. Therefore **in order to have a single e-match light, all three of these relays must be changed**:

- Source relay must close
- Shorting relay must open
- Sink relay must close

The probability that one of the relays has a manufacturing error that allows large enough leak current to ignite an e-match is low, but the probability that an entire batch has the same error given one part already has an error is large. Therefore, the source and sink **relays are a different model to avoid batch manufacturing errors**.

The electromagnetic burst effect of a neighboring e-match ignition are unknown, so **this system protects against electromagnetic induction from black powder** with the following mechanism. Each e-match also has a pull-down resistor on the anode to ground any electromagnetic interference, as well as Multi-Layer Ceramic Capacitor (MLCC) to absorb high-frequency components of any interference.

The retention and primary ejection charges have voltage sensors at the terminal blocks, and all e-match current will be sensed through the sink relay's ground. The backup ejection charge does not need a voltage sensor because there is nothing the controller can do if the backup ejection charge does not ignite.

6.5.4.5 Power System

The PLEC runs off multiple Duracell 9 V batteries in parallel for redundancy and to source the capacity needed for RF transmission and e-match ignition. The controller runs off a 5 V rail, and the XBee and current sensor runs off 3.3 V, so two LM1085 voltage regulators will be used.

If the assembly connector is not connected, the controller system will be powered, but RF transmission will be not possible. **If the assembly connector is connected, but the safety switch is not activated, the controller system will be functional** and the ground station can communicate with the controller, but the load side of the **relays will not have a power source**.

6.5.4.6 E-Match Ignition Current

The nominal resistance of the components in series with the are as follows:

- Output resistance of 9 V batteries: 1.1 Ohms
- Load resistance of source relay: 0.5 Ohms
- Resistance of e-match: 1.2 Ohm
- Load resistance of sink relay: 0.55 Ohms

Therefore the total resistance is under 4 Ohms, so the maximum nominal current that can be supplied to the e-matches is over 2.5 A, and the maximum necessary current that will light an e-match is 1 A, so the **voltage drop across the solid state relays is low enough to not interfere with e-match ignition**.

6.5.4.7 E-Match Ignition Feedback

As previously mentioned, the controller senses the voltage across each e-match, as well as the current flowing through the relay system. Therefore the power dissipated across the e-matches can be calculated, and the controller can hold the relays open to continuously energize the e-matches until current is not longer flowing and voltage across the terminals returns to 9 V.

This systems allows the controller to have a variable timing sequence in case one e-match takes longer to ignite than expected. The controller has several 3.3 V analog inputs, the 9 V differential across the e-matches will be measured with a voltage divider network.

6.5.4.8 Rover Activation

Though the rover software will stay in a low-power mode until it senses that it is no longer enclosed by the ejection housing, the payload ejection controller also **holds a normally closed relay in the open position to prevent the rover battery from powering up the rover**. Once the payload is ready to be ejected, the PLEC will release its signal to the rover, allowing the rover to power up. If the relay connection is damaged or dislodged upon launch, ascent, or descent, the **rover will power up by default**, and continue to remain in low-power mode until the ejection housing opens.

The rover relay wire, though deenergized, will still be mechanically connected to the rover. Therefore, this wire has a pull-pin connection so that when the rover drives forward, this wire will be pulled loose and will **not interfere with rover traversal**.

The rover activation relay wire has factory connections on each bulkhead so that it can be easily replaced. This is to ensure rapid reusability for ejection testing and overall mission success.

6.6 Design Completeness

89 and 90 show assembled views of the payload assembly, and 19 lists the weights of each sum-system.

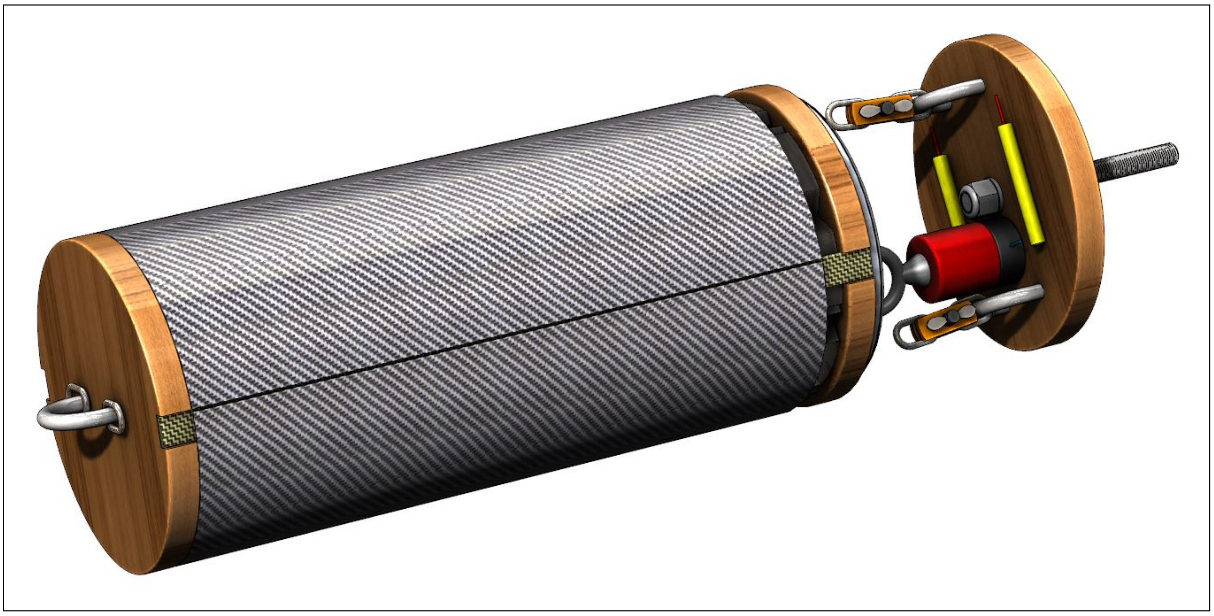


Figure 89: Payload Bay CAD Assembled

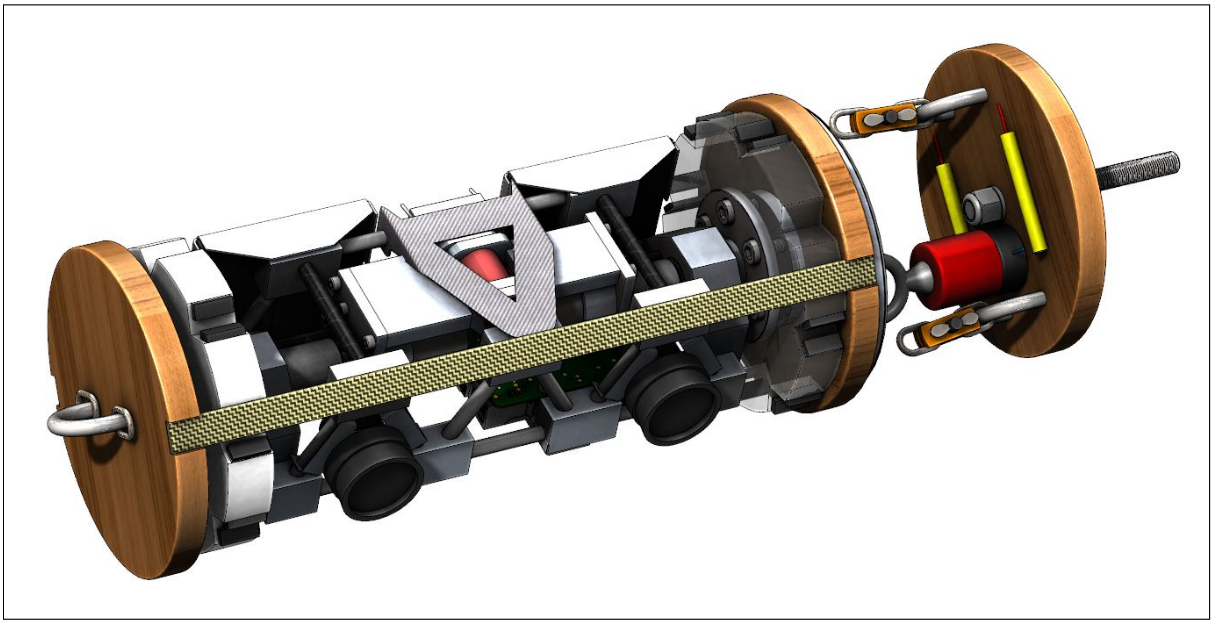


Figure 90: Payload Bay CAD Assembled (Carbon Fiber Wrap Not Pictured)

Table 19: Component Weights

Sub-assembly	**Weight (lb.)**
Drivetrain	2.90
Batteries	0.14
Chassis	0.71
Stabilizer	0.02
Raspberry Pi and Motor Driver	0.11
Solar Assembly	0.35
Sensors	0.20
Misc. Rover Electronics	0.10
Ejection Mechanics	3.63
PLEC	0.44
Total	8.60

7 Project Plan

7.1 Testing

7.1.1 Altimeter Ground Check #01:

Passing Condition:

- Primary altimeters active drogue output at simulated apogee
- Secondary altimeters active drogue output 1 second after simulated apogee

Test Materials Required:

- x2 Stratologger CFs
- x2 Missile Work RRC3s
- Arduino with 4 input relays and baro sensor
- x4 9V Batteries
- Vacuum Chamber

Test Procedural Steps:

1) Connect the drogue output of all 4 altimeters to the input relays of the arduino
2) Connect Arduino and all 4 altimeters to batteries and turn on
3) Place electronics in vacuum chamber, set the chamber from 10.83 psi to 5.16 psi in 20 seconds, then increase back to 10.83 psi in 40 seconds
4) Remove electronics, read data from Arduino and compare timing of calculated altitude with altimeter outputs

Safety Considerations:

- Check all connections on vacuum chamber to ensure no pressure leaks

Results and Necessary Modifications: If the specified altimeters are tested to be unable to perform drogue output at the correct altitudes, alternate altimeter options will need to be explored.

7.1.2 Avionics Fault Resistance Test #02:

This test verifies the fault resistance of the ATU power supply which is defined by the ability of the ATU power supply to provide low noise, continuous, consistent power under extreme circumstances for periods of time exceeding that of the flight of the launch vehicle. This test addresses team generated requirement Recovery System - 6 which states that Avionics electronics in each section of the launch vehicle will have redundant power supplies to create a more robust system.

Passing Condition: If the ripple on each of the rails is less than 10mV as measured by the oscilloscope and the DC value is within 10% of the nominal value while under load then the system has passed.

Test Materials Required:

- Oscilloscope
- DC load

Test Procedural Steps:

1) Connect 5 V rail and 3 V rail to independent DC loads
2) Configure DC load to pull 1 ampere of current from the supply rails
3) Connect oscilloscope leads to output of each rail, ensuring to set the impedance of the probe at the maximum value provided by the oscilloscope
4) Enable power to the circuit by connecting the battery to the input of the power supply circuit.
5) Measure ripple on the load while current is being drawn
6) Measure mean DC voltage value of both 5 V and 3.3 V rails

Safety Considerations:

- Tester will wear a grounding strap to protect circuits from shorting
- Tester will wear safety glasses when conducting tests
- Tester will not power on any circuits until all nodes have been verified to have been connected correctly
- While the circuit is powered on, the tester will not touch the circuit itself, only modifying the test equipment as necessary to create the test environment required for validation

Results and Necessary Modifications: Test has been passed successfully. Batteries and regulators were capable of supplying 1 amp of current with less than 10 mV of ripple on the output. The DC value was measured at 4.983 V and 3.291 V for the 5 V and 3.3 V rails respectively. No test modification will be necessary.

7.1.3 Avionics Battery Life Test #03:

The ATU will need to operate for extended periods of time due to the unknown time which the system may be powered on while waiting to launch or waiting to be recovered. As a result, a long battery life is necessary to ensure recovery is possible as well as tracking of the launch vehicle for the duration of the flight regardless of any time delays that may occur prior, during, or after the launch. This test addresses team generated requirement Recovery System - 6 which states that Avionics electronics in each section of the launch vehicle will have redundant power supplies to create a more robust system.

Passing Condition:

If the ATU power supply provides the specified currents and voltages for a period of greater than 8 hours then the system has passed.

Test Materials Required:

- 2 DC loads

Test Procedural Steps:

1) Configure first DC load to draw 410 mA from the 3.3 V rail
2) Configure second DC load to draw 100 mA from 5 V rail
3) Record the time it takes for the battery to no longer provide nominal voltage and currents to the DC load

Safety Considerations:

- Tester will wear a grounding strap to protect circuits from shorting
- Tester will wear safety glasses when conducting tests
- Tester will not power on any circuits until all nodes have been verified to have been connected correctly
- While the circuit is powered on, the tester will not touch the circuit itself, only modifying the test equipment as necessary to create the test environment required for validation

Results and Necessary Modifications: Test not yet conducted.

7.1.4 Avionics Continuous Transmission Test #04:

The ground station must be in continuous contact with the flight vehicle for the duration of the flight in order to successfully track and recover the flight vehicle once safely landed. The continuous tracking is defined by the ability of the system to provide accurate tracking data at intervals no greater than 5 seconds. The team generated engineering requirement addressed by this test is Recovery System - 6 which states that theavionics system will be able to track position of the launch vehicle without losing communication for a period of greater than five seconds.

Passing Condition:

If a packet arrives at least every five seconds for the duration of the test then the system has passed.

Test Materials Required:

- Independent ATU units
- Transportation vehicle

Test Procedural Steps:

1) Configure RF transceiver to communicate with the base station at a minimum rate of 5 Hz
2) when the system is 10 feet away from the base station Verify that the minimum GPS data arrival rate at the base station is at least 5 Hz by recording data received by the base station on the computer and the time of arrival
3) Once communication has been confirmed move the system away from the base station maintaining line of sight at a speed of 5 mph
4) Travel one mile such that ATU units are one mile apart
5) Track all GPS packet data recorded for the duration of the system movement away from the base station

Safety Considerations:

- **Tester will wear a grounding strap to protect circuits from shorting**
- Tester will wear safety glasses when conducting tests
- Tester will not power on any circuits until all nodes have been verified to have been connected correctly
- While the circuit is powered on, the tester will not touch the circuit itself, only modifying the test equipment as necessary to create the test environment required for validation
- Driver of vehicle will be certified by the state in which the test is done to operate a motor vehicle safely
- Driver of vehicle will obey all traffic laws

Results and Necessary Modifications: Test not yet conducted.

7.1.5 Avionics Transmission Power Test #05:

The ATU and ground station RF transceivers must have high enough Tx power and low enough Rx sensitivity to properly communicate wirelessly. Verification of sufficient power levels is necessary to ensure that the components are capable of facilitating wireless communication under all circumstances that the flight vehicle may encounter. The engineering requirement addressed by this test is 3.10 which states that 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. Additionally, Recovery System requirement 5 is addressed which states that the avionics system will have enough transmission power to communicate with the ground station during the entirety of the flight.

Passing Condition:

If 9/10 range tests succeed and the communication is possible then the system has passed.

Test Materials Required:

- **XCTU range testing software**
- Computer

Test Procedural Steps:

1) **Configure two independent ATU modules to communicate with each other**
2) Place ATU modules two miles apart
3) Perform range test using XCTU tools and record results
4) Repeat step 3 an additional 9 times for a total of 10 tests

Safety Considerations:

- **Tester will wear a grounding strap to protect circuits from shorting**
- Tester will wear safety glasses when conducting tests
- Tester will not power on any circuits until all nodes have been verified to have been connected correctly
- While the circuit is powered on, the tester will not touch the circuit itself, only modifying the test equipment as necessary to create the test environment required for validation

Results and Necessary Modifications:

Test not yet conducted.

7.1.6 Avionics GPS Update Frequency Test #06:

In order to provide the most data possible to ensure analysis and tracking of the flight vehicle is successful, the update rate of the GPS coordinates received by the GPS module will need to be high. This test ensures that the update rate is sufficient for thorough analysis of flight data to take place.

Passing Condition: If GPS coordinates received are collected at a minimum average rate of 5 Hz and coordinates are within 10% of externally verified coordinates, then the system will have passed the test.

Test Materials Required:

- Computer

Test Procedural Steps:

1) **Configure GPS for update rate of 10 Hz via firmware**
2) Connect GPS receiver and microcontroller to computer with serial monitor to collect GPS data as it is received
3) Enable GPS receiver and wait until a fix is acquired
4) Record all GPS data received with time stamps for a period of five minutes

Safety Considerations:

- Tester will wear a grounding strap to protect circuits from shorting
- Tester will wear safety glasses when conducting tests
- Tester will not power on any circuits until all nodes have been verified to have been connected correctly
- While the circuit is powered on, the tester will not touch the circuit itself, only modifying the test equipment as necessary to create the test environment required for validation

Results and Necessary Modifications: Test not yet conducted.

