NASA Student Launch

2014-2015 FRR for Maxi-MAV

March 16, 2015

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Section 1. Summary of FRR Report

1) Team Summary

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2) Launch Vehicle Summary

The launch vehicle has been designed to be efficient in weight, manufacturing, and performance. The vehicle will be constructed out of fiberglass airframe, aluminum, plywood, and various additive manufacturing materials. The design focuses on allowances for expeditious assembly and disassembly. Table 1 shows a brief overview of the launch vehicle.

Overall Length (in)	143
Diameter (in)	6.17
Mass (lbs)	42.9
Motor Choice	CTI 3147-L935-IM-P
Recovery System	Dual deployment

Table 1: Launch vehicle overview.

The launch vehicle will utilize a custom made vortex ring parachute for main and cruciform parachutes for lower airframe and cache capsule.

See section 5.3 for milestone timeline.

3) AGSE/Payload Summary

The AGSE will utilize multiple power screw actuated devices to level the launch platform and erect the rocket to launch position. The launch platform will be in the form of a guide tower with three aluminum extrusions acting as launch rails. A custom payload arm has been designed to retrieve and deliver the payload to the rocket. A science value payload will be attached to the AGSE and will record weather data at multiple points along the height of the AGSE launch platform.

Section 2. Changes Made Since CDR

1) Vehicle Criteria

Due to nature of the scope of the project for this year's vehicle design, all designs had been finalized for the Critical Design Review. Since CDR, the team has focused on construction and manufacturing while following the strict design tolerances to ensure a quality end product. There have been no major design changes since CDR for this very reason.

2) AGSE Criteria

Since CDR, the system process timeline was adjusted after analyzing the costs of motor and gearbox combinations. The adjustment in the timeline allowed for a slower and therefore cheaper motor to be selected while still meeting the time requirement of the centennial challenge. The outriggers have been redesigned after an error was found in the initial load calculations. The loads were recalculated and the original design was found to not meet the team's design requirements. Additionally, the outrigger to ground interface had questionable stability and was therefore redesigned.

3) Project Plan

There have been a few instances where delays in manufacturing various components have delayed verification testing of certain systems. The project timeline and plan had to be adjusted accordingly.

See page 270 to view the updated project plan.

Section 3. Launch Vehicle Criteria

1) Design and Verification of Launch Vehicle

Design Overview

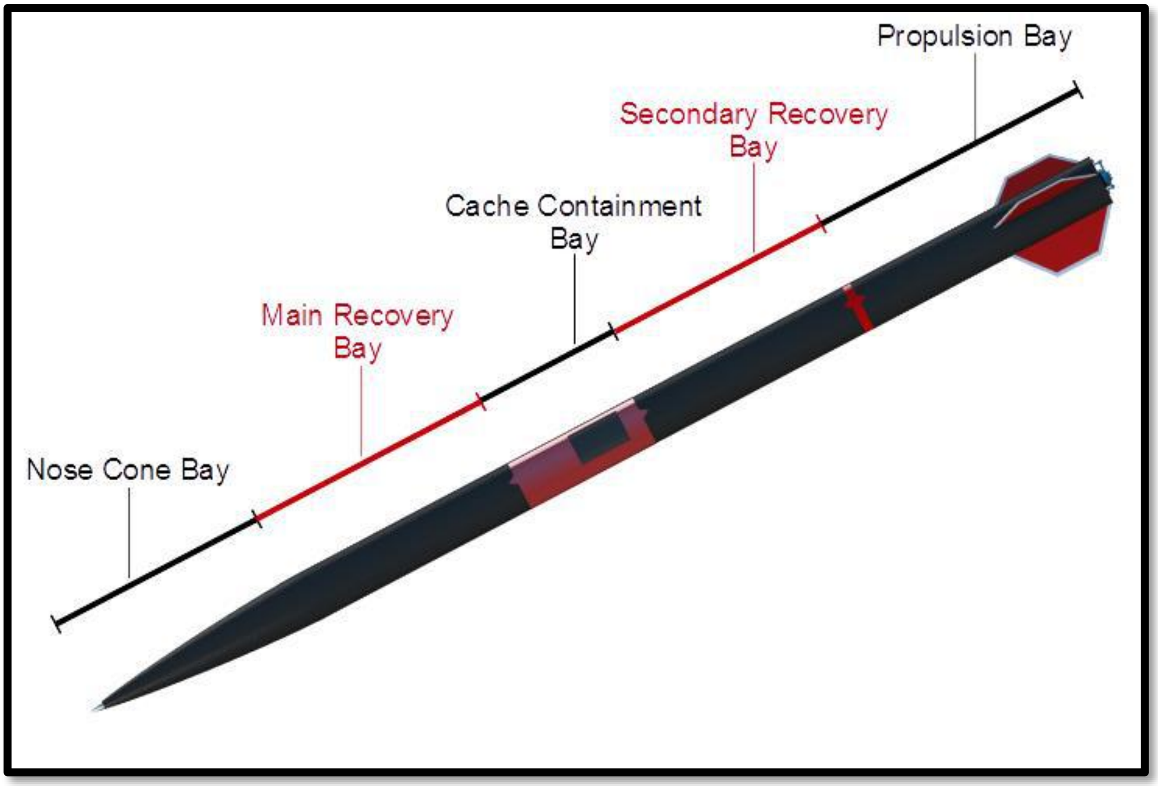


Figure 1: Layout of the primary launch vehicle sections.

The launch vehicle design is focusing on overall efficiency both inside and out. Previous year's competition launch vehicles had their own robust design features that were unique and proven reliable. The launch vehicle designed this year features revamped versions of certain systems while using experiences learned to push the quality and precision of the of all components and assemblies of the launch vehicle. Figure 1 shows the basic layout of all sub sections of the launch vehicle: nose cone bay, main recovery bay, cache containment bay, secondary recovery bay, and propulsion bay.

The launch vehicle is designed to be made of fiberglass airframe, to feature a removable fin system, to feature an integrated fairing deployment system, and to have a dual deploy recovery system. For the launch vehicle's flight to be considered a success, the vehicle must meet multiple flight requirements:

1. Leave the launch pad at over 50 ft/s.
2. Fly to an apogee of 3,000 ft with zero anomalies.
3. Actuate all recovery events at all programmed altitudes.

4. All vehicle section land under the mandated kinetic energy requirements.

Assuming all points are accomplished, the flight and recovery of the launch will be determined to be a success.

Applicable Formulations

Three core values must be calculated to assess the stability and success of the rocket: peak altitude, center of gravity, and center of pressure. The peak altitude is found through a precise sequence of equations. The average mass is first calculated using

$$m_a = m_r + m_e - \frac{m_p}{2} \tag{1}$$

where m_r is the rocket mass, m_e is the motor mass, and m_p is the propellant mass. The aerodynamic drag coefficient (kg/m) is then computed by

$$k = \frac{1}{2}\rho C_D A \tag{2}$$

where ρ is the air density (1.22 kg/m^3), C_D is the drag coefficient, and A is the rocket cross-sectional area (m^2). Equations 1 and 2 are utilized to calculate the burnout velocity coefficient (m/s) using

$$q_1 = \sqrt{\frac{T - m_a g}{k}} \tag{3}$$

where T is the motor thrust , and g is the gravitational constant (9.81 m/s^2). Equations 1, 2, and 3 are then used to compute the burnout velocity decay coefficient (1/s) using

$$x_1 = \frac{2kq_1}{m_a} \tag{4}$$

Equations 3 and 4 are used to calculate the burnout velocity (m/s) using

$$v_1 = q_1 \frac{1 - e^{-x_1 t}}{1 + e^{-x_1 t}} \tag{5}$$

where *t* is motor burnout time (s). The altitude at burnout can then be computed by

$$y_1 = \frac{-m_a}{2k} \ln\left(\frac{T - m_a g - k v_1^2}{T - m_a g}\right) \tag{6}$$

Once the burnout altitude is calculated, the coasting distance must be determined beginning with the calculation of the coasting mass using

$$m_c = m_r + m_e - m_p \tag{7}$$

The coasting mass replaces the average mass in equations 3 and 4; this results in equations 8 and 9 for the coasting velocity coefficient and coasting velocity decay coefficient, respectively:

$$q_c = \sqrt{\frac{T - m_c g}{k}} \tag{8}$$

$$x_c = \frac{2kq_c}{m_c} \tag{9}$$

Equations 8 and 9 can then be utilized to determine the coasting velocity (m/s) using

$$v_c = q_c \frac{1 - e^{-x_c t}}{1 + e^{-x_c t}} \tag{10}$$

The coasting distance can then be computed using

$$y_c = \frac{m_c}{2k} \ln\left(\frac{m_c g + kv^2}{T - m_c g}\right) \tag{11}$$

The peak altitude is then determined using

$$PA = y_1 + y_c \tag{12}$$

The center of gravity location is calculated using

$$cg = \frac{d_n w_n + d_r w_r + d_b w_b + d_e w_e + d_f w_f}{W} \tag{13}$$

where *W* is the total weight, *d* is the distance between the denoted rocket section center of gravity (nose, rocket, body, engine, and fins, respectively) and the aft end. The center of pressure measured from the nose tip is calculated using

$$X = \frac{(C_N)_N X_N + (C_N)_F X_F}{(C_N)_N + (C_N)_F} \tag{14}$$

where C_{NN} is the nose cone center of pressure coefficient (2 for conical nose cones), X_N is the computed by

$$X_N = \frac{2}{3} L_N \tag{15}$$

where L_N is the nose cone length. C_{NF} in equation 14 is the fin center of pressure coefficient calculated using

$$(C_N)_F = \left[1 + \frac{R}{S+R}\right]\left[\frac{4N\left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_f}{C_R + C_T}\right)^2}}\right] \tag{16}$$

where *R* is the radius of the body at the aft end , *S* is the fin semispan , *N* is the number of fins, L_F is the length of the fin mid-chord line, C_R is the fin root chord length, and C_T is the fin tip chord length . X_F in equation 14 is calculated using

$$X_F = X_B + \frac{X_R(C_R+2C_T)}{3(C_R+C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{(C_R C_T)}{(C_R+C_T)}\right] \tag{17}$$

where X_B is the distance from the nose tip to the fin root chord leading edge. X_R is the distance between the fin root leading edge and the fin tip leading edge measured parallel to body. Equations 14 through 17 are also known as the Barrowman Equations (The Theoretical Prediction of the Center of Pressure, 1966). Note that Equation 14 is a simplified form because the rocket has no transition in diameter in the body; thus, the transitional terms have been omitted.

Stability and Construction

The launch vehicle and its internal structure will be constructed primarily of fiberglass, plywood, ABS plastic, and aluminum. The vehicle is designed to house a cache capsule payload within its airframe. To ensure an efficient design, the launch vehicle is designed to host the cache capsule system as high up in the rocket as is reasonably possible.

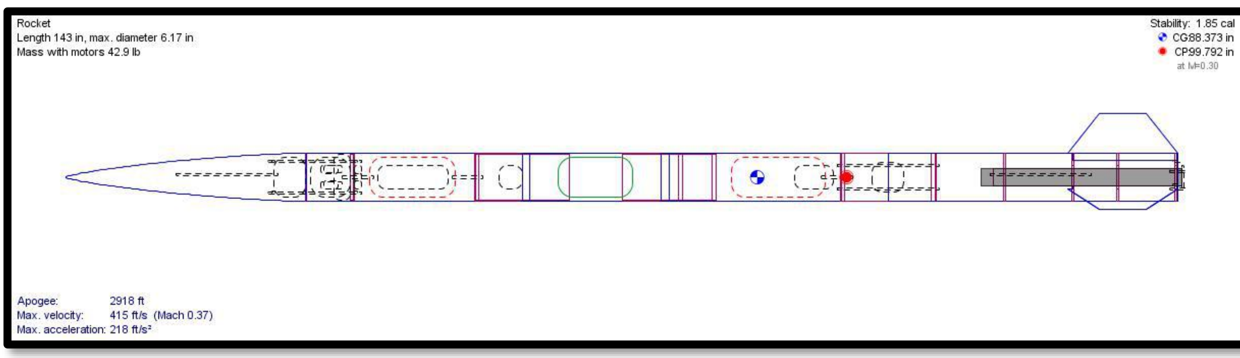


Figure 2: OpenRocket simulation of the launch vehicle.

Figure 2 shows the OpenRocket schematic of the launch vehicle. The vehicle is designed such that the cache capsule system, located inside of the fairing, will be located directly beneath the main recovery system. This allows one of the heavier systems in the vehicle to sit high up in the rocket, thus raising the center of gravity and in return, the stability. The figure also shows the locations of all recovery electronic bays, shown in black. The secondary recovery system is housed below the cache containment bay. The layout of the vehicle sections can be seen again in Figure 1.

The launch vehicle will be constructed by adhering to proven manufacturing processes listed below:

- All sections of the vehicle that are to separate at an event will be joined to their respective coupler with 4-40 nylon shear pins.
- All sections that are to stay intact throughout the course of the entire flight and descent will be joined with 8-32 UNC-2A metal fasteners.

- All bulk plates, centering rings, and permanently secured sections of the rocket will be epoxied using Glenmarc's G5000 two component filled epoxy (physical properties can be seen in Table 2).
- Coupling lengths were chosen based on a 1:1 ratio of airframe diameter to coupling length for rigidity.

Ultimate Tensile Strength (lbs/in^2)	7,600
Compression Strength (lbs/in^2)	14,800

Table 2: Physical property data of Glenmarc's G5000 epoxy.

Challenges	Solutions
Shear pins and metal fasteners shall be installed to not interfere with the guide tower rails.	All fasteners used to secure sections of the launch vehicle shall be installed in line with the fins.
All epoxied components shall be rigidly installed.	A liberal amount of Glenmarc's G5000 epoxy will be used at each joint.
The launch vehicle shall have rigid coupling sections.	The coupling length into a section of airframe shall be equal to that of the body diameter of the launch vehicle.

Table 3: Stability and construction challenges.

Manufacturing Processes

A focus on quality design is only as valuable as the quality of manufacturing processes. A practice in professional and industrial manufacturing was instituted to ensure all components were within design tolerances. The team was able to get hands on experience with all of the manufacturing equipment used to construct all the components for this year's launch vehicle.

The use of computer controlled manufacturing equipment saved time and energy in the design and construction of the launch vehicle. Designs could be changed, and a new part could be readily available in a short period of time.

A Universal Laser Systems ILS12.75 laser cutter was used to cut out all wooden bulkplates and silicone ballast spacers. Having a maximum laser power of 150 watts, the laser cutter, seen below in Figure 3 is able to cut through up to ¾" medium density plywood.

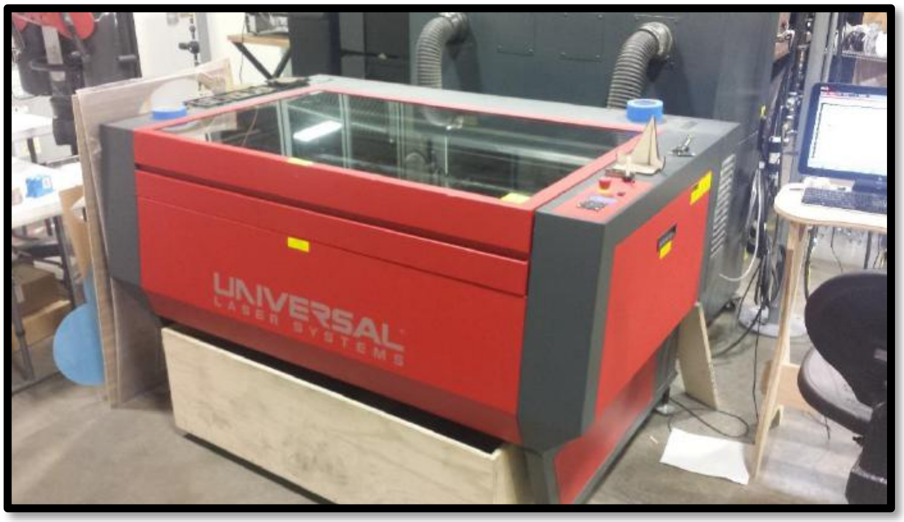


Figure 3: Universal Laser Systems ILS laser cutter.

The launch vehicle's wooden bulkplates were all cut from ½" medium density plywood, so the use of this system was effective. The team members were trained on how to use the software to control the laser cutter and how to improve a design to satisfy a need for ease of manufacturing. There were only a few steps involved in cutting out a part:

1. Create a 2D drawing of the component in question.
2. Convert the 2D drawing to a DXF (similar to the one shown in Figure 4).
3. Import it into the laser cutters software.
4. Attribute tool paths to various 2D vectors to signal where the laser cutter will cut.
5. Import your solid material onto the laser cutter's bed.
6. Begin the laser cutter's program for the model.
7. Remove components when finished.

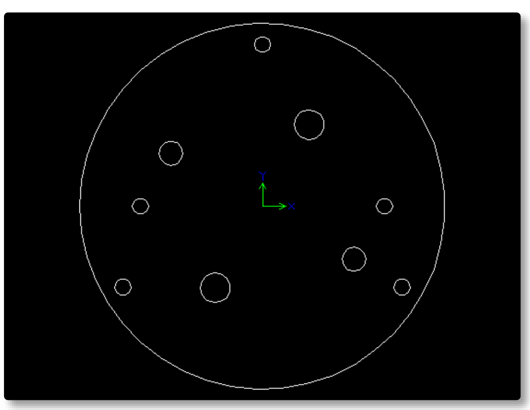


Figure 4: DXF file for a bulkplate inside the launch vehicle.

The use of a MAXIEM 1530 waterjet, shown below in Figure 5, aided in the construction of all fiberglass bulkplates, fins, aluminum centering rings, motor casing retainer, and ballast weights.

Figure 5: MAXIEM 1530 waterjet.

The waterjet opened doors to certain components that would otherwise not be available to the team due to budget constraints. Similar to the laser cutter, team members were able to be trained on the equipment so that they could run the machine themselves. The water jet uses water, pushed through a nozzle in upwards of 50,000 psi, mixed with an abrasive garnet to cut through up to 6 inches of steel. The process of cutting a component from a stock sheet of material is similar to that of the laser cutter. Only a few steps are needed:

1. A 2D file must be created of the component in question.
2. The 2D file must be converted into a DXF file.
3. The DXF must be imported into the MAXIEM software.
4. Each line must be given a tool path.
5. The material being cut must be imported onto the bed of the waterjet.
6. The waterjet nozzle must then be zeroed out in both the X and Y directions, and in a Z direction .070” above the material.
7. The system’s program shall then be started.
8. The part can be removed and cleaned afterwards.

Each aluminum and steel component cut out on the waterjet was sandblasted. This was to give all components a clean surface finish. Each part was sandblasted in a Cyclone Manufacturing 3624 sandblasting cabinet, shown below in Figure 6.

Figure 6: Cyclone Manufacturing 3624 sandblasting cabinet.

Team members were trained on the safety and use of this piece of equipment. Various test samples were supplied to team members for practice. The surface finish of a component being sandblasted can be compared to that of something being spray painted. To ensure an even finish, one must be direct and precise in how they spray down the component. The following lays out how the parts were sandblasted:

1. Insert component into the bed of the sandblaster.
2. Check all seals to ensure they are intact.
3. Turn on the sandblaster.
4. Insert hands into the rubber sleeves and grasp the component and sandblaster nozzle.
5. Use the foot pedal to actuate the sandblaster nozzle to spray down the component.
6. Turn of the sandblaster.
7. Remove component from the bed of the sandblaster.
8. Spray of residual sand via a compressed air hookup.

Track wheels for the door assembly on the launch vehicle were hand machined from Delrin rod stock. Team members were trained on a Clausing hand lathe, shown below in Figure 7, to manufacture these components.

Figure 7: Clausing hand lathe.

The custom rear fin retainer was a component on the launch vehicle that could not be directly manufactured by hand. Having complex geometry, the team used a HAAS VF-2 CNC mill, shown below in Figure 8, to manufacture the component. Team members worked with trained technicians to produce the component.

Figure 8: HAAS VF-2 CNC mill.

To bring the part to fruition a 3D model was created. The tooling for the HASS CNC was then programmed using HSMXpress. With the tooling checked for accuracy, the stock material was placed into the machine, where the machine was zeroed to its correct datum and the program run.

Additive manufacturing played a large role in the design of various systems inside the launch vehicle. Learning to design for manufacturing can be a great tool to have in your toolbox. With the capability of 3D printing components, team members were allowed a bit of freedom in terms of their design. Figure 9 shows how components could be designed to be not only functional, but also aesthetically pleasing.

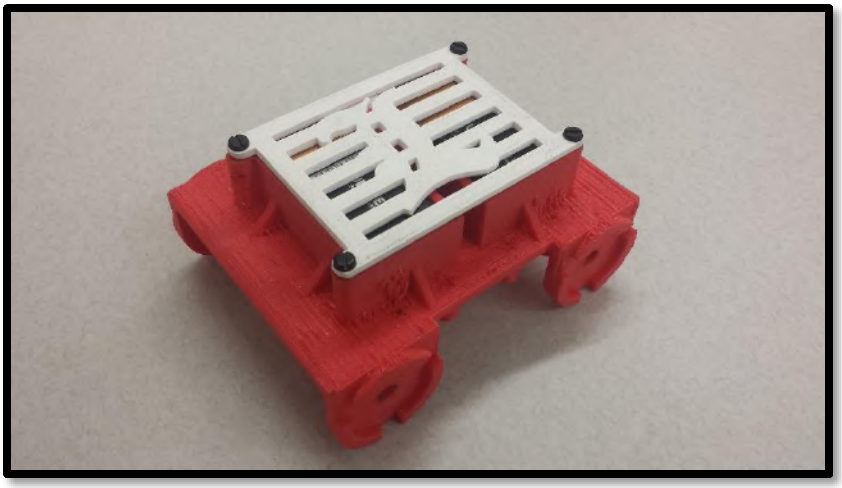


Figure 9: 3D printed altimeter sled with a nod to the University of Louisville.

The team had access to multiple 3D printers: Makerbot Replicators, Stratasys Fortus 400mc, and a Stratasys uPrint SE. Team members became familiar with the user interface of all printer software. Printing on any of the printers required the importing of an STL file of a 3D modeled component.

Figure 10: Stratasys uPrint SE 3D printer.

Challenges	Solutions
All machines shall be operated as intended.	Each team member using a piece of equipment shall go through a complete training course on how the machine operates prior to use.
All machines shall be operated safely.	All required PPE (personal protective equipment) shall be worn at all times while using the equipment. Furthermore, all safety procedures will be followed per the user manual of the piece of equipment.

Table 4: Manufacturing processes challenges.

Nose Cone Design

The Von Karman Nosecone, seen in Figure 11, was chosen due to its performance through subsonic and transonic speeds.

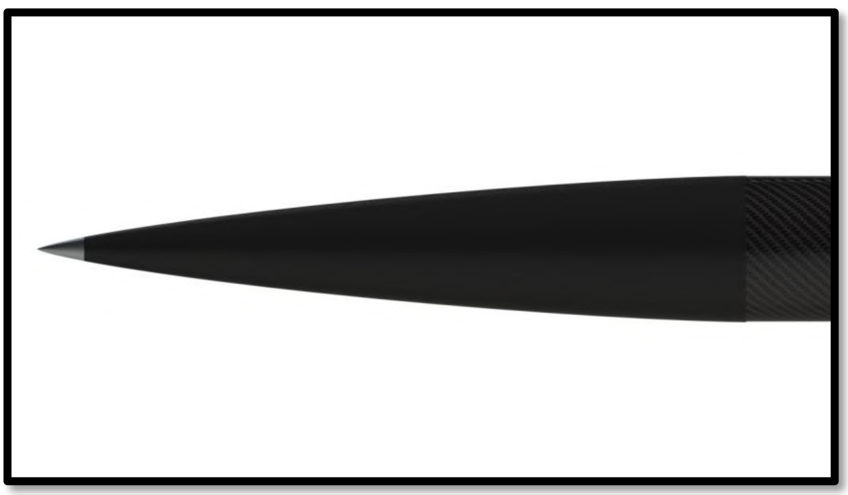


Figure 11: Von Karman nose cone modeled in SolidWorks.

The overall internal dimensions of the Von Karman nosecone also allows for the containment of an avionics bay, thus allowing an efficient use of space. A Garmin GPS unit will be installed inside the nosecone fore of the avionics sled.

Challenges	Solutions
The nose cone shall fully integrate a GPS unit, altimeter, and ballast system.	Proper measurements shall be incorporated into the modeling procedures for creating all systems included inside the nose cone.
Nose cone threaded tip shall be structurally intact.	Before and after each flight, the nose cone will be inspected for damage. In the event that the threaded aluminum nose cone tip was been damaged, it shall be permanently epoxied in placed using Glenmarc's G5000 epoxy.

Table 5: Nose cone design challenges.

Bulkheads Design

Each wooden bulkhead, or bulkplate, was laser cut from ½" medium density plywood. When a bulkhead was closing off a section of airframe or coupler tubing, a 1/8" fiberglass bulkhead was secured to the wooden bulkplate. The fiberglass bulkhead added rigidity to the bulkhead assembly. For fastening threaded rods, U-bolts, and other hardware, building standards were followed. Each threaded nut was matched with its complimenting designated washer, as seen below in Figure 12.

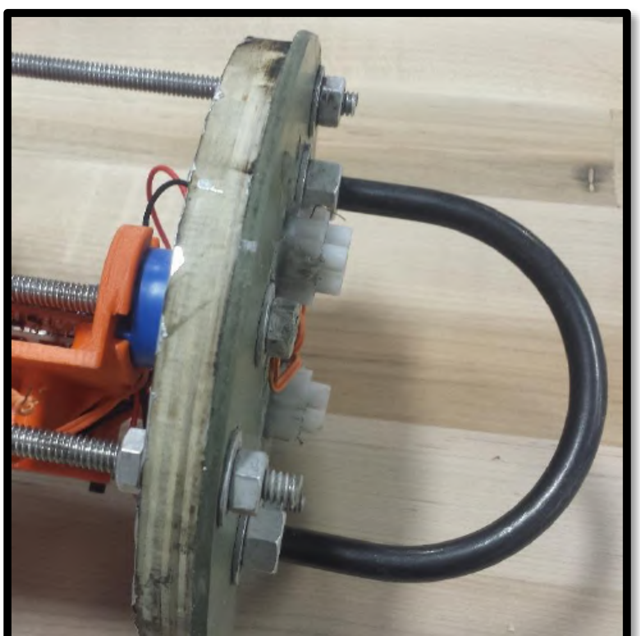


Figure 12: Use of threaded nuts and washers to secure bulkheads and fasteners.

In certain cases, where necessary, split lock washers were used to reduce the chance of bolted connections to come undone due to the vibrations of launch and flight. Similarly, precautions had to be met to ensure electronics were electrically shielded from each other throughout flight. This would alleviate the concern of programmed electronics failing due to interference from various electronic systems. Each bulkhead that was shielding electronics had a layer of aluminum tape applied to its face, as shown below in Figure 13.

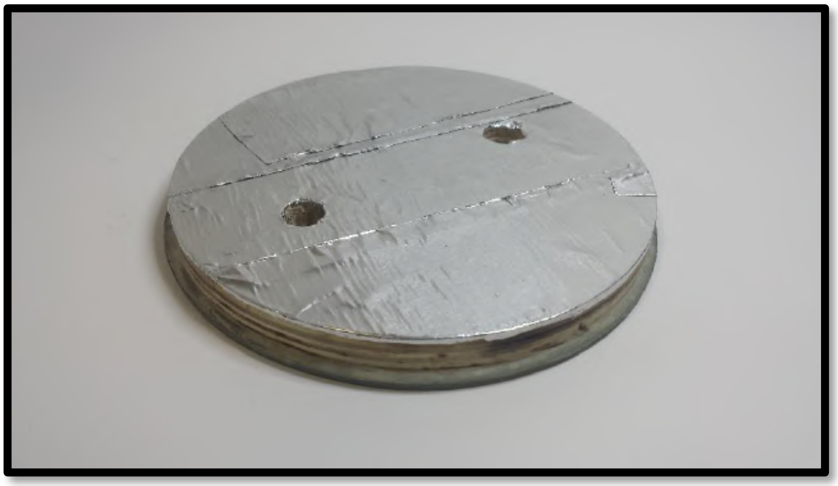


Figure 13: Aluminum tape added to bulkplate to shield sensitive electronics.

Challenges	Solutions
Sensitive electronics shall be shielded from each other.	Each separating bulkhead will have aluminum tape applied to its innermost face.
All connecting fasteners must be properly secured.	Standardized fastener selections will be used for various fastener choices.

Table 6: Bulkhead design challenges.

Ballast System Design

Until the launch vehicle is physically manufactured, the team must rely on the OpenRocket Simulation and hand calculations to estimate the projected apogee of the flight. It is understood that true weights of various components may contradict their calculated, estimated, and/or researched values. This change in weight has the possibility of changing the placement of the center of gravity of the launch vehicle. With safety and stability on the forefront of the design, a weighted ballast system has been designed to allow adjustability to the center of gravity once the rocket is constructed.

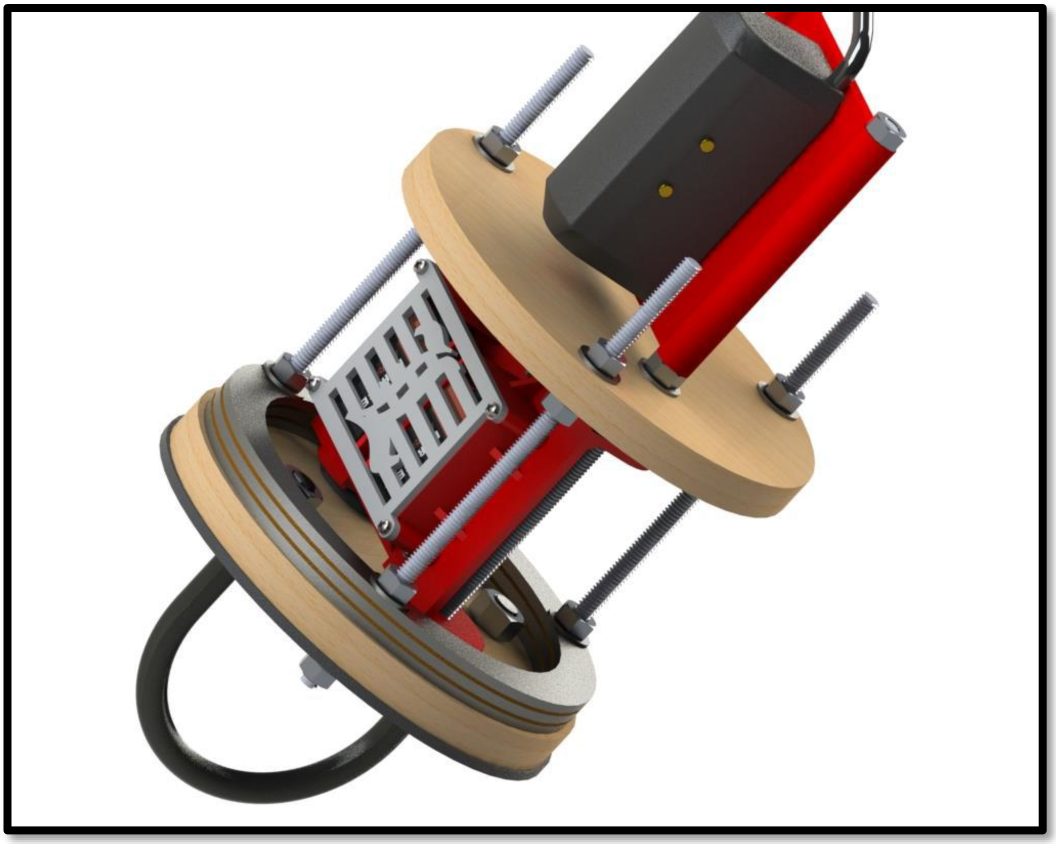


Figure 14: Rendered image of the nose cone's ballast system.

The primary goal in the design of the ballast system is to ensure it did not interfere with any other systems. Figure 14 shows a rendered representation of the nose cone's avionics bay, GPS mounting sled, and vehicle ballast system. By designing the ballast weights to be rings in shape, the avionics are able to mount to the nose cone's bulk plates without interference.

The ballast system consists of three components:

1. AISI 1018 low carbon steel ballast weight rings
2. Silicone rubber ballast spacers
3. ¼"-20 UNC-3A threaded fasteners

Figure 15 shows the detailed drawing for the steel rings used as the weighted ballast.

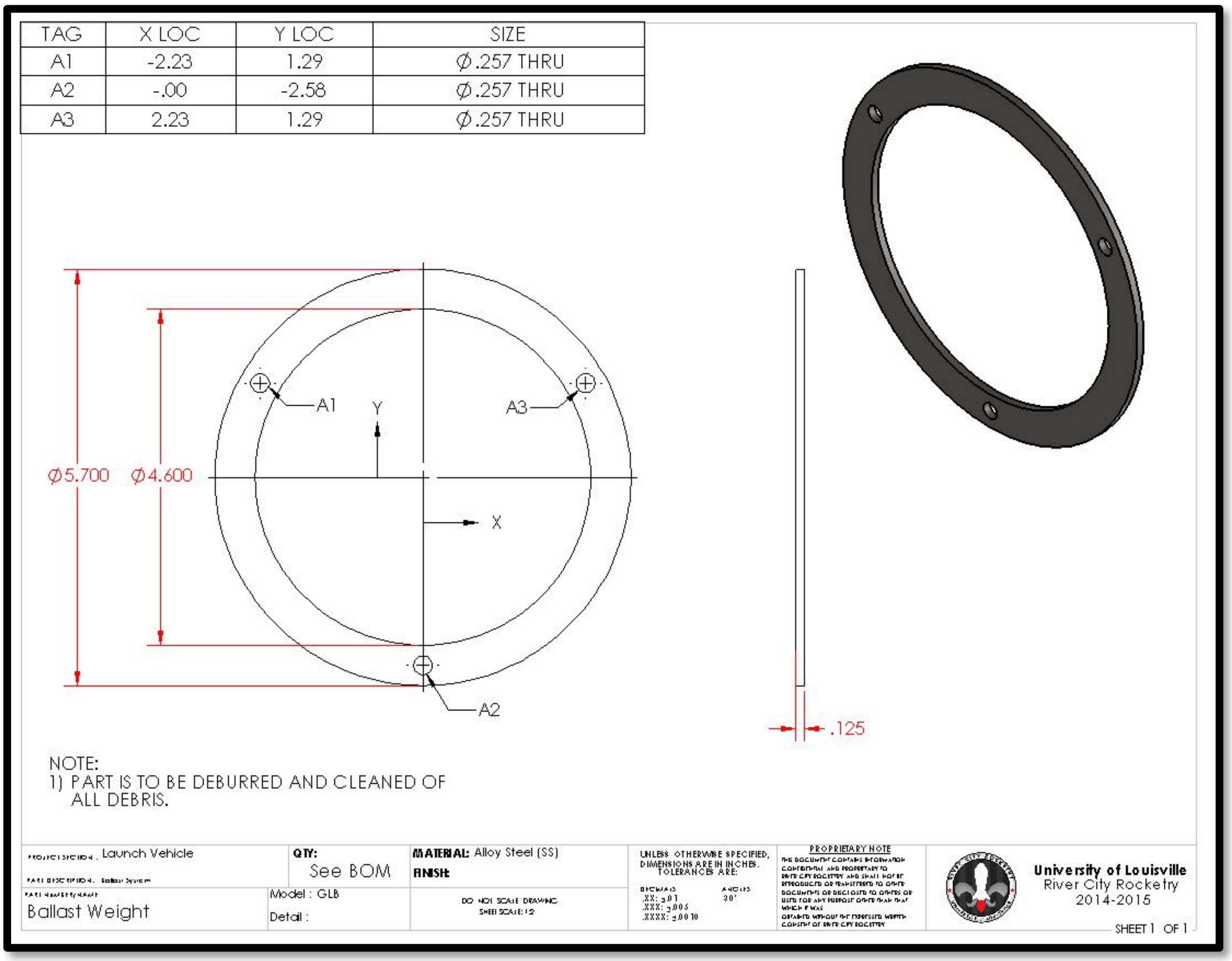


Figure 15: Detailed drawing of the ballast weight.

Figure 16 shows the detailed drawing of the rubber ballast spacer.