7.1.7 Avionics RF Transceiver Data Throughput Test #07:

In the event of an onboard datalogger failure, the ATU will need to transmit all data seen and recorded from all sensors in order to collect all data and ensure nothing is lost in the event of a failed logging mechanism. As a result, the data throughput of the device must be validated to support the higher data rate that would be required in the event of a failure.

Passing Condition: If the average data throughput for the one minute period is at least 75 kbps then the system has passed the test.

Test Materials Required:

- Computer
- 2 independent ATU modules

Test Procedural Steps:

1) Configure each transceiver for API mode and configure network communication between the two units.
2) Transmit a predefined 75 kb dataset continuously for a period of one minute
3) calculate the average data throughput after the one minute period has ended by dividing the number of bits received at the endpoint by the sixty second time period

Safety Considerations:

- Tester will wear a grounding strap to protect circuits from shorting.
- Tester will wear safety glasses when conducting tests.
- Tester will not power on any circuits until all nodes have been verified to have been connected correctly.
- While the circuit is powered on, the tester will not touch the circuit itself, only modifying the test equipment as necessary to create the test environment required for validation.

Results and Necessary Modifications: Test not yet conducted.

7.1.8 Bulkhead Testing #08:

The bulkhead testing was team generated. Bulkhead strength testing to verify that it will hold up to the expected recovery loads. The expected loads will be supplied by Aerodynamics, and were used in creating the tolerances for the ESs. The test will be destructive, meaning that additional bulkheads will need to be manufactured. Bulkheads used in testing will need to be identical to bulkheads used in full scale launch.

Passing Condition:

- Load at failure is at least 1600 lbs.

Test Materials Required:

- Bulkhead
- Threaded rod
- Washers
- Nut
- Linear Scale
- Winch

Test Procedural Steps:

1) Assemble the threaded rod, washers, and nuts to the bulkhead
2) Secure scale and winch to bulkhead
3) Increase the winch force until bulkhead fails
4) Record maximum force applied to the bulkhead

Safety Considerations: Use proper safety glasses and clothing. Have a safe barrier between testing area and people in room.

Results and Necessary Modifications: If the bulkhead is unable to meet the passing conditions after multiple attempts, the thickness of the bulkhead will be increased and then retested until the passing condition is met.

7.1.9 Climb Angle Test #09:

The climb angle assurance will ensure that the complete payload rover will meet the design torque requirements. A maximized climb angle will allow the rover to escape from ruts and climb difficult terrain. **Passing Condition:** The climb angle the rover can accomplish shall be maximized for tilled terrain traversal:

- Lower Limit: 10^o
- Target: 30^o
- Upper Limit: Maximized

Test Materials Required:

- Assembled payload rover
- Electronics including motor driver, power systems, controllers
- Software for basic run procedure
- Expendable protractor

Test Procedural Steps:

1) Place rover on flat surface in tilled field with stabilizer deployed
2) Measure hill angle at least two feet from the front of the rover
3) Record hill measurement
4) Run setup procedure for rover system
5) Move rover forward toward hill
6) Climb to the top of the slope
7) Repeat steps 1-6 for increasing hill angles until step 6 cannot be accomplished

Safety Considerations:

- All participants must wear safety glasses during testing.
- Ensure all testing participants are a minimum of 5 feet from the rover during operation
- Check all safety switches are operational and engaged
- Ensure voltages of Lipo batteries are above critical threshold level

Results and Necessary Modifications: Tests have not been run and will be done after mechanical fabrication of rover. Changes may be done to the ground conditions and the grip of the tires depending on rover performance. If the system performs beyond expectations it will be tested on more difficult ground conditions while the grip of the tires dictates the coefficient of friction between the rover and the ground.

7.1.10 Ground Clearance Test #10:

Ground clearance assurance will ensure that the complete payload rover will meet the design clearance requirements. A maximized ground clearance will allow the rover to traverse uneven and diverse terrain.

Passing Condition: The lowest point of the rover has to have an acceptable ground clearance during travel:

- Lower Limit: 0.25 in.
- Target: 0.6 in.
- Upper Limit: Maximized

Test Materials Required:

- Assembled payload rover
- High precision calipers with 4 in. jaws
- Flat table surface

Test Procedural Steps:

1) Zero the calipers closed in in imperial units
2) Place complete rover on flat table surface
3) Open calipers to lowest point of rover
4) Record measurement from calipers

Safety Considerations:

- Wear gloves when handling any sharp surfaces
- Ensure rover is securely fastened to table surface to not allow it from rolling off the surface

Results and Necessary Modifications: This test has not been done and will be run once the rover is mechanically fabricated. Changes to rover operating orientation and expandability of wheels will be considered depending on performance results.

7.1.11 Final Assembly Testing #11:

This test is a team generated requirement. This testing procedure will allow the team to practice assembling the launch vehicle for the actual launch in Alabama. The procedure will also allow for necessary information for determining the flight path. After the launch vehicle is fully assembled, other measurements and values will be determined.

Passing Condition: There are multiple engineering specifications being addressed, so the passing condition of the tests are as such:

- Total weight of assembled launch vehicle is less than 45 lbs.
- Time required to assemble integrated launch vehicle is less than 2.5 hours
- Available internal volume of launch vehicle is greater than 4500 in.^{3}
- Cost of all components needed to produce the launch vehicle is less than $4000
- Total number of components that need to be integrated is less than 40
- Surface area of the body that is RF transparent greater than 280 in.^{2}

Test Materials Required:

- Precise Scale
- Timer
- Measuring Tape

Testing Procedural Steps:

1) Measure interior space of launch vehicle
2) Start timer
3) Assemble the launch vehicle
   a) Insert payload
   b) Insert AV bays into launch vehicle
   c) Secure AV bays
   d) Attach parachutes to eyebolts
   e) Fold and insert parachute
   f) Slide sections of launch vehicle together
4) Stop Timer
5) Place launch vehicle ton scale
6) Count number of components integrated during build
7) Add cost of each component
8) Measure exposed fiberglass area

Safety Considerations: Wear proper clothing and close toe shoes.

Results and Necessary Modifications: If the launch vehicle cannot be assembled within the necessary time then design changes will be considered. The weight of the launch vehicle can be modified in order to reach the target altitude. If weight is unable to be modified, then changes to aerodynamics can be made.

7.1.12 Launch Vehicle Ejection System Test #12:

Ground ejection testing is imperative to understand the bulkhead force requirements to create separation and eject the parachutes. Without the successful execution of these simple tasks, the launch vehicle will return ballistic, creating a highly dangerous situation. To avoid this, the size of the black powder charge will be tested on the ground using the same shear pins that will be assembled into the launch vehicle. The following test procedures are used to test the various weights of black powder to ensure that the amount used is beyond what is necessary to achieve separation and ejection.

Passing Condition: As part of finding the correct setup for the ejection charges, the following definitions will also apply to each test. Only success is counted as a success, each partial or complete failure is counted as a failure.

- Success: complete separation of sections and parachute ejection from packing. The tether had been fully extended.
- Strength Failure: separation of the sections occurs, the parachutes are ejected (for tests that include parachutes), but the tether is not completely extended.
- Ejection failure: separation of the sections occurs, but the parachutes are not ejected (for tests that include parachutes). The tether is not completely extended.
- Partial separation failure: the sections shear the pins, but the sections do not separate fully. No parachutes are ejected for tests that include parachutes. The tether is not extended a significant amount.

Test Materials Required:

- Black powder ejection charges
  - 3x base ejection size charge based on free volume (separated into 3 equal charges)
  - 3x base ejection size charge + 0.5 g (separated into 3 equal charges)
  - 3x base ejection size charge + 1 g (separated into 3 equal charges)
  - Each ejection charge has been outfitted with an e-match
  - Increase ejection charge size as needed to achieve acceptable success rate
- Pressure sensor
- Ejection interface
  - Full-scale
    - Carbon fiber and honeycomb bulkheads
    - Carbon fiber body tubes
  - Sub-scale
    - Laminated plywood bulkheads
    - Fiberglass body tubes
- 3x nylon #2-56 shear pins for each test
- High pressure sensor

- Duct tape
- Ejection controller (battery) and switch
- Parachute recovery system (for later tests when full setup is required)

Testing Procedural Steps:

1) Attach charges to bulkhead using duct tape
2) Attach pressure sensor to bulkhead and computer
3) Close body tubes and insert shear pins
4) Perform safety protocols described above
5) Initiate test
6) Record results test success or failure qualitatively
7) Record pressure data
8) Repeat as necessary for each charge size

Safety Considerations:

- OSU property specific for testing explosives will be used
- Each tester will be using safety glasses during entire testing process
- Arming switch will be manually disconnected from battery before and after each test
- Each tester will remain a substantial distance away from the launch vehicle when charges are live
- Black powder charges will be significant distance away from any ignition sources
- The status and location of each tester will be verbally confirmed before test is initiated by the safety officer
- "Fire in the Hole" will be verbally announced before each test is initiated by the safety officer
- If any person says anything (except for the verbal announcements and communications), the test will be aborted until deemed safe to continue by the safety officer
- The safety officer will initiate all tests

Results and Necessary Modifications: Testing for the sub-scale launch was completed and cataloged in Table 20. The amount of black powder chosen for the test was 0.141096 oz (4 g) after successful testing determined it was acceptable to use this amount. Modifications to this testing plan for future use include reducing the number of tests on charge sizes that fail to separate the sections, as one failure is reason enough to increase charge size.

Table 20: Subscale Ejection Testing Results

Charge size (oz)	Pass/Fail
0.052911	fail
0.070548	fail
0.088185	fail
0.141096	pass

7.1.13 Maximum Velocity Test #13:

The maximum velocity assurance will ensure that the complete payload rover will meet the design velocity requirements. A maximized ground traversal will allow the rover to move large distances without draining significant battery life.

Passing Condition: The maximum velocity of the rover shall be within an acceptable range:

- Lower Limit: 1 ft./s
- Target: 5 ft./s
- Upper Limit: Maximized

Test Materials Required:

- Assembled payload rover
- Electronics including motor driver, power systems, controllers
- Software for basic run procedure
- 10′ measuring tape
- Stopwatch

Test Procedural Steps:

1) Place rover on flat surface in tilled field with stabilizer deployed
2) Place measuring tape starting at 0′ at the front of the rover
3) Extend the measuring tape to 10′
4) Prepare stopwatch at 0 seconds
5) Run setup procedure for rover system
6) Simultaneously move rover forward at maximum speed and start stopwatch
7) Stop stopwatch once rover travels 10′
8) Record time measurement
9) Repeat steps 1-8 in three different locations

Safety Considerations:

- All participants must wear safety glasses during testing.
- Ensure all testing participants are a minimum of 5 feet from the rover during operation
- Check all safety switches are operational and engaged
- Ensure voltages of Lipo batteries are above critical threshold level

Results and Necessary Modifications: Tests have not been run and will be done after mechanical fabrication of rover. Changes may be done to the ground conditions and the grip of the tires depending on rover performance.

7.1.14 Motor Driver Operational Range Test #14:

This unit test is part of the over-current protection test for team generated requirement. The unit test verifies that the motor drivers can operate for the entire range of battery charge. The battery system on-board the rover ranges from 17V to 12V while the operational range of the driver is 28V to 5V. The results of this test will show that draining battery charge will have no effect on driving the rover.

Passing Condition: Output current does not fluctuate more than 5% for tests run at 0.5 A and 4.1 A for the entire voltage range.

Test Materials Required:

- 18 AWG wire
- DC load machine
- DC power supply
- Digital multimeter
- Dual MC33926 Motor Driver

Test Procedural Steps:

1) Motor driver outputs will be hooked up to DC load machines to simulate two connected motors with the 18 AWG wire
2) Input voltage will be connected to a power supply which can be varied to simulate different battery charge levels
3) Set DC load to 7.2 V for nominal voltage operation range
4) Set DC load to 0.5 A for nominal current operation
5) Connect an ammeter in series with load and motor driver output for both channels to measure supplied current
6) Set enable and direction pins to logic high voltage to drive current to DC load
7) Input voltage will start at highest battery charge level and slowly be reduced to the lowest battery charge level
8) Ammeter will be monitored to see if output current remains constant within a 5% margin
9) Once both channels are verified to supply constant current regardless of input voltage, repeat the test again, except the DC load will be changed to 4.1 A to simulate peak current operation

Safety Considerations:

- Turn off DC power supply if adjustments need to be made to physical connections

Results and Necessary Modifications: Testing has not been completed yet. If the test does not pass, then the software team will need to be notified that a constant speed is not guaranteed so that the navigation algorithm can compensate for slower motor speeds.

7.1.15 Current Sensor Output Range Test #15:

This unit test is part of the over-current protection test for team generated requirement. The unit test verifies current sensor outputs logic high voltage when stalling current is detected. The output will be used later to provide feedback against continuous stalling. If this test does not pass, then the current sensor alternatives explored in the PDR may need to be re-evaluated as a replacement.

Passing Condition:

Threshold logic level high (2.3 V) is outputted when stall currents are reached, and logic level low is registered when motor current draw is less than 4.1 A.

Test Materials Required:

- 18 AWG wire
- DC load machine
- DC Power supply
- Digital multimeter
- INA169 Current Sensor

Test Steps:

1) Connect the current sensor in series with a DC load to simulate current draw from a motor with the 18 AWG wire
2) Power supply is attached in series to the DC load and current sensor
3) DC load will be first set to 7.2 V and 0.5 A
4) Power supply will be output around 7.2 V to supply 0.5 A
5) Use voltmeter/oscilloscope to monitor output voltage pin
6) Output voltage pin should read a value less than 2.3 V
7) Change DC load to 7.2 V and 4.1 A to simulate stall current
8) Measure output voltage pin to see if 2.3 V or is reached, which verifies a logic high signal is displayed when stall currents are detected

Safety Considerations:

- Turn off DC power supply if adjustments need to be made to physical connections

Results and Necessary Modifications: This test was successful, meeting the passing condition specified. At 4.1 A, the current sensor displayed a voltage level of 2.3 V satisfying the logic level high condition. For all other currents tested that were below 4.1 A, the output voltage was lower than 2.3 V, meaning a logic level low is present. The results of this test show that no design changes need to be made.

7.1.16 Over-current Protection Test #16:

The team generated requirement for over-current protection will be verified with this test. This integration test combines the motor driver, motors, and current sensors with the rover microcontroller to see if the over-current protection algorithm cuts off power in the event of stalling. At this point, it is assumed that the basic algorithm has been completed and uploaded to the Raspberry Pi.

Passing Condition:

Motors/wheels will have power cut off within 30 seconds of full movement restriction in either motor.

Test Materials Required:

- Assembled payload rover
- Software with cutoff algorithm loaded on to Raspberry Pi

Test Steps:

1) Navigation algorithm will first start both motors running forward
2) Motors/wheels will be physically restricted from moving
3) Monitor motors/wheels to see if power is cut off within 30 seconds of full movement restriction

Safety Considerations:

- Have the payload rover powered off until tester is ready
- Each tester will wear safety glasses during the entire test

Results and Necessary Modifications: Testing has not been completed yet. If this test does not pass within 30 seconds of stalling, then the current sensor output will need to be adjusted to better match the threshold high logic of the GPIO pins to ensure a functioning feedback loop.

7.1.17 Payload Ejection Mass Test #17:

This test is associated with team generated requirement 4.16. The objective of the test is to determine the final mass of the payload ejection device. Each component will be weighed individually as well as the entire assembly. Mass of the payload and it's ejection housing is critical to flight performance to reach the required AGL.

Passing Condition: The procedure is considered passing if the sum total of equipment mass is verified to be less than the max specification of four pounds. The test should be performed three times to verify results. If any components are modified, the test will need to be repeated and new values reported.

Test Materials Required:

- Rover housing - individual components or entire assembly
- Rover retention and release device(s)
- Black powder ejection charge samples
- High precision scale

Test Procedural Steps:

1) Secure all required equipment and label appropriately
2) Zero the scale with nothing on it
3) Place one piece of equipment on scale
4) Record weight according to appropriate label
5) Repeat steps 2-4 for all components
6) Sum total of equipment mass and verify against design expectations

Safety Considerations:

- Not applicable

Results and Necessary Modifications:

The test will be completed for individual components as they are sourced from vendors or manufactured. If final mass of assembly is over the max specification, design modifications will be explored to reduce mass.

7.1.18 Payload Ejection Test #18:

This test is associated with team generated requirement 4.1.4. The objective of the test is to verify that the payload ejection system design will successfully perform customer requirement 4.5.2. The requirement states that at landing, the team will remotely activate a trigger to deploy the rover from the launch vehicle. Testing will take place outside the propulsion laboratory on the Oregon State University campus. The test outlines an extremely critical portion of the mission criteria. An unsuccessful payload ejection on launch day will inhibit the payload from demonstrating its capabilities.

Passing Condition: Procedure #16 is considered passing if the rover successfully clears the airframe due to the initial or backup black powder charge. Additionally, if the housing is implemented, the rover must be clear to move without entanglement with the housing. If a dummy payload is used, this criteria will be evaluated by the senior team member on site. For final testing, verification will stem from successful clearing of the rover and its ability to travel at least five feet. Passing condition will only be evaluated once final mass of black powder has been selected from initial tests. Passing condition is a 75% success rate.

Test Materials Required:

A team of underclassmen volunteers are responsible for assisting with payload ejection testing. PPE will consist of earplugs and safety glasses for all persons present. An HPR level 1 certified member will be required to pack ejection charges. A list of required equipment is as follows:

- Test apparatus
  - Cinder blocks, airframe retainers, padding, tie-downs
  - Testing airframe
- Payload ejection housing
- Rover or dummy payload
- All retention devices
- E-matches
- Various black powder charges
- Remote igniter
- PPE

Test Procedural Steps:

1) Dr. Nancy Squires or Joe Bevier will need to oversee handling of black powder per USLI competition rules. Reach out to either of them to pack black powder charges prior to ejection testing. Refer to excel file for varying BP mass
2) Confirm testing space at the propulsion laboratory
3) Ensure appropriate safety team members can be present for ejection tests

4) Acquire necessary materials (refer to equipment list) and transport to propulsion lab outdoor test area. Check all equipment is present at the testing site prior to step 5.
5) Have all persons present put on required PPE
6) Secure airframe to ejection testing apparatus
7) Place black powder charge, fixed to aft bulkhead
8) Insert dummy payload into housing or directly into airframe
9) Secure the payload housing to the retention and release device, if used in specific test
10) Clear all persons to appropriate distance from airframe
11) Begin video recording
12) Activate ejection charges remotely after a five second countdown
13) Wait one minute after charges blow to approach the airframe
14) Retrieve rover, document results, take picture of housing/rover
15) Inspect airframe for damages

Safety Considerations: All persons present will be outside of a 50 foot radius from the airframe prior to ignition of the ejection charges. Ignition will occur following verbal confirmation and a five second countdown. Only the sub-team lead or safety officer will approach the airframe following test. Every person present needs to be wearing required PPE.

Results and Necessary Modifications: Testing is projected to begin at the end of January. Following test failure, initial modifications will be applied primarily to black powder ejection charge size. If test failures continue, design will be evaluated based on verbal observations made on site.

7.1.19 Payload Mass Test #19:

Payload mass testing will ensure that the rover meets the design mass requirements. Mass is an important consideration to ensure the vehicle reaches the AGL requirement imposed by NASA.

Passing Condition: The rover mass will be minimized to ensure stability: 4 lbs. target, 10 lbs. max.

Test Materials Required:

- Fully assembled rover
- High precision scale

Test Procedural Steps:

1) Zero the scale with nothing on it
2) Place rover on scale
3) Record weight

Safety Considerations:

- Safety glasses should be worn

Results and Necessary Modifications: Procedure #19 is considered passing if the rover mass is verified to be less than the max specification. The test should be performed three times to verify results. If any components are modified, the test will need to be repeated and new values reported.

7.1.20 Payload Object Detection Testing Procedure #20:

Passing Condition: The passing condition for the payload object detection sensors is ensuring that all electrical properties including voltage and current consumption meet desired metrics. The distance-to-object calculation accuracy is also a key factor in the test pass condition. For all tests verified, a 90% pass rate is considered a successful test.

Test Materials Required:

- Oscilloscope
- Digital Multimeter
- DC Power Supply
- Microcontroller
- Computer w/USB and Serial Monitor
- Ruler/Tape Measure

Test Procedural Steps:

1) Connect the sonar sensor to a microcontroller using a PWM digital input pin
2) Connect the microcontroller to a computer via a serial USB connection. This will allow the sensor range data to be displayed on the serial monitor on the computer and give the microcontroller a 5 V DC power supply
3) Upload the sonar distance measurement program to the microcontroller via the USB serial connection
4) Connect the sonar module V+ pin to a 5 V DC power source to turn the sensor module on
5) Place a roughly 6 in. x 6 in. x 6 in. sized object directly in front of the sensor between 1 ft. and 5 ft. and wait 30 seconds
6) Using the ruler or tape measure, record the distance from the front of the sonar module face to the object that was placed in Step 5
7) Connect the oscilloscope probe to the PWM pin of the sonar module
8) Verify that the pulse width modulation waveform is calculating a range reading at a frequency of 6 Hz +/- 2 Hz
9) Verify that the oscilloscope is showing a waveform in a pulse width modulation format with a logic level of 5 V
10) Open the serial communication monitor on the computer to view the data being created by the sonar distance measurement program
11) Verify that the serial monitor is displaying constant range calculations to the object without any user input or triggering
12) Verify that the distance to the object being reported on the serial monitor is +/- 5% from the actual measured value that was recorded in Step 6

Safety Considerations:

When connecting electrical terminals, ensure to always have power supplies turned off and connect the ground terminal prior to connecting the power terminal. Wear safety glasses and gloves when soldering any electrical connections. Inspect all lab equipment for issues prior to actual testing. **Results and Necessary Modifications:**

All test verifications are completed and passed above the required 90% pass rate. These tests ensure that the object detection sensors operate as desired. All tests will be carried out multiple more times prior to launch to ensure the functionality and reliability of the object detection system.

7.1.21 Payload Robustness Test #21:

Force testing will ensure that the individual rover components and complete assembly meet the design robustness requirements. Large force dissipation through the vehicle is necessary to provide a functional rover for ground movement. **Passing Condition:**

The rover will be able to withstand forces from a large acceleration:

- Lower Limit: 30 lbs.
- Target: 50 lbs.
- Upper Limit: Maximized

Test Materials Required:

- Assembled rover drivetrain
- Assembled chassis
- High precision scale
- Arbor press
- Plate with slots cut
- Towel and rags

Test Procedural Steps:

1) Zero the scale with nothing on it in imperial units
2) Bring the press to at least 10″ above the lowest point
3) Place the scale on the lowest point of the arbor press
4) Place rag on scale to prevent marring to scale
5) Place the plate on the scale
6) Place the component to be tested on the plate with a flat surface directed upwards
7) Place rag on flat component to prevent marring on component surface
8) Bring the press downward on the wheel
9) Slowly increase the pressure until the scale reads 150 lbs.
10) Bring the press to at least 10 in. above the plate
11) Remove component from the scale
12) Repeat steps 1-9 for all components experiencing high compressive loading conditions

Safety Considerations:

- All participants must wear safety glasses during operation
- All measurement equipment must be inspected before use
- If any unusual sounds occur during testing, release pressure and inspect rover before continuing
- Only one tester should operate equipment at a single time

Results and Necessary Modifications: The tests have not been run and will be completed once a complete rover has been assembled. Individual stress analyses have been run on components to ensure no failure from high stresses.

7.1.22 Battery Level Indication and Enable Output Test #22:

Pass Conditions: This test will be considered passed if the data recorded matches the following conditions. At voltage levels greater than 14.8 V, all three LEDs were on, and the voltage on the enable output was less than 1.2 V. At voltages levels between 14.6-14.2 V, only the yellow and red LEDs were on and the voltage on the enable output was less than 1.2 V. At voltage levels between 13.8-12 V, only the red LED was on and the voltage on the enable output was less than 1.2 V. At voltage levels less than 11.8 V, none of the LEDs were on and the voltage on the enable output was greater than 1.4 V.

Test Materials Required:

- Digital DC Load
- Digital Multimeter
- Mini-Hook Test Leads

Test Steps:

1) Turn on digital DC load instrument, and set load to draw 1.37 A of current. Then connect the battery system DC power output to digital DC load. Lastly, activate the DC load to start drawing current from the battery system
2) Record which of the three different colored LEDs are emitting light, measure the voltage on the voltage regulator enable output, and note the DC power output voltage
3) Continually discharge the batteries at a rate of 1.37 A until the DC power output voltage has decreased to 14.6 V. Repeat step 2
4) Continually discharge the batteries at a rate of 1.37 A until the DC power output voltage has decreased to 14.2 V. Repeat step 2
5) Continually discharge the batteries at a rate of 1.37A until the DC power output voltage has decreased to 13.8V. Repeat step 2
6) Continually discharge the batteries at a rate of 1.37 A until the DC power output voltage has decreased to 12 V. Repeat step 2
7) Continually discharge the batteries at a rate of 1.37 A until the DC power output voltage has decreased to 11.7 V. Repeat step 2
8) Disconnect battery system from digital DC load and make sure it is powered off

Safety Considerations:

Team members must not touch the circuit while it is being tested. For the safety of the electronics, all connections should be double checked before connecting the DC load to the batteries.

Results and Necessary Modifications:

This test was successful, meeting every aspect of the pass condition. This verifies that the LEDs will accurately display the batteries voltage level. This also verifies the battery system will never over discharge the batteries.

7.1.23 Battery DC Power Test #23:

Pass Condition:

This test will be considered passed if the data recorded matches the following conditions. The DC power output provided 1.37 A for 30 seconds, and 8.9 A for 3 seconds while maintaining an output voltage between 17-11.8 V. **Test Materials Required:**

- Digital DC Load
- Mini-Hook Test Leads
- Digital Multimeter

Test Steps:

1) Turn on digital DC load instrument, and set load to draw 1.37 A of current. Then connect the battery system DC power output to digital DC load
2) Activate the DC load to start drawing current from the battery system
3) Continually monitor the DC power output voltage level for 30 seconds
4) Once the 30 seconds are up, deactivate the DC load to stop drawing current from the battery system
5) Set digital DC load instrument to discharge at a rate of 8.9 A, then activate the DC load
6) Continually monitor the DC power output voltage level for 3 seconds
7) Once the 3 seconds are up, deactivate the DC load to stop drawing current from the battery system
8) Disconnect battery system from digital DC load and make sure it is powered off

Safety Considerations:

Team members must not touch the circuit while it is being tested. For the safety of the electronics, all connections should be double checked before connecting the DC load to the batteries. **Results and Necessary Modifications:**

This test was successful, meeting every aspect of the pass condition. This verifies the batteries are capable of supplying the nominal and peak values demanded by the rover payload. During testing it was found that the batteries provided above nominal voltage for a little over 30 minutes.

7.1.24 Voltage Regulator DC Power Test #24

Pass Condition:

This test will be considered passed if the data recorded matches the following conditions. With input voltages of 17 V, 14.8 V, and 11.8 V, the 5 V output provided 360 mA for 30 seconds and 640 mA for 3 seconds. With input voltages of 17 V, 14.8 V, and 11.8 V, the 3.3 V output provided 10 mA for 30 seconds. Additionally, the 5 V output voltage did not go above 5.1 V or below 4.9 V, and the 3.3 V output voltage did not go above 3.4 V or below 3.2 V throughout the duration of the test. **Test Materials Required:**

- Digital DC load
- Test Bench Power Supply
- Digital Multimeter
- Mini-Hook Test Leads
- $\frac{1}{8}$ W 330 Ω Resistor

Test Steps:

1) Turn on variable test-bench power supply and set voltage to 17 V
2) Connect variable test-bench power supply to +V_{BATT} and -V_{BATT} of the rover voltage regulator circuit. Also, connect the BS_EN input to -V_{BATT}
3) Connect a constant DC load to the 3.3 V DC power output which will draw 10 mA. A $\frac{1}{8}$ W 330 Ω resistor should work for the desired the load on the 3.3 V output
4) Turn on digital DC load instrument, and set load to draw 360 mA of current. Then connect the rover voltage regulator 5 V DC power output to digital DC load. Lastly, activate the DC load to start drawing current from the 5 V output. Continually monitor the voltage and current being supplied by both the 5 V and 3.3 V outputs and time for 30 seconds
5) Once the 30 seconds are up, deactivate the DC load to stop drawing current from the 5V output
6) Set digital DC load instrument to discharge at a rate of 640 mA, then activate the DC load
7) Continually monitor the voltage and current being supplied by both the 5 V and 3.3 V outputs and time for 3 seconds
8) Once the 3 seconds are up, deactivate the DC load to stop drawing current from the 5 V output
9) Set the test-bench supply's voltage to 14.8 V, and repeat steps 4-8 at a voltage of 14.8 V
10) Set the test-bench supply's voltage to 11.8 V, and repeat steps 4-8 at a voltage of 11.8 V
11) Turn off the test-bench power supply and variable DC load, and disconnect the rover voltage regulator block from both

Safety Considerations: Team members must not touch the circuit while it is being tested. For the safety of the electronics, all connections should be double checked before turning power supply output or digital DC load. **Results and Necessary Modifications:** This test has not yet been completed.

7.1.25 Rover Simplicity #25:

This testing procedure will be implemented to verify that the design of the rover is sufficiently simple. **Passing Condition:**

This procedure is considered passing if the number of moving sub-assemblies can be verified. The primary purpose is to compare between different iterations of the rover design. **Test Materials Required:**

- Completely assembled rover
- Preliminary versions of this test can be conducted by examining the CAD model instead.

Test Procedural Steps:

1) Examine the rover
2) Count the sub-assemblies capable of moving independently

Safety Considerations:

- The person executing this procedure must wear safety glasses.
- Ensure no extremities will be pinched in the moving parts of the rover.

Results and Necessary Modifications:

- The current iteration of the rover has 5 independently moving components:
  - Drivetrain (x2)
  - Solar panel
  - Stabilizer
  - Chassis

7.1.26 Solar Panel Deployment #26:

The solar panel deployment is a major deliverable of the NASA competition. This needs to be a reliable system that will deploy when the rover sends a signal to the servo.

Passing Condition: Procedure #11 will be considered passing if the ratio of successful tests to the number of completed tests is greater than the minimum requirement. A successful test is defined as one where the deployed angle is greater than 90 degrees.

Test Materials Required:

- Assembled solar sub system
- Bench vise
- Raspberry PI with pin connections

Testing Procedure:

1) Place the solar array in a bench vise
   a) If the assembly is attached to the rover, step 1 can be ignored
2) Make sure Raspberry Pi is powered off
3) Make sure solar servo is disconnected
4) Return the actuating panel to less than 5 degrees away from the stationary panel
5) Connect the solar servo to the Raspberry Pi
6) Power on the Raspberry Pi with proper procedure
7) Send command to open solar panels from Raspberry Pi
8) Wait until Raspberry Pi has confirmed the action has finished
9) Measure the angle between the stationary panel and the actuating panel
10) Send command to close panels from Raspberry Pi
    a) If command fails, repeat steps 2-6
11) Repeat steps 7-10 for a total of twenty times

Safety Considerations:

- The person executing this procedure must wear safety glasses

Results and Necessary Modifications: If the solar panel array does not open during the testing phase, design modifications will be explored.

7.2 Team Derived Requirements

Team Requirements			
Subsystem Requirement	**Requirement Description**	**Verification Method**	**Status**
General - 1	All documents pertaining to the USLI competition shall be completed and submitted on time.	Documents will be submitted to mentors for proofreading no less than 7 days prior to due date; documents will be submitted no less than 1 day prior to due date	Incomplete - Will not be completed until the end of the competition.
General - 2	Team members shall host education outreach events with the goal of engaging at least 300 K-12 students in Science, Technology, Engineering and Mathematics (STEM) activities.	Team members will visit local schools through project to teach lessons related to STEM and aerospace topics. The team will work with University administrators to plan and host an engineering and aerospace themed day for students.	Completed - Reached 419 students as of December 14, 2017.
General - 3	The team will design a unique mission patch which will distinguish the OSRT from other USLI teams.	Team members will vote on mission patch design. The patch will be embroidered on team uniform and launch vehicle.	Completed - Final mission patch design was chosen December 5, 2017.
General - 4	The team shall take care to appropriate represent all sponsors with logos and stickers.	Sponsorship officer will ensure that all sponsors are adequately represented on the final launch vehicle assembly and on the team website.	Incomplete - launch vehicle Planned to be assemble for full scale test launch January 20, 2018.
General - 5	At least 25% of team members will have HPR Level 1 Certification prior to competition launch.	Certification launch vehicles will be purchased for all team members seeking HPR Level 1 Certification. They will assemble their own launch vehicle, travel to appropriate launch site, and follow procedure to become Level 1 certified.	Incomplete - Scheduled to be measured at full scale test launch January 20, 2018.