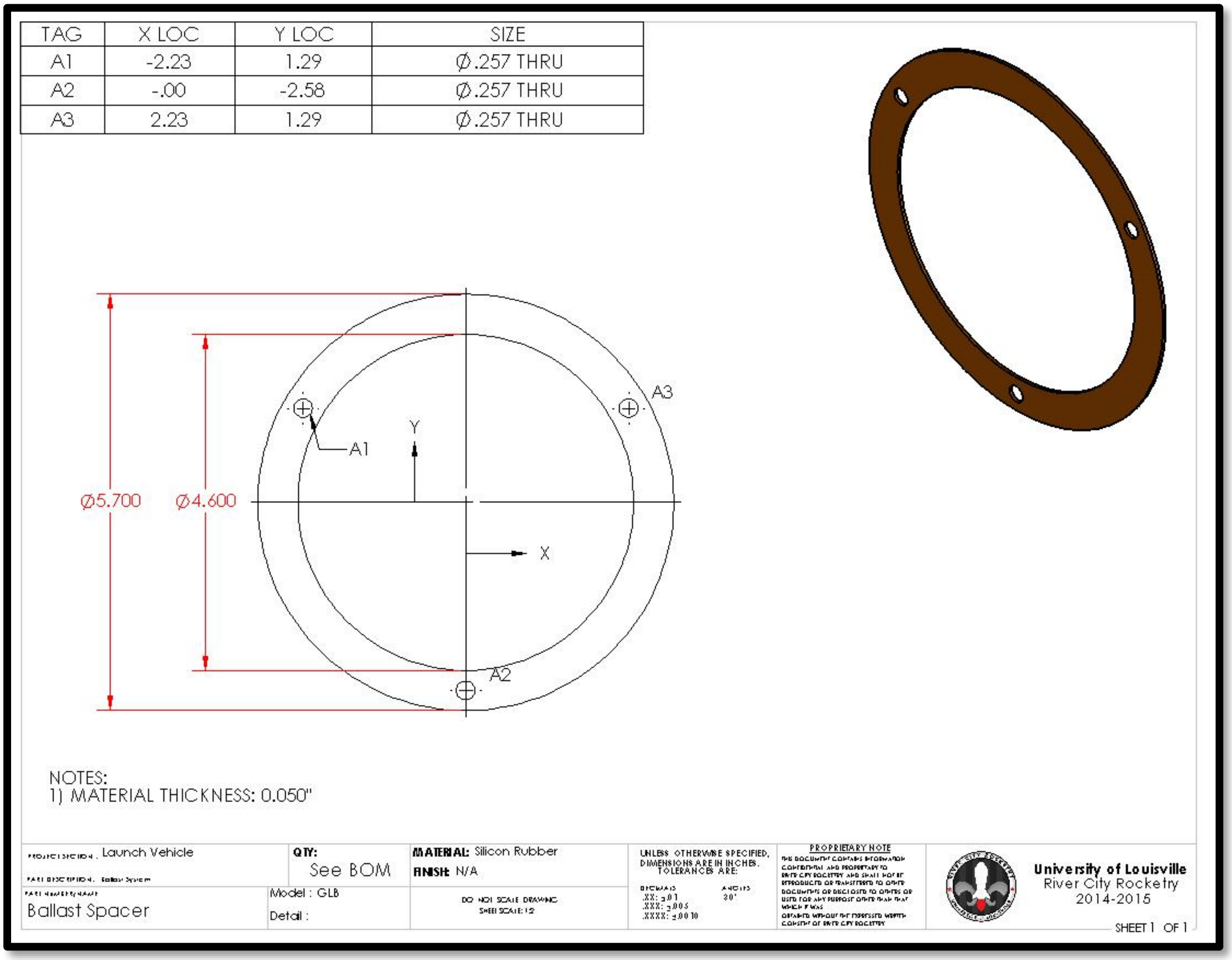


Figure 16: Detailed drawing of the ballast spacer.

The inclusion of the silicone rubber spacers is to dampen vibrations that would occur between the steel rings if there was any play between them. The material thickness of each component was chosen as the optimum choice to allow for logical adjustability. Table 7 shows the masses of the ballast weight and spacer.

Part	Material	Density	Part Mass
Ballast Weight	AISI 1018 Low Carbon Steel	0.282 lbs/in^3	0.308 lbs
Ballast Spacer	Silicone Rubber	0.045 lbs/in^3	0.019 lbs

Table 7: Overview of ballast component masses.

As the launch vehicle is constructed, and weights are updated in the OpenRocket simulation, the team has the ability to control the location of the center of gravity. This will allow for predictable flight stability on launch day. The ballast weights can be added, with a spacer, in line as deemed necessary to keep the center of gravity at a predetermined location.

Challenges	Solutions
3D printed sled integrations shall address vibrational issues.	Rubber dampers have been added to the aft and fore side of each 3D printed sled to absorb vibrations caused by the flight of the launch vehicle.
The CG of the launch vehicle shall be adjustable.	The weighted ballast weigh in at 0.308 lbs each and allow for quick CG adjustability.
The ballast system shall not cause undesired vibrations during flight.	Silicone rubber ballast spacers will be installed between each weighted ballast.

Table 8: Ballast system design challenges.

Propulsion Bay Design

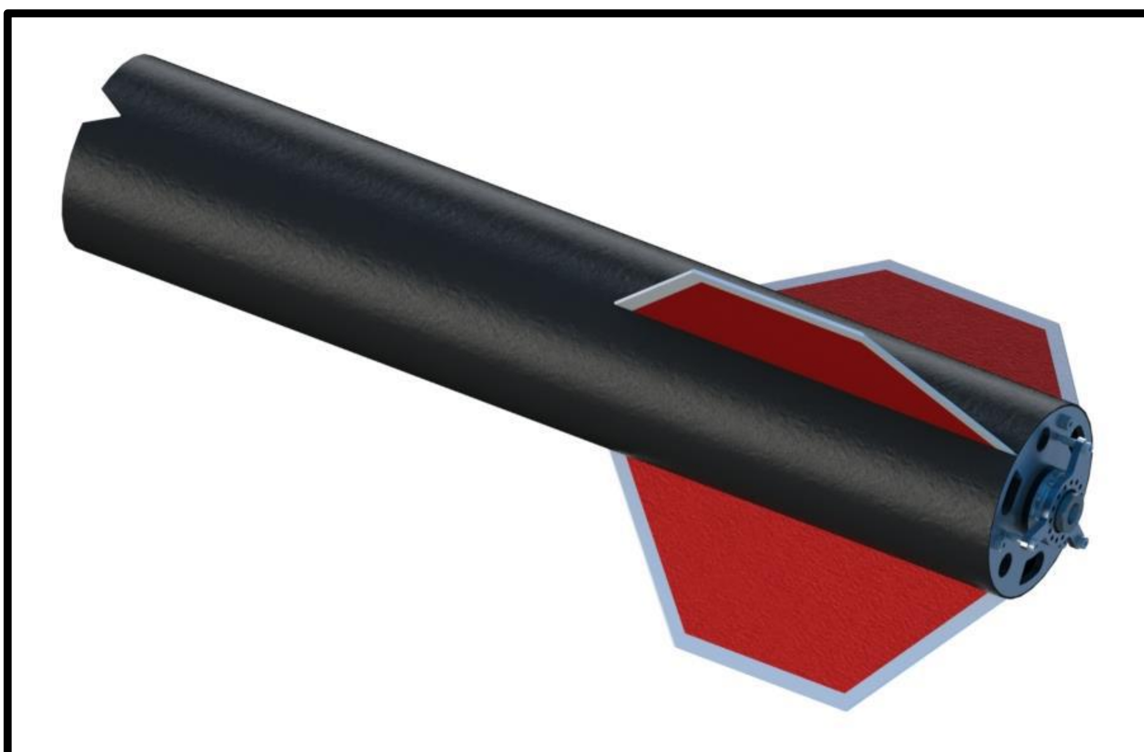


Figure 17: Assembled propulsion bay.

The propulsion bay will serve two specific purposes:

1. Serve as the connection point for the fins.
2. House the motor and casing.

Airframe

The outer airframe of the propulsion bay will consist of 6.0” diameter fiberglass tubing. The slots will be precision cut on a ShopBot CNC wood router to ensure correct alignment of fins during installation. To do this, the team will develop a jig for ease of manufacturing.

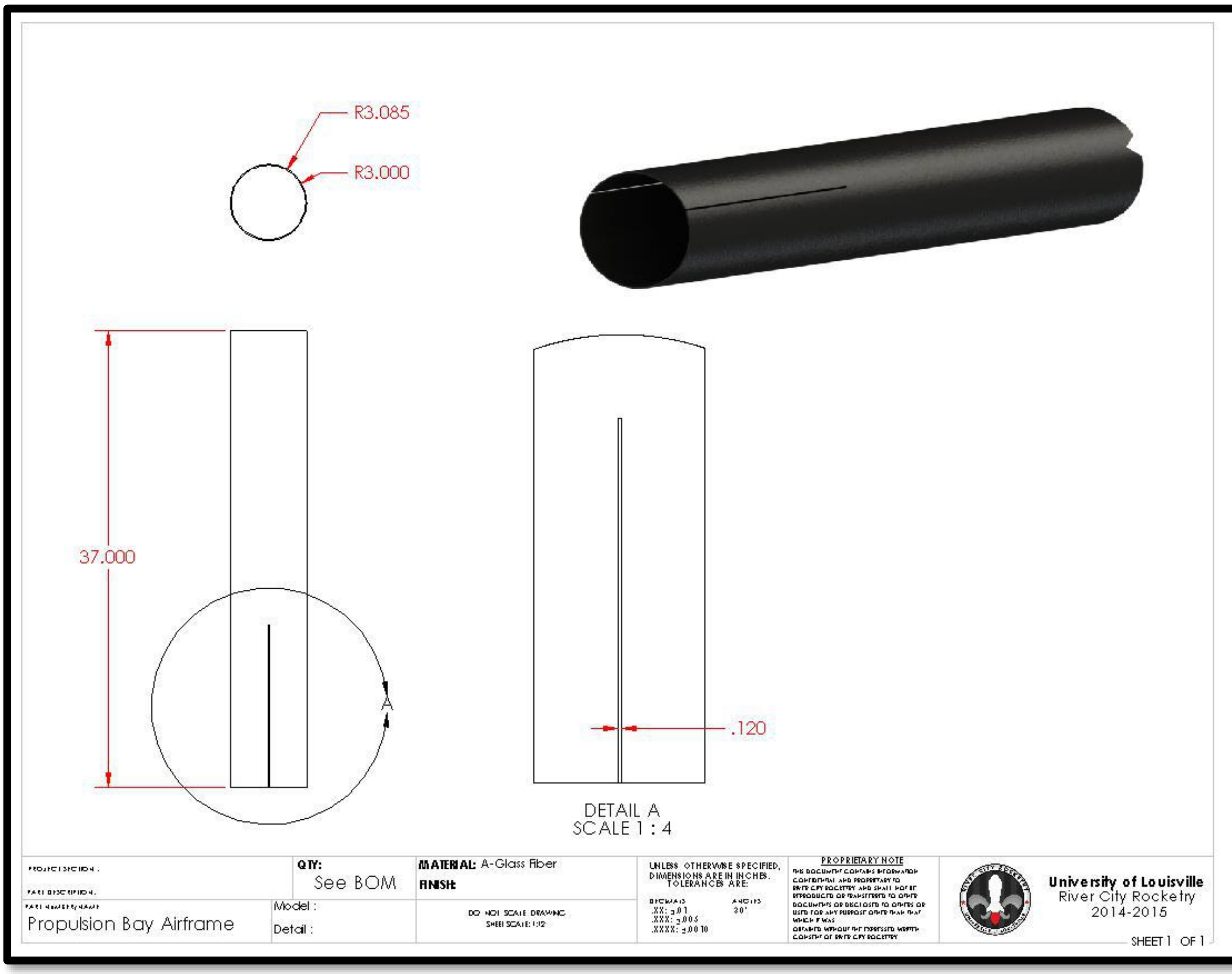


Figure 18: Detailed drawing of propulsion bay airframe.

Motor Tube

The motor tube will consist of 2.13” diameter fiberglass tubing. The motor tube will be cut to house the launch vehicle’s motor with two inches of motor overhang. An aluminum centering ring, cut out on a MAXIEM waterjet, will be epoxied two inches below the fore end of the motor tube.

Fin Mounting Design

To eliminate the reliance of epoxy as the only means of mounting the fins to the launch vehicle, a precision removable fin system is being implemented. The design allows for quick and easy removal and installation of the launch vehicle's fins. This will inherently eliminate the risk of having the rocket incapable of flight in the event of a fin breaking with no time to secure a new fin. Replacement fins will be readily available, and in the event of a damaged fin, a new fin will be able to take the damaged fin's place.

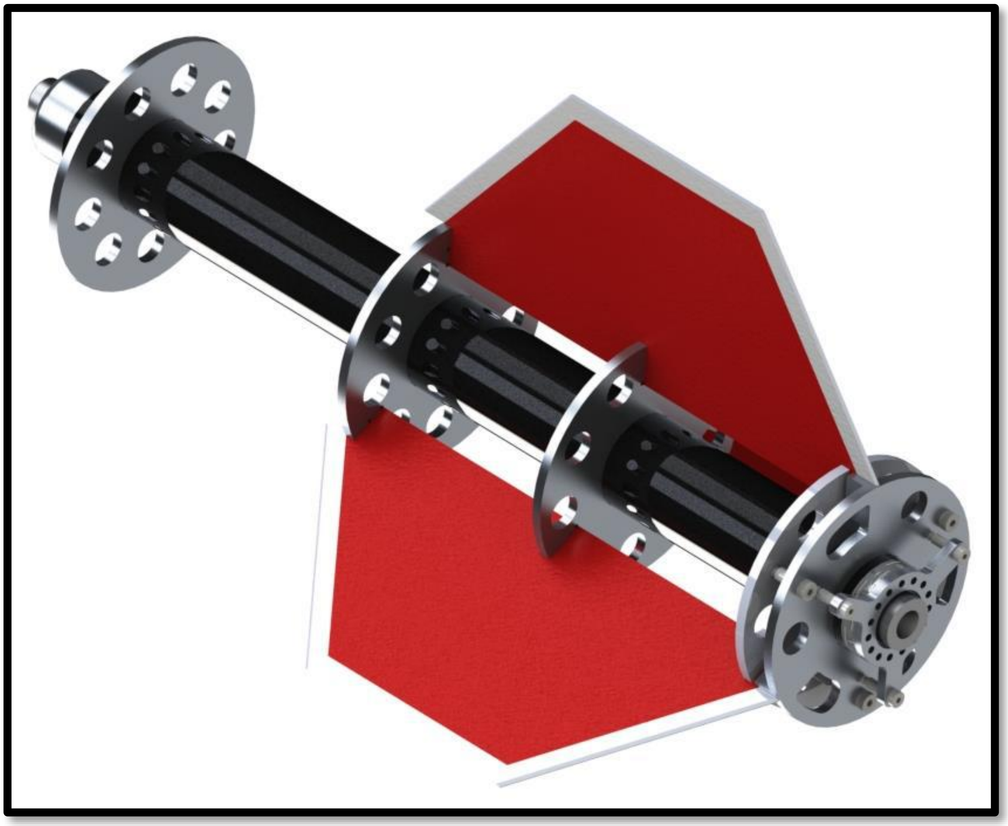


Figure 19: Propulsion bay's removable fin assembly.

Figure 19 shows the assembled removable fin system as it would appear within the propulsion bay. The assembly consists of three centering rings, a rear fin retainer, and a motor casing retainer. The centering rings will be the only components using epoxy to hold them in place around the motor tube. The fin retainer is mounted to the aft centering ring by use of ¼"-20 UNC-3A threaded shoulder screws ¾" in length. With the motor inserted into the motor tube, the motor casing retainer will be mounted to the rear fin retainer with ¼"-20 UNC-3A threaded shoulder screws ¾" in length. All fasteners in the motor tube assembly will be made from 18-8 stainless steel. An exploded representation of how the assembly fastens together can be seen below in Figure 20.

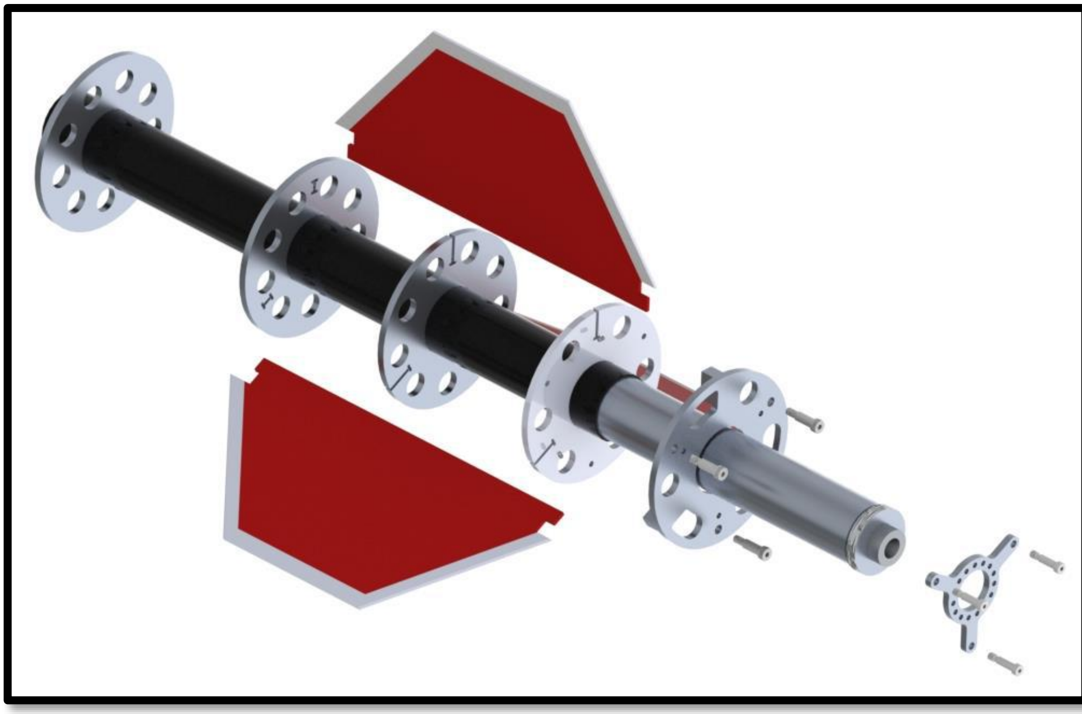


Figure 20: Exploded view of removable fin system.

The lower three centering rings in the motor tube assembly are designed to host the fins. The centering rings and rear fin retainer are designed for a push fit within the launch vehicle's airframe and over the motor tube. Furthermore, a set screw is to be installed into each rear fin retainer tab to firmly secure the fin in its installed position.

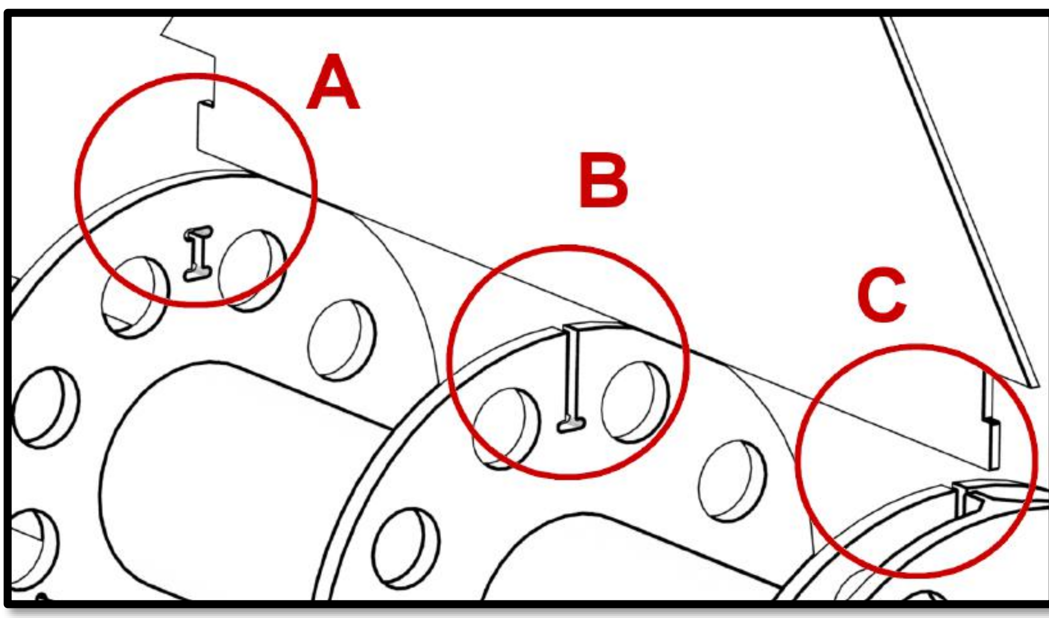


Figure 21: Highlighting the three connections between the fins, centering rings, and fin retainer.

There are three points of connection between the fins and the motor tube assembly

A. Fore centering ring
B. Middle centering ring
C. Aft centering ring and rear fin retainer

The process for installing the fins into the launch vehicle is described in the following three figures with the propulsion airframe not shown. As shown in Figure 22, the fin is to be pressed into the fin slots of the middle and aft centering ring. This fitment will be snug, and the use of a dead blow hammer is recommended to ensure the fin is properly seated.

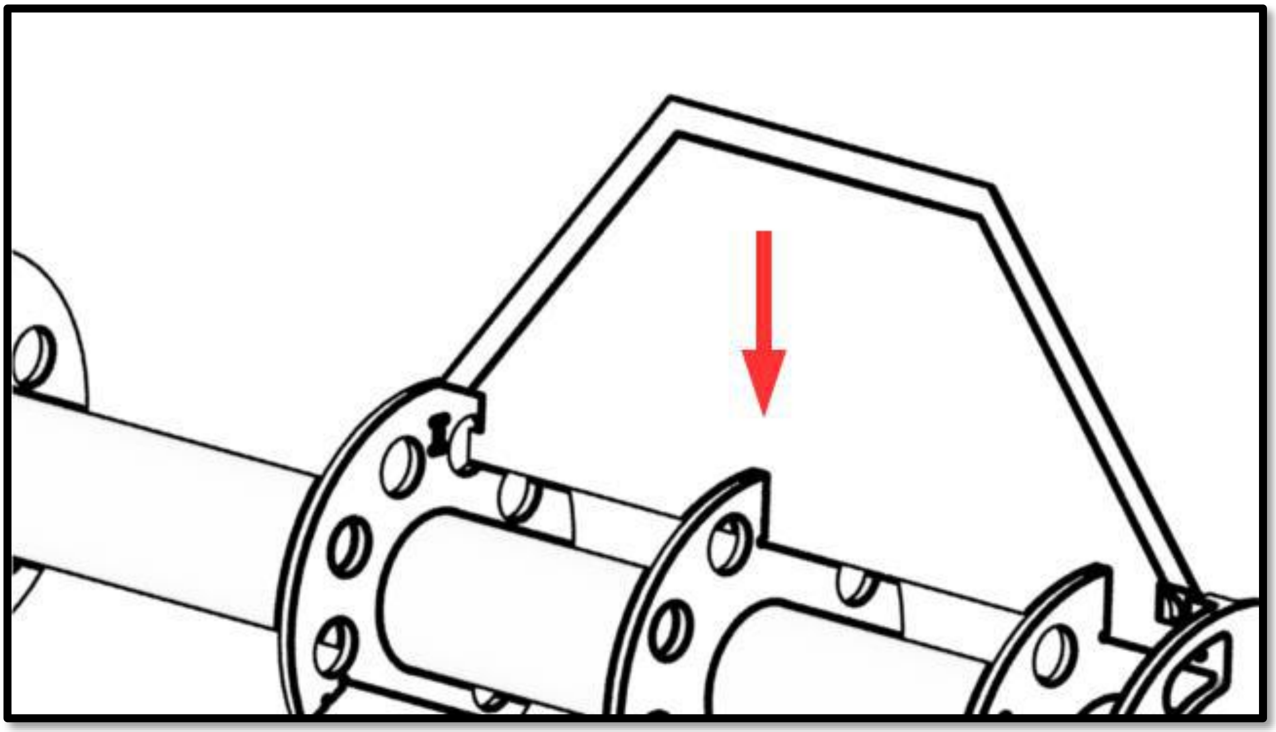


Figure 22: Fin being pushed into centering ring fin slots.

Once the fin is properly seated, the fin is to be pushed forward, as seen below in Figure 23. The fore tab of the fin will have a press fitment into the fore centering ring's fin tab slot. Once again, a dead blow hammer is recommended to be used to tap the fin firmly into the fin tab slot.

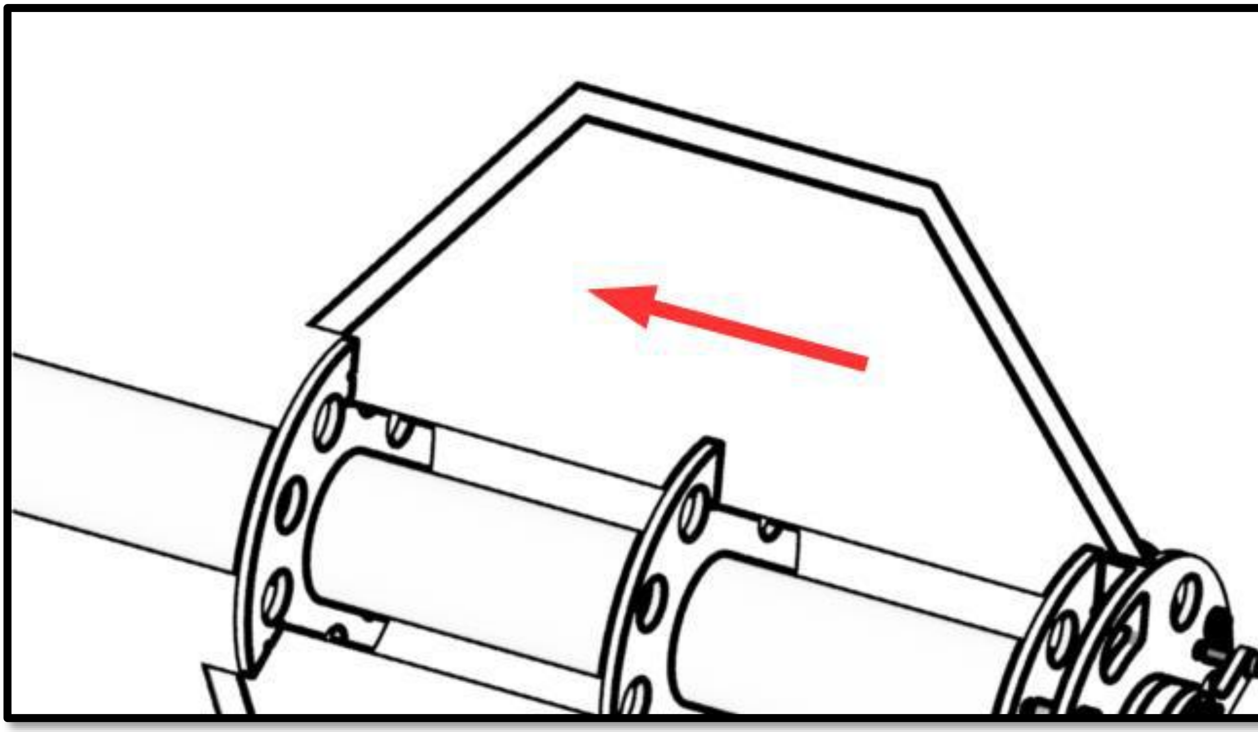


Figure 23: Fin is pushed forward so that the fin tab inserts into aft centering ring.

Upon inspection that the fin is properly seated both down into the fin slots, and forward into the tab slots, the rear fin retainer can be installed onto the aft centering ring. The 6-32 UNC-2A set screw should be installed into the rear fin retainer, as seen below in Figure 23.

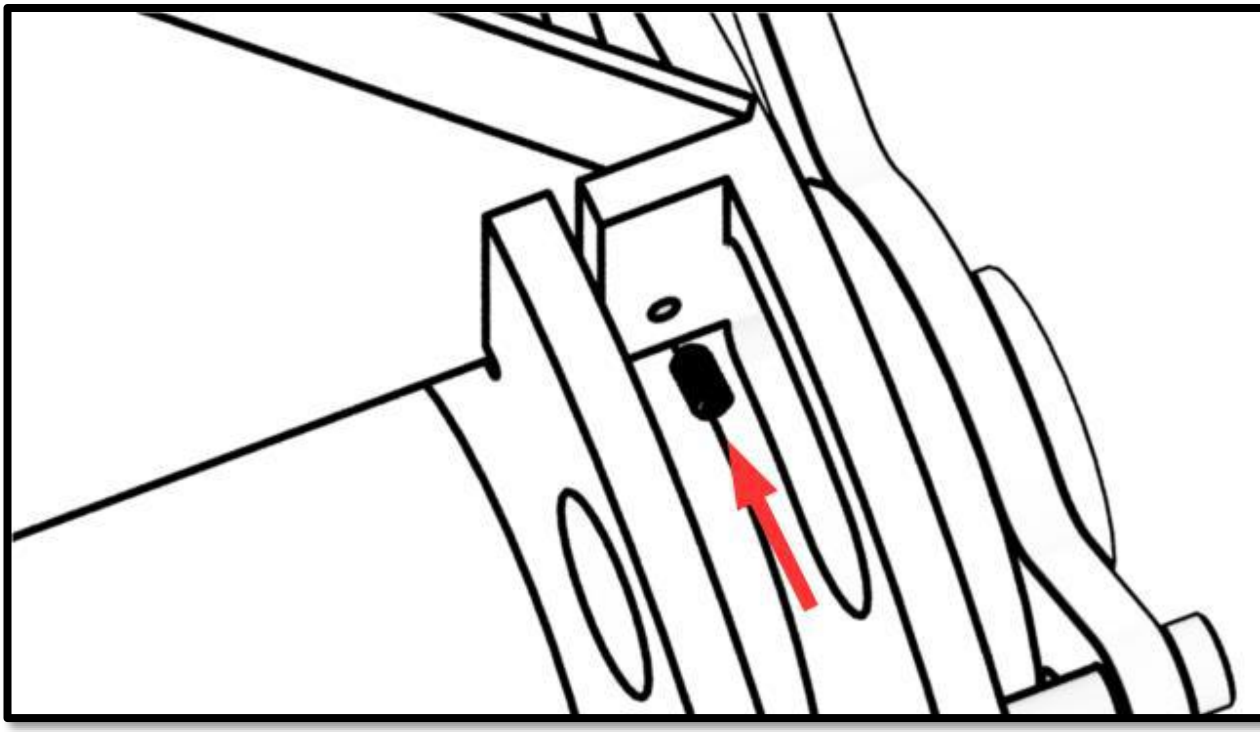


Figure 24: Installing the set screw to secure the fin inside the rear fin retainer.

The set screws used have a thread-locking nylon patch, as seen in Figure 25. This choice of fastener was chosen to reduce the risk of the set screws losing their clamping integrity due to the vibration the launch vehicle will see during flight.

Figure 25: Thread-locking nonmarring flat point set screws.

The rear fin retainer's technical drawing is shown below in Figure 26.

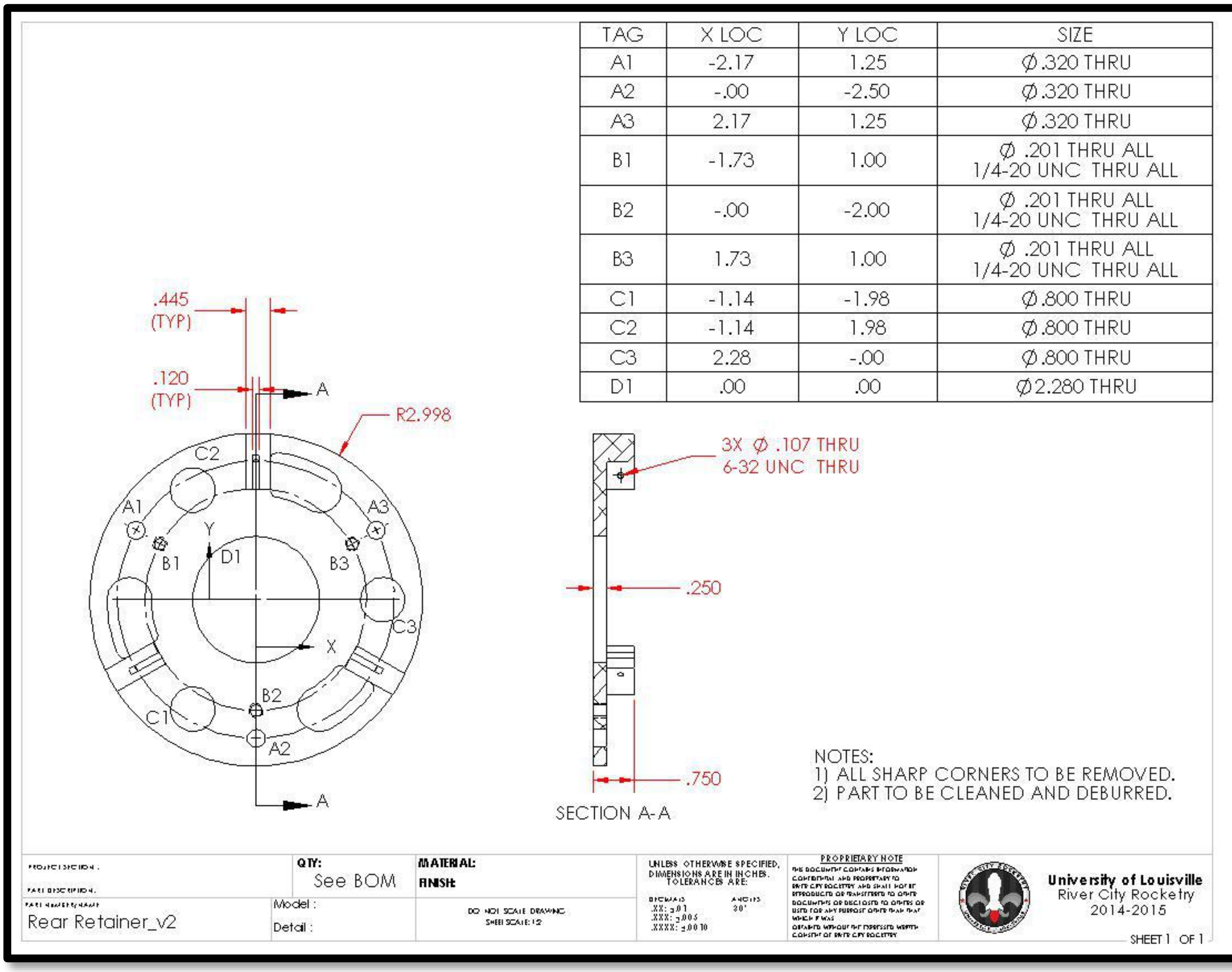


Figure 26: Rear fin retainer technical drawing.

To allow for this addition of set screws into the design of the fin retention system, the rear fin retainer had to be modified. An Allen key has to be able to fit down between the aft centering ring and rear fin retainer to install the set screw. Figure 27, shown below, shows the modification and the clearance for the Allen key.

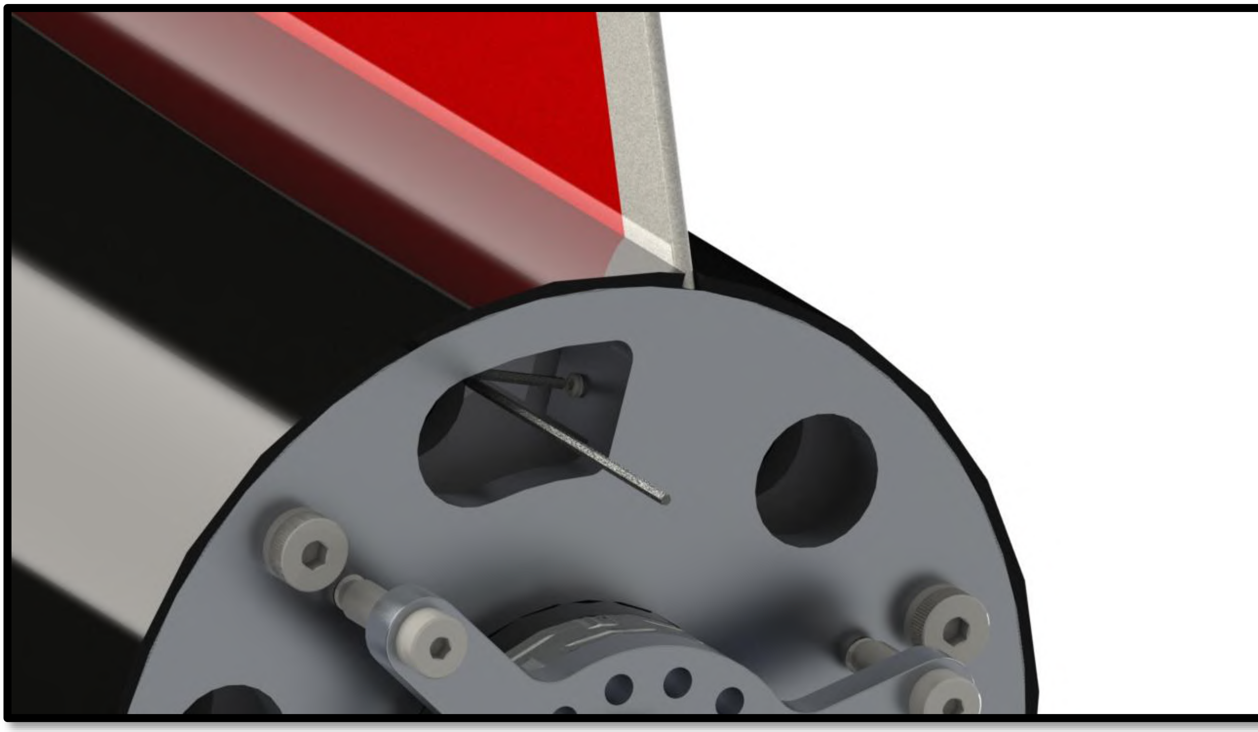


Figure 27: Modified rear fin retainer to allow access for an Allen key.