Team Requirements			
Subsystem Requirement	**Requirement Description**	**Verification Method**	**Status**
General - 6	Team members will wear the same uniform for professional appearance during competition events, to make the OSRT team easily identify and increase team spirit.	A standard team Polo shirt or jacket with team name and mission patch will be ordered for each team member.	Completed - Finished before PDR presentation in December 2017.
General - 7	The team will get underclassmen interested and involved with the USLI project.	The team will reach to underclassmen by advertising our meeting times and work days through the school email system. The team will get the students who are interested in the project involved by giving the task to complete for the project.	Completed - During Fall Term the team was able to get underclassmen involved by having them create a data logger and a rover test bed.
Launch Vehicle - 1	All components will be able to withstand the heat and pressure from ejection charges.	Bulkheads facing ejection charges will be covered with a thermally resistant material; temperature and pressure reading will be taken during ejection ground testing.	
Launch Vehicle - 2	Rocket will not be over stable or susceptible to weather-cocking.	Stability will be limited to maximum of 3.5 at rail exit.	
Launch Vehicle - 3	Launch vehicle will be able to be stowed in a 4x4x2 ft container for shipping.	Rocket will be designed so that it can be disassembled into sections not longer than 4 ft or wider than 2 ft. All parts will be put in a 4x4x2 ft container to verify all sections will fit into the container.	Incomplete - Schedule to verify before full scale test launch January 20, 2018.
Recovery System - 1	Payload will have a clear exit out of the airframe after landing	After separation no bulkheads or airframe components will be between the open end of the fore section and the payload	

Team Requirements			
Subsystem Requirement	**Requirement Description**	**Verification Method**	**Status**
Recovery System - 2	Payload ejection will not obstructed by any of the recovery system after landing	Sub-scale and pre-competition full-scale launches will demonstrate the ability of the recovery system to provide an adequate landing for the payload	
Recovery System - 3	During sub-scale and full-scale launches the maximum loads on the recovery system will remain below a magnitude of 15 g's.	A data logger will be included to record flight trajectory and in-flight forces will verify the maximum loads on the recovery system remained below 15 g's.	Incomplete - Scheduled to be measured at full scale test launch January 20, 2018.
Recovery System - 4	Avionics system will be able to track position of the launch vehicle without losing communication for a period of greater than five seconds.	The avionics system will be tested during the sub-scale and full-scale launches to observe if it loses communication with the base station for more than five seconds.	Incomplete - Scheduled to be measured at full scale test launch January 20, 2018.
Recovery System - 5	Avionics electronics in each section of the launch vehicle will have redundant power supplies to create a more robust system.	The redundant power supplies will be tested by disconnecting the primary power supply, and observing if the secondary power supply begins providing power.	Incomplete - Scheduled to be done during January 2018 testing.
Recovery System - 6	Avionics system will have sufficient battery life to account for waiting 2 hours on the launch pad.	The batteries for the avionics system will be drained at the nominal current draw of the of the avionics system and timed for two hours.	Incomplete - Scheduled to be done during January and February 2018 testing.
Payload - 1	The payload will have on board sensors to provide means of avoiding collisions with objects.	The rover will have two sonar sensors mounted to its front. Through testing, an algorithm will be developed to successfully identify objects and navigate through them.	Incomplete - Scheduled to be done during January and February 2018 testing.

Team Requirements			
Subsystem Requirement	**Requirement Description**	**Verification Method**	**Status**
Payload - 2	The rover will be able to measure its own speed and distance traveled for navigational purposes.	The rover will have an IMU 9DOF to provide the rover with valid gyroscope, compass, and accelerometer data. To verify it is getting valid data sensor will be sending data to a computer which will display live data values while the rover is being driven.	Incomplete - Scheduled to be done during January and February 2018 testing.
Payload - 3	The rover will be able to identify the location of the separate parts of the launch vehicle.	Each section of the launch vehicle that separates during recovery will transmit an ultrasonic signal. The rover payload will have a microphone pair which will be able to pick up the ultrasonic signals coming from the launch vehicle sections. The rover processing unit will then calculate the launch vehicle sections' distance and location relative to the rover.	Incomplete - Scheduled to be done during January and February 2018 testing.
Payload - 4	The payload will prevent damage to motors when stalling conditions are encountered through overcurrent protection.	Rover will be tested to see how it reacts during stall conditions. During operating the motor movement will be prevented and the overcurrent protection system will be tested to see if it recognizes when the motors are stalling. This stall information will then be given to the processing unit to prevent the motors from continued stalling.	Incomplete - Scheduled to be done during January and February 2018 testing.
Payload - 5	The rover frame must have sufficient vertical clearance to avoid low level debris.	After rover is assembled it will be tested driving over various debris to verify it can drive over low level debris.	Incomplete - Rover is scheduled to be assembled by January 21, 2018

Team Requirements			
Subsystem Requirement	**Requirement Description**	**Verification Method**	**Status**
Payload - 6	The rover wheels must navigate through a variety different terrain.	The rover will be tested driving through saft dirt, wet dirt, mild vegetation, and mild hills.	Incomplete - Scheduled for January and February testing.
Payload - 7	The rover will have expandable wheels upon deployment to increase ground clearance.	The wheels will be compressed and placed in carbon fiber ejection sleeve. The ejection sleeve will them be removed and wheels will be tested if they expand to full size or not.	Incomplete - Rover is scheduled to be assembled by January 21, 2018
Payload - 8	The rover will be able to move forward and backwards as well as turn right and left, to give the rover more mobility to move away from the launch vehicle.	The rover will be built with two motors that can move backwards and forwards and can move independently of the other. A rear stabilizer will be deployed in order to keep the rover from flipping over while it moves. The rover will be tested by programming it to move forward, backward, turning left, and turning right.	Incomplete - Rover is scheduled to be assembled by January 21, 2019. Testing is planned for January and early February.
Payload - 9	The rover batteries will have enough capacity to supply all of rover's electronics for 25 minutes.	The batteries will be drained with a load equivalent to the nominal rover current draw of 1.37 A and timed for how long the batteries remain above their cutoff voltage of 12 V.	Completed - December testing showed the batteries were able to provide 1.37 A for more than 30 minutes.
Payload - 10	The batteries will have an automatic cut-off switch to prevent over discharging of the batteries.	The batteries will be drained to their critically low voltage level to see if the battery system disables the voltage regulator once the voltage has dropped below 12 V.	Completed - December testing showed the battery system disabled the voltage regulator while battery voltage was below 12 V.

Team Requirements			
Subsystem Requirement	**Requirement Description**	**Verification Method**	**Status**
Payload - 11	The batteries will have an LED indication of battery life to make testing the rover easier.	The battery level indicator will be monitored while the batteries are slowly discharged. The glsLEDs will be monitored to make sure the three LEDs indicate which of the three stages of the LiPo discharge curve the batteries are currently in.	Completed - December testing showed the LED Battery Indication had the correct LEDs on for the two non linear and the linear portion of the LiPo discharge curve.
Payload - 12	The voltage regulators on the rover's power supply will provide two output voltages at 5 V and 3.3 V while accepting a range of input voltages.	The voltage regulator will be supplied by a variable power supply and varied to the max and min values the batteries will provide. Then the output voltages will be measured to make sure they are still at 5 V and 3.3 V at each input voltage.	Completed - January testing showed the voltage regulators supplied 5 V and 3.3 V while receiving input voltages from 17 V to 12 V.
Payload - 13	The rover will remain completely powered off until the rover has been ejected to preserve battery life.	The rover will have a relay which will keep the batteries disconnected from the rover while it is receiving power from a magnetic connector. Once the rover is ejected the magnetic connector will disconnect and the batteries will be connected to rover. This will be tested by seeing if the rover gets power on upon ejection.	Incomplete - Rover is scheduled to be assembled by January 21, 2019. Testing is planned for January and early February.

Team Requirements			
Subsystem Requirement	**Requirement Description**	**Verification Method**	**Status**
Payload - 14	The team will design a custom PCB to integrate all of the electrical subsystems of the rover.	The team will design and layout a schematic that includes all of the electrical subsystems on the rover. After the PCB is produced each part of the circuit will be tested for functionality.	Incomplete - Custom PCB is scheduled to be completed and tested by end February.
Payload - 15	The rover parts will remain attached and electrical systems continue operating during heavy vibration.	The rover will be placed on a shake table which will simulate the vibration the rover will receive during launch and recovery. After vibration testing, all parts must remain mounted on the rover and all electrical systems must still work.	Incomplete - Rover is scheduled to be assembled by January 21, 2019. Testing is planned for January and early February.
Safety - 1	All team members that use the manufacturing and machining facilities at OSU will have appropriate certification.	All team members who need to use the OSU Machine Product and Realization Laboratory (MPRL), the woodshop or the composites manufacturing lab will get appropriate certification from the administrator of said lab before use.	Completed - All team members using machining facilities have previous received certification to use them.
Safety - 2	Additional team members to assist the Safety Officer in explicitly promoting team safety and the preparation of safety documents.	Each sub-team will identify a Safety Liaison to assist the Team Safety Officer	Completed - Three team members volunteered to be their sub team's Safety Liaison in November 2017.
Safety - 3	The team will secure all hazardous material so that only certified personnel can access them.	Hazardous materials will be kept in a separate area of the team workspace secured with a lock. Only team leaders, Safety Officer, and team mentors will have access to the hazardous materials.	Completed - Hazardous materials have been locked away in cabinets as of November 2017.

Team Requirements			
Subsystem Requirement	**Requirement Description**	**Verification Method**	**Status**
Safety - 4	The team will follow all safety rules and guidelines set by the NAR, TRA, and OSU.	Safety Officer will be familiar with both NAR/TRA safety regulations and OSU safety codes, will ensure the team abides by all rules	Incomplete - Will not be completed till rules have been followed through the whole competition.
Safety - 5	The team will have written checklists with instructions on how to safely assemble the rover, recovery systems, and launch vehicle.	The team member responsible for designing the part being assemble on the rover, recovery systems, or launch vehicle will write a formal checklist, providing instructions so that anyone on the team can safely assemble the part without them being present.	Incomplete - Scheduled to be done before full scale test launch.
Safety - 6	The team will create a comprehensive list FMEAs for each subsystem of the project, to mitigate as many of the failure modes as the team can.	Every team member will create a FMEA for each and every part of the project they are working on. The FMEAs will then be organized into sub-teams, so they can be easily referenced.	Completed - All FMEAs were written for the Critical Design Review (CDR).

7.3 NASA Requirements

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	I	Students will do every part of the project besides motor assembly and installation of black powder charges.
1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.	I	Documentation regarding project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations have recorded in both the project proposal and the PDR report.
1.3	Foreign National (FN) team members must be identified by the PDR and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities.	I	A list of FN team members will be compiled and emailed to NASA representatives before the PDR.
1.4	The team must identify all team members attending launch week activities by the CDR. Team members will include:	I	A list of all team members attending launch week will be compiled and emailed to NASA representatives before the CDR.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
1.5	The team will engage a minimum of 200 participants in educational, hands-on STEM activities, as defined in the Educational Engagement Activity Report, by Flight Readiness Review (FRR). An educational engagement activity report will be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 31 of the handbook. To satisfy this requirement, all events must occur between project acceptance and the FRR due date.	D	Every educational outreach activity the team will engage in will be documented using the template provided in the USLI handbook and the entirety of this documentation will be provided to NASA by the conclusion of the competition.
1.6	The team will develop and host a Web site for project documentation.	I	A functioning website for the team will be hosted online and publicly accessible.
1.7	Teams will post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.	I	All competition deliverables will be made available at or before their respective deadlines on the website.
1.8	All deliverables must be in PDF format.	I	All deliverables hosted on the website will have the .pdf extension.
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	I	The PDR document will have a table of contents including all sections.
1.10	In every report, the team will include the page number at the bottom of the page.	I	The PDR document will have page numbers at the bottom of each page.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. Cellular phones can be used for speaker-phone capability only as a last resort.	I	The team will maintain all tech equipment necessary to perform teleconferences.
1.12	All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.	I	The team will not utilize custom launch pads; those provided by Student Launch will be used.
1.13	Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 Code of Federal Regulations (CFR) Part 1194) Subpart B-Technical Standards (http://www.section508.gov): §1194.21 Software applications and operating systems. §1194.22 Web-based intranet and internet information and applications.	I	Accessibility options for those with disabilities will be gradually implemented as content will be added to website.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
1.14	Each team must identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the NAR or TRA for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the launch vehicle for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attends launch week in April.	I	The team has identified a single mentor, Joe Bevier, in the project proposal.
2.1	The vehicle will deliver the payload to an apogee altitude of 5,280 feet AGL.	A	OpenRocket and MATLAB simulations will be performed to verify that the vehicle's apogee is 5,280 feet.
2.2	The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner. Teams will receive the maximum number altitude used in determining the altitude award winner. Teams will receive the maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5,280 ft. AGL.	I	Commercially available barometric altimeters will be used in launch vehicle. At least one altimeter will be able to verify apogee altitude on-site

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
2.3	Each altimeter will be armed by a dedicated 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.	I	Each altimeter on board both the sub-scale and full-scale vehicles will have arming switches accessible from outside the vehicle.
2.4	Each altimeter will have a dedicated power supply.	I	Each altimeter will be designed to be individually powered by a single external battery.
2.5	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	I	Arming switch will be rotary based and capable of being locked on
2.6	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	D	The launch vehicle shall be recovered after the full scale test and reset to a prelaunch state.
2.7	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	I	The vehicle will land in 3 pieces: Nose cone, payload and recovery, and aft section.
2.8	The launch vehicle will be limited to a single stage.	I	The launch will occur with only a single stage of the L850W motor firing.
2.9	The launch vehicle will be capable of being prepared for flight at the launch site within 3 hours of the time the Federal Aviation Administration flight waiver opens.	T	During the launch vehicles full scale testing phase the preparation of the launch vehicle will be timed.