Fin Design

To remove unwanted drag, the launch vehicle will have three fins. The fins will be constructed from G12 fiberglass. A material thickness of 1/8” was chosen for the fins as the launch vehicle will fly solely at subsonic speeds. The fins will be cut out using an MAXIEM waterjet. With one of the primary reasons for the implementation of this system being that a damaged fin could quickly be replaced, a total of 6 fins have been cut out, as seen below in Figure 28. By using the waterjet to cut out the fins, each fin can reasonably be said to be identical in every way.

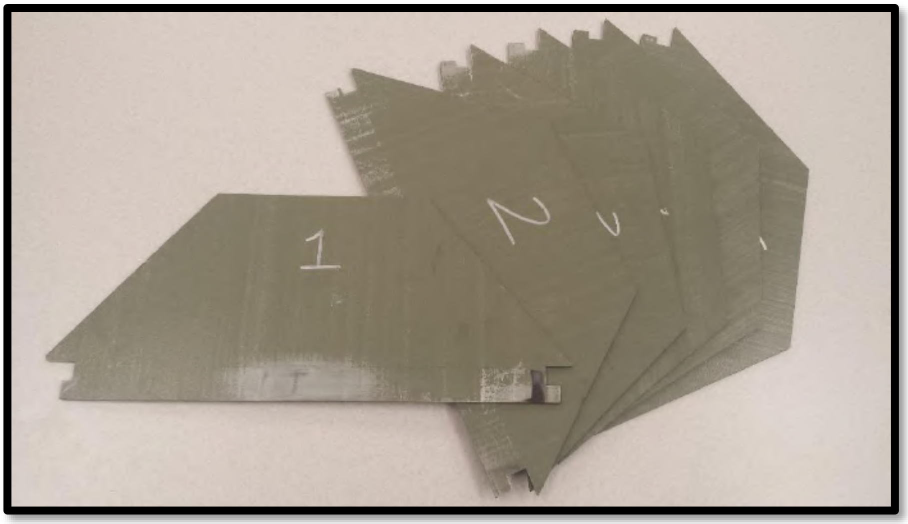


Figure 28: All six fins cut out by use of the waterjet.

By having multiple fins cut out, each fin slot can be assigned a certain fin for ease of installation. Due to the minor changes of thickness in a large fiberglass sheet, each fin slot was designated two fins, as seen below in Figure 29. Each fin was specifically sanded at all contact points to fit a specific location. This ensures a snug fit when installed and eliminates the need for a shim to be inserted with each fin.

Figure 29: Fin designation located on the propulsion bay.

Figure 30, below, shows the detailed drawing of the launch vehicle's fin.

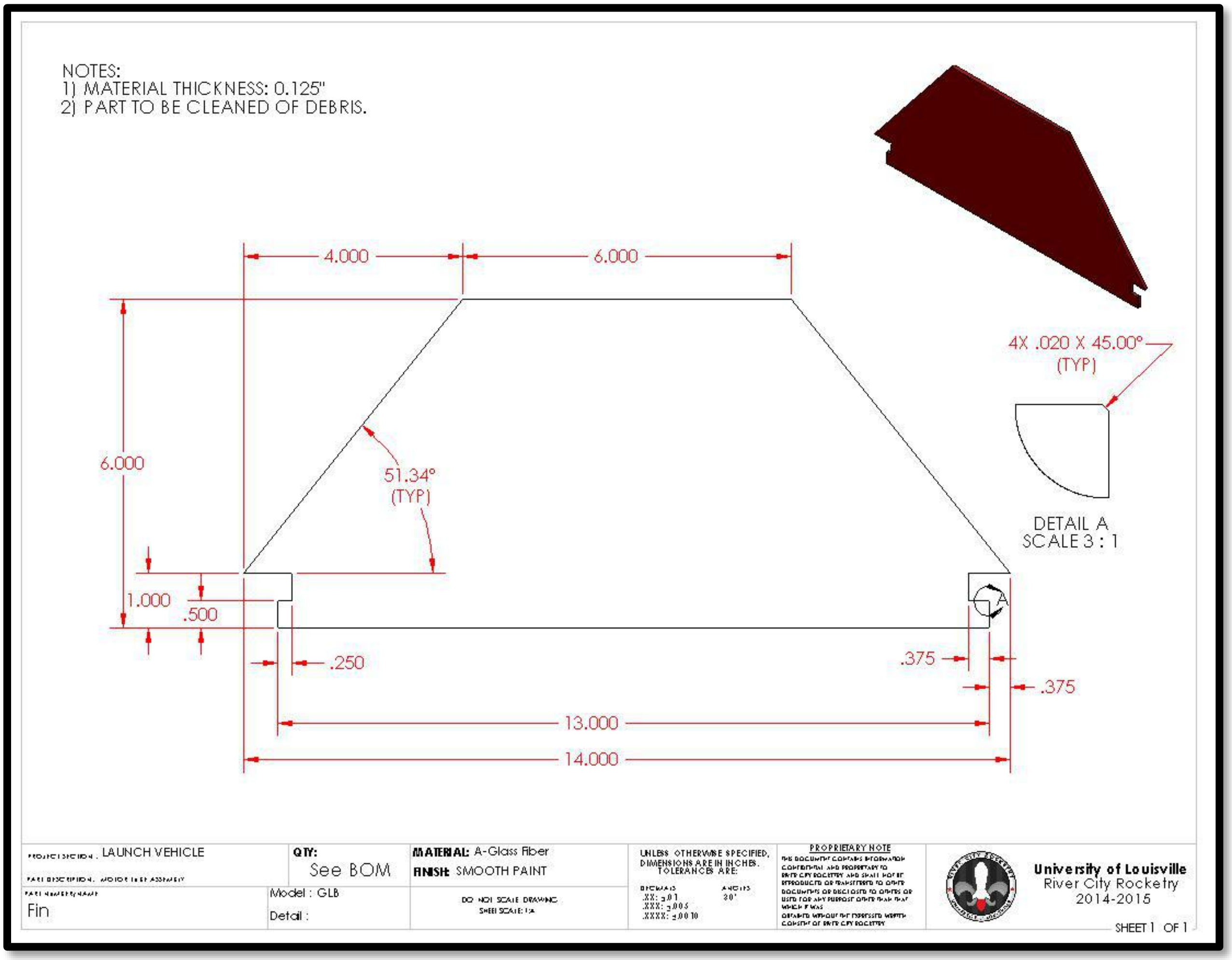


Figure 30: Detailed drawing of the launch vehicle's fin.

The fin is a trapezoidal fin. The geometry of the fin that extends out of the rocket's airframe is symmetric about its center axis. Basic geometry of the fins are as follows:

- Tip Chord: 6"
- Fin Height: 5"
- Root Chord: 14"
- Sweep Angle: 51.34°
- Tab Height: 1"

The leading edges of both extended fin tabs are chamfered, as per the detailed drawing, for smooth insertion into the launch vehicle.

Centering Ring Design

All centering rings will be machined from 6061-T6 aluminum while maintaining tolerances within the thousandth of an inch. Blanks will be cut out using an MAXIEM abrasive waterjet. The blanks will be machined to spec using a 3-axis HAAS CNC mill. The centering rings are designed to allow a push fit fitment between the centering ring fin slots and the fin. To save weight, each centering ring has excess material removed, as seen in Figure 31. Sets of equally spaced holes of 0.80” diameter will be cut in between each of the machined fin slots.

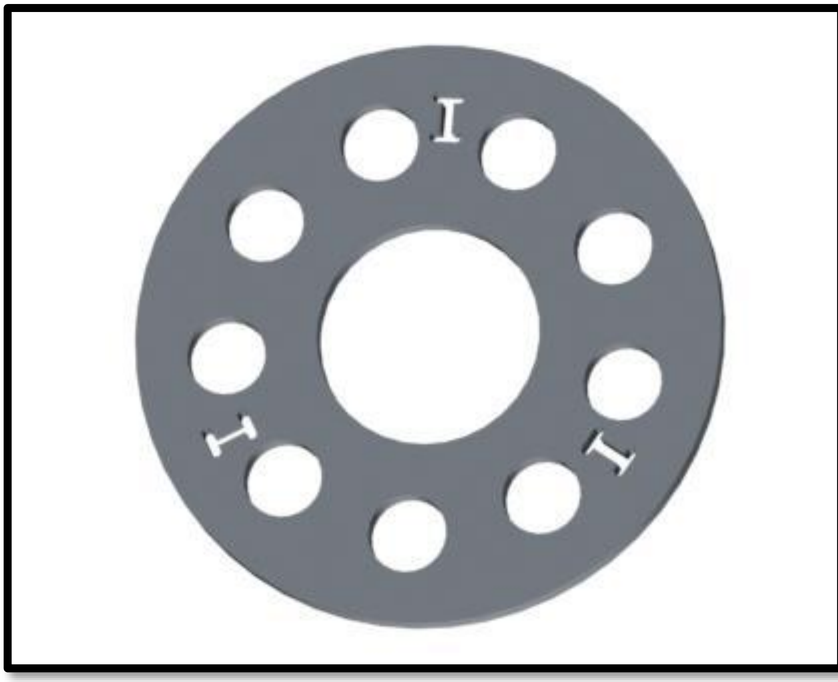
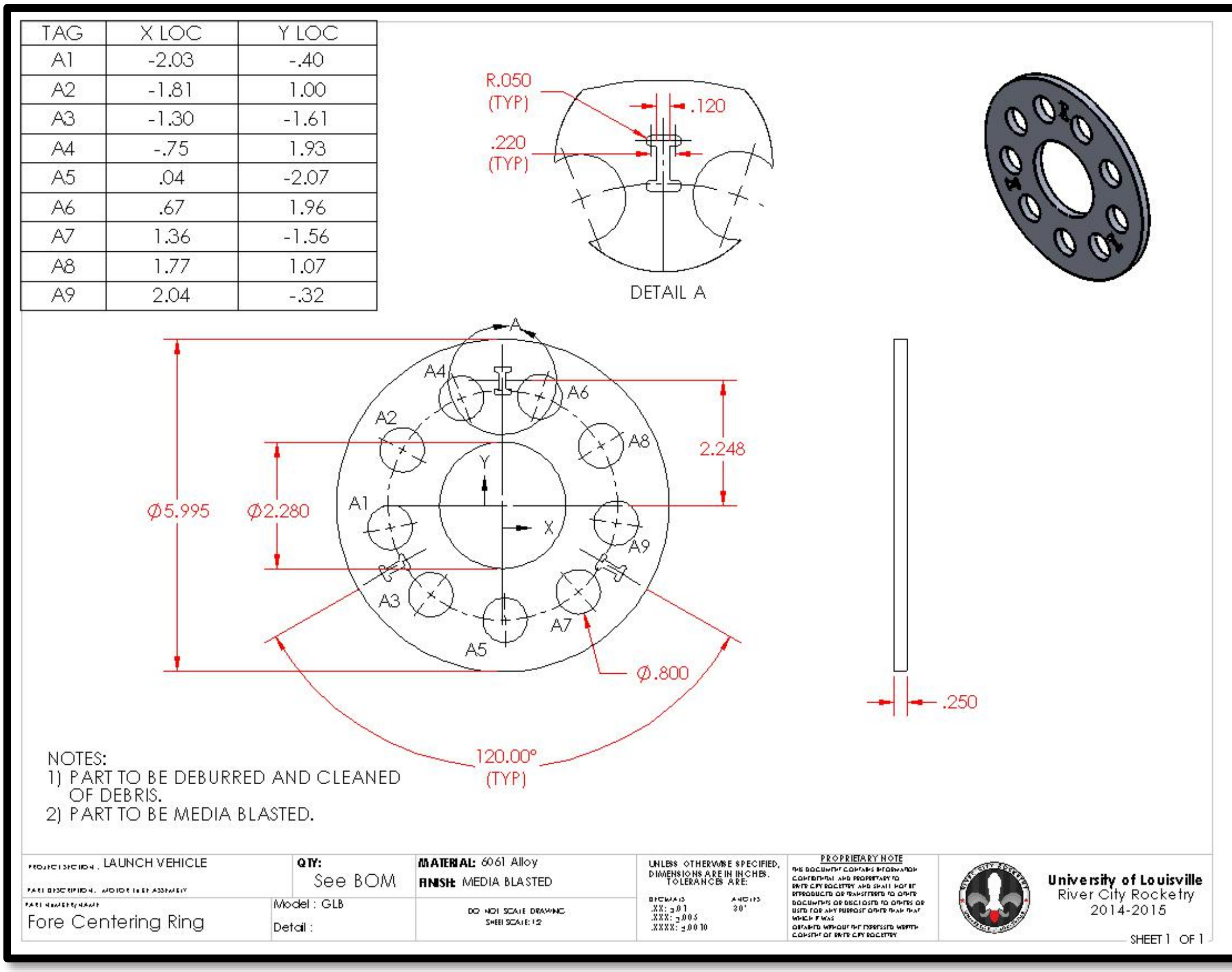


Figure 31: View of the fore centering ring in the removable fin system.

The fore centering ring, in the removable fin system, will have three through slots machined into them. The slots have equal spacing of 120° between them. The detailed drawing below, in Figure 32, shows the general geometry of the centering rings.



TAG	X LOC	Y LOC
A1	-2.03	-.40
A2	-1.81	1.00
A3	-1.30	-1.61
A4	-.75	1.93
A5	.04	-2.07
A6	.67	1.96
A7	1.36	-1.56
A8	1.77	1.07
A9	2.04	-.32

Figure 32: Detailed drawing of the fore centering ring.

The middle and aft centering ring will be identical in every fashion except the aft centering ring will have mounting holes for the rear fin retainer. Through slots, with equal width and spacing as the fore centering ring, will be machined into the middle and aft centering ring. These two centering rings are slotted such that the fins will be able to slide through the airframe and into the centering rings during installation. The width of each slot is subject to change once the fin material is obtained and measured for precise thickness.

Motor Retention

It is important that the motor casing is properly secured through the entirety of the launch. The design of the motor casing retainer essentially needs to be able to support the weight of the motor, and withstand the force from the main parachute deploying.

Figure 33, below, shows the detailed geometry of the casing retainer.

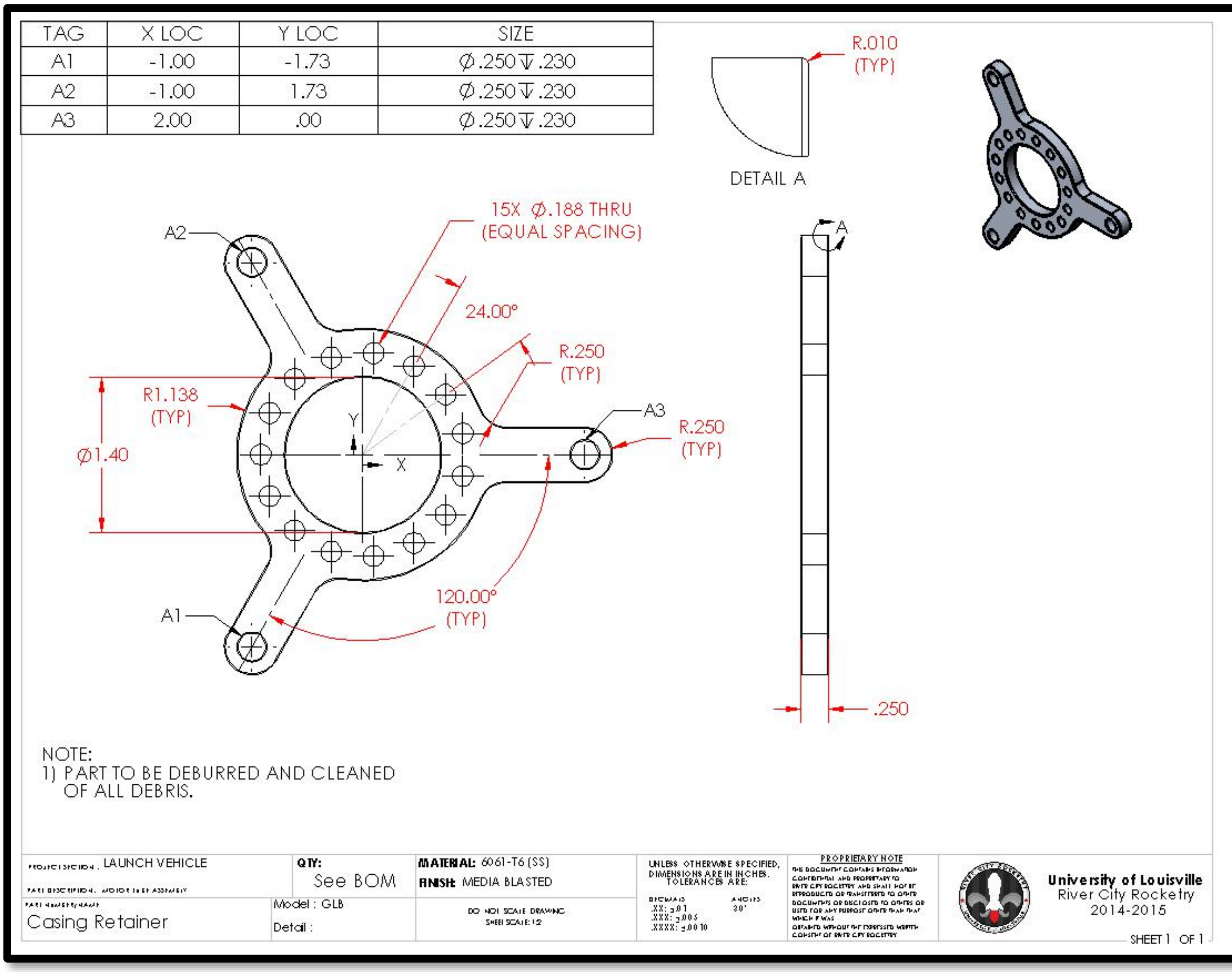


Figure 33: Detailed drawing of the motor casing retainer.

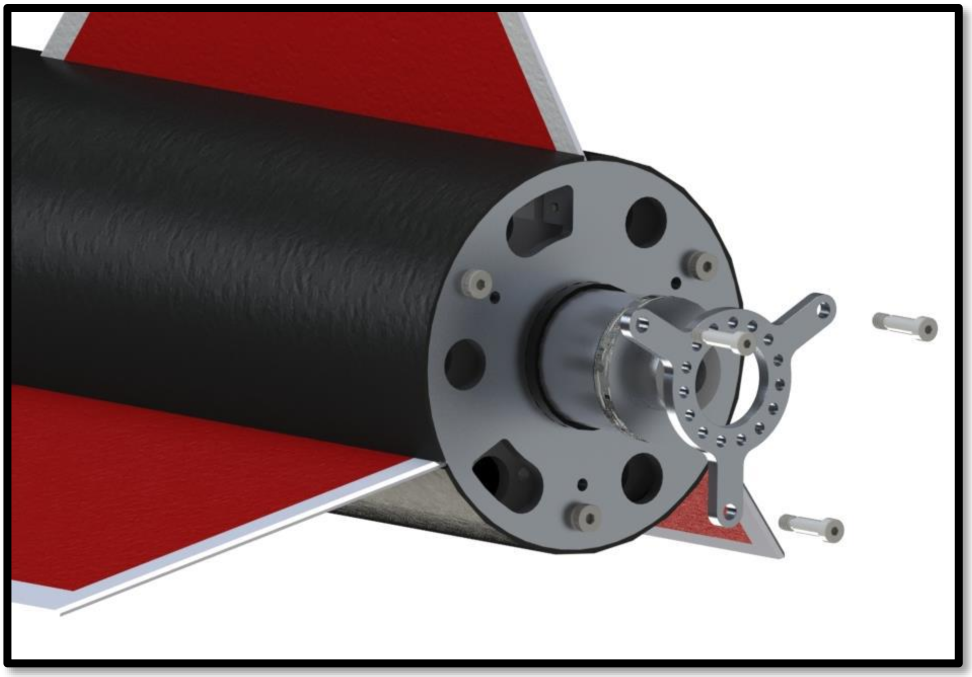


Figure 34: Motor retention components exploded view.

Prior to installation, the fins and rear fin retainer must be installed. As seen above in Figure 34, the motor casing retainer is fastened into place with three shoulder screws. The installation of the casing retainer takes place after the motor casing has been inserted into the motor tube. The casing retainer will be machined from 6061-T6 aluminum while maintain tolerances within the thousandth of an inch using a 3-axis HAAS CNC mill. Figure 35 shows the completed and fully assembled motor retention and removable fin system.

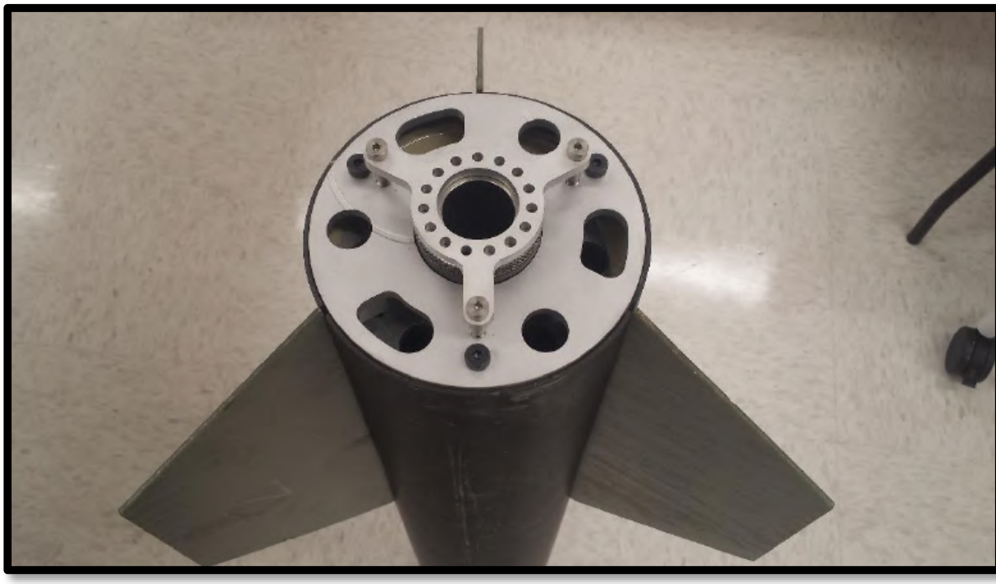


Figure 35: Fully assembled motor retention and removable fin system.

Table 9, below, lists material properties for the components found in the propulsion bay.

Material	Components	Characteristics
6061-T6 Aluminum	Centering Rings Rear Fin Retainer Motor Casing Retainer	Density: 0.098 lbs/in^3 Tensile Strength: 35,000 psi
G12 Fiberglass	Fins	Density: 0.069 lbs/in^3 Tensile Strength: 120,000 psi
Carbon Fiber	Propulsion Bay Airframe Motor Tube	Density: 0.050 lbs/in^3 Tensile Strength: 120,000 psi
18-8 Stainless Steel	Shoulder Screws	Density: 0.290 lbs/in^3 Tensile Strength: 90,000 psi

Table 9: Material properties of components in the propulsion bay.

Challenges	Solutions
Fin slots must all line up to allow fins to be installed and uninstalled without issue.	All centering rings shall be cut out using a CNC waterjet to ensure the parts stay within design tolerances.
Fins shall be rigid upon installation.	A rear fin retainer incorporates a rear fin tab retaining set screw to rigidly hold the fin in place. Furthermore, each fin is sanded to fit within its own designated position to ensure a firm fitment.
The motor tube shall be structurally secured in place.	All centering rings will be epoxied to the motor tube and propulsion bay airframe using Glenmarc's G5000 epoxy.
The motor casing shall be contained throughout flight.	An aluminum casing retainer will be cut out using a CNC waterjet, and will be secured to the rear fin retainer via shoulder screws.

Table 10: Propulsion bay design challenges.

Lower Avionics Bay Design

The need to safely jettison the propulsion bay from the secondary requires the implementation of a lower avionics bay. This section will be constructed primarily out of 6" fiberglass coupler tubing, plywood bulkplates, G12 fiberglass bulkplates, and aluminum fasteners.

The design of the lower avionics bay serves to purposes. It will host the necessary avionics to control necessary recovery events, and contain an on board GoPro camera to capture video documentation of the flight. To be deemed successful the completed assembly must contain:

1. Two StratoLoggers
2. Two 9 V Duracell batteries
3. GoPro Hero camera
4. A window that allows for clear video documentation

The use of additive manufacturing will be used to create the avionics sled and GoPro sled. The sleds will be printed out of ABS plastic. Bulkplates will separate the avionics sled from the GoPro sled. Aluminum tape shielding will be used between all bulkplate sections.

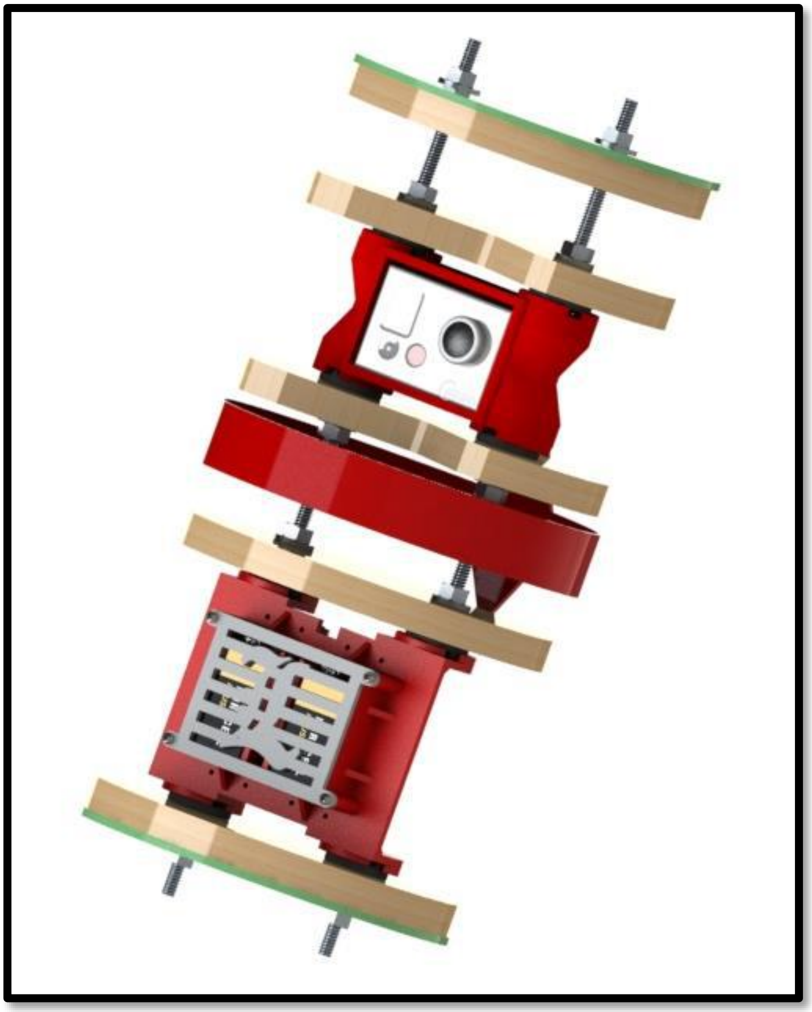


Figure 36: Lower avionics bay with the coupler tubing removed.

Challenges	Solutions
The GoPro must have a clear view outside of the launch vehicle.	A window has been cut out of the avionics bay, and adjacent section of airframe. Furthermore, a thin piece of Lexan has been epoxied and bolted to the inside of the coupler tubing to shield the bay from the environments during flight.
Sensitive electronics shall be shielded from each other.	Each separating bulkhead will have aluminum tape applied to its innermost face.
3D printed sled integrations shall address vibrational issues.	Rubber dampers have been added to the aft and fore side of each 3D printed sled to absorb vibrations caused by the flight of the launch vehicle.

Table 11: Lower avionics bay design challenges.

Cache Containment Bay and Fairing Payload Integration

A design of a reusable fairing has been implemented to safely secure and deploy the cache capsule. The use of this system allows for the sensitive electronics to be shielded from the ejection charges of the secondary recovery bay.

Overview of Physical Integration

Wound fiberglass is inherently under constant compressive forces. When cutting the fiberglass airframe perpendicular to the axis of the airframe, the compression goes unnoticed, as you are not specifically deforming the structural integrity of the wound material. However, when cutting the fiberglass down the axis of the airframe, it becomes apparent that the wound material will want to compress inwards onto itself. This permanent deformation to the integrity of the wound fiberglass material will cause the two halves of the airframe, when placed together, to take on a more oblong shape.

Figure 37: Representation of fiberglass deformation.

To counteract this issue, the team has designed and implemented a solution to ensure no deformation to the section of airframe of the fairing so that when the two halves were placed together, they formed a perfect circle. All bulkplates and coupler tubing were installed prior to cutting the airframe as depicted in Figure 38 and Figure 39 below.

Figure 38: Fairing with coupler tubing installed.

Figure 39: Fairing with bulkplates installed.

After the epoxy had dried, a jig, seen below in Figure 40, was built so that a table saw could be used to precisely cut the fairing in half.

Figure 40: Fairing cutting jig.

Having the bulkheads already epoxied in place did not allow the fairing airframe and coupler tubing to deform a noticeable amount. This allowed for the system to keep its cylindrical shape, thus allowing for proper integration into the launch vehicle.

Design and Verification of Fairing Integration

The fairing can be divided into three main sections: the altimeter housing, cache payload housing, and fairing retention bay. Each section has its own primary role in ensuring the safe deployment and recovery of the cache payload. The main components that make up the fairing, including airframe and bulk plates, can be visualized as equally divided into separate halves.

Altimeter Housing

In order to save space within the confinements of the fairing, standalone altimeter housing units have been designed and are being fabricated to power and control a single StratoLogger. This called for no separate altimeter bay. The team designed an altimeter housing that is being 3D printed from ABS plastic, shown below in Figure 41. The enclosure will incorporate a StratoLogger, a 9V battery, an acrylic glass face plate, and a screw switch that would be used to activate the altimeter.

Figure 41: Altimeter housing assembly.

The decision to use 3D printing of this component allowed for a unique design. The outer body of the housing has an outer diameter that matches the inner diameter of the coupler tubing where it sits in the fairing assembly. The housing hosts a body extrusion that will safely house a standard 9V battery. A vented lid was 3D printed separately. The lid is screwed in place and properly constrains the battery in place. Included in the 3D printed design are raised extrusions that will also be properly tapped to allow for the StratoLogger, screw switch, and the acrylic glass front plate to be securely mounted to the altimeter housing.

Figure 42: Exploded view of the altimeter housing.

Furthermore, there is a hole in the back of the altimeter housing which can be seen in more detail below in Figure 43. Once assembled, this hole will line up with a hole that will be drilled into the coupler tubing the altimeter housing rests in. This hole will allow access to the screw switch so that the altimeter can be armed on the Launchpad as well as provide an ambient pressure vent for the StratoLogger.

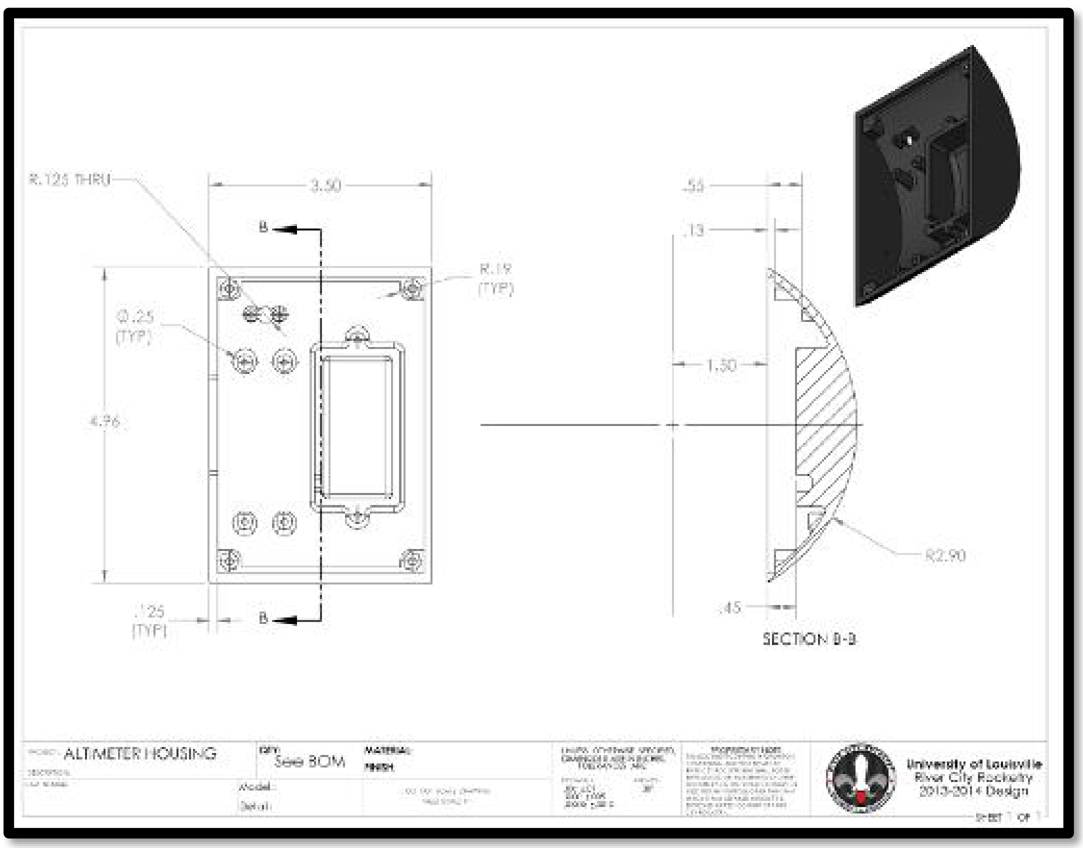


Figure 43: Altimeter housing basic dimensional drawing.

Utilizing information from StratoLogger's website, the port hole size for the altimeter housing was determined. Table 12 shows the information gathered and calculated from StratoLogger's website.

Avionics Bay			
Diameter (inches)	Length (inches)	Volume (in^3)	Single Port Hole Size (in)
1.6	6.0	12.06	0.032
2.1	6.0	20.78	0.048
3.0	8.0	56.55	0.113
3.0	12.0	84.82	0.17
3.9	8.0	95.57	0.202
3.9	12.0	143.35	0.302
5.5	12.0	285.10	N/A
7.5	12.0	530.14	N/A

Table 12: StratoLogger's volume to port hole size comparison.

In order to decide on the appropriate port hole size, the volume of the altimeter housing was calculated. This value was cross referenced against the information in Table 12 and the volume one step higher was chosen as guidance. A safety factor of 1.5 was chosen to influence the size of the final port hole size.

Volume (in^3)	12.92
Single Port Hole Size (in)	0.17
Safety Factor	1.5
Final Port Hole Size (in)	0.255

Table 13: Altimeter housing port hole analysis.

Table 13 shows the data used to determine the final port hole size for the altimeter housing. With the safety factor applied, it was determined that the ¼ inch hole used for the screw switch was adequate enough to act as a proper port hole for the StratoLogger.

Fairing Pyro Cap

The primary objective of the fairing is to safely deploy the cache payload. The fairing has been constructed in such a way that the two halves of the fairing want to remain open in its equilibrium state. In order for the fairing to stay closed, thus encapsulating the payload, a 3D printed ABS plastic pyro cap and shell will be used to securely constrain the fairing shut. The shell that secures around the pyro cap is comprised of two sections, "Shell A" and "Shell B". With the fairing being primarily completely symmetric in shape and split in halves, each bulkplate is a semicircle in shape. Each shell is securely mounted to its own semicircle bulkplate on one half of the fairing.

In the design of the pyro cap system, tolerances were a key item of concern. The shells had to be able to snuggly fit together, but could not be toleranced so tight that they would become stuck together if accidentally closed too tightly. In order to countreract this the radial dimension of the mating flange of Shell B was calculated and designed to a specific tolerance. Table 14 shows the maximum and minimum clearances for the fitment of Shell B into Shell A.