General Requirements

REQ#	Requirement Description	Verif. Meth.	Verification Plan
2.10	The launch vehicle will be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board components.	I	Avionics sensors, altimeters, and the rover payload will have enough battery life to remain in launch ready state for more than one hour. This will be verified in full scale testing, and electronics bench testing.
2.11	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.	I	The launch vehicle will be compatible with 12-Volt direct current firing system provided by NASA and the Range Service Provider (RSP).
2.12	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	I	The launch vehicle shall be designed in such a way that it will be compatible with the launch pad provided by Range Services.
2.13	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).	I	The L850W motor has been selected for the launch vehicle uses APCP, and has been approved by TRA.
2.13.1	Final motor choices must be made by the CDR.	I	The team will adhere to the design and project schedule in the Gantt chart, with final motor design choices done before CDR.
2.13.2	Any motor changes after CDR must be approved by the NASA RSO, and will only be approved if the change is for the sole purpose of increasing the safety margin.	I	In the event any motor changes are made after the CDR, a RSO will be contacted and review the proposed changes before any design choices are finalized.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
2.14	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:	I	The launch vehicle shall contain no pressure vessels.
2.14.1	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.	I	The launch vehicle shall contain no pressure vessels.
2.14.2	Each pressure vessel will include a pressure relief valve that sees the full pressure of the valve that is capable of withstanding the maximum pressure and flow rate of the tank.	I	The launch vehicle shall contain no pressure vessels.
2.14.3	Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.	I	A full query shall be created of the pressure tanks previous uses, original purpose, and pressure cycles induced on the system.
2.15	The total impulse provided by a College and/or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	I	The motor shall be an L class motor with 1430 Newton-seconds total impulse.
2.16	The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	A	Analysis will be done with OpenRocket and MATLAB to verify minimum static stability margin of 2.0.
2.17	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	A	Analysis will be done with OpenRocket and MATLAB to verify rail exit velocity.
2.18	All teams will successfully launch and recover a sub-scale model of their launch vehicle prior to CDR. Sub-scales are not required to be high power launch vehicles.	I	A sub-scale launch shall be conducted before the critical design review

General Requirements			
REQ#	Requirement Description	Verif. Meth.	Verification Plan
2.18.1	The sub-scale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the sub-scale model.	I	The sub-scale launch vehicle shall be an accurate representative form of the full scale system.
2.18.2	The sub-scale model will carry an altimeter capable of reporting the model's apogee altitude.	I	During the design phase and construction of the sub-scale launch vehicle the system shall be fitted with an altimeter capable of recording apogee altitude.
2.19	All teams will successfully launch and recover their full-scale launch vehicle prior to FRR in its final flight configuration. The launch vehicle flown at FRR must be the same launch vehicle to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight:	I	Full-Scale launch will occur in Brothers, OR. before 1/12/18
2.19.1	The vehicle and recovery system will have functioned as designed.	D	Upon recovery of the full scale launch, each sub team shall confirm and verify their specific system was working as intended.
2.19.2	The payload does not have to be flown during the full-scale test flight. The following requirements still apply:	I	Payload or substitute mass will be flown

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
2.19.2.1	If the payload is not flown, mass simulators will be used to simulate the payload mass.	D	Prior to full scale launch the payload will be substituted for a mass that will mimic the rough shape and weight of the payload itself.
2.19.2.1.1	The mass simulators will be located in the same approximate location on the launch vehicle as the missing payload mass.	D	In the event mass simulators of the payload is used during the full scale launch the substitute of the payload will be placed in the exact location of the payload.
2.19.3	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 demonstration flight.	D	In the event additional systems are added to the surface of the launch vehicle, those systems will be included during the full scale launch as well.
2.19.4	The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulates, as closely as possible, the predicted maximum velocity and maximum acceleration of the launch day flight.	I	In the event the full scale motor is not used during launch, a replica of smaller scale shall be used. This replica will contain characteristics similar to the full scale motor.
2.19.5	The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	I	In a full scale test launch the rover payload will be tested with the launch vehicle. No extra ballast will be added only the rover, aero/recovery, and avionics sensors will be contained within the launch vehicle payload.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
2.19.6	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.	I	The USLI team will comply with all safety instructions given by a RSO.
2.19.7	Full scale flights must be completed by the start of FRRs (March 6th, 2018). If the Student Launch office determines that a re-flight is necessary, then an extension to March 28th, 2018 will be granted. This extension is only valid for re-flights; not first-time flights.	T	A full scale test launch of the launch vehicle and payload will be completed before the FRR in March.
2.20	Any structural protuberance on the launch vehicle will be located aft of the burnout center of gravity.	I	All fins as well as external appendages shall be placed around the launch vehicles center of gravity.
2.21	Vehicle Prohibitions	I	Vehicle will not use any prohibited components or technologies
2.21.1	The launch vehicle will not utilize forward canards.	I	The launch vehicle shall be designed without forward canards.
2.21.2	The launch vehicle will not utilize forward firing motors.	I	The launch vehicle has only one motor facing aft of the launch vehicle.
2.21.3	The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	I	The L850W is not a sparky motor.
2.21.4	The launch vehicle will not utilize hybrid motors.	I	The L850W is not a hybrid motor.
2.21.5	The launch vehicle will not utilize a cluster of motors.	I	The L850W is the only motor present on the launch vehicle.
2.21.6	The launch vehicle will not utilize friction fitting for motors.	I	The team will use threaded screw caps to secure the motor.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
2.21.7	The launch vehicle will not exceed Mach 1 at any point during flight.	I	Through the use of on board avionics sensors in flight data will be collected during test flights and analyzed after the flight.
2.21.8	Vehicle ballast will not exceed 10% of the total weight of the launch vehicle.	I	After the first full scale assembly has been completed weight measurements will be taken to ensure the payload is less than 10% of the launch vehicle weight.
3.10	An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	I, T	A telemetry unit will be placed in the launch vehicle to communicate with a ground station; the system will be tested prior to launch
3.10.1	Any launch vehicle section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.	I	Separate telemetry units will be placed in each part of the launch vehicle which lands untethered
3.10.2	The electronic tracking device will be fully functional during the official flight on launch day.	I, D	Avionics will be visually inspected before flight; communication verification between avionics and ground station will be performed prior to launch
3.11	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing)	I, T	Recovery controllers will be Electromagnetic Interference (EMI) shielded and all wires will be shielded; excitation testing will be performed on the final recovery system without black powder
3.11.1	The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	I	Recovery and telemetry units will be placed in different sections of the launch vehicle with EMI shielding over all recovery components

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
3.11.2	The recovery system electronics will be shielded from all on-board transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	I	Antennas will be stored as far away from recovery controllers as possible; EMI shielding on recovery controllers
3.11.3	The recovery system electronics will be shielded from all on-board devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	I	The use of magnetic component will be minimized; all recovery wires will use twisted pairs
3.11.4	The recovery system electronics will be shielded from any other on-board devices which may adversely affect the proper operation of the recovery system electronics.	I	Recovery electronics will be sealed off from ejection gases with a bulkhead, wire connections will pass through bulkheads with a sealed connector
4.1	Each team will choose one design experiment option from the following list.		
4.2	Additional experiments (limit of 1) are allowed, and may be flown, but they will not contribute to scoring.		
4.3	If the team chooses to fly additional experiments, they will provide the appropriate documentation in all design reports, so experiments may be reviewed for flight safety.		
4.5.1	Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.	T, D	The designed rover will be successfully ejected from the launch vehicle housing during the full scale test launch and on official launch day. A custom designed ejection method will be created in order to accomplish this task.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
4.5.2	At landing, the team will remotely activate a trigger to deploy the rover from the launch vehicle.	T, D	The rover will be ejected from the launch vehicle casing using black powder charges. To conserve battery life, the rover systems will be turned on with a physical spring loaded relay once its been ejected successfully.
4.5.3	After deployment, the rover will autonomously move at least 5 ft. (in any direction) from the launch vehicle.	T, D	The rover will use GPS, sonar, IMU 9DOF, and passive detection to avoid obstacles and navigate to a desired location. The rover frame will be durable and will have sufficient ground clearance. The rover will also use treaded wheels and a rear stabilizer in order to travel 5 feet in rough terrain.
4.5.4	Once the rover has reached its final destination, it will deploy a set of foldable solar cell panels.	T, D	A custom designed, durable enclosure for the solar panels will be deployed using a servo motor on board the rover.
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	I	Each sub-team shall create a checklist of their required items. These checklists shall be compiled and verified by the Safety Officer and prepared for the LRR. All team members shall verify checklists and comply with them at launch.
5.2	Each team must identify a student safety officer who will be responsible for all items in section 5.3.	I	The team Safety Officer is Timothy Lewis.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
5.3	The role and responsibilities of each safety officer will include, but not limited to:	I	Safety Officer will manage all roles required of them
5.3.1	Monitor team activities with an emphasis on Safety during:	I	Safety Officer will be present during all team activities which pose a safety risk
5.3.1.1	Design of vehicle and payload	I	The Safey Officer shall be at all internal design reviews to raise issues of safety that could affect chosen designs.
5.3.1.2	Construction of vehicle and payload	I	Before construction begins the Safety Officer shall brief all involved team members on potential hazards and mitiagtion and shall stand bay to provide assistance in fulfilling safety protocols.
5.3.1.3	Assembly of vehicle and payload	I	Before assembly begins the Safety Officer shall brief all involved team members on potential hazards and mitiagtion and shall stand bay to provide assistance in fulfilling safety protocols.
5.3.1.4	Ground testing of vehicle and payload	I	Before ground testing begins the Safety Officer shall brief all involved team members on potential hazards and mitiagtion and shall stand bay to provide assistance in fulfilling safety protocols.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
5.3.1.5	Sub-scale launch test(s)	I	Before sub-scale launch the Safety Officer shall complete a checklist for launch with the help of the members taking part if the launch. The Safety Officer shall then brief said members on the rules and regulation of the launch site and each members role during the launch. A final check off of all components shall then be carried out by the Safety Officer.
5.3.1.6	Full-scale launch test(s)	I	Before full-scale launch the Safety Officer shall complete a checklist for launch with the help of the members taking part if the launch. The Safety Officer shall then brief said members on the rules and regulation of the launch site and each members role during the launch. A final check off of all components shall then be carried out by the Safety Officer.
5.3.1.7	Launch day	I	Before Launch Day the Safety Officer shall complete a checklist for launch with the help of the members taking part if the launch. The Safety Officer shall then brief said members on the rules and regulation of the launch site and each members role during the launch. A final check off of all components shall then be carried out by the Safety Officer.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
5.3.1.8	Recovery activities	I	The Safety Officer shall communicate with the appropriate range officers to determine the appropriate time to collect the launch vehicle and prepare team members for possible hazards of doing so.
5.3.1.9	Educational Engagement Activities	I	For all Education Activities that require a safety component (model launches, launch vehicle demos) the Safety Officer shall prepare a briefing and safety analysis. The team shall then coordinate with the appropriate educators such that they understand the possible risks involved. All team members who preform the outreach activity shall receive the briefing and if the Safety Officer is unable to attend another member of the outreach group shall be deputized to function as the Safety Officer for that event, with the full understanding that their actions as a temporary Safety Officer must follow all guidelines as such.
5.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities	I	The Safety Officer shall be the team member during activities carrying all procedures and checklists to ensure that all activities follow the predetermined order and meet the preset requirements.

General Requirements			
REQ#	**Requirement Description**	**Verif. Meth.**	**Verification Plan**
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and Material Safety Data Sheet (MSDS)/chemical inventory data sheet	I	The Safety Officer shall collect all required forms and analyses and make them available both in hard copy and online for all team members should they be needed. New versions shall replace older editions.
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	I	The Safety Officer shall be in charge of collecting, compiling and reviewing all hazard analyses, failure mode analyses and procedures.
5.4	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	I	The team shall communicate with the RSO for all test launches. Any concerns of said RSO shall either be addressed by the launch or the launch rescheduled to allow for more time to address them. The team understands that the decisions of the RSO are final, and the RSO has the power to postpone or cancel any launch activities.
5.5	Teams will abide by all rules set forth by the Federal Aviation Administration (FAA).	I	The team has knowledge of all appropriate FAA regulations and shall abide by them.

Team Parts									Purchased To Date				Expected Purchases			
Num.	Component	Description	QTY	Unit Cost	Total Amount	Supplier	SKU	Category	Expense	Fund	Donation	Source	Expense	Fund	Donation	Source
1-1	Apparrel	USLI T-Shirt	24	$ 14.75	$ 354.00	4imprint	-	Misc	-	-	-	-	-	-	-	-
1-2	Apparrel	USLI Polo	24	$ 31.25	$ 750.00	4imprint	-	Misc	-	-	$ 750.00	AIAA	-	-	-	-
1-3	Fabrication	T800 Prepreg Carbon Fiber Woven Sheet, 50 in x 5 yd	1	$ 654.45	$ 654.45	Fibre Glast	3111-C	Material	-	-	-	-	$ 654.45	OSGC	-	-
1-4	Fabrication	Bagging Film, 50 in x 5 yd roll	1	$ 29.95	$ 29.95	Fibre Glast	1688-C	Tools	-	-	-	-	$ 29.95	OSGC	-	-
1-5	Fabrication	Peel Ply, 50 in x5 yd roll	1	$ 59.95	$ 59.95	Fibre Glast	582-C	Tools	-	-	-	-	$ 59.95	OSGC	-	-
1-6	Fabrication	High Temperature Release Film, 50 in x 5 yd roll	1	$ 119.95	$ 119.95	Fibre Glast	1782-C	Tools	-	-	-	-	$ 119.95	OSGC	-	-
1-7	Fabrication	Bleeder and Breather, 50 in x 5 yd roll	2	$ 4.75	$ 9.50	Fibre Glast	579-C	Tools	-	-	-	-	$ 9.50	OSGC	-	-
1-8	Fabrication	Sealant Tape 1 in	3	$ 29.95	$ 89.85	Fibre Glast	584-A	Tools	-	-	-	-	$ 89.85	OSGC	-	-
1-9	Fabrication	Vacuum Valve Fitting	2	$ 39.95	$ 79.90	Fibre Glast	910-A	Tools	-	-	-	-	$ 79.90	OSGC	-	-
1-10	HPR Cert	4 in rocket with G class motors	12	$ 45.00	$ 540.00	-	-	Misc	-	-	$ 540.00	AIAA	-	-	-	-
									Expenses TD		**Donations TD**		**Expenses Exp.**		**Donations Exp.**	
			Total:		**$ 2,687.55**				**$ -**		**$ 1,290.00**		**$ 1,043.55**		**$ -**	