Maximum (in)	0.013
Minimum (in)	0.003

Table 14: Fitment clearances for Shell B into Shell A.

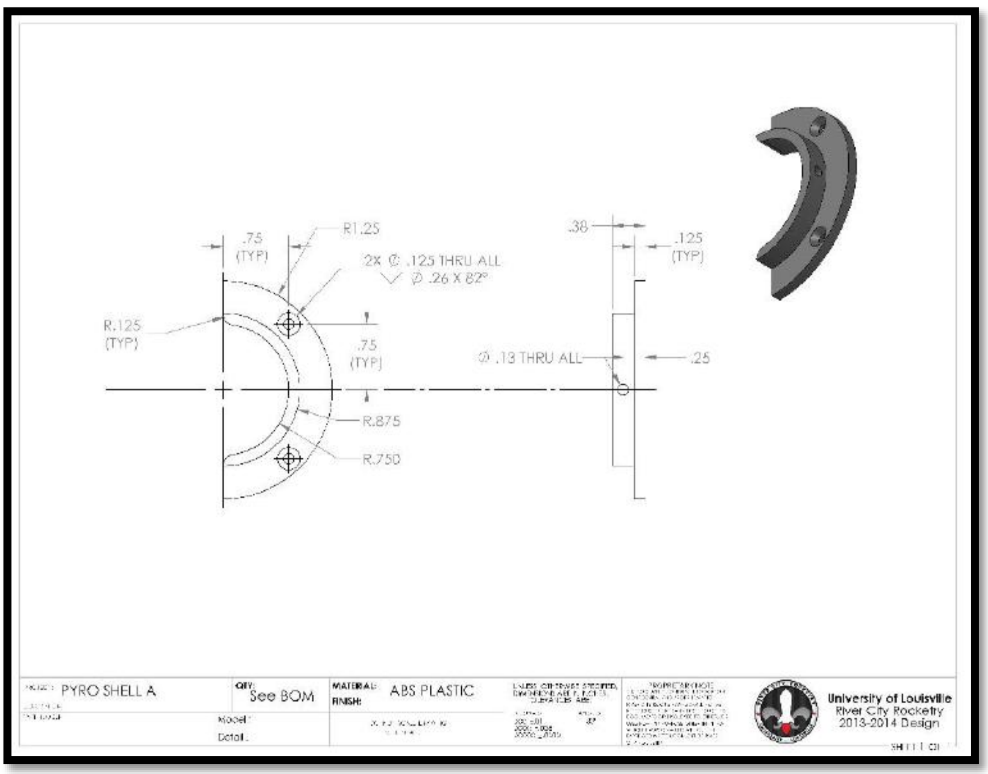


Figure 44: Detailed drawing of Shell A.

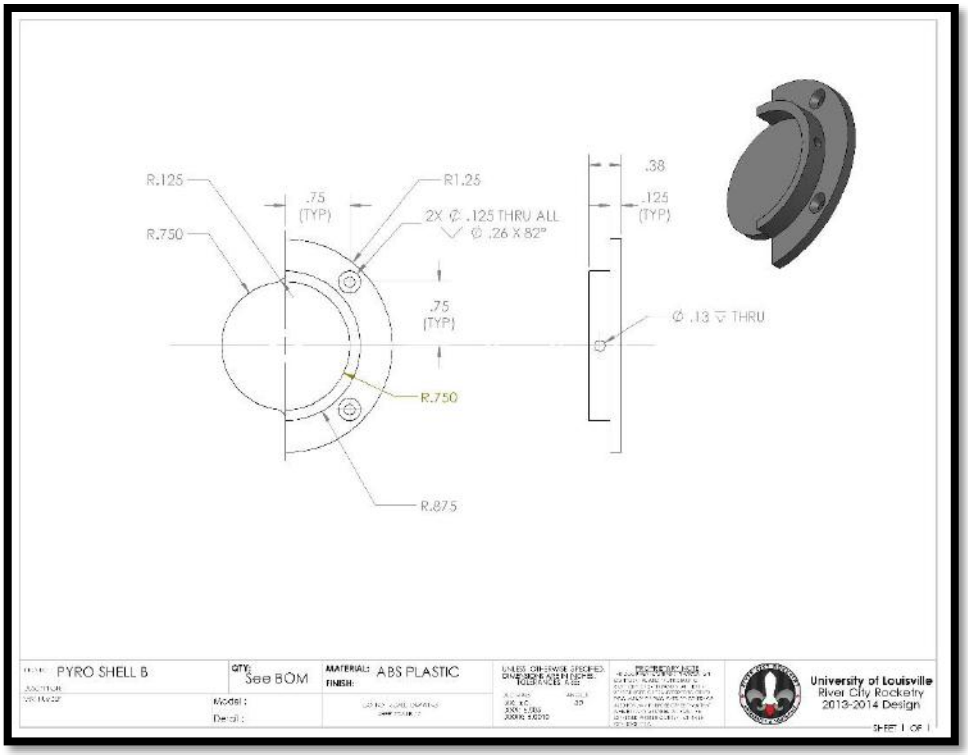


Figure 45: Detailed drawing of Shell B.

Similar to the tolerances going into the design of the two shell halves, the pyro cap went under the same rigorous design criteria to ensure a clearance fitment into the shells. Figure 46 shows the clearance fitment for the pyro cap into the assembly.

Maximum (in)	0.026
Minimum (in)	0.006

Table 15: Fitment clearances for the pyro cap into the shell components.

The pyro cap is designed to house two separate chambers for black powder charges. This is to ensure all rocket systems are fully redundant. To save space, the design was modified such that there are two concentric semi-circle black powder wells.

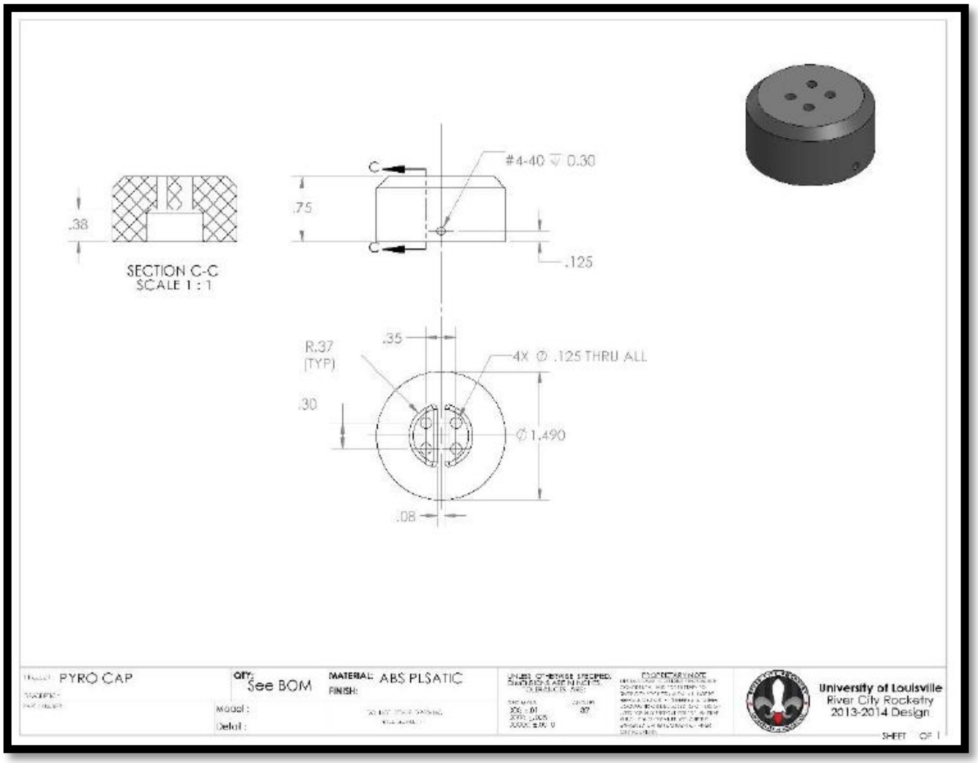


Figure 46: Detailed drawing of the pyro cap.

Diameter	.75 in3	Black Powder in Wells	
Depth	.38 in	1	2
Volume	.07 in3	0.7 g	1 g
**Volume is accurate. The well is not an exact half semi-circle as there is a .08 in wall between wells*			

Table 16: Pyro cap black powder well dimensions.

Table 16 the overall dimensions of the black powder chambers. By including two black chamber wells, the system is fully redundant. This is further accomplished by having two access ports for electronic matches in each black powder well. This was to ensure that in the event which the primary chamber's ignition fails to jettison the pyro cap, the secondary well will fire with more overall pressure.

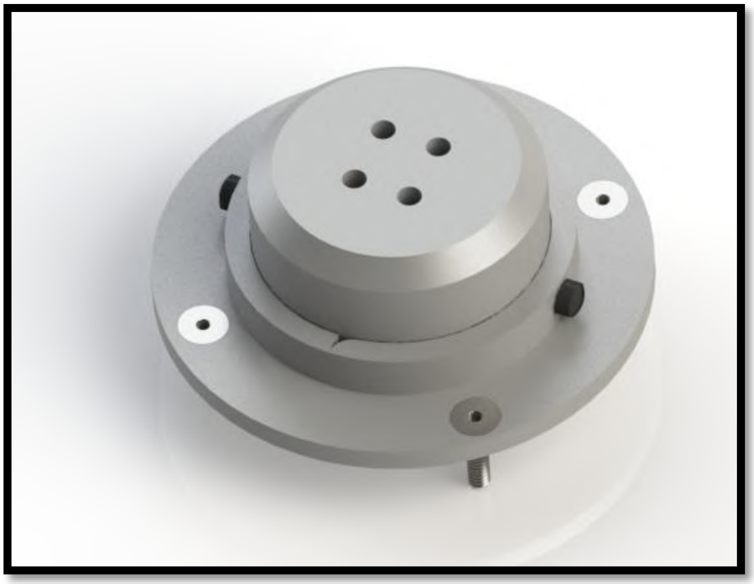


Figure 47: Pyro cap assembly.

The pyro cap is secured into place by two 4-40 nylon screws, as shown in Figure 47. A #4-40 threaded eyebolt is to be epoxied into the top of the pyro cap. A section of Kevlar wound nylon cord will be tied from the eyebolt on the pyro cap to the eyebolt mounted to the bulkplate to the side of the pyro cap assembly. This will ensure that when the pyro cap is jettisoned from the fairing that it will not free fall to the ground where it could cause damage personnel or property.

Payload Integration and Recovery Section

The cache containment section of the fairing is self-contained. This means that the section is completely separated from the elements. The cache payload has to be constrained safely within the fairing. In order to do so the chosen method of constraint is being foam machined on a CNC to a precise geometric structure to securely house the cache payload.

The team tested Pactiv's 2 inch thick polystyrene insulation sheets. Structurally, the foam is rigid, and easy to machine. This is proving useful in shaping it to conform to the body of the cache capsule.

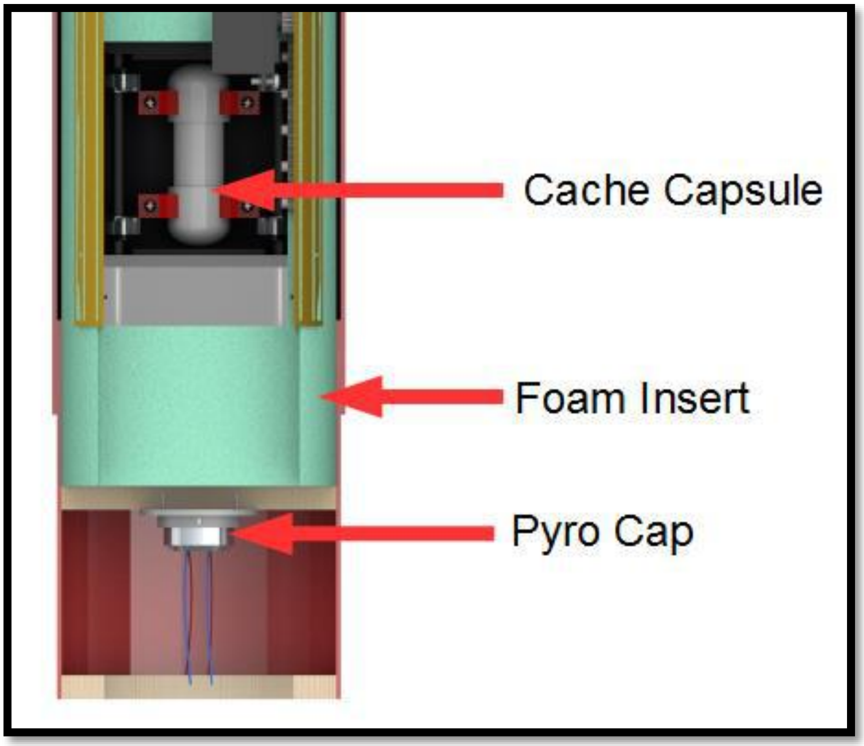


Figure 48: Integration of the cache capsule into the fairing.

Figure 48 depicts the layout of the integration of the cache payload into the fairing.

The actuation of the fairing is controlled at the fore end of the fairing assembly. The sections are joined by a 304 stainless steel hinge. The hinge's pin is contained inside a polyacetal bushing. This allows a low coefficient of friction in the hinge. A stainless steel U-bolt is mounted on either side of the upper fairing bulkplates. A set of two steel springs join the two U-bolts. This set up, shown below in Figure 49 causes the fairings static state, without the pyro cap installed, to be open.

Figure 49: View of spring actuated payload ejection system.

Challenges	Solutions
The fairing shall be able to open reliably.	An aluminum hinge with polyacetal bushings and a stainless steel hinge rod was chosen as the connection between each half. The low coefficient of friction of the hinge has proved more than adequate.
The fairing shall be able to deploy the internal payload.	A pyro cap is connected to two StratoLoggers that will jettison at a predetermined altitude and actuate the fairing. This will allow for the payload to swiftly fall out of the fairing under its parachute.
The payload shall be safely secured within the fairing.	Foam inserts that have been machined on the CNC ShopBot will secure the payload throughout flight and contain it until deployment.

Table 17: Cache containment bay and fairing payload integration challenges.

Mass Report

Upon construction, each section of the launch vehicle was fully assembled and prepped for weigh-in. By using the real weights of each system, a more accurate simulation for the flight and safety of the launch vehicle could be constructed. Please reference Mission Performance Predictions on page 88 for a more in depth look at the stability of the launch vehicle.

Section of Launch Vehicle	**Length of Section (in)**	**Mass (lbs)**
Nose Cone	30.85	4.90
Main Recovery Bay	27.5	3.47
Cache Containment Bay	16.75	6.34
Secondary Recovery Bay	28	8.02
Propulsion Bay	37	14.37
Witness Rings	2	0.20
Motor	N/A	5.60
	Total Mass	**42.90**

2) Recovery Subsystem

Overview

The recovery system must fulfill the following requirements in order for the mission to be considered a success.

1. The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.
2. All independent sections must have a maximum kinetic energy of 75 ft-lb_f at landing.
3. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.
4. The recovery system shall contain redundant, commercially available altimeters, each with an independent arming switch that is accessible from the exterior of the rocket airframe.
5. Each altimeter shall have a dedicated power supply.
6. Each arming switch shall be capable of being locked in the ON position for launch.
7. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.
8. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.
9. The recovery systems electronics shall not be adversely affected by any other on-board electronic devices during flight.

The details on how these requirements are to be met are discussed in the following section.

Parachute Design

Recovery Flight Path

To allow for the ejection of the cache capsule, the rocket will be recovered in three independent sections. A pictorial representation of the recovery sequence is shown in Figure 50.

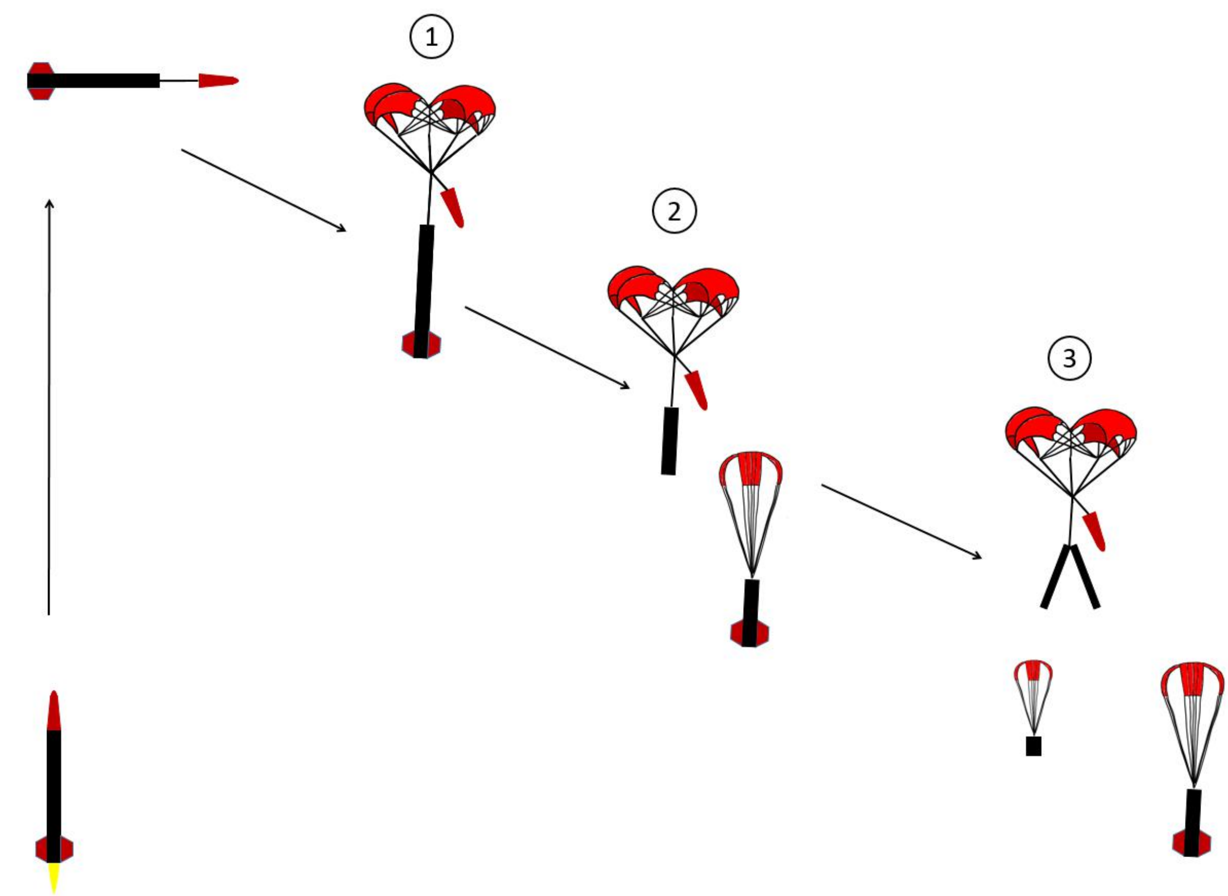


Figure 50: Recovery sequence of events.

A description of the recovery sequence and the altitude at which each event occurs is described in Table 18.

Event	Altitude (ft.)	Description
1	3,000	Apogee. Nose cone ejection. Entire rocket under main parachute acting as drogue.
2	1,500	Eject lower airframe. Both upper and lower airframes now falling under main parachutes.
3	1,000	Fairing deployment. Cache capsule ejection. All independent sections now under main parachutes.

Table 18: Recovery events and descriptions.

Geometry
The recovery system has potential risks that can be mitigated through optimizing certain criteria in the parachute design. The parachute criteria and risks mitigated are described in Table 19.

Parachute criteria	**Risk mitigated**
Low opening force.	Shock from the upper airframe parachute could be enough to break shear pins, causing the lower airframe to prematurely detach.
Minimal oscillation.	Excessive oscillation of upper airframe during ejection of cache capsule could result in cache capsule not deploying correctly.

Table 19: Parachute criteria and how risks are mitigated.

The performance characteristics from multiple parachute geometries were compared to select the optimal geometry for the recovery system. The considered geometries are shown in Table 20.

Parachute Geometry	**C_D**	**C_X**	**Oscillation**
Rotafoil	0.85-0.99	1.05	0^o-2^o
Vortex ring	1.5-1.8	1.1-1.2	0^o-2^o
Cross (Cruciform)	0.6-0.85	1.1-1.2	0^o-3^o
Triconical Polyconical	0.8-0.96	1.8	10^o-20^o
Annular	0.85-0.96	1.4	6^o

Table 20: Parachute performance characteristics comparison.

The vortex ring was selected as the main parachute for the upper airframe due to the efficiency of the parachute, low opening force and low oscillation. The vortex ring is a rotating parachute, consisting of four panels. The panels are not stitched together like the gores of more conventional parachutes, but are tethered together with a series of lines that maintain the shape of the panels and induce the autorotation of the parachute upon decent.

Due to the complexity of the vortex ring, it was decided to use a simpler parachute for both the lower airframe and the cache capsule recovery systems. The risks that are mitigated by the low opening forces and oscillation of the vortex ring do not apply to the lower airframe and the cache capsule recovery. To reduce complexity, furthermore reducing the risk of failure, a cruciform parachute was selected for the lower airframe and cache capsule recovery systems.

The major advantage of the cruciform parachute is its simplicity. The construction of the cruciform is significantly easier than that of the vortex ring. Additionally, due to the simplicity of the geometry and shroud lines, the parachute is significantly easier to pack. This reduces the risk of failure of deployment.

The disadvantage to the cross design is the tendency for oscillation about the vertical axis. Since nothing is needing to be deployed from either of the sections utilizing a cruciform parachute, it is not necessary to maintain low levels of oscillation. Since too much oscillation could collapse the parachute and send the rocket or cache capsule into free fall, the suspension lines will be lengthened to prevent harsh oscillating as the sections descend. Longer suspension lines will stabilize the rocket and capsule. This will also improve the risk of the payload drifting when it lands on the ground.

Layout
The vortex ring will be manufactured in accordance with the schematic shown in Figure 51.

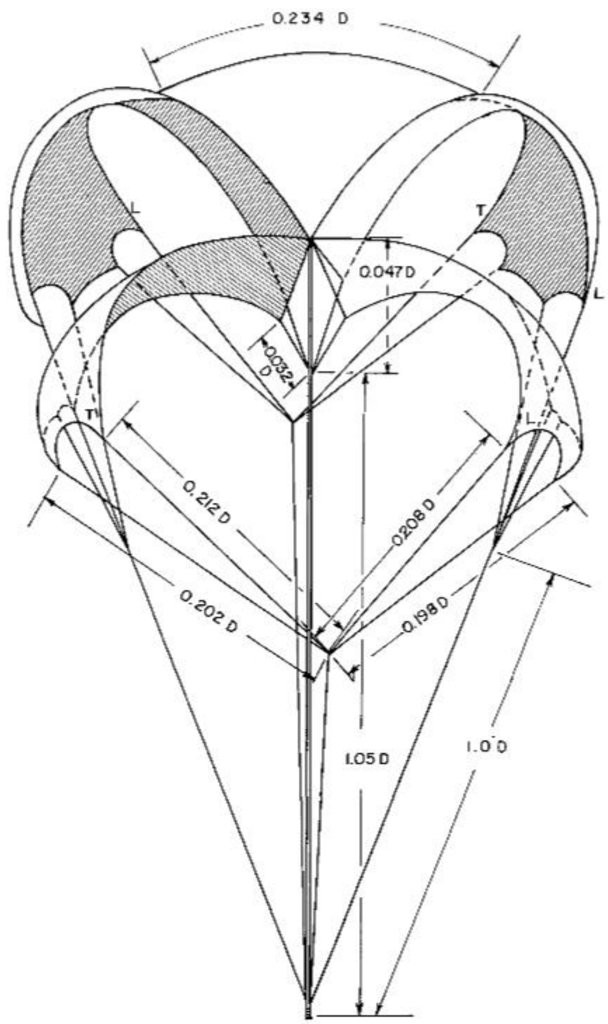


Figure 51: Vortex ring schematic for lines that tether the panels together.

For organizational purposes during construction, the parachute was broken down into four sections. Each panel and its corresponding lines each formed one section. Schematics of the four sections are shown in Figure 52. Every line on the parachute was given a unique number and is indicated by a circle. Each of the shroud lines are connected with lines from other panels at uniquely numbered connection points which are indicated by a triangle.

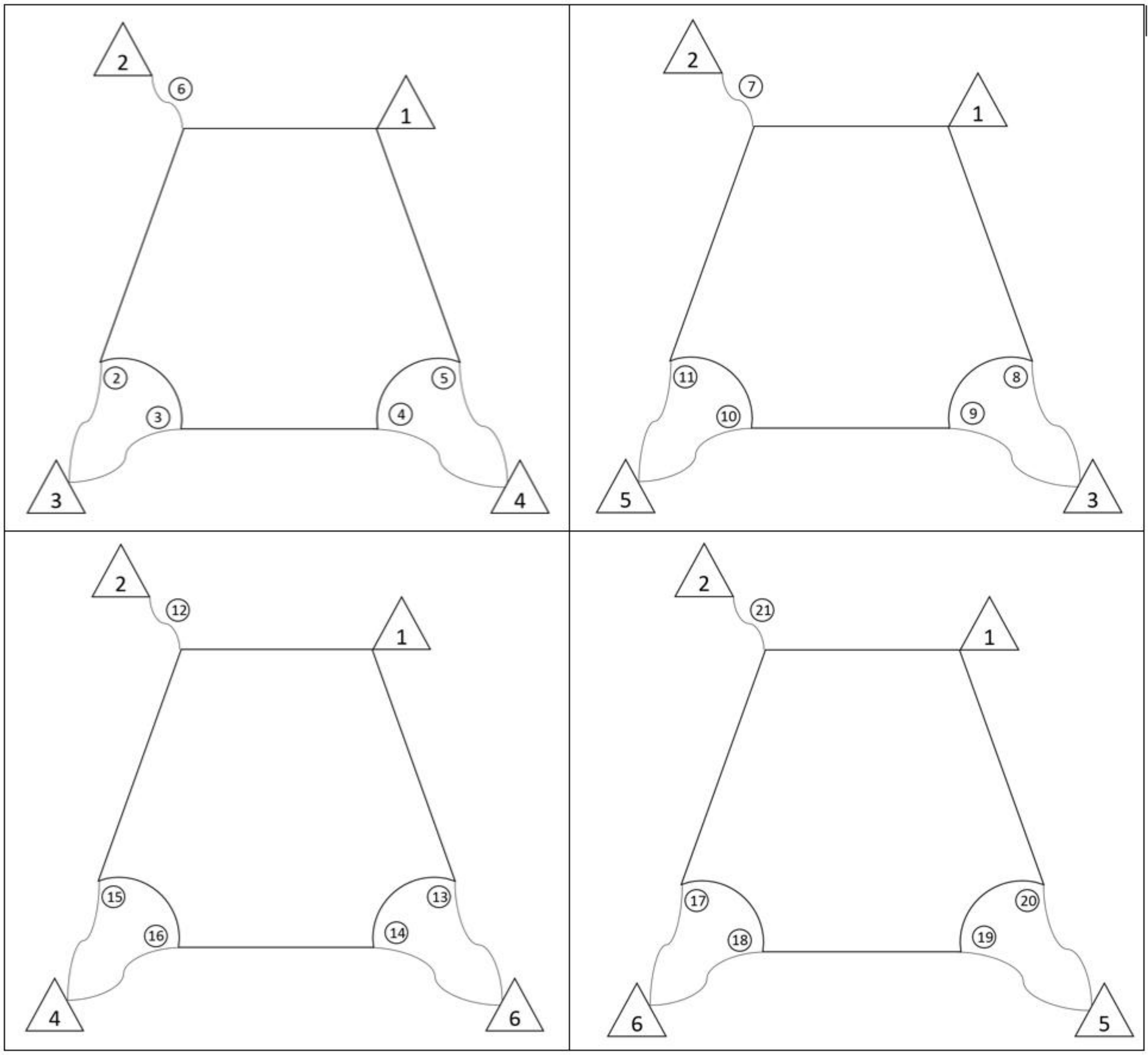


Figure 52: Vortex ring parachute divided into four sections with corresponding lines and connection point labels.

The lengths of each of the lines were calculated using a relationship to the parachute diameter in feet, which are listed in Table 21. The actual length of the subscale parachute lines were calculated and are shown in the table. The baseline for the equations for each line came from Figure 51. Six inches was added to both ends of each line in order to allow for manufacturing processes.

Lines	Equation	Subscale length [in]
5, 8, 13, 20	2.544D+12	23.45
4, 9, 14, 19	2.424D+12	22.90
3, 10, 16, 18	2.376D+12	22.69
2, 11, 15, 17	2.05D+12	21.23
Centerline	12.16D+6	62.70
Head	0.564D+12	14.54
6, 7, 12, 21	0.384D+6	7.728
Suspension Line	12D+6	60.00

Table 21: Line length equations for subscale vortex ring.

Since the team has no previous experience with the vortex ring parachute and the given planforms were not fully defined, some experimentation was done in order to achieve the optimal parachute. As a result of the experimentation, the equations given were modified to those given in Table 21.

The original parachute that was manufactured presented several problems. First, it did not rotate and second, it required high speeds to inflate. In order to resolve these problems, a few modifications were made. Lines 2, 11, 15, and 17 were all shortened. Since the vortex ring is an auto rotational parachute, the panels need to be maintained at a pitch that allows the parachute to act as a propeller blade. By shortening these lines, the initial pitch of the panels increased, causing the panel to have a higher tendency to rotate. The increased rotation also increases the lift generated by the parachute. Additionally, the length of the centerline was addressed. By shortening the centerline, the parachute held a tighter shape, resulting in the parachute more easily inflating.

Since the modifications to these two lines altered the performance of the parachute, the parachute was incrementally tested to determine the optimal dimensions in order to achieve the highest coefficient of drag and the most stable parachute. The tests were run by attaching the parachute to a 10 foot metal pole that was strapped to and sticking out the side of a vehicle as shown in Figure 53.

Figure 53: Subscale parachute test rig.

This setup avoided the blunt body effects that the parachute would have seen would it have been directly behind the vehicle. At the end of the metal rod was a pulley, around which the parachute was attached and connected to a force gage. Through these readings, the coefficient of drag was determined. Each test was run three time at an average velocity of 20 mph and the average force measurement was taken to verify precise results.

To test the optimal length of lines 2, 11, 15, and 17, the original length was first tested. While the parachute stayed inflated at all times, the parachute did not rotate about a centralized point. When the lines were shortened by 4 inches, the parachute became unstable, consistently deflated, and had high oscillations. It was determined that the ideal configuration was to shorten the lines by 2 inches. This resulted in a stable parachute that constantly stayed inflated and rotated at a consistent rate around a single point. The coefficient of drag was calculated using

$$C_d = \frac{2F_d}{\rho v^2 A} \qquad (18)$$

where F_D is the force due to drag, ρ is the density of air, v is the velocity, and A is the effective area of the parachute.

The force measurements and calculated drag coefficients are shown in Table 22.

Configuration	Run	Force	C_D
Original	1	9	1.30
	2	9	1.30
	3	10	1.45
	Average	9.33	1.35
Shortened 2”	1	10	1.45
	2	9	1.30
	3	10	1.45
	Average	9.67	1.40
Shortened 4”	1	8	1.16
	2	8	1.16
	3	7	1.01
	Average	8.67	1.11

Table 22: Subscale ground testing results for alterations to lines 2, 11, 15, and 17.

After analyzing the quantitative and qualitative data collected from the tests, the ideal alteration was to shorten lines 2, 11, 15, and 17 by two inches.

Another series of tests was run in order to determine the optimal length of the centerline, as shown in Table 23. All of the tests were run with the same parameters as the initial tests and lines 2, 11, 15, and 17 were secured at their optimal length.

Configuration	Run	Force	C_D
Original	1	10	1.45
	2	9	1.30
	3	10	1.45
	Average	9.67	1.40
Shortened 2”	1	9	1.30
	2	10	1.45
	3	10	1.45
	Average	9.67	1.40
Shortened 4”	1	N/A	N/A
	2	N/A	N/A
	3	N/A	N/A
	Average	N/A	N/A

Table 23: Subscale ground testing results for alterations to centerline length while holding lines 2, 11, 15, and 17 at the optimal length of 2” shorter than the original.

After analyzing the quantitative and qualitative data collected from the tests, the ideal alteration was to shorten the center line by two inches. While the coefficient of drag did not change from the original configuration, the vortex ring was more stable during testing with the center line shortened. When the centerline was shortened by four inches, the parachute became extremely unstable and would not stay inflated. Even though we ran tests with this configuration, the performance of the parachute was inconsistent, preventing accurate force readings from being taken.

The completed subscale parachute is pictured in Figure 54 with all modifications made from the testing.

Figure 54: Completed subscale vortex ring parachute.

After the equations were modified from the sub-scale testing, the dimensions for the subscale lines and panels were calculated. Shown in Table 24 are the calculated line length dimensions for the full scale vortex ring parachute.

Lines	Equation	Full scale length [in]
5, 8, 13, 20	2.544D+12	42.17
4, 9, 14, 19	2.424D+12	40.75
3, 10, 16, 18	2.376D+12	40.18
2, 11, 15, 17	2.05D+12	27.17
Centerline	12.16D+6	150.20
Head	0.564D+12	18.7
6, 7, 12, 21	0.384D+6	10.55
Suspension Line	12D+6	148.3

Table 24: Calculated dimensions for full scale vortex ring parachute.

The shroud lines and the lines used to tether together the panels are design based off of the schematic shown in Figure 51. All lengths are functions of the nominal diameter of the parachute.

The two cruciform parachutes will be constructed using the schematic shown in Figure 55.

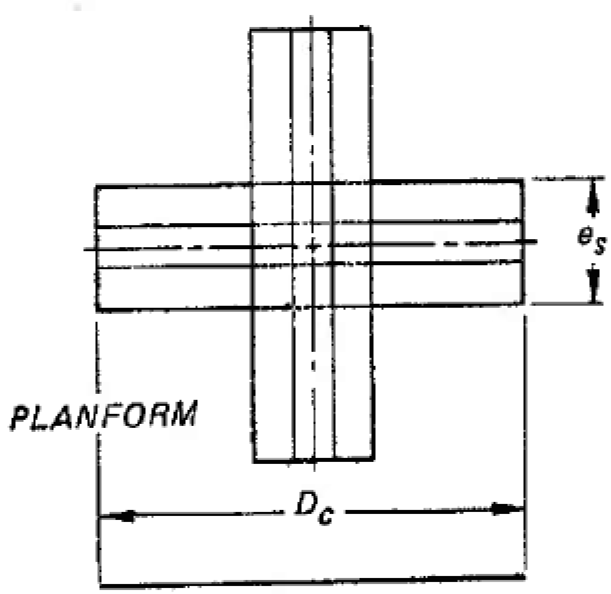


Figure 55: Cruciform construction schematic.

The ratio of the dimensions are defined using the following relationship:

$$\frac{e_s}{D_c} = 0.263\ to\ 0.333 \quad (19)$$

The parameters are related to the nominal diameter of the parachute using

$$D_o = 2D_c e_s - e_s^2 \tag{20}$$

The inflated profile of the cruciform parachute is shown in Figure 56.

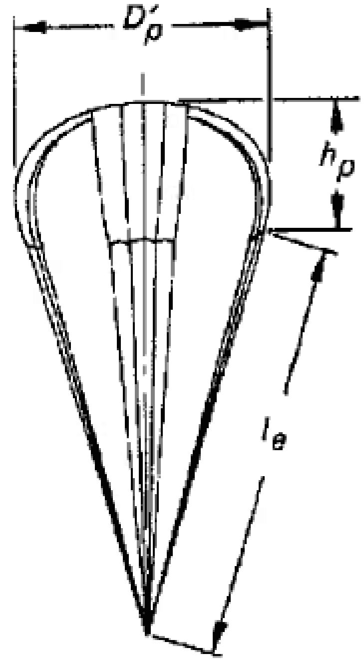


Figure 56: Inflated cruciform parachute schematic.

The length of the suspension lines for the cruciform parachute are represented by the following ratio:

$$\frac{I_e}{D_o} = 1 \; to \; 2 \tag{21}$$

Since the oscillation of the cruciform parachute has been an identified risk that can be mitigated through lengthening the suspension lines, the upper end of the ratio was used to calculate the length of the suspension lines. The dimensions calculated for the parachutes for the lower airframe and the cache capsule are shown in Table 25.

Section of rocket	e_s (ft)	D_c (ft)	l_e (ft)
Lower airframe	5.4	18.2	19.5
Cache capsule	1.7	5.7	6.2

Table 25: Calculated dimensions for cruciform parachutes.

The lower airframe will be secured to the upper airframe using shear pins. Calculations will be made to ensure that the shock of the opening of the main parachute will not prematurely shear the pins. At 1,250 ft, a second charge will be ignited, separating the lower airframe from the upper airframe. The lower airframe will fall under its own independent recovery system.

Parachute Materials

The canopy of the parachutes will be made of MIL-C-44378 0.75 oz. rip stop nylon. The rip stop nylon was selected due to the high strength-to-weight ratio. Its strength is derived from the crosshatching of reinforcing fiber, which prevents tears from propagating through the fabric. Dacron was considered due to its comparable strength to rip stop nylon, but it was counted out due to its stiffness, making it difficult to pack. Additionally, rip stop nylon is cheaper and more readily available than Dacron, making rip stop nylon the optimal material.

Manufacturing Processes

In manufacturing the parachutes, each panel was traced onto the ripstop nylon. Since the panels for the cruciform parachutes are a rectangular shape, they were measured out and traced by hand. Due to the curvatures and angles on the vortex ring panels, this was more difficult to do. A SolidWorks model of the panel was created per the dimensions shown in Figure 57. The additional material on each edge is to account for the material lost into each hem.

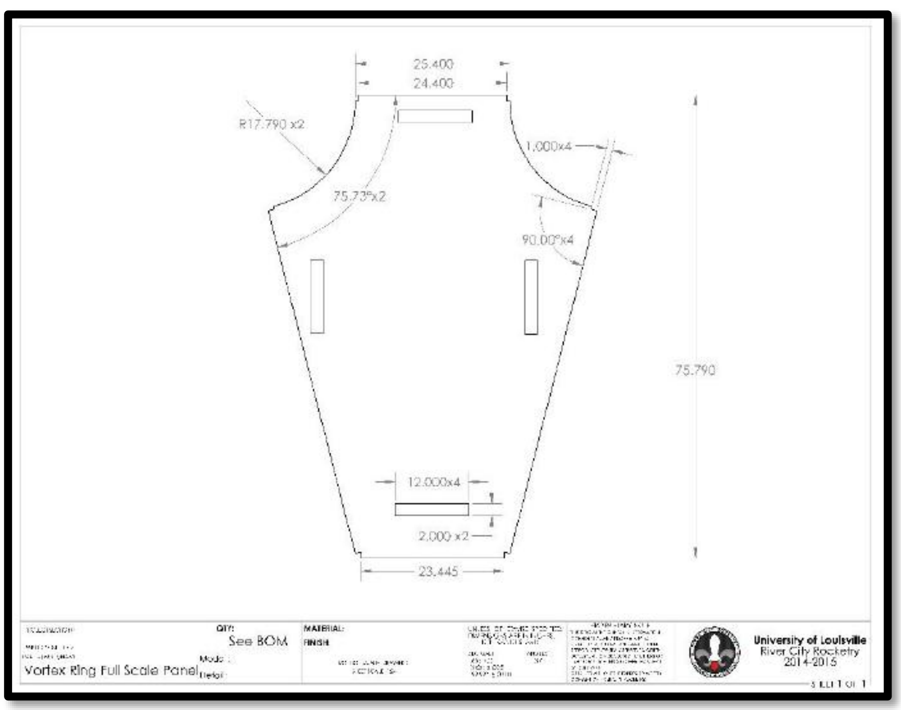


Figure 57: SolidWorks drawing of vortex ring panel.

The image was then projected onto a flat surface. The four rectangles seen in Figure 57 were used to calibrate the projector to ensure that the image was not distorted. The ripstop nylon was then hung from the wall and the image was traced as shown in Figure 58.

Figure 58: Vortex ring panel tracing setup.

Once each panel was traced, they were cut using a hot knife and straight edge. Utilizing the hot knife to cut the panel cauterized the edges, helping prevent fraying throughout the life of the parachute.

Each hem was constructed by folding over the material two times. This helped prevent the material from fraying by keeping the cut edge contained within the seam. Layers of tape double sided tape were used with each fold to help hold the hem together during manufacturing and to add rigidity to the seam, resulting in a cleaner hem.

A similar process was used for the hems for the cruciform parachute hems. For the cruciform parachutes, the suspension lines were sewn into the hems. To do this, the suspension lines were folded into the hem at the first fold of the fabric. The process of completing each hem is outlined in Figure 59.

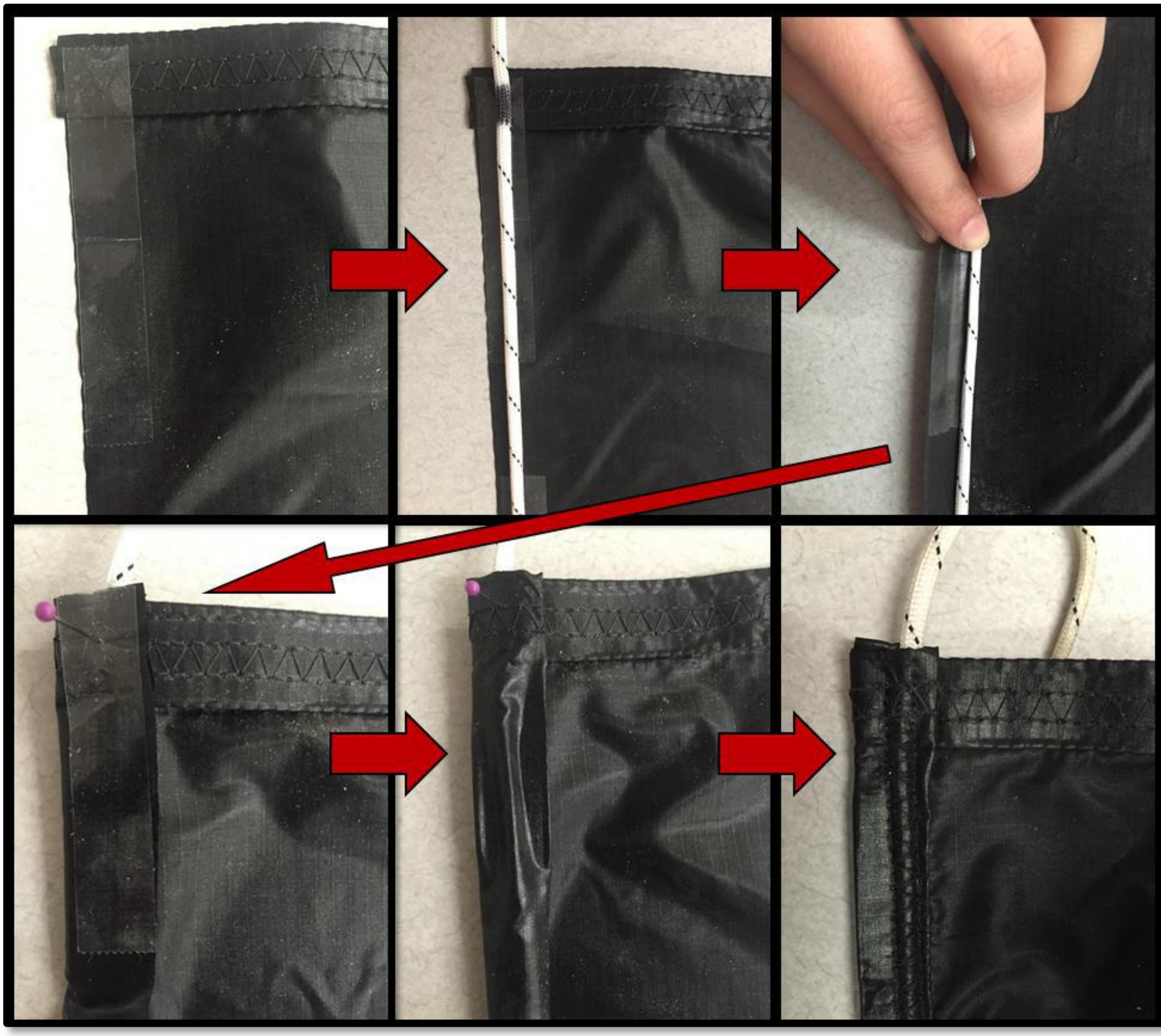


Figure 59: Parachute hem manufacturing process.

The suspension lines will be made of 1/8 inch nylon para-cord with 400 lb tensile strength. Six inches of line will be used for every location at which the lines need to be stitched into a panel or secured to another line. At the five connection points, four lines must be joined together. This is done by first placing two lines side by side and securing together using a zig-zag stitch. Both pairs of lines should be secured together in this manner. The two pairs of secured lines are then stacked on top of each other and secured using a zig-zag stitch. The line connection pattern is shown in Figure 60.

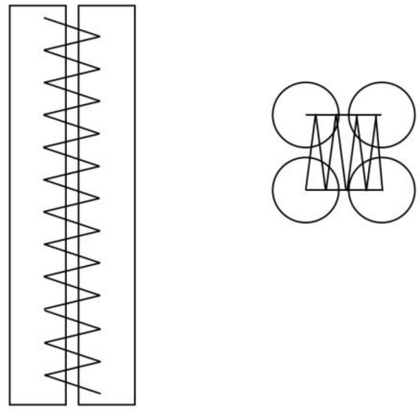


Figure 60: Suspension line connection pattern.

This connection is then wrapped in electrical tape to help prevent lines from snagging on the deployment bag or other lines as shown in Figure 61. Originally shrink tubing was going to be used to cover the groupings, but it was found that the shrink tubing added rigidity to the grouping once heated. While electrical tape still adds some level of rigidity, it is still more flexible than the shrink tubing, but provides the same level of protection.

Figure 61: Method of wrapping groupings of stitched suspension lines in electrical tape to prevent snagging.

Custom deployment bags will be constructed out of canvas that has been sprayed with a fire retardant coating. Canvas has previously been used by the team and has proved to be durable and fire resistant, protecting the parachute from any pyrotechnic activities.

Deployment Bags and Packing

Each parachute has a custom deployment bag that is designed for that specific parachute to aid it a successful deployment. The packing technique is also critical. For the vortex ring parachute, standard packing methods are not ideal because they lead to tangling lines. In order to avoid this, a unique packing method was established and is detailed step by step below.

1. Hook suspension lines into a QuickLink and lay the parachute out flat, ensuring that the lines are taught. A good way to ensure that it is laid out properly is to run with the parachute first to inflate it and let it fall naturally. This ensures that the panels are not twisted or that the lines are not tangled prior to packing.

Figure 62: Step one of vortex ring parachute packing.

2. Roll the panel fabric tightly. Make sure not to completely roll one panel at a time. All panels should be rolled at once. If an individual panel is rolled, it will likely stay twisted during deployment.

Figure 63: Step two of vortex parachute packing.

3. Fold the rolled fabric accordion style until the entire section of fabric has been folded.

Figure 64: Step three of vortex parachute packing.

4. Insert the folded panels into the deployment bag.

Figure 65: Step four of vortex ring parachute packing.

5. Neatly tuck all suspension lines into loops on deployment bag, continually moving in the counterclockwise direction until the entire length of the suspension lines are secured into the deployment bag.

Figure 66: Step five of vortex ring parachute packing.

Harnessing

The harness that connects the suspension lines to the launch vehicle are made of 9/16 inch tubular nylon with a tensile strength of 500 lbs, there will be one harness per parachute. Six inches of the nylon will be folded over and stitched together to secure to either an eye-bolt or a U-bolt. The stitched section will be covered with heat-shrink tubing in order to add an extra layer to prevent the section from coming unstitched and to prevent anything from getting caught on the lines.

Also, to prevent the shock chord from getting tangled during deployment, the shock chord is folded accordion style and taped together using blue painters tape. The painters tape holds the shock chord together in an organized manner, but is also weak enough that it easily breaks during deployment. This packing method is shown in Figure 67.

Figure 67: Shock chord packing method.

Since the rocket is approximately 12 feet tall, the rule of having the shock chord a minimum of three times the length of the rocket was utilized. Since the harness for the vortex ring attaches to both the nosecone and the fairing, this was split into two unequal lengths to prevent the sections from contacting during recovery as shown in Figure 68.

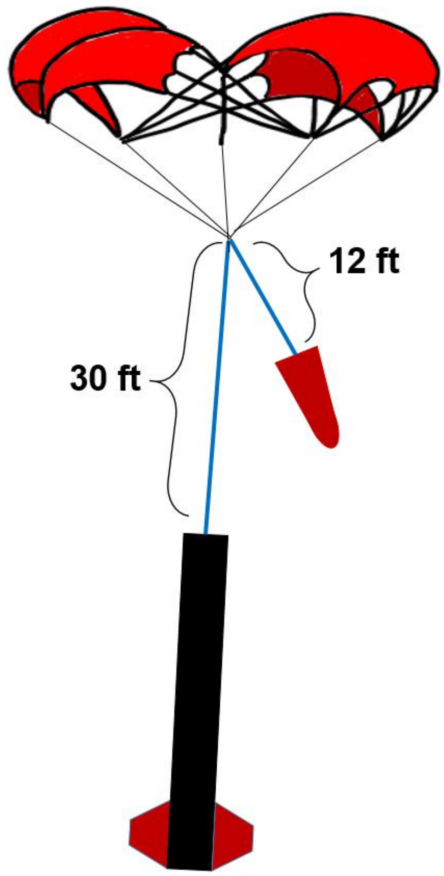


Figure 68: Main parachute harnessing scheme.

The rule of having shock chord three times a minimum of three times the length of the rocket was also utilized in determining the length of shock chord from the cruciform parachute. The harnessing lengths and connection hardware are shown in Table 26.

Connection location #1	Location #1 connection hardware	Connection location # 2	Location #2 connection hardware	Harness length [ft]
Nosecone	U-bolt and QuickLink	Vortex ring	QuickLink to swivel	12
Vortex ring parachute	QuickLink to swivel	Fairing	Stitched loop in harness to U-bolts	30
Cruciform parachute	QuickLink to swivel	Propulsion bay	QuickLink to U-bolt	18

Table 26: Recovery harness lengths.

In order to prevent lines from twisting up on themselves when the vortex ring is rotating, a swivel will be used in the configuration shown in Figure 69.

Figure 69: QuickLink and swivel configuration for vortex ring to harness connection.

Each harness is connected via QuickLinks. QuickLinks have proven reliable and make for easy assembly and disassembly on launch day.

Bulkheads

Each bulkhead used in the rocket is custom made and consists of two parts. The first half of the bulkhead is be a plate cut from half inch plywood using a laser cutter. A plate will also be cut from 1/8th inch G10 fiberglass using a water jet. Each of the wooden bulkheads will be epoxied to the fiberglass plates using ProLine 4500 high temperature epoxy. Once the bulkheads have been epoxied, holes will be drilled in order to mount the connecting hardware for the recovery harnesses. A sample bulkhead is shown in Figure 70.

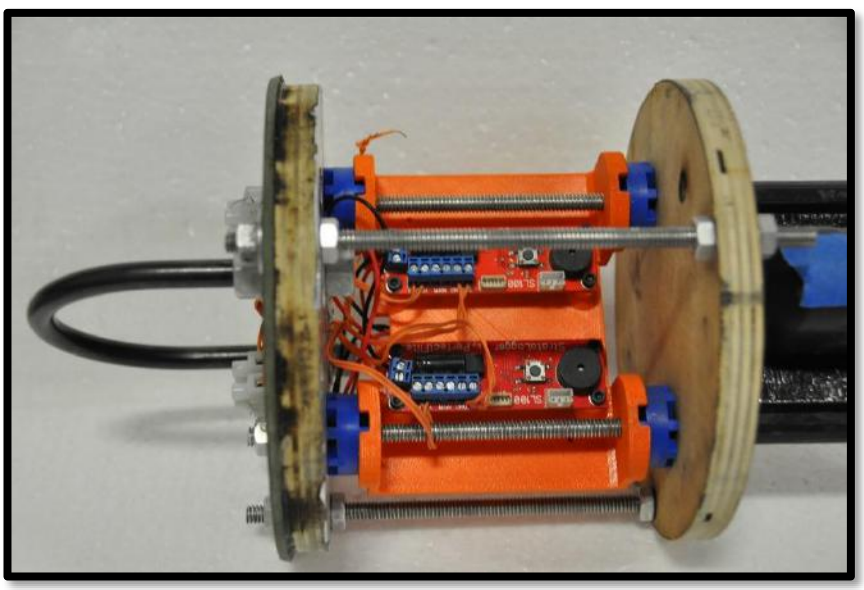


Figure 70: Custom fabricated bulkhead configuration.

The bulkheads will carry the load for the shock seen in recovery events. Each of the three events induce a different amount of stress. The maximum stresses seen during each event are detailed in Table 27.

Parachute	Maximum force (lb_m)
Vortex ring	166.05
Cruciform (lower airframe)	181.49
Cruciform (cache capsule)	31.94

Table 27: Maximum forces induced by parachute opening.

Bay Layout

For each recovery event, there is a uniquely designed recovery bay. The main recovery bay schematic is shown in Figure 71.

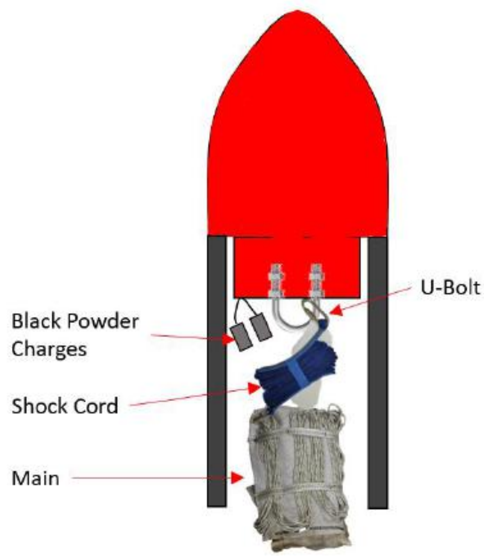


Figure 71: Main recovery bay schematic.

For the deployment of the main parachute, shock chord and the main parachute will be packed directly below the nosecone. Black powder charges will be fired to separate the nosecone and upper airframe from the remainder of the rocket and to push the main parachute out of the rocket. The main parachute will then be connected to the two sections of the rocket via two harnesses

The second recovery event is the ejection of the lower airframe. The schematic of the lower airframe ejection is shown in Figure 72.

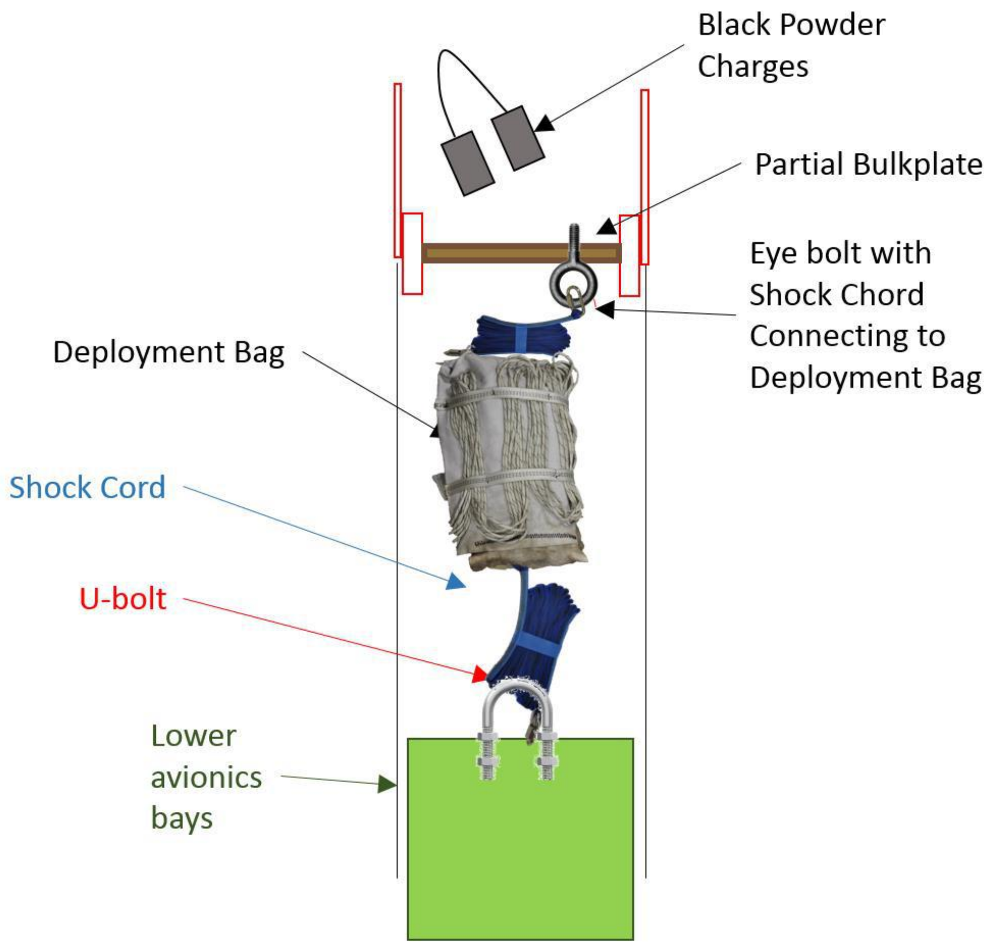


Figure 72: Lower airframe deployment recovery schematic.

Black powder charges will sit below the parachute and above the motor casing. This will separate the rocket and push out the parachute. The deployment back will be attached to and eyebolt on the fairing that will pull the deployment bag off of the parachute. The recovery harness will be attached to the lower airframe via an eyebolt that is threaded into the motor casing.

The final recovery event is the deployment of the cache capsule. A schematic of the cache capsule deployment schematic is shown in Figure 73.

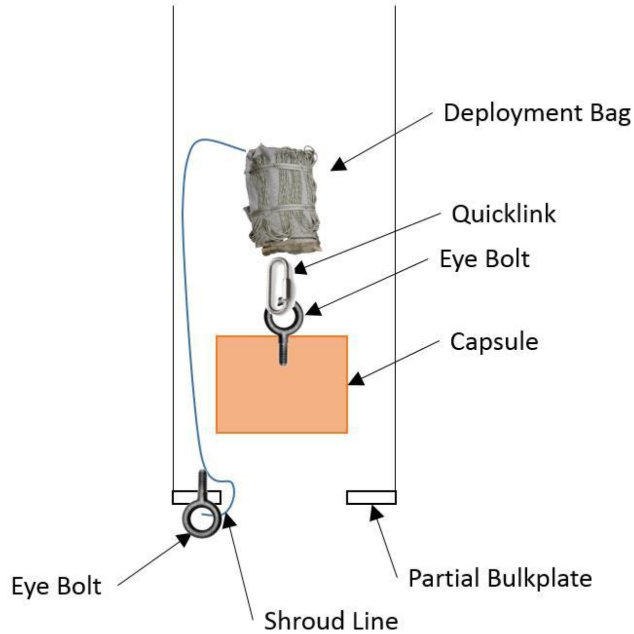


Figure 73: Cache capsule deployment schematic.

Once the pyro cap is fired and the fairing is allowed to open, the capsule will fall out the fairing. The parachute will be packed in a deployment bag directly above the capsule. The deployment bag will be connected to the fairing by securing a line from the bag to an eyebolt. This will secure the deployment bag to the fairing and allow for the capsule parachute to properly deploy.

Testing

Since the team did not have any experience with this geometry of parachute, a subscale version was constructed. The subscale parachute ground testing described earlier verified the C_D and ensured successful deployment. The subscale parachute was tested in flight with the subscale rocket. During flight it was determined that the lengths of shock chord were too short, causing the parachute to become tangled before coming out of the deployment bag. Due to this lesson learned, more attention was given to the harness length and attachment scheme to avoid the same problem.

One advantage of the vortex ring is that there are no scale effects upon the drag coefficient. Therefore, the information gathered from the sub-scale tests were able to be accurately translated to the full scale parachute.

The full scale parachute underwent ground testing prior to flight in order to ensure proper inflation and rotation, resulting in an adequate force of drag. The parachute as folded and packed into the deployment bag to verify that the packing method and the deployment bag were efficient and did not introduce any problems into the system. Shown in

Figure 74 are some pictures from ground testing that demonstrate the rotational properties of the vortex ring.

Figure 74: Vortex ring during ground testing.

After the parachutes were ground tested, ejection charge testing was completed. This verified that the charges were appropriately sized, making sure that the charge was large enough to separate the sections of airframe and push out the recovery. At the same time the testing proved that the charge was small enough that unnecessary stresses were not introduced into the system from excessive shock.

Once the recovery system had been verified during ground testing and ejection charge testing, the parachute was flown in a full scale test. During the test, a lot was learned about the packing method. In the parachute packing section of the report, it was discussed that it is critical that all panels be rolled at once and not one at a time. This flaw in the packing was discovered through the full scale test. One of the panels had gotten rolled individually, causing it to stay twisted during the entirety of the flight. Despite this dilemma, the other three panels still inflated and allowing the parachute to still rotate, generating enough lift to bring the rocket safely to the ground. A keychain camera was attached to the shock chord from the vortex looking upward to be able to watch vortex ring's performance afterwards. A screen shot of the video is shown in Figure 75.

Figure 75: Image of vortex ring parachute from below during full scale test flight.

Avionics

Each section of the rocket that will be independently recovered has its own avionics bay on board. The avionics bays each contain two altimeters and a GPS tracking device as shown in Figure 76.

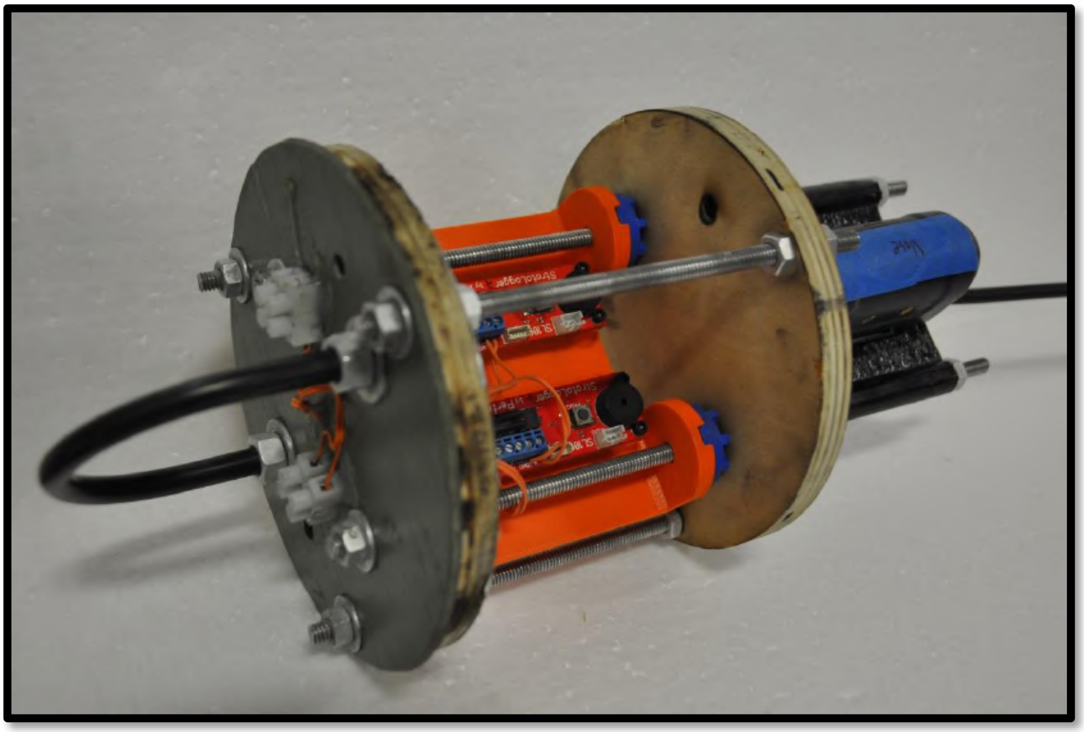


Figure 76: Avionics bay including altimeter and GPS sleds.

Custom sleds have been designed for each of these components. All of the sleds are 3D printed out of ABS and are mounted on ¼ inch threaded rods between sets of bulkplates. ABS was selected for weight reduction purposes. Additionally, in the event that a section of the rocket would fall with too much kinetic energy, 3D printed ABS parts are not as likely to shatter as the alternative material selections.

For the deployment of the upper airframe main parachute, separation of the lower airframe, and deployment of the cache capsule, PerfectFlite StratoLoggers, pictured in Figure 77, will be used. These will be used to trigger black powder ejection charges.

Figure 77: PerfectFlite StratoLogger

The PerfectFlite StratoLogger altimeter records its altitude at a rate of 20Hz with a 0.1% accuracy. In previous testing, the altimeter was found to be accurate to ±1 foot. Testing was also performed to test the maximum e-match capacity of the main and drogue terminals. Four e-matches were able to be fired off simultaneously during testing. Additionally, the StratoLogger can be configured to provide a constant serial (UART) stream (9600 baud rate, ASCII characters) of the device's current altitude over ground.

Testing was performed on each of the Stratologgers to ensure that the altimeters utilized during flights were fully functional prior to launch. In order to verify that the StratoLoggers function correctly, the setup shown in Figure 78 was used.

Figure 78: Pressure vessel used to test StratoLoggers.

A sealed chamber with a gauge measured in inches of mercury was used as a pressure vessel to simulate the change in altitude that each StratoLogger experiences during a flight. An electric pump was used to siphon the air out of the pressure vessel. The StratoLoggers were tested in pairs on the board as shown in Figure 79.

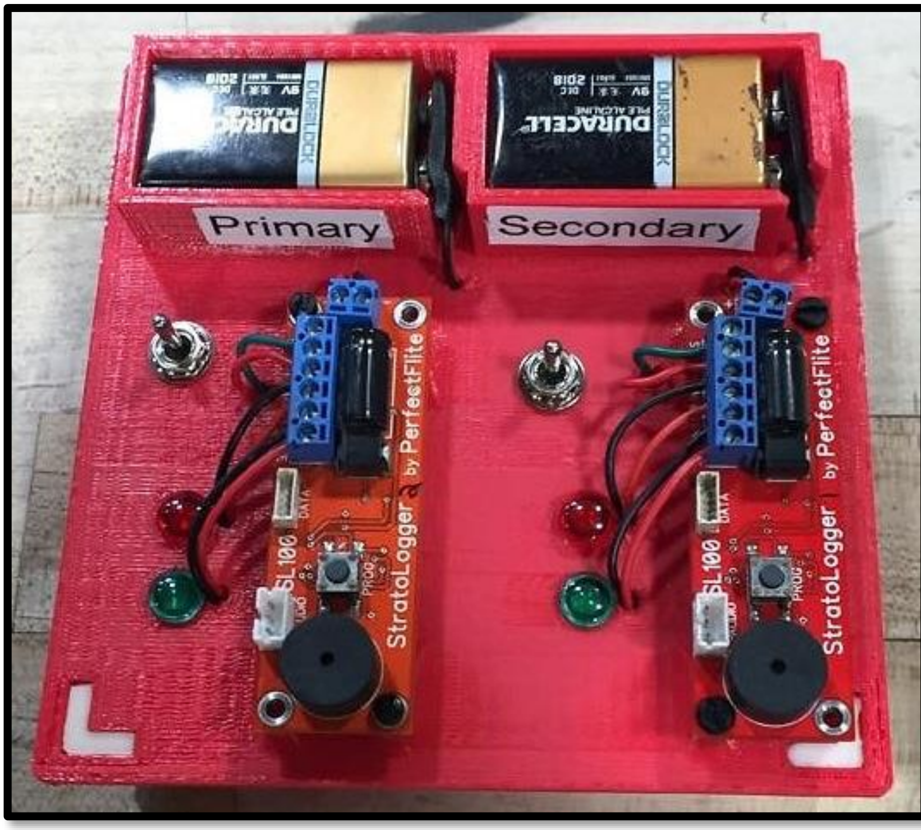


Figure 79: StratoLogger testing apparatus.

The StratoLoggers were powered by standalone 9V batteries and were wired to independent sets of LEDs. The green LED would light to indicate the status of the drogue charge firing and the red LED would light to indicate the status of the main charge firing.

After allowing the StratoLoggers to finish their startup processes, the board was placed inside the pressure vessel which, after sealed, was evacuated of air and taken to a pressure simulating an altitude of approximately 15,000 ft, which is above the desired apogee of 3,000 ft. Following this, the pump was then shut off and air allowed to slowly leak back into the chamber, thus simulating the descent from apogee.

One StratoLogger was set to act as the primary altimeter with the other acting as the redundant altimeter. The primary altimeter was programmed to send the "fire" signal at 700 ft with no delay and the redundant altimeter was set to send the "fire" signal at 650 feet with a delay of 1.5 seconds. The delay was chosen to allow time to differentiate when the charges were firing due to the rapid increase of pressure when removing the vacuum. All six StratoLoggers were tested in this manner with six successes.

Once an altimeter has been marked for passing testing, they can be integrated into the avionics bays. The avionics bays for the upper and lower airframe will be identical. Custom altimeter sleds have been designed and 3D printed to house the altimeters as shown in Figure 80.

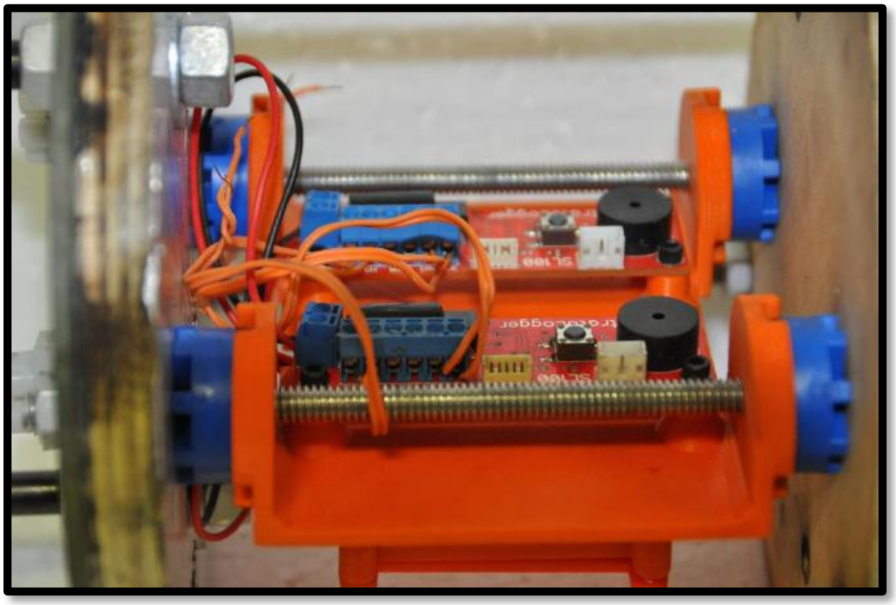


Figure 80: Altimeter sled.

Each StratoLogger will be mounted using four 4-40 screw onto four 18-8 stainless steel hex standoffs. Each StratoLogger is powered by an individual Duracell 9V battery. Duracell batteries have been selected due to their reliability. Since the leads are internally soldered, the chance of battery failure from vibrations during flight is less likely than with a battery that does not have internally soldered leads. The batteries are mounted on the opposite side of the altimeter sled and held in place with a cover that is mounted using four 4-40 screws, as shown in Figure 81.

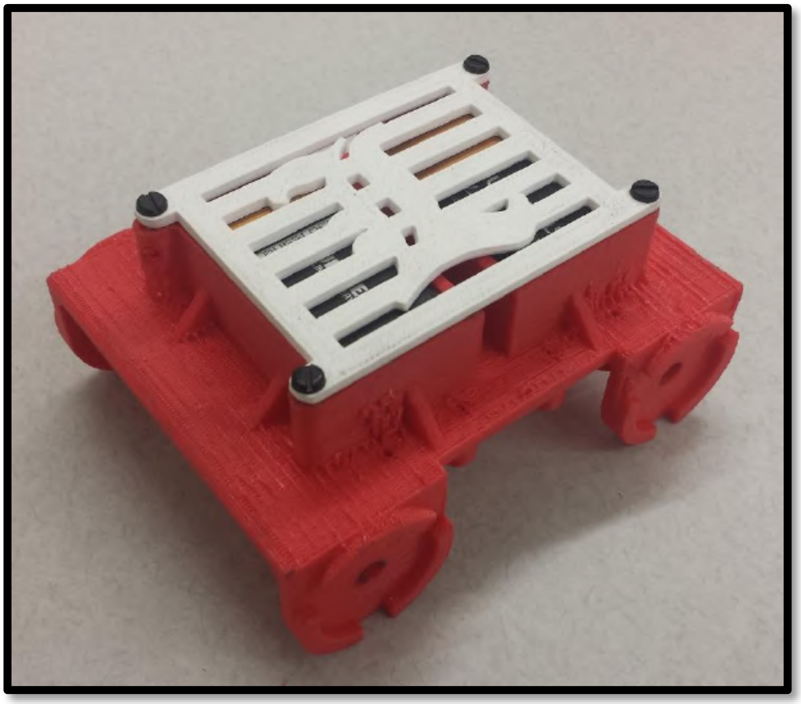


Figure 81: Battery clips view of altimeter sled.