Aero/Recovery Parts									Purchased To Date				Expected Purchases			
Num.	Component	Description	QTY	Unit Cost	Total Amount	Supplier	SKU	Category	Expense	Fund	Donation	Source	Expense	Fund	Donation	Source
2-1	Separation	Black Powder (FFFF)	1	$ 18.35	$ 18.35	Buffalo Arms Co.	GOEX4F	Material	-	-	$ 18.35	AIAA	-	-	-	-
2-2	Seperation	Zip-Ties 4" (100 ct)	1	$ 7.01	$ 7.01	McMaster-Carr	7130K15	Hardware	$ 7.01	Student	-	-	-	-	-	-
2-3	Seperation	Latex Tube (3/8") 10 ft	2	$ 20.41	$ 40.82	Amazon	-	Material	$ 20.41	Student	-	-	$ 20.41	OSGC	-	-
2-4	Seperation	Firewire Initiator 24" Leads (80 ct.)	1	$ 54.40	$ 54.40	Firewire	-	Component	$ 54.40	OSGC	-	-	-	-	-	-
2-5	Parachute	Iris Ultra Std. Parachute 84"	2	$ 276.00	$ 552.00	Fruity Chutes	IFC-84	Component	-	-	-	-	$ 469.20	OSGC	$ 82.80	Fruity Chutes
2-6	Parachutes	X-Type 24" Thin Mill	2	$ 12.05	$ 24.10	Top Flight	PAR-24TM	Component	-	-	-	-	$ 24.10	OSGC	-	-
2-7	Parachutes	Nomex Blanket 18"	2	$ 24.00	$ 48.00	Fruity Chutes	NB-18	Component	-	-	-	-	$ 40.80	OSGC	$ 7.20	Fruity Chutes
2-8	Parachutes	Nylon 1" Webbing 60'	1	$ 19.95	$ 19.95	Country Brook	WNTL-SOR-1	Material	-	-	-	-	$ 19.95	OSGC	-	-
2-9	Parachutes	3000lb Swivel	5	$ 9.00	$ 45.00	Fruity Chutes	SWIV-3000	Component	-	-	-	-	$ 38.25	OSGC	$ 6.75	Fruity Chutes
2-10	Parachutes	Kevlar 1" Braided Sheild 1'	25	$ 1.65	$ 41.25	CT Sales	K743	Material	-	-	-	-	$ 41.25	OSGC	-	-
2-11	Parachutes	Quest Recovery Wadding	1	$ 7.48	$ 7.48	Apogee Components	05750	Component	$ 7.48	OSGC	-	-	-	-	-	-
2-12	Parachutes	GreenFiber Cellulose Insulation	1	$ 11.95	$ 11.95	Home Depot	211904	Material	-	-	-	-	$ 11.95	OSGC	-	-
2-13	Parachutes	1/4" Quick Link	7	$ 4.76	$ 33.32	McMaster-Carr	3711T23	Component	-	-	-	-	$ 33.32	OSGC	-	-
2-14	Tracker	Active 28dB GPS Antenna	3	$ 13.61	$ 40.83	Digikey	AA.105.301111	Electronics	$ 27.22	OSGC	-	-	$ 13.61	OSGC	-	-
2-15	Tracker	Sparkfun Venus GPS Breakout	2	$ 49.95	$ 99.90	Sparkfun	GPS-11058	Electronics	$ 49.95	AIAA	-	-	$ 49.95	OSGC	-	-
2-16	Tracker	Teensy 3.6 Microcontroller	3	$ 30.00	$ 90.00	Sparkfun	DEV-14057	Electronics	$ 60.00	AIAA, OSGC	-	-	$ 30.00	OSGC	-	-
2-17	Tracker	SparkFun FT231X Breakout	1	$ 12.95	$ 12.95	Sparkfun	BOB-13263	Electronics	-	-	-	-	$ 12.95	OSGC	-	-
2-18	Tracker	Xbee Pro 900MHz Tranceiver	4	$ 39.00	$ 156.00	Digikey	XBP9B-DMST-002	Electronics	$ 117.00	OSGC	-	-	$ 39.00	OSGC	-	-
2-19	Tracker	RP-SMA-Male to SMA-Female Adapter	1	$ 6.13	$ 6.13	Digikey	ACX1248-ND	Electronics	$ 6.13	OSGC	-	-	-	-	-	-
2-20	Tracker	Male to Male SMA Cable	1	$ 13.03	$ 13.03	Digikey	J4124-ND	Electronics	$ 13.03	OSGC	-	-	-	-	-	-
2-21	Tracker	N Male to SMA Female Adapter	1	$ 6.94	$ 6.94	Digikey	367-1017-ND	Electronics	$ 6.94	OSGC	-	-	-	-	-	-
2-22	Ejection	MissleWorks RRC3 Altimeter	2	$ 71.95	$ 143.90	Apogee Components	09095	Electronics	$ 143.90	AIAA	-	-	-	-	-	-
2-23	Ejection	Stratologger CF	2	$ 58.80	$ 117.60	Apogee Components	9104	Electronics	-	-	-	-	$ 117.60	OSGC	-	-
2-24	Ejection	Jolly Logic Chute Release	5	$ 130.95	$ 654.75	Apogee Components	09157	Electronics	$ 130.95	AIAA	$ 523.80	Jolly Logic, John L.	-	-	-	-
2-25	Tracker	Terrawave Yagi Base Antenna	1	$ 62.00	$ 62.00	Scanner Master	T09130Y11206	Electronics	$ 62.00	OSGC	-	-	-	-	-	-
2-26	Tracker	11V to 3.3 and 5V Vreg	5	$ 5.00	$ 25.00	Digikey	-	Electronics	$ 15.00	EECS	-	-	-	-	-	-
2-27	Tracker	Monopole 900MHz Whip Antenna	3	$ 20.00	$ 60.00	Mouser	-	Electronics	$ 40.00	OSGC	-	-	$ 20.00	OSGC	-	-
2-28	Tracker	3.3V LDO	4	$ 5.00	$ 20.00	Digikey	-	Electronics	$ 15.00	EECS	-	-	$ 5.00	OSGC	-	-
2-29	Avionics	7.4V Turnigy 2200mAh LiPo Hardpack	5	$ 16.54	$ 82.70	Amazon	-	Electronics	$ 82.70	OSGC	-	-	-	-	-	-
2-30	Avionics	Custom PCB 4 Layer 10cmx5cm (10 ct.)	1	$ 92.90	$ 92.90	DFRobot	-	Electronics	-	-	-	-	$ 92.90	OSGC	-	-
2-31	Avionics	FingerTech Mini Power	10	$ 6.94	$ 69.40	Robot Shop	RB-Ftr-46		$ 34.70	OSGC	-	-	$ 34.70	OSGC	-	-
2-32	Data-Logger	BeagleBone Black	2	$ 54.99	$ 109.98	Arrow	-	Electronics	$ 54.99	AIAA	-	-	$ 54.99	OSGC	-	-
2-33	Data-Logger	BeagleBone Black Proto Cape	2	$ 9.95	$ 19.90	RobotShop	RB-Spa-1105	Electronics	$ 9.45	OSGC	$ 0.50	Robot Shop	$ 9.95	OSGC	-	-
2-34	Data-Logger	Adafruit 9-DOF IMU Breakout	2	$ 34.95	$ 69.90	RobotShop	RB-Ada-215	Electronics	$ 33.20	OSGC	$ 1.75	Robot Shop	$ 34.95	OSGC	-	-
2-35	Data-Logger	SparkFun Pressure Sensor Breakout	2	$ 59.95	$ 119.90	Robot Shop	RB-Spa-966	Electronics	$ 56.95	OSGC	$ 3.00	Robot Shop	$ 59.95	OSGC	-	-
2-36	Data-Logger	SparkFun Barometric Sensor Breakout	2	$ 14.95	$ 29.90	Sparkfun	SEN-11048	Electronics	$ 14.95	AIAA	-	-	$ 14.95	OSGC	-	-
2-37	Data-Logger	Adafruit High-G Accelerometer Breakout	2	$ 24.95	$ 49.90	Adafruit	1413	Electronics	$ 24.95	AIAA	-	-	$ 24.95	OSGC	-	-
2-38	Avionics	2.5mm Male Header Pins (10 ct.)	10	$ 0.59	$ 5.90	Digikey	S1011EC-40-ND	Electronics	$ 5.90	OSGC	-	-	-	-	-	-
2-39	Avionics	Rosin Flux Paste	1	$ 10.70	$ 10.70	Amazon	-	Material	$ 10.70	OSGC	-	-	-	-	-	-
2-40	Avionics	18AWG Wire	1	$ 28.48	$ 28.48	Amazon	-	Material	$ 28.48	OSGC	-	-	-	-	-	-
2-41	Aero	5 in 4:1 Ogive nosecone	1	$ 84.95	$ 84.95	Apogee Components	20540	Component	-	-	-	-	$ 84.95	OSGC	-	-
									Expenses TD		**Donations TD**		**Expenses Exp.**		**Donations Exp.**	
			Total:		**$ 3,187.17**				**$ 1,133.40**		**$ 547.39**		**$ 1,399.63**		**$ 96.75**	

Structures/Propulsion Budget									Purchased To Date				Expected Purchases			
Num.	Component	Description	QTY	Unit Cost	Total Amount	Supplier	SKU	Category	Expense	Fund	Donation	Source	Expense	Fund	Donation	Source
3-1	Body Tube	5.3 in OD CF/G12 Body Tube	1	Donated	$ 1,750.00	ICE	-	Body	-	-	$ 1,750.00	ICE	-	-	-	-
3-2	Body Tube	Acme Confromal Launch Guide - 6 in	1	$ 12.35	$ 12.35	Giant Leap Rocketry	-	Component					$ 12.35	OSGC	-	-
3-3	Coupler	2-56 Nylon Shear Screws (100 ct)	1	$ 5.55	$ 5.55	McMaster-Carr	95133A277	Hardware	$ 5.55	AIAA	-	-	-	-	-	-
3-4	Bulkhead / Fin	Yellow Sealant Tape - 25 ft	2	$ 9.94	$ 19.88	Fiber Glast	580-A	Material	-	-	-	-	$ 19.88	OSGC	-	-
3-5	Eyebolt	Galvanized Steel Eyebolt w/ Shoulder 3/8 in -16	4	$ 6.36	$ 25.44	McMaster-Carr	3019T16	Hardware	-	-	-	-	$ 25.44	OSGC	-	-
3-6	Nut	Stainless Steel Nylon Locknut 3/8 in -16 (10 ct.)	1	$ 9.83	$ 9.83	McMaster-Carr	90098A120	Hardware	-	-	-	-	$ 9.83	OSGC	-	-
3-7	Washer	Stainless Steel Washer 3/8 in (25 ct.)	1	$ 8.20	$ 8.20	McMaster-Carr	92503A130	Hardware	-	-	-	-	$ 8.20	OSGC	-	-
3-8	Threaded Rod	Threaded Steel Rod 3/8-16, 4 ft	2	$ 5.88	$ 11.76	McMaster-Carr	98957A135	Hardware	-	-	-	-	$ 11.76	OSGC	-	-
3-9	Thread Lock	Locktite Red	1	$ 4.89	$ 4.89	-	-	Material	-	-	$ 4.89	Student	-	-	-	-
3-10	Thread Lock	Locktite Blue	1	$ 3.53	$ 3.53	-	-	Material	-	-	$ 3.53	Student	-	-	-	-
3-11	Epoxy	G5000 RocketPoxy	1	$ 34.99	$ 34.99	MadCow Rocketry	G5000-RP-PNT	Material	-	-	$ 34.99	AIAA	-	-	-	-
3-12	Mouting	1515 Rail Buttons	1	$ 4.65	$ 4.65	Apogee Rockets	13063	Component	$ 4.65	OSGC	-	-	-	-	-	-
3-13	Nose Tip	6061 Al 3.75 in OD x 6 in	1	$ 48.82	$ 48.82	McMaster-Carr	8974K96	Material					-	-	-	-
3-14	Motor case	AeroTech RMS-75/3840 Motor Case	1	$ 390.55	$ 390.55	Apogee Rockets	60062	Component	-	-	$ 390.55	John L.	-	-	-	-
3-15	Forward Closure	AeroTech 75mm Forward Closure	1	$ 101.65	$ 101.65	Apogee Rockets	60160	Component	-	-	$ 101.65	John L.	-	-	-	-
3-16	Aft Closure	AeroTech 75mm Aft Retainer	1	$ 80.25	$ 80.25	Apogee Rockets	60169	Component	-	-	$ 80.25	John L.	-	-	-	-
3-17	Reload Kit	AeroTech L1390G-P	2	$ 199.99	$ 399.98	Apogee Rockets	ARO-12139P	Component	-	-	-	-	$ 399.98	OSGC	-	-
									Expenses TD		**Donations TD**		**Expenses Exp.**		**Donations Exp.**	
			Total:		**$ 2,912.32**				**$ 10.20**		**$ 2,365.86**		**$ 487.44**		**$ -**	

Payload Budget									Purchased To Date				Expected Purchases			
Num.	Component	Description	QTY	Unit Cost	Total Amount	Supplier	SKU	Category	Expense	Fund	Donation	Source	Expense	Fund	Donation	Source
4-1	Chassis	Al stock 2.25 x 2.25 x 6	1	$ 24.84	$ 24.84	McMaster-Carr	9008K55	Material	$ 24.84	OSGC	-	-	-	-	-	-
4-2	Chassis	Al stock 7/8 x 1 x 24 in	2	$ 15.82	$ 31.64	McMaster-Carr	8975K922	Material	$ 15.82	OSGC	-	-	-	-	-	-
4-3	Chassis	Al stock 2 x 1.5 x 12	1	$ 25.89	$ 25.89	McMaster-Carr	8975K253	Material	$ 25.89	OSGC	-	-	-	-	-	-
4-4	Chassis	CF rod 0.25 x 48	3	$ 11.11	$ 33.33	Dragonplate	-	Material	$ 33.33	OSGC	-	-	-	-	-	-
4-5	Chassis	6061 Al. .032 x 4 x 24 in	1	$ 9.17	$ 9.17	McMaster-Carr	89015K152	Material	$ 9.17	OSGC	-	-	-	-	-	-
4-6	Chassis	6061 Al. .5 x 1 x 24 in	2	$ 8.24	$ 16.48	McMaster-Carr	8975K11	Material	$ 16.48	OSGC	-	-	-	-	-	-
4-7	Chassis	LH Torsion Spring	1	$ 6.47	$ 6.47	McMaster-Carr	9271K708	Component	$ 6.47	OSGC	-	-	-	-	-	-
4-8	Chassis	RH Torsion Spring	1	$ 6.47	$ 6.47	McMaster-Carr	9271K674	Component	$ 6.47	OSGC	-	-	-	-	-	-
4-9	Drivetrain	10mm Set Screw Key Hub	2	$ 20.00	$ 40.00	Robotshop	RB-Nex-99	Hardware	$ 38.00	OSGC	$ 2.00	Robot Shop	-	-	-	-
4-10	Drivetrain	High-Load Oil-Embedded Thrust Bearing	4	$ 2.02	$ 8.08	McMaster-Carr	3750K1	Component	$ 8.08	OSGC	-	-	-	-	-	-
4-11	Drivetrain	Permanently Lubricated Ball Bearing	2	$ 11.04	$ 22.08	McMaster-Carr	2342K164	Component	$ 22.08	OSGC	-	-	-	-	-	-
4-12	Drivetrain	Permanently Lubricated Stainless Steel Ball Bearing	2	$ 15.40	$ 30.80	McMaster-Carr	4648K5	Component	$ 30.80	OSGC	-	-	-	-	-	-
4-13	Drivetrain	HDPE Sheet 3/4 x 6 x 12 in	3	$ 19.06	$ 57.18	McMaster-Carr	8619K791	Material	$ 19.06	OSGC	-	-	-	-	-	-
4-14	DriveTrain	6061-T6 Al Rod 2-1/2 in OD x 3 in	1	$ 15.95	$ 15.95	McMaster-Carr	1610T17	Material	$ 15.95	OSGC	-	-	-	-	-	-
4-15	Drivetrain	4140 Alloy Steel Rod	1	$ 2.68	$ 2.68	McMaster-Carr	8927K95	Hardware	$ 2.68	OSGC	-	-	-	-	-	-
4-16	Drivetrain	6 mm x 6 mm Aluminum Flexible Shaft Coupling	2	$ 1.81	$ 3.62	Banggood	994356	Hardware	-	-	-	-	$ 3.62	OSGC	-	-
4-17	Drivetrain	Abrasion-Resistant Polyurethane Rubber, 60A Durometer	1	$ 31.60	$ 31.60	McMaster-Carr	8997K53	Hardware	$ 31.60	OSGC	-	-	-	-	-	-
4-18	Drivetrain	4-40 SHCS, 7/8 in length	3	$ 10.30	$ 30.90	McMaster-Carr	91251A114	Hardware	-	-	-	-	$ 30.90	OSGC	-	-
4-19	Drivetrain	4-40 Set Screw, 1/8 in length	3	$ 13.88	$ 41.64	McMaster-Carr	94105A104	Hardware	-	-	-	-	$ 41.64	OSGC	-	-
4-20	Drivetrain	4-40 Set Screw, 3/8 in length	3	$ 9.16	$ 27.48	McMaster-Carr	94355A141	Hardware	-	-	-	-	$ 27.48	OSGC	-	-
4-21	Drivetrain	Polyurethane sheet, 1/8 in thick, 1 in wide, 48 in long, 60A durometer	1	$ 21.73	$ 21.73	McMaster-Carr	8997K51	Hardware	$ 21.73	OSGC	-	-	-	-	-	-
4-22	Drivetrain	GHM-04 Spur Gear Head Motor	6	$ 21.95	$ 131.70	Robotshop	RB-Hsi-04	Component	$ 43.90	OSGC	-	-	-	-	-	-
4-23	Solar	Solar Cells	3	$ 13.13	$ 39.39	Digikey	SLMD960H12L-ND	Component	$ 39.39	OSGC	-	-	-	-	-	-
4-24	Solar	6-32 UNC Extra Short Mounting Screws (25 ct.)	1	$ 11.04	$ 11.04	McMaster-Carr	91253A165	Hardware	$ 11.04	OSGC	-	-	-	-	-	-
4-25	Solar	6-32 UNC Short Mounting Screws (50 ct.)	1	$ 4.49	$ 4.49	McMaster-Carr	91253A145	Hardware	$ 4.49	OSGC	-	-	-	-	-	-
4-26	Solar	6-32 UNC Hex Nuts (100 ct.)	1	$ 3.94	$ 3.94	McMaster-Carr	93181A007	Hardware	$ 3.94	OSGC	-	-	-	-	-	-
4-27	Solar	SAE 12 Thin Washer (100 ct.)	1	$ 6.78	$ 6.78	McMaster-Carr	90945A760	Hardware	$ 6.78	OSGC	-	-	-	-	-	-
4-28	Solar	SAE 4 Thin Washer (100 ct.)	1	$ 9.60	$ 9.60	McMaster-Carr	91950A043	Hardware	$ 9.60	OSGC	-	-	-	-	-	-
4-29	Solar	Servo Motor	1	$ 13.99	$ 13.99	Servo City	FUTM0710	Component	$ 13.99	OSGC	-	-	-	-	-	-
4-30	Battery	Turnigy Graphene 950 mAh LiPo	4	$ 9.65	$ 38.60	HobbyKing	9067000119-0	Electronics	-	-	-	-	$ 38.60	OSGC	-	-
4-31	Power	IMAX B6AC V2 Professional Balance Charger	1	$ 43.53	$ 43.53	HobbyKing	9052000068-3	Electronics	$ 43.53	OSGC	-	-	-	-	-	-
4-32	Power	Male JST Battery Pigtail (10 ct.)	1	$ 2.15	$ 2.15	HobbyKing	AM-9017A	Electronics	$ 2.15	OSGC	-	-	-	-	-	-
4-33	Power	1000pF Capacitor	4	$ 0.46	$ 1.84	Digikey	490-9509-1-ND	Electronics	$ 1.84	OSGC	-	-	-	-	-	-
4-34	Power	.033 uF Capacitor	4	$ 0.34	$ 1.36	Digikey	399-4236-ND	Electronics	$ 1.36	OSGC	-	-	-	-	-	-
4-35	Power	4.7 uF Capacitor	2	$ 1.22	$ 2.44	Digikey	490-7556-1-ND	Electronics	$ 2.44	OSGC	-	-	-	-	-	-
4-36	Power	10 uF Capacitor	10	$ 2.01	$ 20.10	Digikey	490-7518-1-ND	Electronics	$ 20.10	OSGC	-	-	-	-	-	-
4-37	Power	100 uF Capacitor	4	$ 0.95	$ 3.80	Digikey	445-173291-1-ND	Electronics	$ 3.80	OSGC	-	-	-	-	-	-
4-38	Power	Sch Diode	4	$ 0.45	$ 1.80	Digikey	1N5821RLGOSCT-ND	Electronics	$ 1.80	OSGC	-	-	-	-	-	-
4-39	Power	22 uH Inductor	4	$ 4.36	$ 17.44	Digikey	M8935-ND	Electronics	$ 17.44	OSGC	-	-	-	-	-	-
4-40	Power	3.3 ohm Resistor	4	$ 0.29	$ 1.16	Digikey	BC4130CT-ND	Electronics	$ 1.16	OSGC	-	-	-	-	-	-
4-41	Power	10 ohm Resistor	4	$ 0.24	$ 0.96	Digikey	BC3243CT-ND	Electronics	$ 0.96	OSGC	-	-	-	-	-	-
4-42	Power	3.83k ohm Resistor	4	$ 0.20	$ 0.80	Digikey	PPC3.83KXCT-ND	Electronics	$ 0.80	OSGC	-	-	-	-	-	-
4-43	Power	12k ohm Resistor	2	$ 0.24	$ 0.48	Digikey	BC3245CT-ND	Electronics	$ 0.48	OSGC	-	-	-	-	-	-
4-44	Power	20k ohm Resistor	2	$ 0.20	$ 0.40	Digikey	PPC20.0KXCT-ND	Electronics	$ 0.40	OSGC	-	-	-	-	-	-
4-45	Controls	Pololu Dual MC33926 Motor Driver for Raspberry Pi (Partial Kit)	3	$ 29.95	$ 89.85	Pololu Robotics & Electronics	-	Electronics	$ 29.95	EECS	-	-	-	-	-	-
4-46	Controls	Raspberry Pi 3	1	$ 35.00	$ 35.00	adafruit	3055	Electronics	$ 35.00	AIAA			-	-	-	-
4-47	Controls	BLS-275SV Brushless Servo	1	$ 249.99	$ 249.99	Servo City	FUTM0144	Electronics	-	-	-	-	$ 249.99	OSGC	-	-