There are two slots sized for a 9V battery. The two batteries are retained through the use of a 3D printed cover that is mounted using four 4-40 screws. Four rubber dampeners, as shown in Figure 82, are incorporated into the stack-up to reduce the shock and vibrations that the altimeters see throughout the course of the launch and recovery.

Figure 82: Rubber dampener.

Each altimeter will be locked into the on position through use of a Featherweight screw switch, shown in Figure 83. The switches allow for easy arming of altimeters while the rocket is upright in the ASGE. Access holes will be drilled and marked on the outer airframe to allow for arming.

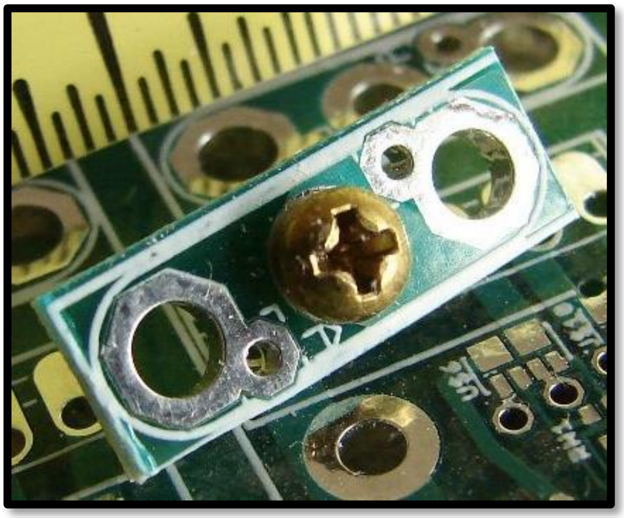


Figure 83: Featherweight screw switch.

To satisfy the GPS requirement, both of the avionics bays will use a Garmin Astro DC 40. The Garmin tracker will be mounted in the rocket on a custom 3D printed sled, shown in Figure 84. The Garmin Astro's have a range of 7 miles line of sight and approximately 2.5 miles in dense woods. The unit operates at a frequency of 151,880 MHz and a wattage of 2W.

There will be a wooden bulk plate dividing the GPS units and altimeters in the avionics bay. The entire inside of the avionics bay will be covered in aluminum tape in order to shield the altimeters from the GPS unit as well as any other transmitted signals from the AGSE that may interfere.

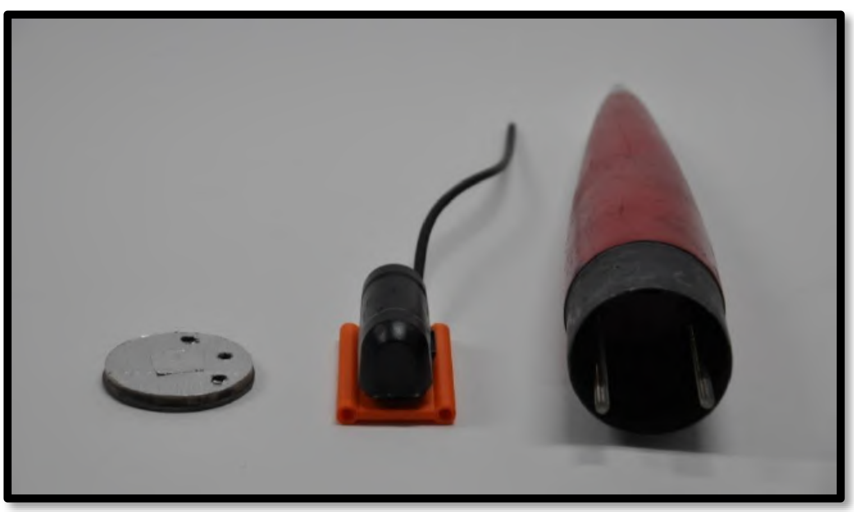


Figure 84: Garmin tracker mounted on custom 3D printed sled.

To satisfy the GPS requirement for the cache capsule, the capsule will house an Eggfinder GPS tracking system, shown in Figure 85. This has been switched from the TeleMetrum since we no longer need to fire a black powder charge from within the capsule. Additionally, the Eggfinder will be half the cost of the TeleMetrum.

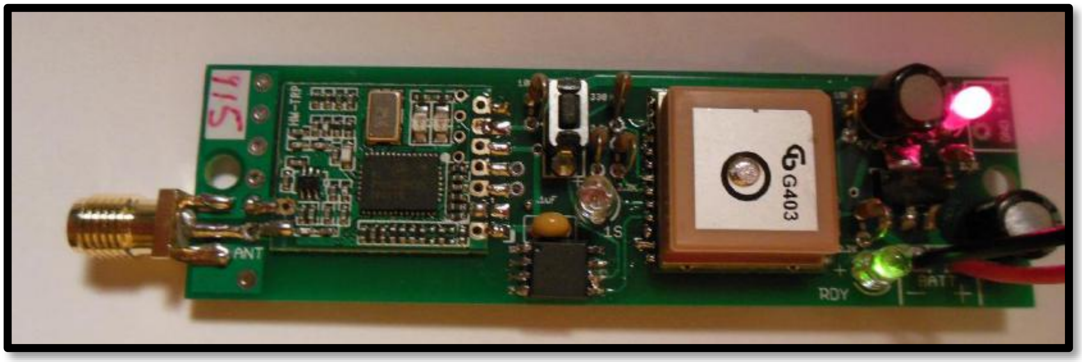


Figure 85: Eggfinder GPS tracking device.

The Eggfinder, is a 0.9"x3"x0.4" board that weighs only 20 grams. The GPS has been tested and is reliable up to 8000 ft, which is well within the expected range of the rocket. The Eggfinder operates at a frequency of 900 MHz at 100mW.

Electrical Schematics

Each recovery event will be controlled with a unique avionics bay. The following wiring schematics detail the components utilized and the activation set point for each PerfectFlite StratoLogger.

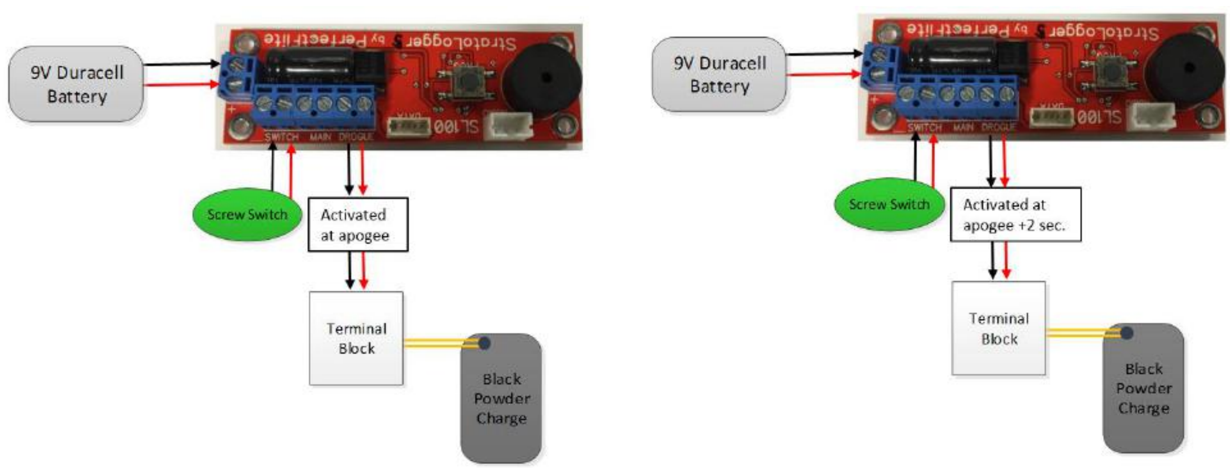


Figure 86: Main recovery electrical schematic.

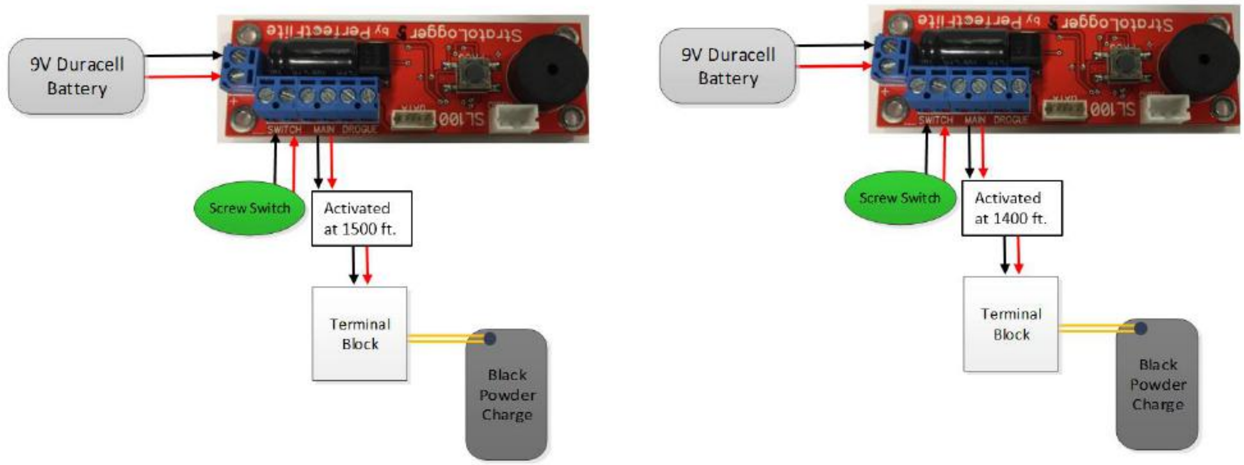


Figure 87: Lower airframe recovery electrical schematic.

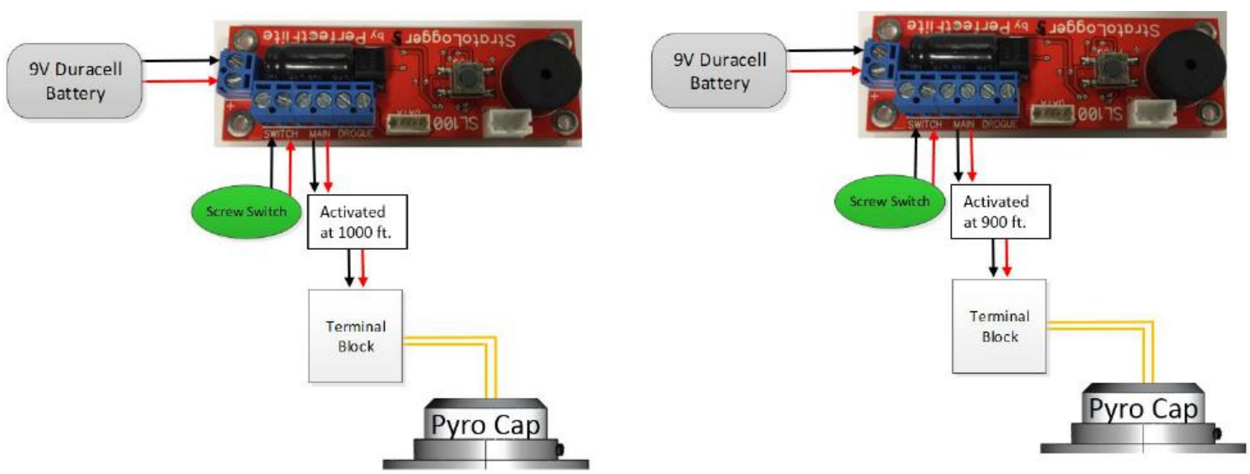


Figure 88: Fairing recovery electrical schematic.

Redundancy has been incorporated into each recovery event with multiple altimeters and black powder charges. Each recovery event utilizes two Stratologger altimeters. In the event that the primary altimeter would malfunction, the secondary altimeter will actuate the event. Each altimeter is connected to its own black powder charge. In the event that the primary black powder charge would leak and not ignite, the secondary black powder charge will be enough to separate the sections of airframe.

Challenges

The primary recovery challenges are shown in Table 28.

Challenge	Solution
Avoiding parachute tangling during ejection.	All parachutes will be stored in deployment bags which will be custom made and tailored to each individual parachute.
Custom made parachute with unknown drag coefficient.	A parachute will be tested to determine the drag coefficient which will be used in sizing and construction of the remaining parachutes.
Eject cache capsule without damaging the parachute.	A non-explosive actuator release will be used to release the cache capsule from the upper airframe. The system does not produce any fragmentation or debris, making it safe to operate near a parachute.

Table 28: Recovery challenges.

3) Mission Performance Predictions

Performance Criteria

The following criteria must be satisfied for a mission success:

1. Rocket returns completely reusable, or with easily repairable damage.
2. An apogee no more than 75 feet above or below 3,000 feet is attained.
3. Horizontal drift of 1,000 feet or less is experienced in winds of 20 mph.
4. Vertical velocity does not exceed Mach 0.6.
5. Velocity at rail exit is not below 50 ft/s (assuming 10 foot rail).
6. Kinetic energy upon landing, of all recovered sections, does not exceed 75 lb-ft.
7. The rocket must retain a 1.8 or greater stability margin during ascent.

Overall Launch Vehicle Characteristics

An OpenRocket model of the full scale design, shown in Figure 89, has been created to simulate the launch vehicle's layout, physical properties and flight. Using the simulation software within the OpenRocket software, the following values were obtained:

- Overall Length: 143.0 in
- Overall Diameter: 6.17 in
- Overall Mass: 42.9 lbs
- Stability Margin: 1.85 caliber (From tip: CG – 88.37 in, CP – 99.79 in)

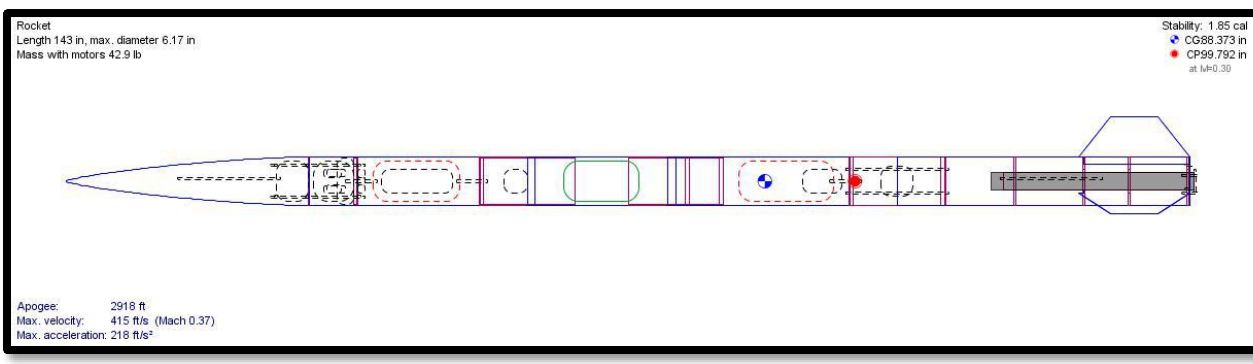


Figure 89: OpenRocket schematic of the full scale launch vehicle.

Critical Mass Components and Statement

Using the OpenRocket software, mass measurements from previous years, and general estimations the mass of the launch vehicle has been accounted for as best as possible. While still in the early stages of design, it is important to account for the mass of various components as best as possible.

Table 29 lists the various weights of each section of the launch vehicle.

Section of Launch Vehicle	Length of Section (in)	Mass (lbs)
Nose Cone	30.85	4.90
Main Recovery Bay	27.5	3.47
Cache Containment Bay	16.75	6.34
Secondary Recovery Bay	28	8.02
Propulsion Bay	37	14.37
Witness Rings	2	0.20
Motor	N/A	5.60
	Total Mass	**42.90**

Table 29: Mass and length evaluation of critical launch vehicle sections.

The motor choice, laid out in the following section, has been made on the assumption of a 15-20% mass increase over the course of the project. This increase in mass will come from unforeseen needs in the overall design. By utilizing the launch vehicle's ballast system, the team will be able to hit close to the 3,000 foot benchmark.

Motor Selection

The full scale launch vehicle will use a Cesaroni L935-IM. Based on the team's familiarity with motors from this supplier, Cesaroni was the sole choice for motor selection. Cesaroni motors are known for their ease of use, reliability, and performance characteristics. A thrust curve detailing the L935-IM's thrust versus time is shown in Figure 90.

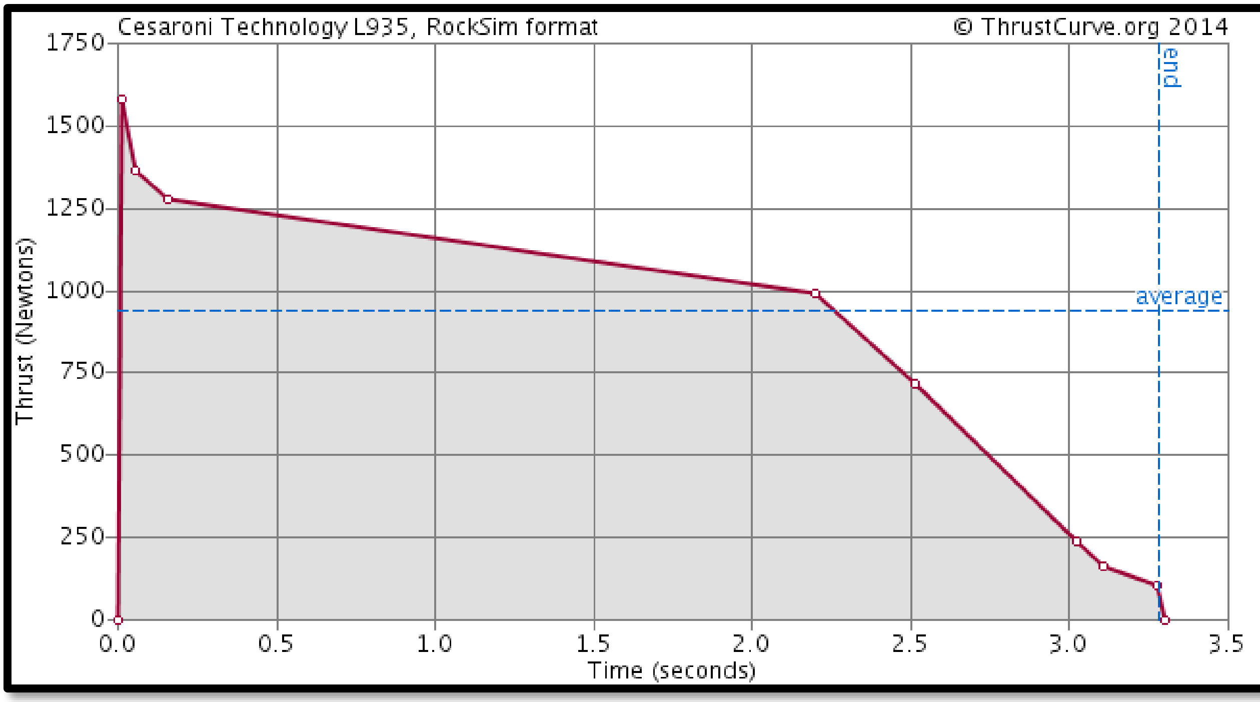


Figure 90: Thrust curve of the CTI 3147-L935-IM-P motor.

The motor was chosen to bring the launch vehicle's simulated apogee to just above 3,400 feet, knowing that number will drop as the vehicle's gains more mass through the unforeseen needs during manufacturing. To ensure a sufficient launch rail exit velocity, the choice to go with an Impulse Max (IM) motor was an obvious choice. Table 30 lists simulated vehicle information and motor details as justification for the motor selection.

Thrust-to-Weight Ratio	4.89
Rail Exit Velocity	61.7 ft/s
Projected Altitude	2919 ft
Maximum Acceleration	227 ft/s^2
Motor Burn Time	3.4 sec
Maximum Motor Thrust	1585.6 N
Average Motor Thrust	933.8 N
Total Motor Impulse	3146.8 N-sec

Table 30: Justification for motor selection.

The following plots shown in Figure 91 through Figure 94 display various simulation results indicating the proper motor selection, CG and CP locations.

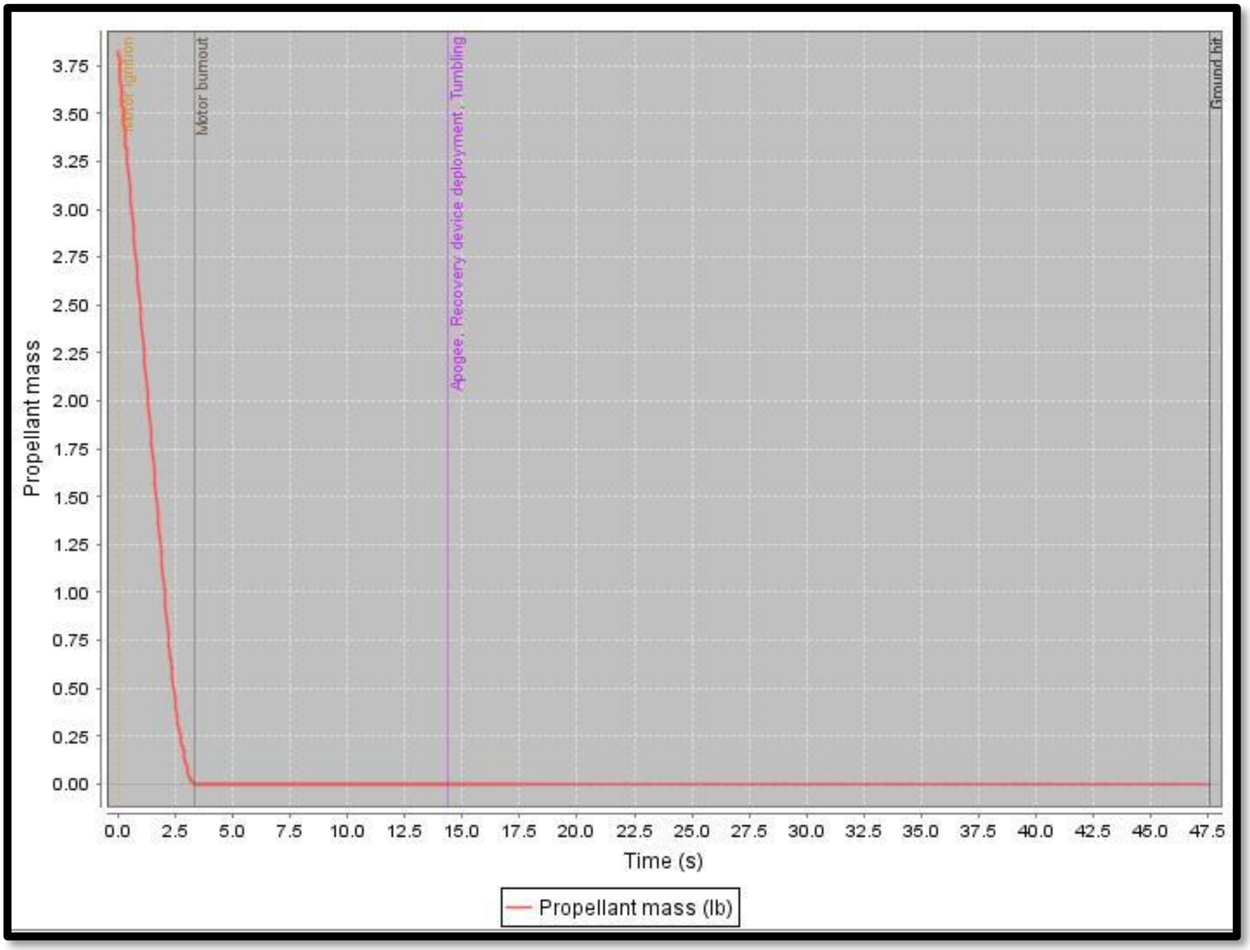


Figure 91: A plot of mass propellant versus time.

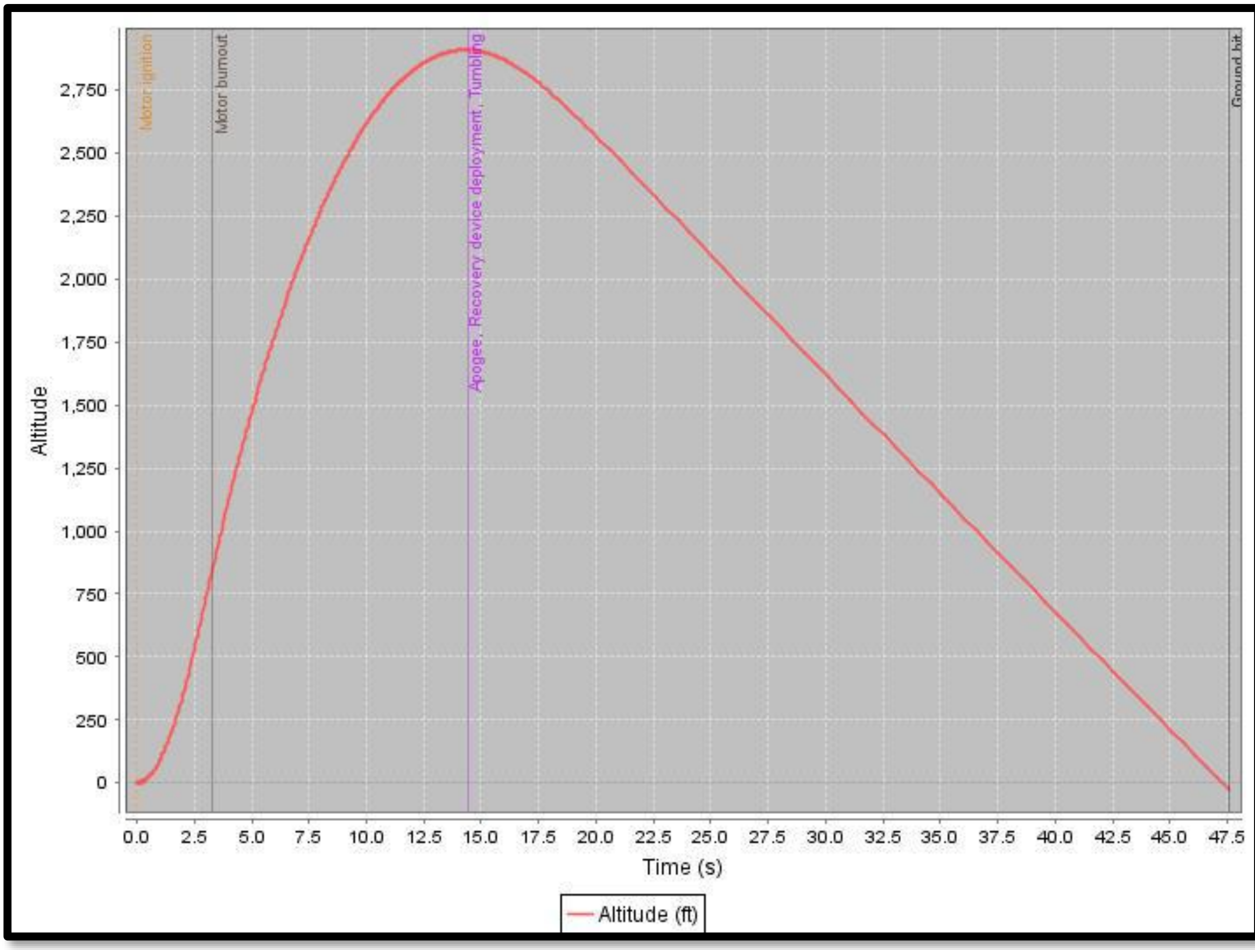


Figure 92: A plot of altitude versus time.

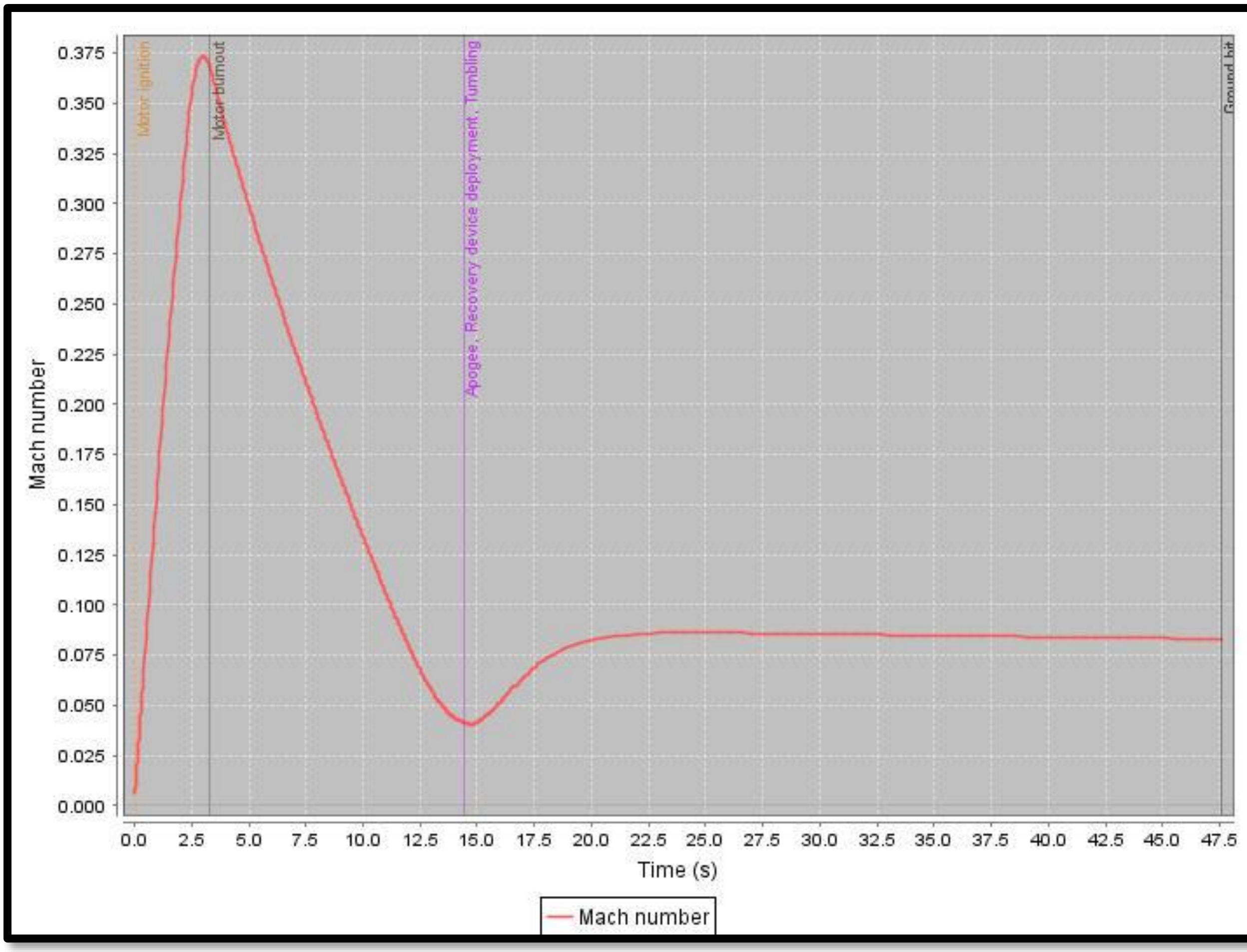


Figure 93: A plot of Mach number versus time.

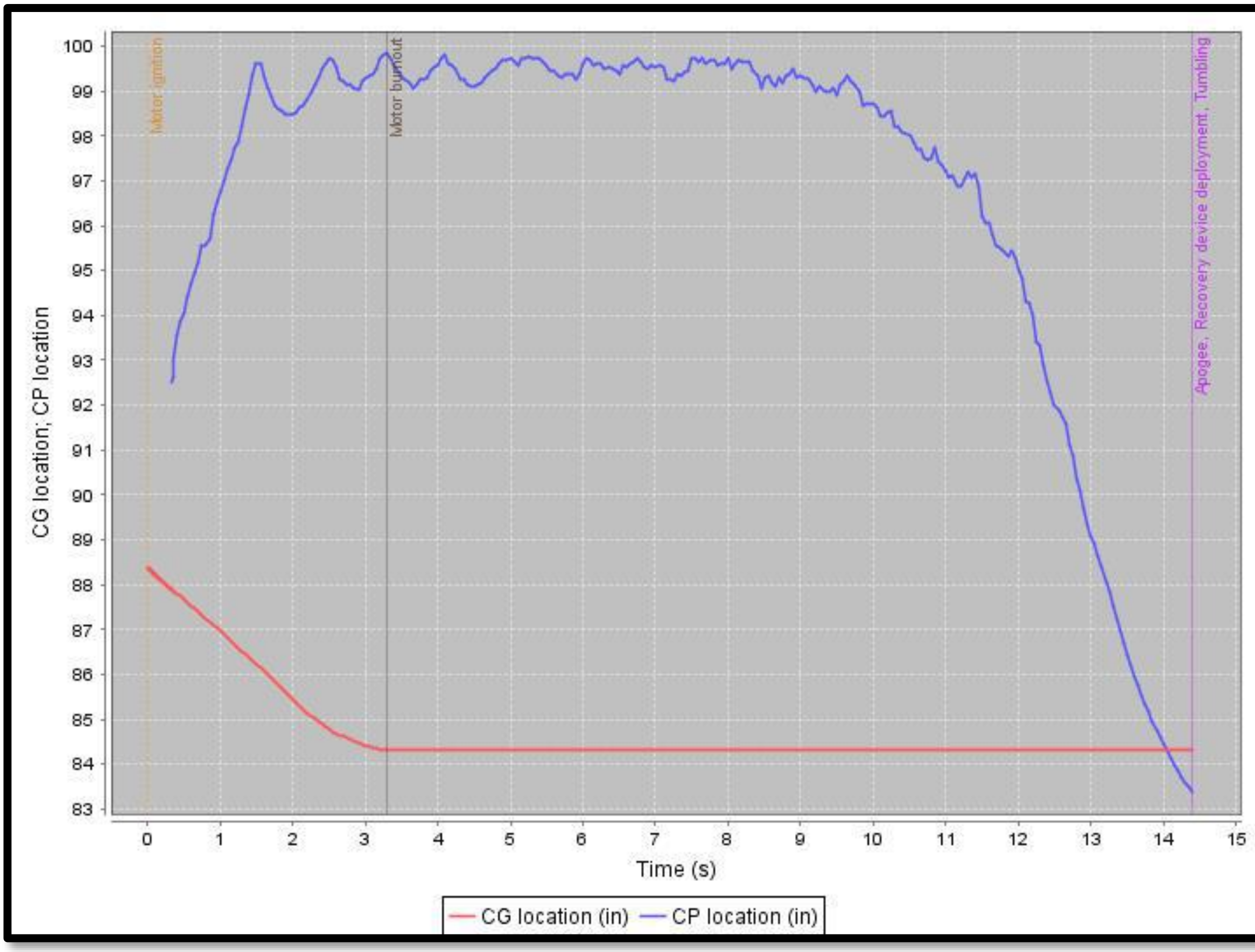


Figure 94: A plot of CG and CP locations versus time.

Table 31, below, shows the simulated altitude of the launch vehicle against various wind speeds. To ensure an accurate flight model, each simulation will be run prior to a launch with a live reading of the wind speed at the launch site.

Wind speed (mph)	Simulated altitude (feet)
0	2926
5	2909
10	2893
15	2879
20	2883

Table 31: Altitude simulations against various wind speeds.

Designing an efficient high powered launch vehicle has its own inherent challenges. To ensure safety and vehicle performance the team will focus on tackling various design challenges with various solutions. Furthermore, the team must make sure their overall design stays within the constraints laid out by the Statement of Work. Table 34, below details the various challenges and their related solutions.

Recovery: Drift and Kinetic Energy

Drift calculations have been performed to understand how far the rocket will drift given a range of wind speeds. The calculations were computed in increments of 5 mph, ranging from perfect conditions of 0 mph to the worst case scenario of 20 mph. Shown in Table 32 is a chart including each of the calculated points. Also shown in Table 32 are the allowable errors in the drift calculations for each of the wind speeds.

Wind speed (mph)	Distance drift from launch pad (ft)	Allowable Error (%)
0	0	undefined
5	388	580
10	776.5	240
15	1165	127
20	1553	70

Table 32: Drift calculations.

Since the competition launch field allows for a drift distance of a half a mile, the rocket will remain safe from obstacles during recovery even in the worst case scenario winds.

A MatLab script was written to be able to easily calculate the drift for any possible wind speed. During launches, members are to run the script for drift calculations to ensure that the predicted drift radius is clear of any hazardous obstacles. Since the script may not be able to be run on a server immediately prior to launch, a graph has been derived from the calculated set points to allow for members to approximate the distance that the rocket will drift from the launch pad. This graph is shown in Figure 95.