4-48	Sensors	Vishay BC Components Load Resistor	10	$ 0.24	$ 2.40	Digikey	BC3245CT-ND	Electronics	$ 2.40	EECS	-	-	-	-	-	-
4-49	Sensors	Ohmite 14AFR047E Shunt Resistor	10	$ 2.02	$ 20.20	Digikey	14AFR047E-ND	Electronics	-	-	-	-	$ 20.20	OSGC	-	-
4-50	Sensors	INA169 Current Sensor	3	$ 8.95	$ 26.85	Robot Shop	RB-Spa-901	Electronics	-	-	-	-	$ 25.51	OSGC	$ 1.34	Robot Shop
4-51	Sensors	9DoF IMU Breakout	2	$ 24.95	$ 49.90	Sparkfun	SEN-13284	Electronics	-	-	-	-	$ 49.90	OSGC	-	-
4-52	Sensors	MB7360 HRXL-MaxSonar-WR (Compact IP67 Casing)	2	$ 109.95	$ 219.90	MaxBotix	MB7360-200	Electronics	$ 109.95	EECS	-	-	-	-	-	-
4-53	Sensors	Piezoelectric Buzzer	2	$ 3.15	$ 6.30	Digikey	102-1116-ND	Electronics	$ 6.30	OSGC	-	-	-	-	-	-
4-54	Sensors	Microphone	2	$ 2.79	$ 5.58	Digikey	102-4474-ND	Electronics	$ 5.58	OSGC	-	-	-	-	-	-
4-55	Power	TPS54386PWPR	2	$ 2.67	$ 5.34	Digikey	296-23109-1-ND	Electronics	-	-	-	-	$ 5.34	OSGC	-	-
4-56	Connection	Shielded wire, 4 strand 24 ft	3	$ 9.95	$ 29.85	Jameco	644383	Tools	-	-	-	-	$ 29.85	OSGC	-	-
4-57	Connection	Shielding Tape	4	$ 20.85	$ 83.40	Jameco	1643551	Tools	-	-	-	-	$ 83.40	OSGC	-	-
4-58	Ejection	Large capacity ejection canister	25	$ 2.50	$ 62.50	Apogee Components	-	Hardware	-	-	-	-	$ 62.50	OSGC	-	-
4-59	Ejection	Terminal Block	3	$ 3.41	$ 10.23	Apogee Components	-	Hardware	-	-	-	-	$ 10.23	OSGC	-	-
4-60	Ejection	HDPE Rod	1	$ 46.71	$ 46.71	McMaster-Carr	8624K681	Hardware	-	-	-	-	$ 46.71	OSGC	-	-
4-61	Ejection	6061 Aluminum Rod	1	$ 37.68	$ 37.68	McMaster-Carr	1610T48	Hardware	-	-	-	-	$ 37.68	OSGC	-	-
4-62	Retention	Ratworks Advanced Retention and Release Device	1	$ 119.00	$ 119.00	Aerocon Systems	-	Hardware	$ 119.00	OSGC	-	-	-	-	-	-
4-63	Retention	Defy Gravity Tether L2	1	$ 85.00	$ 85.00	Apogee Components	29151	Hardware	$ 85.00	OSGC	-	-	-	-	-	-
4-64	Retention	Eyebolt	2	$ 14.21	$ 28.42	McMaster-Carr	33045T33	Hardware	-	-	-	-	$ 28.42	OSGC	-	-
4-65	Housing	Soft Foam	1	$ 10.33	$ 10.33	Amazon	-	Hardware	-	-	-	-	$ 10.33	OSGC	-	-
4-66	Housing	Hard Foam	1	$ 8.75	$ 8.75	Amazon	-	Hardware	-	-	-	-	$ 8.75	OSGC	-	-
									Expenses TD		**Donations TD**		**Expenses Exp.**		**Donations Exp.**	
			Total:		**$ 2,079.00**				**$ 953.02**		**$ 2.00**		**$ 811.05**		**$ 1.34**	

Sub-Scale Budget									Purchased To Date				Expected Purchases			
Num.	Component	Description	QTY	Unit Cost	Total Amount	Supplier	SKU	Category	Expense	Fund	Donation	Source	Expense	Fund	Donation	Source
5-1	Stucture	3/8-16 x 6 ft Threaded Rod	1	$ 14.27	$ 14.27	McMaster-Carr	90322A659	Hardware	$ 14.27	Student	-	-	-	-	-	-
5-2	Stucture	3/8-16 Lock Nuts	1	$ 3.22	$ 3.22	McMaster-Carr	94895A029	Hardware	$ 3.22	Student	-	-	-	-	-	-
5-3	Stucture	3/8 in - 16 Washers	1	$ 6.65	$ 6.65	McMaster-Carr	98023A029	Hardware	$ 6.65	Student	-	-	-	-	-	-
5-4	Stucture	5/16 in - 18 Galvanized Steel Eyebolt	2	$ 6.16	$ 12.32	McMaster-Carr	3019T15	Hardware	$ 6.16	OSGC	-	-	-	-	-	-
5-5	Stucture	5/8 in Quick-Links	3	$ 8.82	$ 26.46	McMaster-Carr	8947T28	Hardware	$ 26.46	OSGC	-	-	-	-	-	-
5-6	Stucture	1515 launch rail buttons	1	$ 4.65	$ 4.65	Apogee Components	13063	Hardware	$ 4.65	OSGC	-	-	-	-	-	-
5-7	Stucture	2-56 x 1/4 in Steel Screws	1	$ 3.30	$ 3.30	McMaster-Carr	91783A077	Hardware	$ 3.30	OSGC	-	-	-	-	-	-
5-8	Airframe	Mad Dog 4 ft Rocket	1	$ 209.00	$ 209.00	Madcow	EK-MDDD-G12	Component	$ 209.00	AIAA	-	-	-	-	-	-
5-9	Motor	AeroTech 54 mm Forward Closure	1	$ 58.84	$ 58.84	Apogee Components	60145	Component	$ 58.84	OSGC	-	-	-	-	-	-
5-10	Motor	AeroTech 54 mm /1706 Motor Case	1	$ 139.10	$ 139.10	Apogee Components	60043	Component	-	-	$ 139.10	John L.	-	-	-	-
5-11	Motor	AeroTech 54mm Aft Closure	1	$ 48.15	$ 48.15	Apogee Components	60149	Component	-	-	$ 48.15	John L.	-	-	-	-
5-12	Plywood	1/2 in 9ply Plywood 5 x 5 ft	1	$ 42.00	$ 42.00	Braid Brothers	1/2BALPLY5x5	Material	$ 42.00	Student	-	-	-	-	-	-
5-13	Coupler	2-56 Nylon Shear Screws (100 ct)	1	$ 5.55	$ 5.55	McMaster-Carr	97263A705	Hardware	$ 5.55	OSGC	-	-	-	-	-	-
									Expenses TD		**Donations TD**		**Expenses Exp.**		**Donations Exp.**	
			Total:		**$ 573.51**				**$ 380.10**		**$ 187.25**		**$ -**		**$ -**	

Payload Testing Budget									Purchased To Date				Expected Purchases			
Num.	Component	Description	QTY	Unit Cost	Total Amount	Supplier	SKU	Category	Expense	Fund	Donation	Source	Expense	Fund	Donation	Source
6-1	Ejection Testing	1/4 in - 20 x 1 in Long Socket Head Screws (25 ct.)	1	$ 6.06	$ 6.06	McMaster-Carr	90128A247	Hardware	-	-	-	-	-	-	$ 6.06	OSU Shop
6-2	Ejection Testing	1/4 in - 20 x 1.5 in Long Socket Head Screws (50 ct.)	1	$ 11.22	$ 11.22	McMaster-Carr	91251A546	Hardware	-	-	-	-	-	-	$ 11.22	OSU Shop
6-3	Ejection Testing	1/4 in - 20 x 1 in Long Flat Bolt (25 ct.)	2	$ 8.59	$ 17.18	McMaster-Carr	91263A562	Hardware	-	-	-	-	-	-	$ 17.18	OSU Shop
6-4	Ejection Testing	1/4 in Washers 18-8 SS (100 ct.)	1	$ 3.37	$ 3.37	McMaster-Carr	92141A029	Hardware	-	-	-	-	-	-	$ 3.37	OSU Shop
6-5	Ejection Testing	1/4 in - 20 Locking Hex Nuts (50 ct)	1	$ 4.45	$ 4.45	McMaster-Carr	91831A029	Hardware	-	-	-	-	-	-	$ 4.45	OSU Shop
6-6	Ejection Testing	6061 Al Sheet Metal, 24 in x 14 in, 14ga. (0.063 in)	1	$ 12.00	$ 12.00	McMaster-Carr	89015K69	Hardware	-	-	-	-	-	-	$ 12.00	OSU Shop
6-7	Ejection Testing	6061 Al Sheet Metal, 24 in x 14 in, 1/8 in thick	1	$ 21.99	$ 21.99	McMaster-Carr	89015K232	Hardware	-	-	-	-	-	-	$ 21.99	OSU Shop
6-8	Ejection Testing	6061 Al Sheet Metal, 6 in x 24 in, 1/8 in thick	1	$ 29.69	$ 29.69	McMaster-Carr	89015K237	Hardware	-	-	-	-	-	-	$ 29.69	OSU Shop
6-9	Ejection Testing	1/2 in x 6 ft 1144 Carbon Steel Rod	1	$ 19.65	$ 19.65	McMaster-Carr	6628K29	Hardware	-	-	-	-	$ 19.65	OSGC	-	-
6-10	Ejection Testing	1/4 in x 3 ft 1144 Carbon Steel Rod	1	$ 3.90	$ 3.90	McMaster-Carr	6628K23	Hardware	-	-	-	-	$ 3.90	OSGC	-	-
6-11	Ejection Testing	6061 Al Bar, 1 in x 2 in x 6 ft	1	$ 78.12	$ 78.12	McMaster-Carr	8975K237	Hardware	-	-	-	-	-	-	$ 78.12	OSU Shop
6-12	Ejection Testing	80/20 T-Slot Al, 30mm x 60mm x 6 ft	5	$ 42.27	$ 211.35	80/20 Inc.	30-3060	Hardware	-	-	-	-	-	-	$ 211.35	OSU Shop
6-13	Ejection Testing	6061 Al 90 degree Angle, 1 in x 4 ft (tall on outside)	1	$ 8.83	$ 8.83	McMaster-Carr	8982K4	Hardware	-	-	-	-	$ 8.83	OSGC	-	-
6-14	Ejection Testing	1/2 in Key Hub	4	$ 11.00	$ 44.00	AndyMark	am-0077a	Hardware	-	-	-	-	$ 44.00	OSGC	-	-
					Amount				**Expense TD**		**Donated TD**		**Expense Exp.**		**Donations Exp.**	
			Total:		**$ 471.81**				**$ -**		**$ -**		**$ 76.38**		**$ 395.43**	

Travel Budget								Purchased To Date				Expected Purchases			
Num	Description	Category	QTY	Sub-QTY	Unit Cost	Total Amount	Priced By	Expense	Fund	Donation	Source	Expense	Fund	Donation	Source
7-1	Airfare PDX to HSV, round trip, 4/4 - 4/8	Transportation	15	1	$559.60	$ 8,394.00	United Airlines	-	-	-	-	$ 8,394.00	Student	-	-
7-2	Rental Car (cars/day, days, cost/day)	Transportation	4	6	$41.00	$ 984.00	Enterprise, Economy, HSV	-	-	-	-	$ 984.00	OSGC	-	-
7-3	Hotel (rooms/night, nights, cost/room)	Lodging	7	6	$105.09	$ 4,413.78	USLI Hotel Block	-	-	-	-	$ 4,413.78	OSGC	-	-
7-4	Lunch (persons/day, days, cost/day)	Food	15	5	$19.70	$ 1,477.50	2016 Corporate Travel Index	-	-	-	-	$ 1,477.50	OSGC	-	-
7-5	Dinner (persons/day, days, cost/day)	Food	15	5	$37.39	$ 2,804.25	2016 Corporate Travel Index	-	-	-	-	$ 2,804.25	OSGC	-	-
								Expense TD		**Donated TD**		**Expense Exp.**		**Donations Exp.**	
				Total:		**$ 18,073.53**		**$ -**		**$ -**		**$ 18,073.53**		**$ -**	

7.4 Timeline

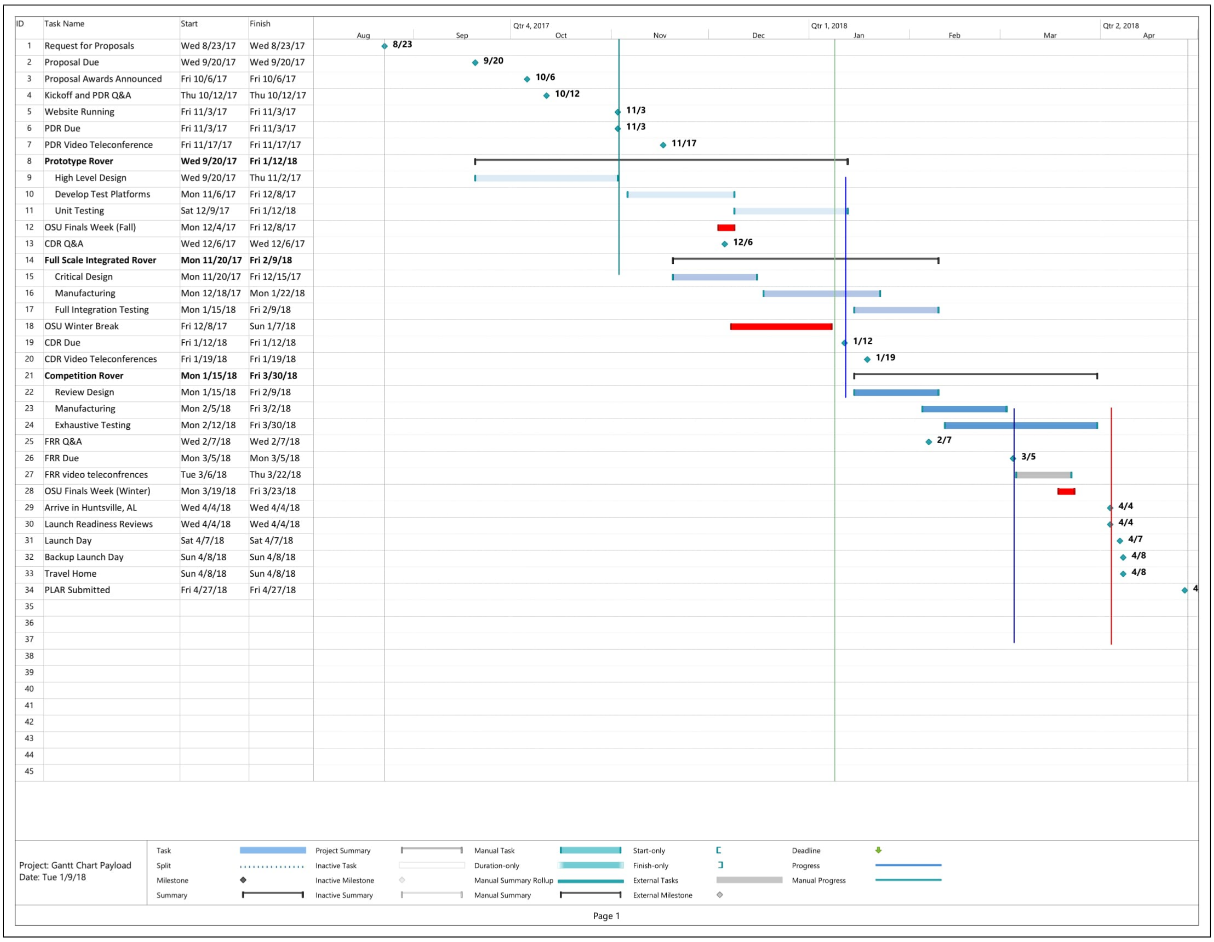


Figure 91: Payload Timeline

ID	Task Name	Start	Finish
1	Request for Proposals	Wed 8/23/17	Wed 8/23/17
2	Proposal Due	Wed 9/20/17	Wed 9/20/17
3	Proposal Awards Announced	Fri 10/6/17	Fri 10/6/17
4	Kickoff and PDR Q&A	Thu 10/12/17	Thu 10/12/17
5	Website Running	Fri 11/3/17	Fri 11/3/17
6	PDR Due	Fri 11/3/17	Fri 11/3/17
7	PDR Video Teleconference	Fri 11/17/17	Fri 11/17/17
8	**Design**	**Wed 9/20/17**	**Fri 12/8/17**
9	Recovery System Fully Designed	Wed 9/20/17	Fri 12/8/17
10	Aerodynamic System Fully Designed	Wed 9/20/17	Fri 12/8/17
11	OSU Finals Week (Fall)	Mon 12/4/17	Fri 12/8/17
12	CDR Q&A	Wed 12/6/17	Wed 12/6/17
13	OSU Winter Break	Fri 12/8/17	Sun 1/7/18
14	**Testing Phase 1**	**Fri 12/8/17**	**Tue 1/30/18**
15	Subscale Launch Vehicle	Fri 12/8/17	Tue 1/30/18
16	Ground Ejection Testing	Sat 12/30/17	Fri 1/5/18
17	Subscale Launch Vehicle	Sat 1/6/18	Sat 1/6/18
18	CDR Due	Fri 1/12/18	Fri 1/12/18
19	CDR Video Teleconfrences	Tue 1/16/18	Wed 1/31/18
20	**Assembly**	**Sun 1/7/18**	**Fri 2/2/18**
21	Aerodynamic Subsystem Assembled	Sun 1/7/18	Fri 1/19/18
22	Recovery Subsystem Assembled	Sun 1/7/18	Fri 1/19/18
23	Subsystems Assembled on Rocket	Sun 1/21/18	Fri 2/2/18
24	FRR Q&A	Wed 2/7/18	Wed 2/7/18
25	**Testing Phase 2**	**Sat 2/17/18**	**Fri 3/2/18**
26	Full Scale Launch 1	Sat 2/17/18	Sat 2/17/18
27	Finalize Parts for Full Scale Launch 2	Sun 2/18/18	Fri 3/2/18
28	Full Scale Launch 2	Sat 3/3/18	Sat 3/10/18
29	FRR Due	Mon 3/5/18	Mon 3/5/18
30	FRR Video Teleconfrences	Tue 3/6/18	Thu 3/22/18
31	OSU Finals Week (Winter)	Mon 3/19/18	Fri 3/23/18
32	Arrive in Huntsville, AL	Wed 4/4/18	Wed 4/4/18
33	Launch Readiness Reviews	Wed 4/4/18	Wed 4/4/18
34	Launch Day	Sat 4/7/18	Sat 4/7/18
35	Backup Launch Day	Sun 4/8/18	Sun 4/8/18
36	Travel Home	Sun 4/8/18	Sun 4/8/18
37	PLAR Submitted	Fri 4/27/18	Fri 4/27/18

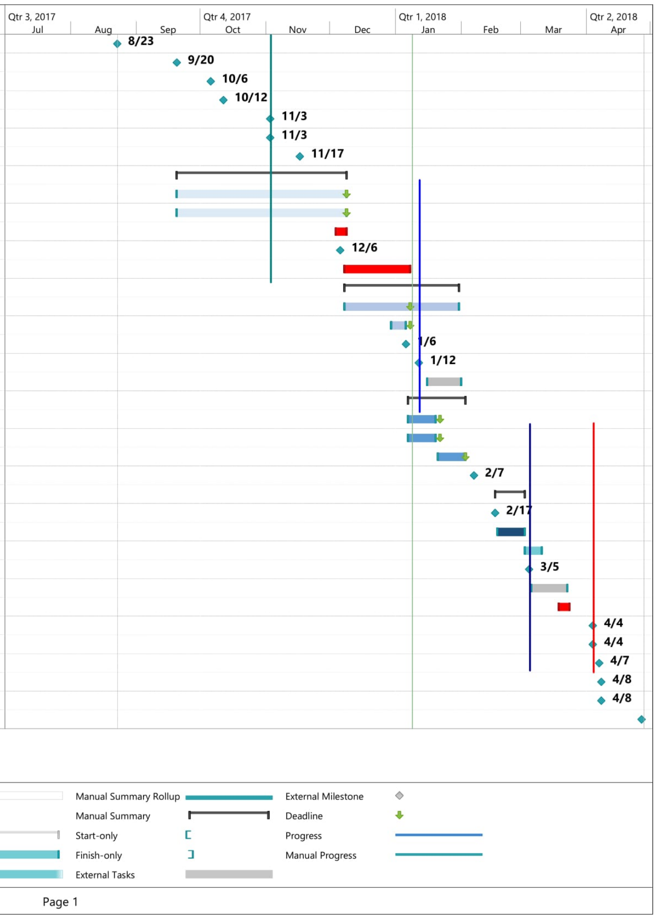


Figure 92: Aerodynamics Timeline

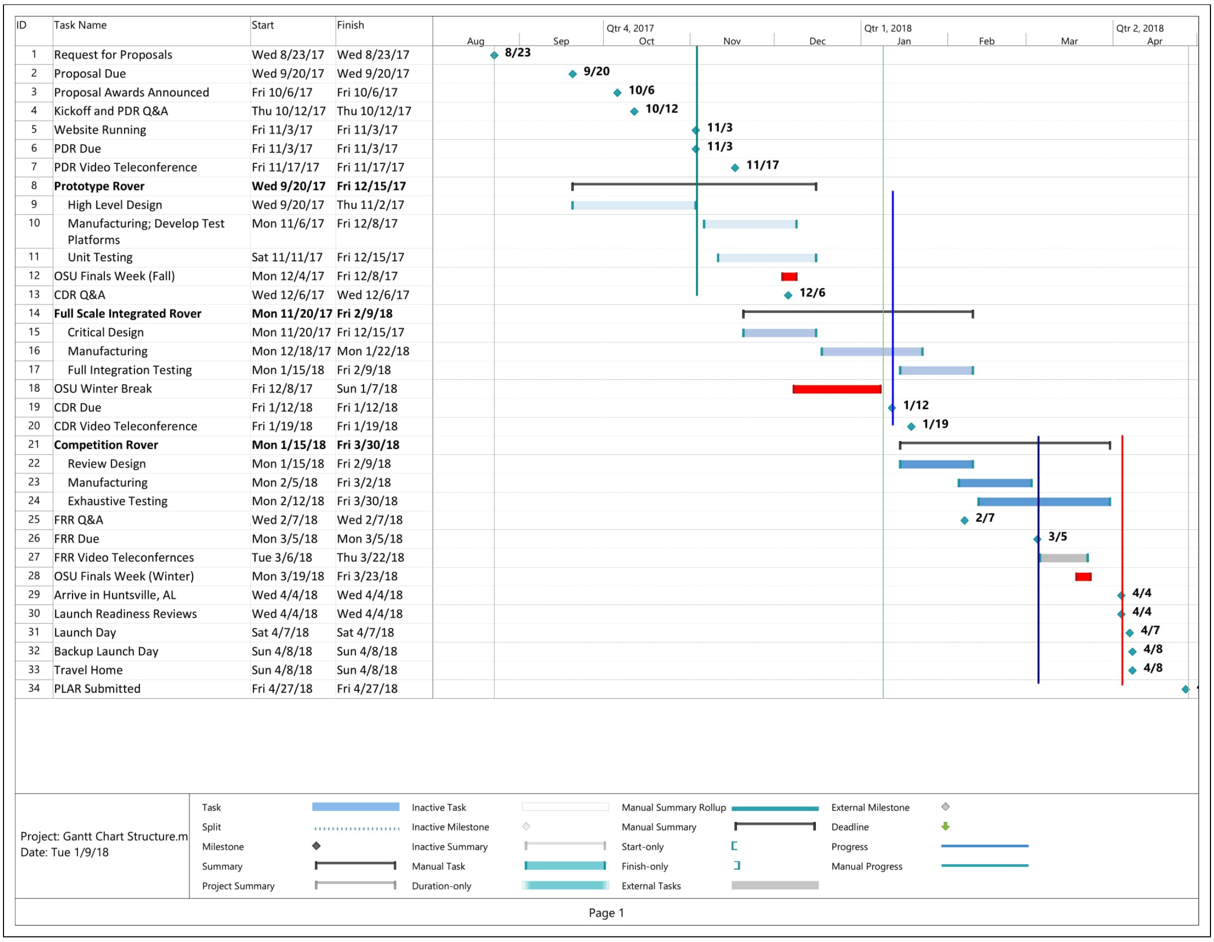


Figure 93: Structures Timeline

8 Educational Outreach

8.1 Mission Statement and Success Criteria

The mission for educational outreach is to reach as many students as possible in the allotted time between September 2017 to March 2018. Utilizing the collection of experiment lesson plans generated from the combined experience of the team, the outreach program works with teachers to align with their lesson plans and schedules. Selection of schools is initially based on alumni connections to the schools from members of the team and then further connections from other teaching professionals. The mission shall be considered a success when the following have been completed for each event:

- Scheduling accommodates to the teacher's availability
- Lesson plans are chosen by the teachers from the wide selection of topics provided
- Each outreach event shall use a combination of direct and indirect interactions
- The program reach a minimum of 200 students
- Students stay engaged and have hands on interactions with STEM field subject matter
- The team receives positive reviews from the teaching staff of the host school

8.2 Structure of the Program

8.2.1 Completed Outreach Events

Without precedent USLI teams to build off of for an educational outreach program, the team developed their own approach utilizing contacts of team members to establish events with schools in the area. Starting the team off was the outreach event with Silver Crest School eighth graders including the Silver Crest Rocket Club & Rock-It-Girls club teams. The event included a tour of the AIAA facilities and lab space that the engineering students are able to use followed by a presentation on the fundamentals of rocketry. The finale of the day was a build session where students got to build model rockets alongside with team members. After finishing the build, the rockets were then stuffed and given primed motors by team members before launching everyone's rockets in an on-campus field. Each student got to keep their custom rocket and enjoy a build and presentation on rocketry.

Repeating the same structure as the first event, the team then traveled to Philomath Middle School to again do a presentation and rocket launch with the students. As the school is especially smaller, it was meet with great enthusiasm to work and learn from current college students. Despite the fact that the team had some issues with the launching station, the students were still able to work and enjoy a build day about rocketry.

Expanding the program with a larger audience, the team moved to Sprague High School and over the course of four class periods taught and interacted with a total of 191 students ranging from freshman to seniors. Working with the school's counseling office, the team scheduled to teach two Advancement Via Individual

Determination (AVID) classes per period for four periods. After congregating the classes into the school's cafeteria, the team presented a PowerPoint on the team and what it means to be an engineering major in college. Then after dividing the classes into three main groups, the team began three interactive experiments designed to engage and teach students the fundamentals of rocketry, aerodynamics, and electromagnetism:

- Rocketry: Providing practical demonstrations on the structure and build of rockets, students were given instruction on building matchstick rockets. Utilizing tin foil, wooden matchsticks, and tape the students got to build and launch rockets in a trial by error study of rocket fundamentals.
- Aerodynamics: Using paper cones with fins to manipulate drag forces, the students created various fins of different shapes and sizes from paper and attached them to the paper cones. The newly made paper cones with fins were then dropped over a large fan to see the effects of drag from different fins.
- Electromagnetism: Demonstrating the electromagnetic pull generated by a field, the students watched a pre-made electromagnetic train demonstration after which they had the opportunity to build their own personal electromagnetic motor using a D-battery, paper clips, duct tape, neodymium magnets, and magnet wire.

Based off the success of running stations, the team generated a collection of experimental stations that can be used and modified for any grade in school. These documents were then printed and collectively shown to the teachers at the next event in Walker Middle School. The teachers chose electromagnetism and mousetrap cars for their event. Taking place over the course of eight different period and three different science teachers, the team taught all eighth grade science classes for that day or roughly 191 students. The students worked in each station and got hands on work under the supervision and instruction of a team of two to three capstone team members. Additionally, the team brought an augmented reality simulator for our current rover design that the students were able to play with on an iPad.

8.3 Preparation and Planning

As the 2017-2018 USLI Capstone team at Oregon State is our first competitive team in our school's history, the educational outreach program especially strives to build relationships that will last for the coming year along with a proper continuity for the next team. To that end, the following have been made to aid with future educational outreach events in both electronic and paper form:

- Lesson Plans for over fifteen different subjects that can be related to either rocketry specifically or STEM fields. These are used for teachers to choose what best aligns with their current teaching plan and what materials are required.
- Contact list of schools that the team have reached out to with emails, names, and numbers. Additionally, the contact information for educational outreach managers for the Salem-Keizer district have been added as they can help facilitate outreach events with schools that college students could not.
- All outreach forms submitted to NASA for reference to the next outreach coordinator.

- A list of supplies left over from previous events and their locations in the school.

Appendix A

Electrical Schematics

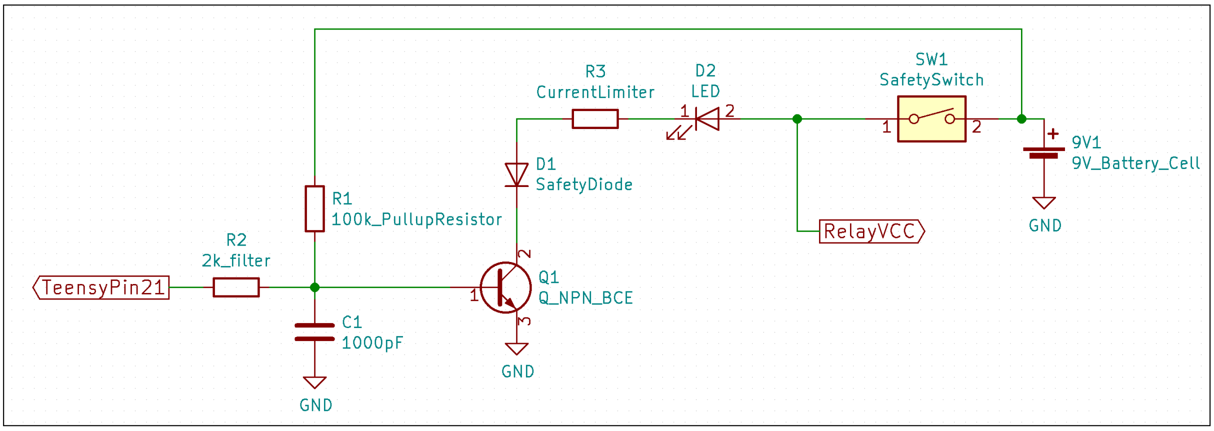


Figure 94: Payload Ejection Controller LED Indicator Conditioning

APPENDIX B

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