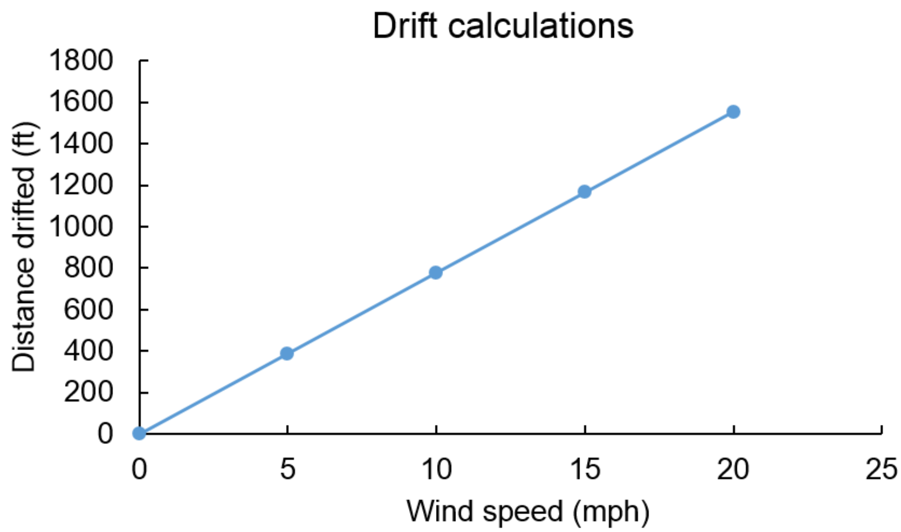


Figure 95: Distance rocket drifts from the pad for all wind speeds possibly encountered during a launch.

The calculated drift is considered acceptable. Due to the teams familiarity with the competition launch site, it was determined that the drift needed to be less than a half mile to avoid any potential hazards. The current recovery schematic keeps the entire system well within the limits. As the design of the rocket progresses forward, calculations will be updated with hard data such as the mass of each component of the rocket and the coefficient of drag of the parachute. Currently these inputs are theoretical. Through testing we will be able to more accurately predict the drift on launch day.

A plot of altitude versus time for the upper airframe falling under the vortex ring parachute is shown in Figure 96.

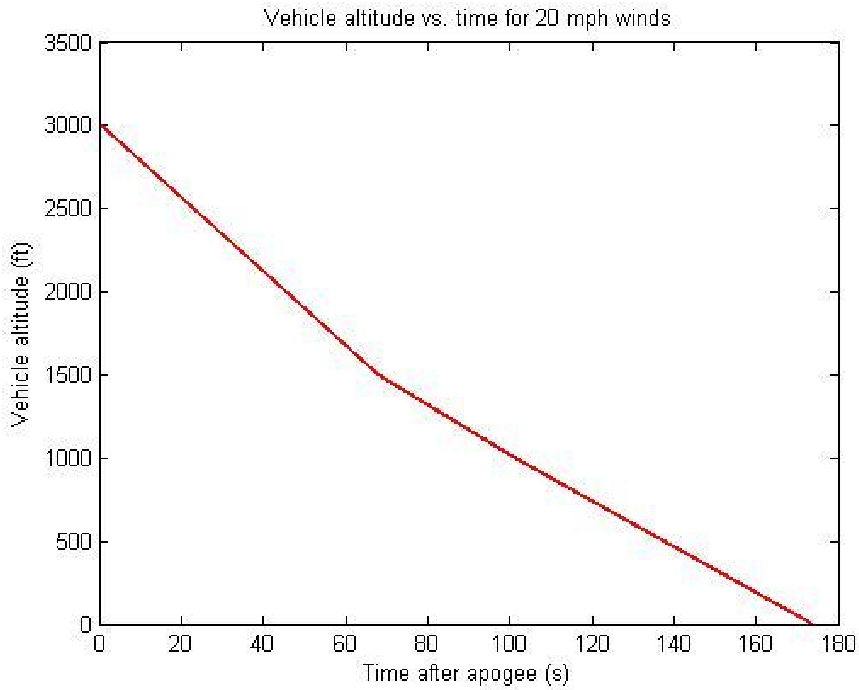


Figure 96: Upper airframe altitude versus time plot for worst case scenario.

The decent velocity versus time is shown in Figure 97 for the vortex ring.

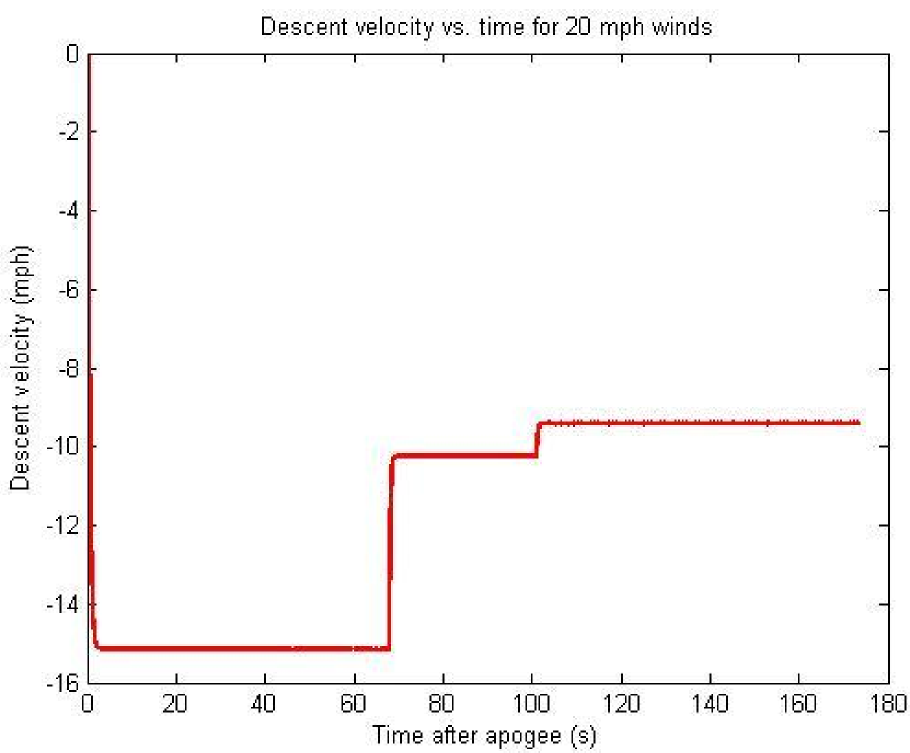


Figure 97: Upper airframe decent velocity versus time for worst case scenario.

The two drops in velocity are from where sections of the rocket are dropped off. Initially, the vortex ring will be allowed to fall faster, preventing the system from drifting. As the lower airframe and the cache capsule are dropped off of the upper airframe, the vortex ring becomes appropriately sized for the load that it is carrying, allowing the upper airframe to be successfully recovered.

The terminal velocity of each section of the rocket was calculated using

$$V=\sqrt{\frac{2Eg_c}{m}} \tag{22}$$

where E is the kinetic energy, g_c is the dimensional constant, and m is the total mass of the section to be recovered. A value of 75 ft-lbs was used for the maximum kinetic energy since this was the requirement established in the statement of work to determine the minimum size of the parachute. The steady state velocity under parachute was calculated using

$$V=\sqrt{\frac{2mg}{\rho C_d A}} \tag{23}$$

where g is acceleration due to gravity, ρ is the density of air, C_D is the coefficient of drag of the parachute, and A is the effective area of the parachute. The equations were combined in the following equation to solve for the necessary effective area of the parachute.

$$A=\frac{m^2 g}{\rho C_d E g_c} \tag{24}$$

The nominal diameter of the parachute was calculated using

$$D_o=\sqrt{\frac{4A}{\pi}} \tag{25}$$

The area, diameter and velocity were calculated for each of the three recovery systems on board the rocket. Multiple iterations of the calculations were run, altering the allowable kinetic energy in order to achieve decent velocities that could be withstood by each of the systems. The calculations are shown in Table 33.

Section of rocket	Mass (lb_m)	Area (ft^2)	Velocity (ft/s)	E (lb_f-ft)
Upper airframe	14.71	29.2	16.20	60
Lower airframe	20.75	132.2	13.64	60
Cache capsule	2.7	13.4	15.44	10

Table 33: Parachute area, diameter, decent velocity, and kinetic energy calculations.

Prior to the lower airframe and cache capsule detaching, the main parachute will function more like a drogue parachute due to the additional weight. The main will provide stability while still allowing the section to fall rapidly until the lower two sections separate, eliminating significant drift.

Challenges

Challenges	Solutions
The vehicle shall deliver the payload to, but not exceeding, an apogee altitude of 3,000 feet above ground level (AGL).	Efficiently document and record all material and component weights throughout the design and manufacturing of the launch vehicle. Maintain accurate OpenRocket simulations and hand calculations to ensure correct motor selections.
The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in the competition scoring.	Each section of the launch vehicle that falls under its own parachute, including the cache containment section, will have its own barometric altimeter. For complete redundancy, each section will have a secondary backup altimeter as well.
The launch vehicle shall be designed to be recoverable and reusable.	Each parachute will be designed to ensure sections of the launch vehicle land with a kinetic energy below the maximum kinetic energy laid out in the Statement of Work. Landing within these constraints will leave our launch vehicle in a reusable state.
The launch vehicle shall have a maximum of four (4) independent sections.	Our launch vehicle will be comprised of 4 independent sections: the nosecone, the main recovery bay, the payload containment bay, and the propulsion bay. Each section will either fall under their own parachute or will be tethered to another section's recovery.

The launch vehicle shall be limited to a single stage.	Having a limited altitude of 3,000' eliminates any need for staging of our launch vehicle. Motor selections have been made to accomplish all necessary altitude requirements on a single stage launch vehicle.
The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.	A comprehensive launch procedure checklist will be constructed by the team to allow for accurate and expedited vehicle assembly while preparing for flight.
The launch vehicle shall 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 component.	The power supplies for all AGSE components, altimeters, and flight event devices have been chosen to eliminate the chances of power failure for an extended period of time.
The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system.	The launch vehicle will utilize the provided and proven launch igniters provided with the Cesaroni motors. The igniters are designed to ignite the vehicle's motor by use of a standard 12 volt direct current firing system.
The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	The team will be using a Cesaroni L910 two grain C-Star motor for its full scale launch vehicle. The team has never had a motor failure in the past while using Cesaroni motors.
The total impulse provided by a launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	The total impulse of the Cesaroni L910 two grain C-Star motor is 2,856.1 Newton-seconds.
Any team participating in Maxi-MAV will be required to provide an inert or replicated version of their motor matching in both size and weight to their launch day motor. This motor will be used during the LRR to ensure the igniter installer will work with the competition motor on launch day.	The team will be 3D printing an exact replica of the motor used in the full scale flight for the LRR. It will be custom weighted to ensure the inert replica matches the launch day motor in both size and weight.

Pressure vessels on the vehicle shall be approved by the RSO and shall meet the criteria laid out in the Statement of Work.	The current design of the launch vehicle and AGSE does not require the use of any pressure vessels. If the design changes to include such a system, NASA and the RSO will be notified, and the criteria mentioned in the Statement of Work will be met.
All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model.	The team will design a 1:2 scaled model of the full scale launch vehicle. The subscale launch vehicle will be used to test stability and integration of various systems seen in the full scale launch vehicle.

Table 34: Solutions to various challenges set out by the statement of work.

4) Interfaces and Integration

Cache Capsule

The cache capsule must fulfill the following requirements in order for the mission to be considered a success.

1. Provide a location for the cache to be placed by the arm.
2. Secure the cache inside the capsule during flight.
3. Be ejected from the rocket at a designated altitude.

Design

To contain the payload within the rocket, a capsule will be mounted inside one of the rocket's bays which is shown in

Figure 98 and Figure 99. The overall size of the capsule with the doors closed is 8.375" x 5.25" x 2.7".

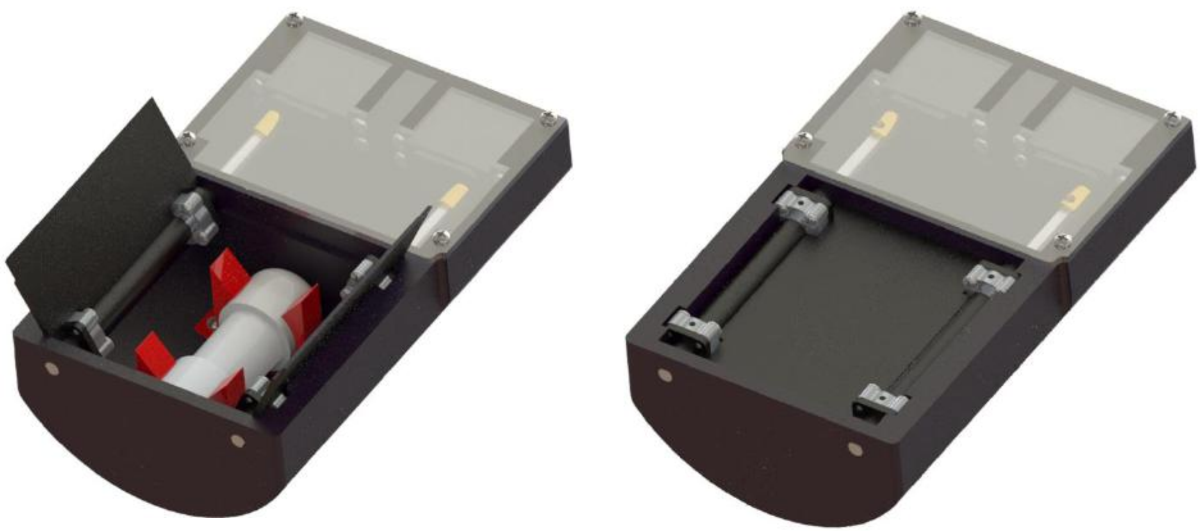


Figure 98: Payload capsule with open (left) and closed (right) doors.

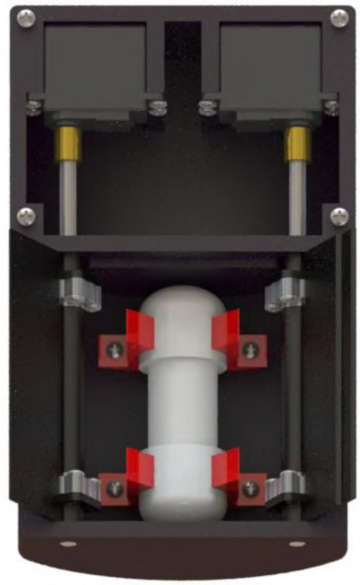


Figure 99: Top view of payload capsule.

The capsule will be 3D printed out of ABS plastic due to its irregular geometry. The outside of the capsule will have the same radius as the inside of the rocket. The cache capsule is designed to be a completely independent system that can function without any dependence on the rocket. There are two separate compartments, one contains the payload and the other contains any necessary electronics, including the Eggfinder GPS module and Arduino. The electronics compartment will have a clear acrylic cover that screws into the capsule body using four #6-32 UNC screws.

The lower section contains two retaining clips, shown in Figure 100. The clips are sized to fit around the PVC caps of the cache. This allows for the gripper on the robotic arm to have room to grip the cache until it is fully inserted into the clips.

Figure 100: Retaining clip.

The two angled faces serve as a guide for the robotic arm if the alignment is not precisely in the middle of the clip. The angles guide the cache to the centered location. When a force is applied by the robotic arm, the retaining clip will flex, allowing the cache to slide into place. Once the cache has been pushed into place, the clips will snap back to their original position, forming a compression fit. This compression fit will secure the cache during the remainder of the ground operations and throughout launch and recovery.

A benefit to the retaining clips is that the system can function no matter what orientation the rocket is at. This protects the cache from shifting positions during flight. This also gives the team the flexibility to rotate the system and install the cache from any angle.

Once the payload is put into the clips and the payload arm is retracted the doors will begin to close. The linear door is operated via a Hitec HS-5485HB servo which outputs 89 oz-in of torque. The servos is be located at the back of the electronics section. There is an attachment point designed into the electronics section for the servos to slide in screw into using four #6-32 UNC screws. A single plastic gear rack, mounted to the actuating door will connect the door to the servo. The rack will slide through an opening between the cache section and electronics section of the container. The rack will be mounted to the sliding door using #4-40 UNC bolts. A view of the door and rack and pinion system is show in below in ____ and _____ respectively.

Figure 101: Capsule door.

A track has been designed into the capsule body for the door to slide through which is ¼ inch larger than the internal width of the capsule body. This allows for the door to actuate easily through the track will preventing the door from falling out of the capsule body during while falling under parachute.

On the bottom of the payload compartment, a flange will be located where the door rests once closed. The doors will also rest on the top of the payload clips so there are no interference issues. The payload clips will screw into the bottom of the capsule using two #6-32 UNC screws.

Challenge	Solution
Secure cache in place.	Clips allow for easy insertion and retention of cache. Analysis has been performed to optimize the dimensions of clips to apply a sufficient force to retain the cache while minimizing the force applied by arm to insert cache.
Close doors of capsule autonomously after the arm is out of the way.	Servo to close door is activated by a switch on a time delay. Testing will be performed to ensure the necessary timing of events.

Table 35: Cache Capsule Challenges

Door System

Design

To keep the ground station and launch vehicle systematically autonomous, a retractable door has been incorporated into the launch vehicle. The door is located in the cache containment bay on the launch vehicle, as seen in Figure 102 The door, when activated via on-board electronics, will be opened by a servo motor. With the door opened, the payload can be inserted into the cache containment. Once the payload is in place, the door will be told to close, at which point the servo motor will actuate the door closed.

Figure 102: Depiction of the cache containment bay.

There are two primary criteria that were taken into account when designing the door assembly.

1. The door has to be large enough to allow both the arm and the payload to fit through it when open.
2. The door, when closed, has to have a proper seal around its edges so as to ensure air, foreign objects, and debris will not enter the airframe and cause flight instability.

The door is designed to be 3D printed by use of a Stratasys Fortus 400mc printer. Per testing of the door design, ABC PC was chosen due to the strength to weight characteristics of the material

Track System

Figure 103 shows the layout of the door and track assembly. The system is designed so that its vertical path is constrained by the two 3D printed ABS PC guides. After stress analysis, ABS PC was settled on for the rail guides due to the need for both low weight and low strength needed. By having the door linearly open instead of rotationally, we are able to save space inside the launch vehicle.

Figure 103: Complete door and track assembly.

Delrin track wheels will be installed into the door and track system using 4-40 UNC-2A threaded shoulder pins, as seen in Figure 104. Delrin was the material of choice for the track wheels for having a low static coefficient of friction between itself and the ABS PC track guides.

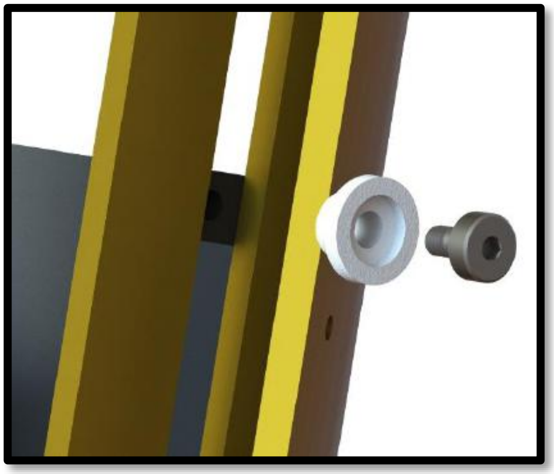


Figure 104: Exploded view of the track guide system.

These wheels will run along the track of the guides, thus allowing smooth movement within the airframe of the launch vehicle.

Door Sealing

The door must be able to seal itself against the airframe upon closure. Relying on the servo motor alone, was deem insufficient. The team is incorporating a magnetic sealing system for the door. One of the N52 neodymium magnets can be seen installed in the door in Figure 105 below.

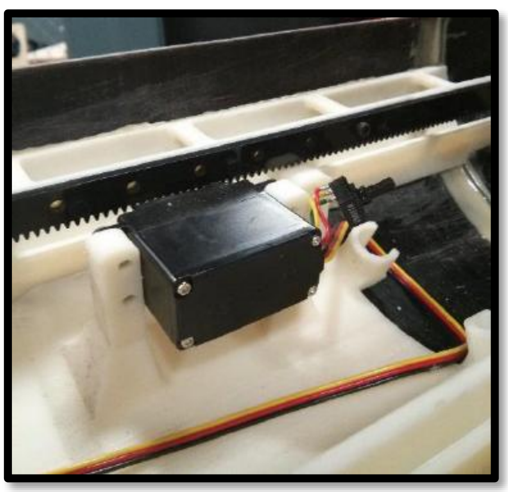


Figure 105: View of servo mount with N52 magnet mount

There is a neodymium magnet at each corner of the door. When the door is closed, the magnets align with their respective magnet and airfoil assembly which is epoxied on the outside of the airframe. These airfoil targets can be seen on the outside of the cache containment bay in Figure 102.

With a gap of 0.125 inches, as seen in Figure 106, the team used online calculators found on the magnet's supplier's (K&J Magnetics, Inc.) website to get generalized pull force values between the two neodymium magnets.

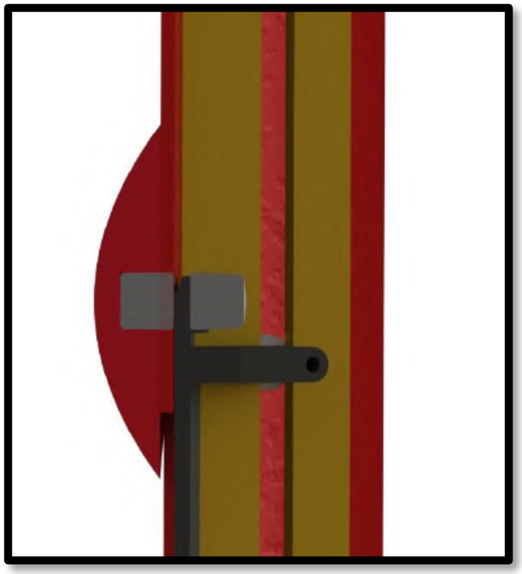


Figure 106: View of the gap between the neodymium magnet and ferrous target.

These force values changed with the change in geometry of the magnet. To increase the attractive force between the two components, the neodymium magnet was chosen to be as large as the door's geometry allowed. The geometry of the magnet can be seen below in Figure 107.

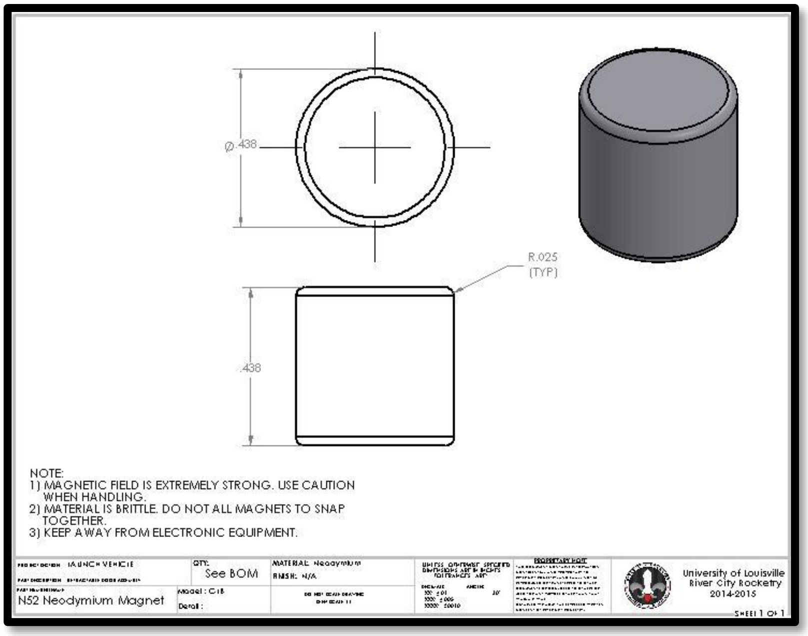


Figure 107: Detailed drawing of the N52 neodymium magnet.

With the geometry defined, the team extrapolated a pull force value of 3.01 lbs between the two N52 neodymium magnets. Figure 108, below, shows a plot of distance between magnets versus pull force.

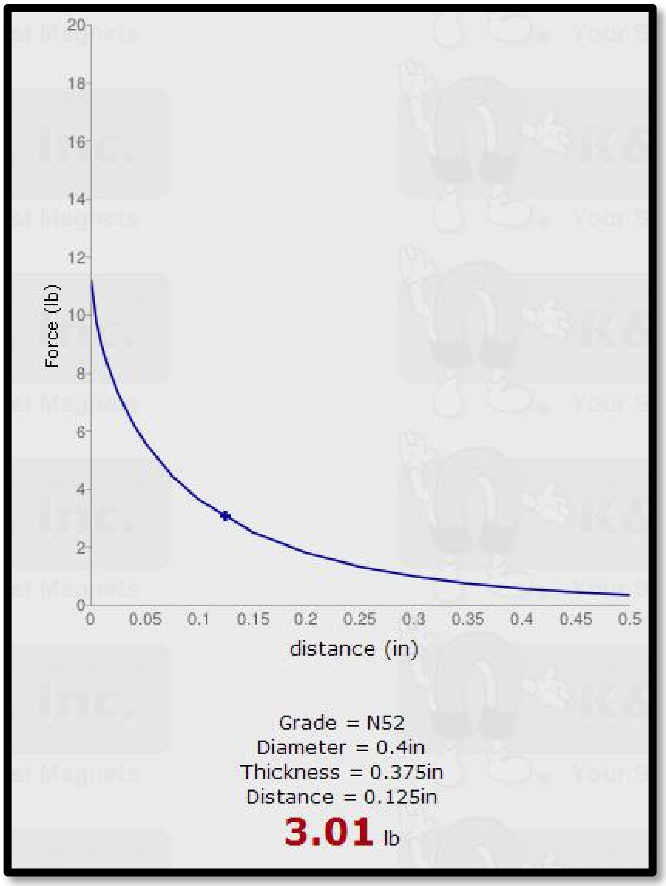


Figure 108: Graph of distance between magnet and ferrous target versus pull force.

Neodymium Magnet Grade	N52
Diameter (in)	0.4
Thickness (in)	0.375
Distance from Target (in)	0.125
Pull Force (lbs)	3.01
Number of Magnet pairs	4
Combined Pull Force on Door (lbs)	12.04

Table 36: Geometric and force values of the magnets.

The combined pull force on door from the neodymium magnets pairs was deemed sufficient for the system's needs.

Door Actuation

The door's motion is controlled by a Hitec continuous rotation servo. The servo, which is mounted to the door as seen in Figure 105.

The design uses a linear rack and pinion gear system to drive the door. The pinion is directly attached to the servo motor by use of internal servo teeth. When the door closes, the pinion moves along the rack, and causes the polyethylene track wheels to move along their guide.

Both guides have the same track machined into them. The right guide, as seen in Figure 105 and below in Figure 109, has the rack for the gear system attached to threaded slots in the rail guide using #8-32 UNC 2A bolts.

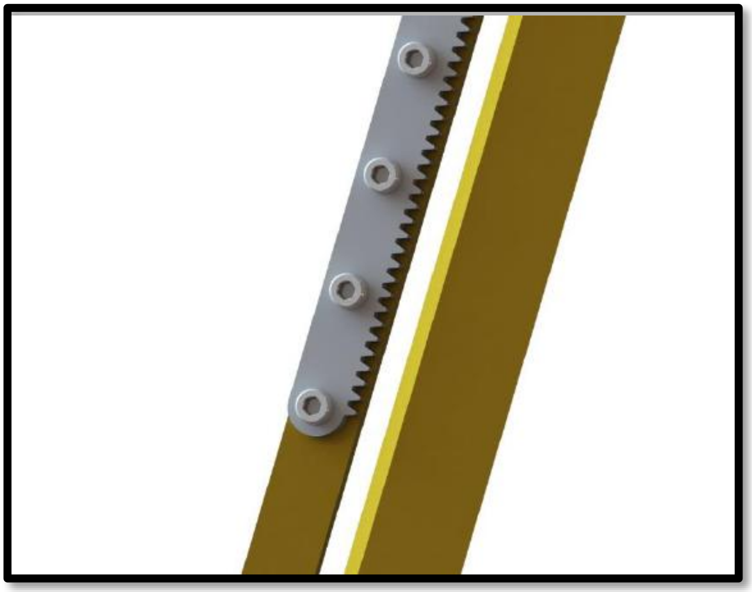


Figure 109: Bottom view of the lower guide with gear system rack.

The previous design of the track guides used two paths that the track wheels were to run along. This designed was replaced by one where both track wheels run one track.

Table 37 lists the various materials and their properties of the components that make up the retractable door assembly.

Material	Components	Characteristics
6061-T6 Aluminum	Pinion Gear	Density: 0.098 lbs/in^3 Tensile Strength: 35,000 psi
ABS Plastic	Airfoil Magnet Mounts	Density: 0.0376 lbs/in^3 Tensile Strength: 65,000 psi
Neodymium	Magnets	Density: 0.267 lbs/in^3 Tensile Strength: 10,667 psi
18-8 Stainless Steel	Shoulder Screws	Density: 0.290 lbs/in^3 Tensile Strength: 90,000 psi

Delrin	Track Wheels	Density: 0.034 lbs/in^3 Tensile Strength: 5,800 psi
Fiberglass	Airframe	Density: 0.0650 lbs/in^3 Tensile Strength: 38,000 psi

Table 37: Material properties of components found in the retractable door assembly.

Challenges

To make sure the door system integrates with the rocket and functions as intended certain solutions were sought for various design challenges, as seen in Table 38.

Challenges	Solutions
Door shall be designed such that the cache payload and arm device fit during payload insertion.	Proper dimensional analysis will be conducted to ensure there are no clearance issues throughout the design and revision of any payload containment and insertion systems.
The door shall be autonomously closed.	On-board computer electronics will work hand in hand with ASGE systems to synchronize payload insertion and door actuation movements.
The door shall not be allowed to open during flight.	Using the continuous servo motor, and N52 magnets, the door is "locked" shut to be certain the door will not open itself during flight

Table 38. Solutions to various door design challenges.

5) Subscale Flight Verification and Results

Subscale Testing Plan

In order to test the design of subsystems of the final launch vehicle assembly, the team constructed a one half scale model. To facilitate a standard dual deployment recovery configuration, the cache containment bay featured in the full scale model was replaced with an altimeter bay. Additionally, recovery bay sizes were adjusted to allow adequate room for all recovery equipment. The final subscale launch configuration is shown in Figure 110 below.

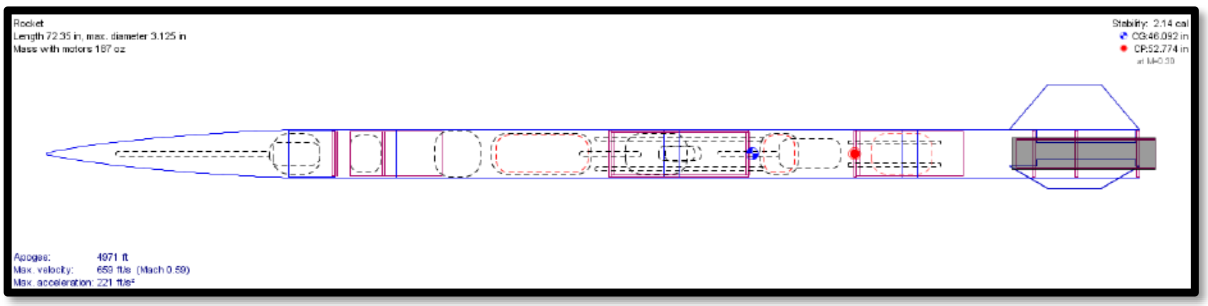


Figure 110: Subscale launch vehicle configuration.

The launch characteristics of the subscale model are similar to the full scale vehicle to ensure adequate vehicle design testing. A comparison of the full scale and subscale flight characteristics are shown in Table 39 below.

Property	Subscale	Full scale	Comparison (% difference)
Center of Gravity: Length (%)	63.71	58.71	7.85
Center of Pressure: Length (%)	72.94	69.70	4.44
Rail Exit Velocity (ft/s)	57.6	56.7	1.56
Max. Acceleration (ft/s^2)	222	237	6.33

Table 39: Comparison of vehicle launch characteristics.

The similarity of launch vehicle characteristics shown in Table 39 verified that the overall vehicle design is adequate for a safe launch.

Subscale Flight Test Results

A concept design of the Bluetooth on-board live feed device was constructed for testing during subscale flight. The module was thus placed in a separate bay located above the propulsion bay. The configuration is shown and bay are shown in Figure 111

Below. The Bluetooth test results are completely covered in the Testing subsection of the Electronics Systems section.

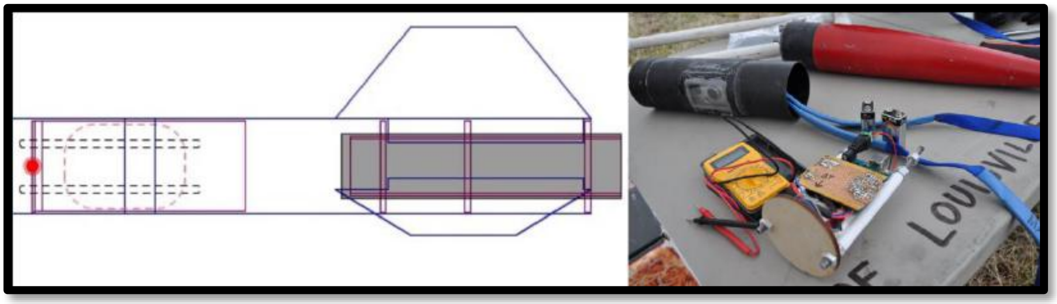


Figure 111: Bluetooth bay configuration.

The rocket was launched to an altitude of 4902 feet with the main parachute deploying at 600 feet. At 500 feet, a secondary, redundant altimeter was set to fire a black powder ejection charge to prevent recovery ejection failure. The lower altitude was selected due to sustained high speed winds. The results from the onboard primary altimeter are included in Figure 112 below. The redundant altimeter data has not been included due to data recording and transfer error.

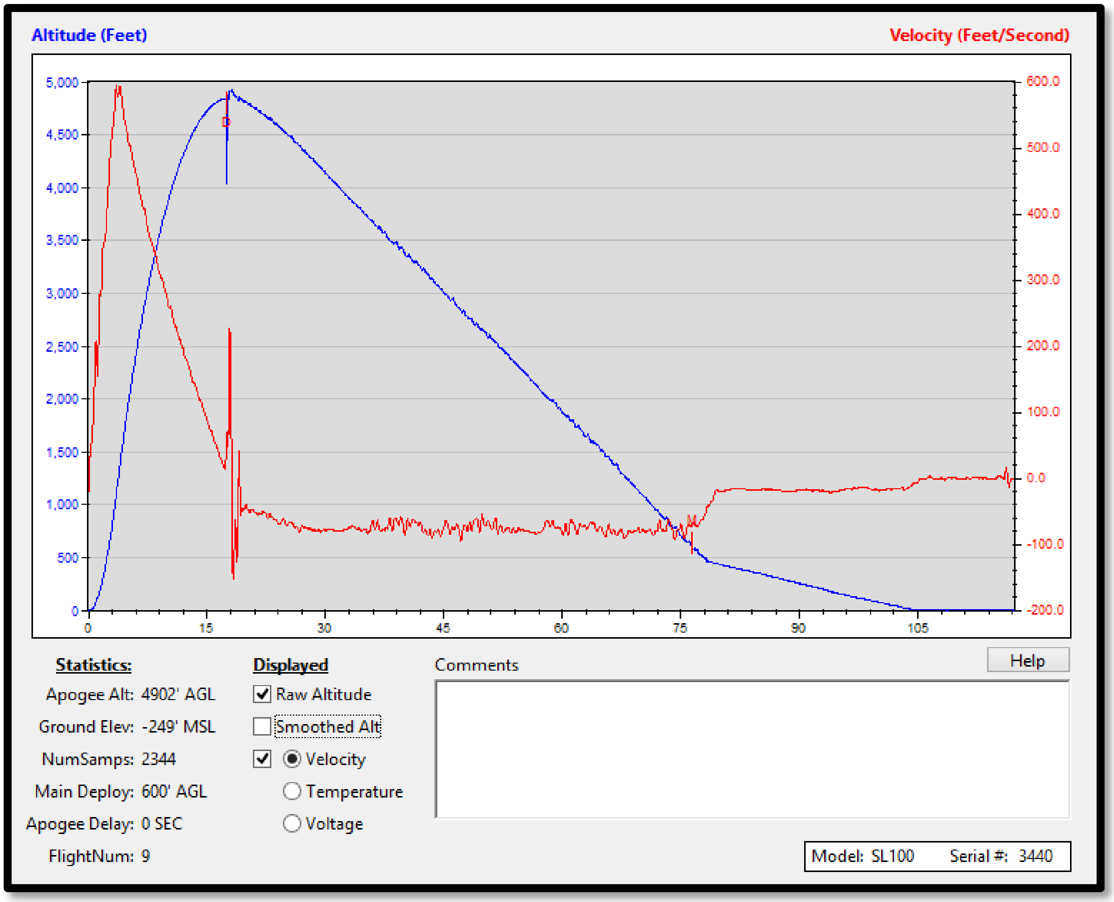


Figure 112: Primary altimeter flight results.

The simulated flight of the subscale model predicted an altitude of 4924 feet using launch day weather characteristics. A comparison of the altitude prediction from the simulation to the actual recorded the team produced an error of 0.4%. The acquired flight results promoted confidence in the team's ability to accurately model the full scale rocket prior to flight.

Two primary lessons were learned from the subscale launch, the first being a need for ground calibration and testing of all altimeters. The programming of the redundant altimeter called for the secondary drogue parachute ejection charge to fire one second following apogee. During the test flight, both primary and secondary altimeters ejected the drogue parachute at apogee, effectively doubling the ejection charge used in the drogue parachute bay. This amount of black powder caused significantly higher force to be seen by the connection between the propulsion bay and the altimeter bay. This force caused a failure in the epoxy joint connecting the propulsion bay to the altimeter bay.

The second lesson learned, directly related to the altimeter calibration, was to ensure a proper epoxy joint is used at each required point. It was determined that the joint failed due to lack of properly mixed and applied epoxy. To solve this problem in the full scale vehicle, steps will be taken to verify each epoxy joint properly mates each component.

6) Full-Scale Flight Verification and Results

Full Scale Testing Plan

A full scale test of the final launch vehicle assembly without internal electronics was performed to verify the safety of the model. The cache containment and cache related electronics were not included in the test flight to prevent any damage in the event of any anomalies during flight and recovery. The final launched assembly is shown in Figure 113 below.

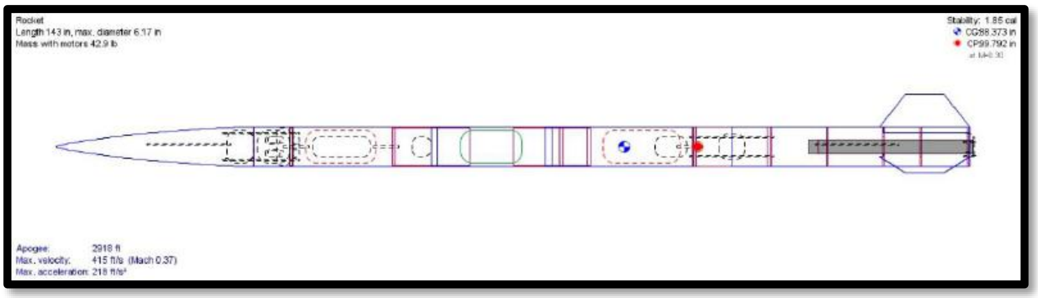


Figure 113: Full scale launch vehicle configuration.

The predicted launch vehicle flight characteristics are given below in

Property	Full scale
Center of Gravity (in from nose)	88.37
Center of Pressure (in from nose)	99.79
Rail Exit Velocity (ft/s)	61.7
Max. Acceleration (ft/s^2)	227
Predicted Altitude (ft)	2910

Table 40: Comparison of vehicle launch characteristics.

Full Scale Flight Test Results

The rocket was launched to an altitude of 2721 feet with the main vortex ring deploying at apogee feet. Figure 114, below, shows the full scale launch vehicle leaving the guide tower during its first test flight.

Figure 114: First flight of the full scale launch vehicle.

A secondary, redundant altimeter was set to fire a black powder ejection charge at apogee plus one second. The delay of one second was chosen to prevent over pressurization of the bay which would occur if both charges fired at the same time. The results from the onboard primary and secondary altimeters are included in Figure 115 and Figure 116 below.

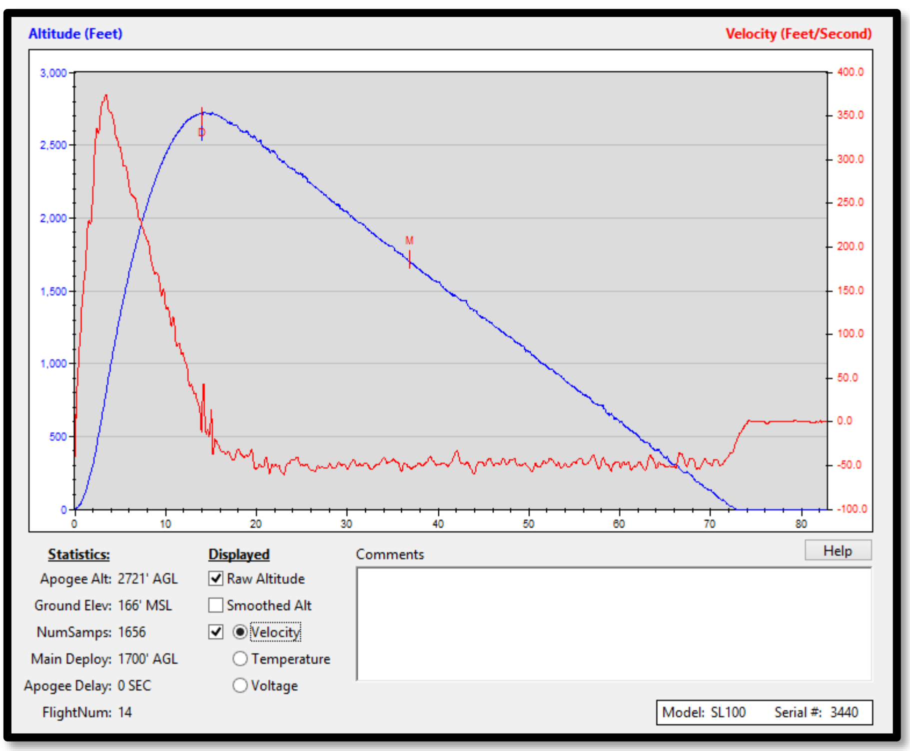


Figure 115: Primary altimeter flight results.

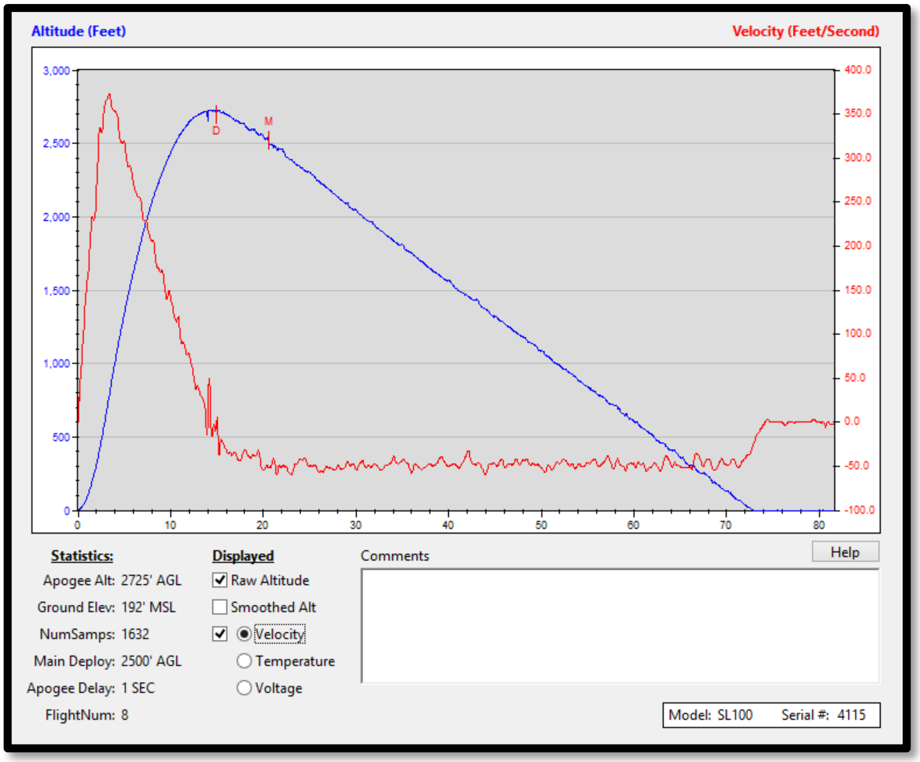


Figure 116: Secondary altimeter flight results.

All sections of the launch vehicle remained under parachute throughout decent, and landed safely. Upon visual inspection, all components of the launch vehicle were without damage and capable of another flight, if necessary.

The simulated flight of the full-scale model predicted an altitude of 2910 feet using launch day weather characteristics. A comparison of the altitude prediction from the simulation to the actual recorded the team produced an error of 6.5%. The team will be addressing various methods to reduce weight from sections where possible. A few methods currently under consideration are listed below:

- Determine if steel recovery fasteners can be replaced with aluminum fasteners by reviewing components' maximum rated load capacities.
- Determine if steel U-bolts can be replaced with aluminum U-bolts by reviewing component's maximum rated load capacities.
- Cut out weight-saving "windows" in the fiberglass airframe of sections of the launch vehicle and replace said "window" with a Lexan screen.
- Drill holes in coupling sections that will not affect the overall rigidity of the system.
- Determine if recovery bays can be shortened to save weight while still allowing fitment of all recovery systems.
- Determine if secondary parachute could be reduced in size and still descend within allotted requirements.

- Eliminate the use of the GoPro inside the launch vehicle.
- Drill holes to reduce weight in bulkheads that are not structurally important or shielding altimeters from an event charge.

After the launch, the team analyzed all of the digitally recorded and physical data from both the rocket and the launch platform. The goal was to determine where the launch vehicle might have lost altitude from integration with the guide tower. During setup, the launch vehicle felt tight inside of the guide tower. The guide tower was strapped in to an open trailer and transported six hours to the launch field. It was determined that the vibrations during transportation caused certain components to move slightly out of alignment.

To decrease the chances of this becoming an issue in the future, a small section of airframe will be inserted into the guide tower for transportation. Having a section of airframe inside of the guide tower, similar to the representation in Figure 117, will stop the extruded aluminum rails from possibly flexing during transportation.

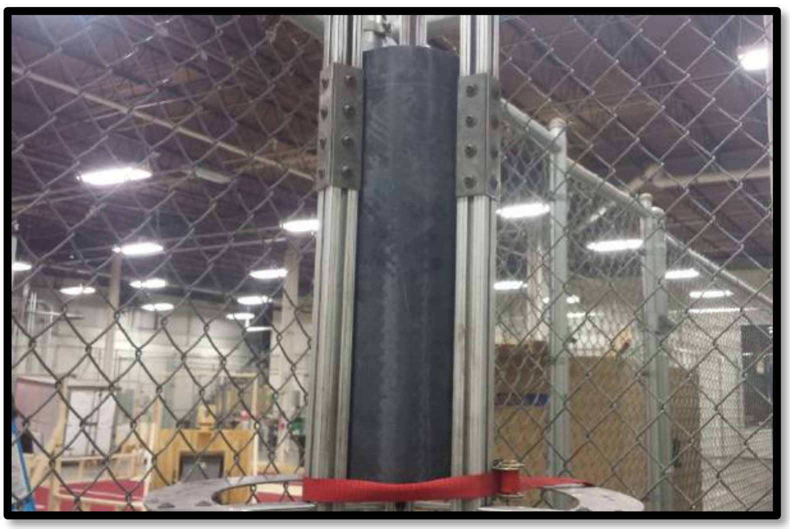


Figure 117: Mockup of the spare airframe inside of the guide tower.

The section of airframe will be from a stock piece of fiberglass airframe that directly matches the dimensions of that used on the full-scale launch vehicle. Additionally, the team will be using talcum powder to line the guide tower's rails. Being non-conductive and having friction reducing characteristics, talcum powder will aid in eliminating undesirable friction between the launch vehicle and the guide tower's extruded aluminum rails. Focusing on removing weight where available and adding a friction reducing powder to the guide tower's rails, the team plans to have the launch vehicle achieve an apogee nearer to the 3,000 foot altitude.

The team determined that it needs to have a more standardized method of properly measuring black powder charges on launch day. While doing ground testing prior to the launch, an error in black powder measurement caused over pressurization of the main recovery bay. This over pressurization caused an epoxy join failure in the fore section of the fairing. The team was able to re-epoxy damaged components prior to launch. Using a small scale to measure black powder charges in open environments can prove to be mildly cumbersome. A new method has been implemented. A powder measuring kit, shown below in Figure 118, will be used to accurately measure the total grams of black powder to be used in each charge. The use of this system will eliminate the need for a scale, and allow for very accurate physical measurements of black powder.

Figure 118: Lee Precision powder measuring kit.

7) Safety

Safety Officer Responsibilities

Emily is the safety officer for the River City Rocketry team during the 2014-2015 season. She is responsible for ensuring the overall safety of the team, students and public throughout all team activities, as well as assuring compliance with all laws and regulations. The following are the Safety Officer's specific responsibilities:

- Provide a written team safety manual that includes hazards, safety plans and procedures, PPE requirements, MSDS sheets, operator manuals, FAA laws, and NAR and TRA regulations.
- Confirm that all team members have read and comply with all regulations set forth by the team safety manual.
- Identify safety violations and take appropriate action to mitigate the hazard.
- Establish and brief the team on a safety plan for various environments, materials used, and testing.
- Establish a risk matrix that determines the risk level of each hazard based off of the probability of the occurrence and the severity of the event. Ensure that this type of analysis is done for each possible hazard.
- Oversee testing being performed to ensure that risks are mitigated.
- Remain active in the design, construction, testing and flight of the rocket in order to quickly identify any new potential safety hazards and to ensure the team complies with the team safety plan.
- Enforce proper use of Personal Protective Equipment (PPE) during construction, ground tests, and test flights of the rocket.
- Make MSDS sheets and operator manuals available and easily accessible to the team at all times.
- Provide plan for proper purchase, storing, transporting, and use of all energetic devices.
- Ensure compliance with all local, state, and federal laws.
- Ensure compliance with all NAR and TRA regulations
- Ensure the safety of all participants in educational outreach activities, providing PPE as necessary.

Emily has written a team safety manual that each team member was required to review and sign indicating compliance. The document includes hazards, proper safety plans and procedures, PPE requirements, MSDS sheets, FAA laws, and NAR and TRA regulations. The manual will be revised throughout the year as a need arises. Emily is responsible for making sure that each team member has read and acknowledged the safety manual and will continue to enforce all statements in the safety manual. The manual can be found on the team website so that it is easily accessible for all team members at all times.

Hazard Analysis

Risk Assessment Matrix

By methodically examining each human interaction, environment, rocket system and component, hazards have been identified and will continue to be brought to the team's attention. Each hazard has been assigned a risk level through the use of a risk assessment matrix, found in Table 43, by evaluating the severity of the hazard and the probability that the hazard will occur.

A severity value between 1 and 4 has been assigned to each hazard with a value of 1 being the most severe. In order to determine the severity of each hazard, the outcome of the mishap was compared to an established set of criteria based on the severity of personal injury, environmental impact, and damage to the rocket and/or equipment. This criteria is outlined below in Table 41.

Severity		
Description	**Value**	**Criteria**
Catastrophic	1	Could result in death, significant irreversible environmental effects, complete mission failure, monetary loss of $5k or more.
Critical	2	Could result in severe injuries, significant reversible environmental effects, partial mission failure, monetary loss of $500 or more but less than $5k.
Marginal	3	Could result in minor injuries, moderate environmental effects, complete failure of non-mission critical system, monetary loss of $100 or more but less than $500.
Negligible	4	Could result in insignificant injuries, minor environmental effects, partial failure of non-mission critical system, monetary loss of less than $100.

Table 41: Severity criteria.

A probability value between 1 and 5 has been assigned to each hazard with a value of 1 being most likely. The probability value was determined for each hazard based on an estimated percentage chance that the mishap will occur given the following:

- All personnel involved have undergone proper training on the equipment being used or processes being performed.
- All personnel have read and acknowledged that they have a clear understanding of all rules and regulations set forth by the latest version of the safety manual.
- Personal Protective Equipment is used as indicated by the safety lab manual and MSDS.
- All procedures were correctly followed during construction of the rocket, testing, pre-launch preparations, and the launch.

- All components were thoroughly inspected for damage or fatigue prior to any test or launch.

The criteria for the selection of the probability value is outlined below in Table 42.

Probability		
Description	**Value**	**Criteria**
Almost Certain	1	Greater than a 90% chance that the mishap will occur.
Likely	2	Between 50% and 90% chance that the mishap will occur.
Moderate	3	Between 25% and 50% chance that the mishap will occur.
Unlikely	4	Between 1% and 25% chance that the mishap will occur.
Improbable	5	Less than a 1% chance that mishap will occur.

Table 42: Probability criteria.

Through the combination of the severity value and probability value, an appropriate risk level has been assigned using the risk assessment matrix found in Table 43. The matrix identifies each combination of severity and probability values as either a high, moderate, or low risk. The team's goal is to have every hazard to a low risk level by the time of the competition launch. Those that are not currently at a low risk level will be brought down through redesign, new safety regulations, or any other measures seen fit to reduce risk. Risk levels will also be reduced through verification of systems.

Risk Assessment Matrix				
Probability Value	**Severity Value**			
	Catastrophic-(1)	Critical-(2)	Marginal-(3)	Negligible-(4)
Almost Certain- (1)	2-High	3-High	4-Moderate	5-Moderate
Likely-(2)	3-High	4-Moderate	5-Moderate	6-Low
Moderate-(3)	4-Moderate	5-Moderate	6-Low	7-Low
Unlikely-(4)	5-Moderate	6-Low	7-Low	8-Low
Improbable-(5)	6-Low	7-Low	8-Low	9-Low

Table 43: Risk assessment matrix.

Preliminary risk assessments were completed for possible hazards that were identified during the early stages of design. Acknowledging the each hazard early brought attention to particular failure mechanisms. As the design continued to move forward, the team continued to design with these possible failures in mind. The team worked to mitigate the hazards during the design phase. Testing has been performed at either the complete assembly, sub-assembly, or component level to verify the safety of the procedure. The identified hazards can be found below.

Lab and Machine Shop Risk Assessment

Construction and manufacturing of parts for the rocket will be performed in both on-campus and off-campus labs. The hazards assessed in Table 88 are risks present from working with machinery, tools, and chemicals in the lab.

Launch Pad Functionality Risk Assessment

The hazards outlined in Table 89 are the risks linked to the launch pad functionalities of the ASGE. Due to high importance of a stable launch tower, the system will be rigorously tested prior to any launches.

Vehicle Erector Risk Assessment

The hazards outline in Table 90 are the risks associated with the vehicle erector. Risks have been considered for when the system is non-operational and operational.

Igniter Installation Risk Assessment

The hazards outlined in Table 91 are risks associated with the autonomous igniter installation process. This is of particular concern since we do not want to risk a premature ignition of the motor.

Ground Station Risk Assessment

The hazards outlined in Table 92 are risks associated with the ground station. The ground station provides the foundation for the entire AGSE, therefore risks associated with the ground station are critical to mission success.

Payload Retrieval Arm Risk Assessment

The hazards outlined in Table 93 are risks associated with the payload retrieval arm. The payload arm interfaces with multiple components and has multiple opportunities for hazards.

Main Controller Risk Assessment

The hazards outlined in Table 94 are risks associated with the main controller. The master controller is the backbone of the AGSE and is critical to mission success therefore these risks are of high importance.

Leveling System Risk Assessment

The hazards outlined in Table 95 are risks associated with the leveling system. A level launch platform is critical to a successful launch so risks associated with this system are of high priority.

Master Controls Risk Assessment

The hazards outlined in Table 96 are risks associated with the master controls. The master controls are important safety interlocks for the AGSE, so risks associated with these controls are of high importance.

Stability and Propulsion Risk Assessment

The hazards outlined in Table 97 are risks associated with stability and propulsion. The team has multiple members of the team with certifications supporting that they can safely handle motors and design stable rockets of the size that the team will be working with. This area is considered a low risk for the team, but it is still important to address any potential problems that the team may face throughout the project.

Recovery Risk Assessment

The hazards outlined in Table 98 are risks associated with the recovery. Since there are three recovery systems onboard, many of the failure modes and results will apply to all of the systems but will be stated only once for conciseness.

Cache Capsule Risk Assessment

The hazards outlined in Table 99 are risks that are related to the cache capsule. This includes potential risks during assembly, operation, launch, and recovery of the capsule.

Vehicle Assembly Risk Assessment

The hazards outlined in Table 100 are risks that could potentially be encountered throughout the assembly phase and during launch preparation.

Environmental Hazards to Rocket Risk Assessment

The hazards outlined in Table 101 are risks from the environment that could affect the rocket or a component of the rocket. Several of these hazards resulted in a moderate risk level and will remain that way for the remainder of the season. These hazards are the exception for needing to achieve a low risk level. This is because several of these hazards are out of the team's control, such as the weather. In the case that environmental hazards present themselves on launch day, putting the team at a moderate risk, the launch will be delayed until a low risk level can be achieved. The hazards that the team can control will be mitigated to attain a low risk level.

Hazards to Environment Risk Assessment

The hazards outlined in Table 102 are risks that construction, testing or launching of the rocket or AGSE.

NAR Safety Code

The below table describes each component of the NAR High Power Rocket Safety Code, effective August 2012, and how the team will comply with each component. This table has also been included in the team safety manual that all team members are required to review and acknowledge compliance.

NAR Code	Compliance
1. **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.	Only Darryl, the team mentor, and certified team members are permitted to handle the rocket motors.
2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	The Mechanical Engineering team will be responsible for selecting the appropriate materials for construction of the rocket.
3. **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 feet of these motors.	Motors will be purchased through Wildman Rocketry and will only be handled by certified members of the team who are responsible for understanding how to properly store and handle the motors. Additionally there is a portion on motor safety in the team lab manual that the entire team is responsible for understanding.
4. **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 onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	All launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any safety issues.
5. **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 batter and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The team will comply with this rule and any additional precautions that the Range Safety Officer makes on launch day.
6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

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 NFPA 1127.	
7. **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.	The teams ASGE will function as the launch pad for the rocket. The ASGE will be rigorously tested for stability before a launch will be allowed. The length of the tower will be designed to ensure that in any allowable wind condition, the rocket will be able to attain a rail exit velocity that will ensure a stable flight. The ASGE will have a blast deflector integrated into the design. The team will be familiar with and comply with the minimum distance table at all launches.
8. **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.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

9. **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 feet, whichever is greater, or 1000 feet 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 feet).	All team launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any rocketry safety issues.
10. **Launcher Location.** My launcher will be 1500 feet 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.	The team will comply with this rule and any determination the Range safety Officer makes on launch day.
11. **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.	The Recovery team will be responsible for designing and constructing a safe recovery system for the rocket. A safety checklist will be used on launch day to ensure that all critical steps in preparing and packing the recovery system and all necessary components into the rocket are completed.
12. **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.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

Table 44: NAR safety code compliance.

Team Safety

A team safety meeting will be held prior to any construction, tests or launches in order to ensure that every team member is fully aware of all team safety regulations as detailed in the team safety manual. Each team member is required to review and acknowledge the safety manual. As revisions are made and released, team members are responsible for remaining up to date with team safety regulations. The team safety manual covers the following topics:

- Lab Workshop Safety
- Material Safety
- Energetic Materials
- Personal Protective Equipment regulations
- Launch Safety Procedures
- Educational Engagement Safety
- MSDS sheets
- Lab specific rules

Should a violation to the contract occur, the violator will be revoked of his or her eligibility to access to the lab and attend launches until having a meeting with the safety officer. The violator must review and reconfirm compliance with the safety rules prior to regaining eligibility.

Prior to each launch, a briefing will be held to review potential hazards and accident avoidance strategies. Briefings will cover the following items:

- Information on the waiver times and altitudes to ensure that the team completes all launches at appropriate altitudes before the waiver expires.
- Review of launch site regulations – stress on attentiveness during launches.
- Draw attention to any hazards that are particular to that day due to the environmental conditions.
- Address any hazards that have not yet been mitigated that may be encountered during preparations and testing.
- Delegate launch day checklists to appropriate personnel to ensure that all tasks get completed in an efficient manner.

In order to prevent an accident, a thorough safety checklist have been created and will be reviewed on launch day. Individual checklists will be created for each subsystem. The checklists include the following information:

- Required tools.
- Required hardware.
- Required PPE.
- Explicit step-by-step instructions to be checked off after completion.
- Caution statements indicating steps where specific PPE is required.
- Danger statements indicating steps where there is a particular hazard to personnel involved and what should be done to mitigate that hazard.

- Warning statements indicating importance in a procedure. Describe if a certain procedure is not followed completely, then a particular event will happen, resulting in the occurrence of a particular hazard.
- Signatures required from two representatives that all steps have been completed.

Throughout preparations, it will be the responsibility of the safety officer to confirm that each of the necessary tasks for a successful launch is completed. Safety checklists must be printed in color so that the warning, danger and caution symbols stand out, drawing the appropriate attention to the step. Two team members are required to sign off, verifying that each required task has been completed in order to ensure a safe launch. Once all subsystem checklists are completed, a final checklist must be completed and final approval granted by the safety officer and captain. The safety officer has the right to call off a launch at any time if it is determined that anything is unsafe or at a high risk level.

Local/State/Federal Law Compliance

The team has reviewed and acknowledged regulations regarding unmanned rocket launches and motor handling. Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, and NFPA 1127 "Code for High Power Rocket Motors" documentation is available to all members of the team in the team safety manual.

Motor Safety

Darryl, the team mentor, who has obtained his Level 3 TRA certification, will be responsible for acquiring, storing, and handling the teams rocket motors at all times. Team members that have attained a minimum their Level 2 certification, are also permitted to assist in this responsibility. By having obtained a Level 2 certification, the individual has demonstrated that he or she understands the safety guidelines regarding motors. Any certified member of the team that handles or stores the team's motors is responsible for following the appropriate measures. The motors for both test and competition launches will be transported by car to the launch site.

Rocket motors shall be stored in accordance with the regulations set forth by NFPA 1127. All energetic materials shall be stored in a red, indoor magazine, bearing the words "EXPLOSIVES – KEEP FIRE AWAY" in white. The magazine shall not be stored in a residence and will be stored in a detached garage or outbuilding by a certified team member or mentor. No more than 50 lbs of propellant shall be stored together at any given point in time.

Safety Compliance Agreement

The University of Louisville River City Rocketry team understands and will abide by the following safety regulations declared by NASA. All team members are required to sign a safety compliance form prior to any construction, testing, or attending launches. By signing the safety compliance agreement, team members acknowledge that they have read and understand all safety requirements set forth by the safety officer in the safety manual. The following statements are included in the agreement:

1. I agree to comply with all safety rules and regulations set forth by the safety manual.
2. I have read and am familiar with the entire safety manual.
3. I understand that it is my responsibility to remain up to date with the latest version of the safety manual, which will be sent out upon revision.
4. If I violation these regulations, I realize that I may not be able to participate in construction or launch activities.
5. I will strive to follow these safety procedures and encourage safety throughout the team and at educational events.

8) Vehicle Top Safety Hazards

All failure modes and effects for the vehicle have been analyzed and are detailed in the risk mitigations charts found in Appendix III – Risk Assessment. While all modes are important to analyze, five modes stood out as being either the more likely to occur or to have worse consequences than the others. Each of these critical modes have been analyzed in more detail below.

1. **Environmental Hazards**
   Probability: 1, Almost Certain
   Severity: 4, Negligible

   Description: There are a wide variety of environmental hazards that the rocket could encounter. Since weather conditions and surrounding environmental obstacles all pose similar outcomes and have similar mitigation strategies, they have been lumped into one category.

   Outcome: Particular weather conditions could prohibit the rocket from being tested. Moisture could damage electrical components of the rocket. Additional environmental obstacles could cause components of the rocket to become damaged or un-retrievable during recovery.

   Mitigation: Field and weather conditions are always heavily monitored leading up to and on launch day. This allows for launches to be rescheduled for times when the weather is more idea. Additionally, fields that are not equipped for the team to safely launch the rocket are not used during testing. Due to the drift calculations, the team knows the area that needs to be clear of obstacles in order to achieve a successful flight. The rocket and recovery systems were designed to be compatible with the competition field in Huntsville.

2. **Bulkhead failure**
   Probability: 5, Improbable
   Severity: 1, Catastrophic

   Outcome: Should a bulkhead failure occur, internal components supported by the bulkheads, such as electronics, will no longer be secure and will potentially incur damage during flight. Should the bulkheads fail that are connection points for recovery systems, recovery will be partially ineffective, potentially allowing a section of the rocket to fall freely.

   Mitigation: All bulkheads have been designed to withstand the force from takeoff and recovery events with an acceptable factor of safety. Bulkheads that see minimal loading will be secured into place using RocketPoxy. Bulkheads that see exceptional loading due to recovery events are reinforced with fasteners as necessary. All bulkheads are inspected before and after each launch to ensure that the epoxy bond is not showing signs of failure such as cracking or dis-bonding.

3. **Parachute lines become tangled**
   Probability: 4, Unlikely
   Severity: 2, Critical
   Outcome: If the parachute lines become tangled, the panels will not inflate as intended, causing the parachute to have a lower coefficient of drag than if it were fully inflated.

   Mitigation: Each parachute has a unique deployment bag that has been constructed in order to ensure that the lines are kept from tangling during packing, flight, and deployment. Each of the deployment bags have loops stitched into the bag into which the shroud lines can be tucked. This strategy is utilized to ensure that during deployment, the lines will come straight out of the bag without getting tangled. Ground testing is performed prior to flights to guarantee the packing method allows for a clean deployment.

4. **Parachute does not inflate**
   Probability: 5, Improbable
   Severity: 1, Catastrophic

   Outcome: If the parachute does not inflate, it will not provide the expected drag force. Depending on the level of inflation will affect the severity of the recovery failure. This failure mode could result in catastrophic damage to components of the rocket.

   Mitigation: Packing methods for each of the different styles of parachutes have undergone significant testing to maintain confidence in proper deployment and inflation. The lines are all checked during packing to ensure that they will not be pulled in such a way that will prevent the parachute from completely inflating.

5. **Fairing does not open**
   Probability: 4, Unlikely
   Severity: 2, Critical

   Outcome: The cache capsule will not be deployed if the fairing does not open. This will result in a mission failure with regards to ejecting the capsule. However, the capsule will still be safety recovered within the fairing should it not open.

Mitigation: The system for opening the fairing has been tested on the ground prior to launch. The springs are tested for ensure that the tension is enough to open the fairing prior to each launch. In order to prevent the springs from stretching out, the springs are not to be left on the fairing except when preparing for launch. Also, the black powder charge that is used to release the fairing has redundant e-matches and altimeters connected. This gives one more level of confidence that the charge will be fired.

Section 4. AGSE/Payload Criteria

1) Systems Overview

Overview

To be considered a success, the AGSE must meet the following requirements:

1. Teams will position their launch vehicle horizontally on the AGSE.
2. A master switch will be activated to power on all autonomous procedures and subroutines.
3. After the master switch is turned on, a pause switch will be activated, temporarily halting all AGSE procedure and subroutines. This will allow the other teams at the pads to set up, and do the same.
4. Once the launch services official has inspected the launch vehicle and declares that the system is eligible for launch, he/she will activate a master arming switch to enable ignition procedures.
5. The Launch Control Officer (LCO) will activate a hard switch, and then provide a 5-second countdown.
6. At the end of the countdown, the LCO will push the final launch button to initiate launch.
7. All AGSE systems shall be fully autonomous.
8. The system must suffer no setbacks when the pause button is initiated.
9. The system must complete all tasks within 10 minutes.
10. The capture and containment system must be able to retrieve the payload from outside of the vehicle MOLD line and from the ground.
11. No forbidden technologies will be utilized. The forbidden technologies are as follows
    a. Sensors that rely on Earth's magnetic field
    b. Ultrasonic or other sound-based sensors
    c. Earth-based or Earth-orbit-based radio aids (e.g. EGPS, VOR, cell phone, etc…)
    d. Open Circuit pneumatics
    e. Air breathing systems

In addition to the above requirements, the following controls parameters must be met to be considered a success.

1. A master switch to power all parts of the AGSE, the switch must be easily accessible and hardwired into the AGSE
2. A pause switch to temporarily terminate all actions performed by the AGSE. The switch must be easily accessible and hardwired into the AGSE

3. A safety light that indicates that the AGSE is powered on. The light must be amber/orange in color. It will flash at a frequency of 1 Hz when the AGSE is powered on, and will be solid in color when the AGSE is paused while power is still supplied.
4. An all systems go light to verify all systems have passed safety verifications and the rocket system is ready to launch.

To accomplish the above requirements, the AGSE has been broken up into sub-stations shown in Table 45.

Sub-Station	Responsibility
Payload Capture and Containment	Locate, capture, and place the payload inside the launch vehicle. The containment responsibility has been placed with the launch vehicle.
Ground Station	House all control electronics in addition to all prerequisite switches and indicator lights.
Launch Platform	Support and guide vehicle during launch procedures and launch.
Vehicle Erector	Raise vehicle from horizontal position to 5 degrees of vertical.
Igniter Installer	Install igniter after vehicle has been safely erected.

Table 45: AGSE sub-stations.

Figure 119: Fully deployed system.

The overall system dimensions are shown in Table 46.

Overall mass (lb_m)	Overall width (in)	Overall height (fully erected) (in)	Overall height (closed) (in)	Overall length (in)
395.75	78.23	131.84	42.04	211.39

Table 46: Overall system dimensions.

Changes since CDR

Table 47 shows the changes since proposal for the overall system. Each sub-system changes will be shown in their system description.

Change	Justification of change
Adjusted system timeline.	Motor specifications and cost requirements.

Table 47: Changes since CDR.

System Timeline

Per the SOW, the ground station has ten minutes to complete the proposed tasks. However, the centennial challenges have stated that five minutes is the target time. To accomplish these task in the required time, a system timeline has been developed and is shown in Figure 120.

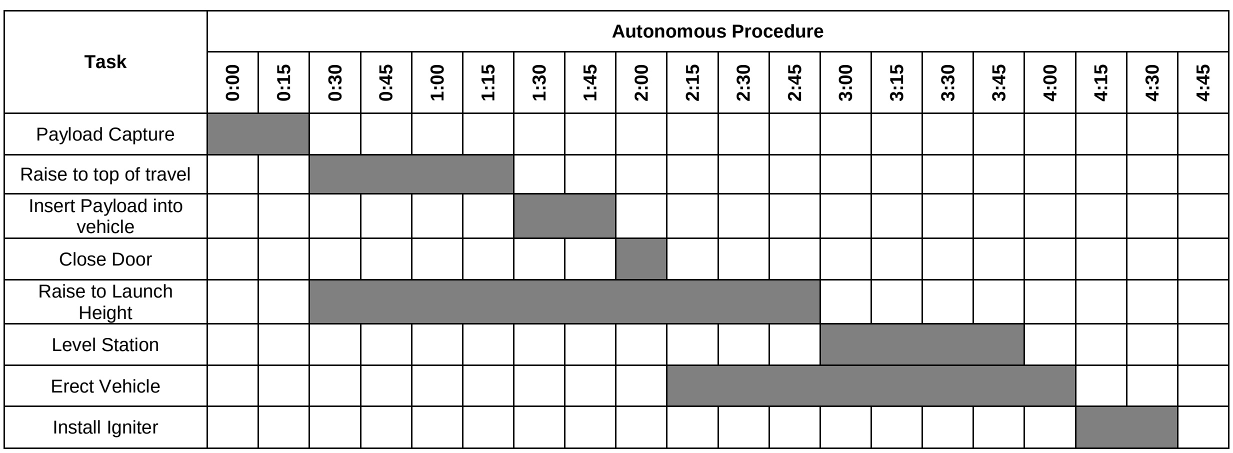


Figure 120: System timeline.

2) Ground Station

The ground station must be capable of meeting the following requirements to be considered a success.

1. Provide a stable platform for all AGSE sub systems to mount to.
2. Integrate all necessary electronics for AGSE sub systems.
3. Provide protection for critical systems.
4. Maintain stability prior to, during, and post launch.
5. Be reusable.
6. Be transportable in passenger vehicles.

Figure 121: Ground station.

Table 48 shows the overall dimensions of the ground station.

Overall length (in)	Overall width (in)	Overall height (in)	Overall mass (lb_m)
211.39	78.23	28.58	273.36

Table 48: Overall system dimensions in launch ready deployed configuration.

Changes since CDR

The changes since preliminary design review are shown in Table 49.

Change	Justification for change
Outrigger geometry adjusted.	Ease of manufacturing and design safety.
Removed machined surface on middle module gusset.	Reduce manufacturing time.
Outrigger nut connection modified.	Ease of manufacturing and costs.

Table 49: Ground station changes since CDR.

Design

The design of the ground station consists of a modular framework and three outrigger stability and raising systems. The ground station was designed in a modular fashion for ease of transportation. The modular sections will separate via 8 quick release pins. An exploded view of the ground station in a stowed/travel configuration is shown in Figure 122.

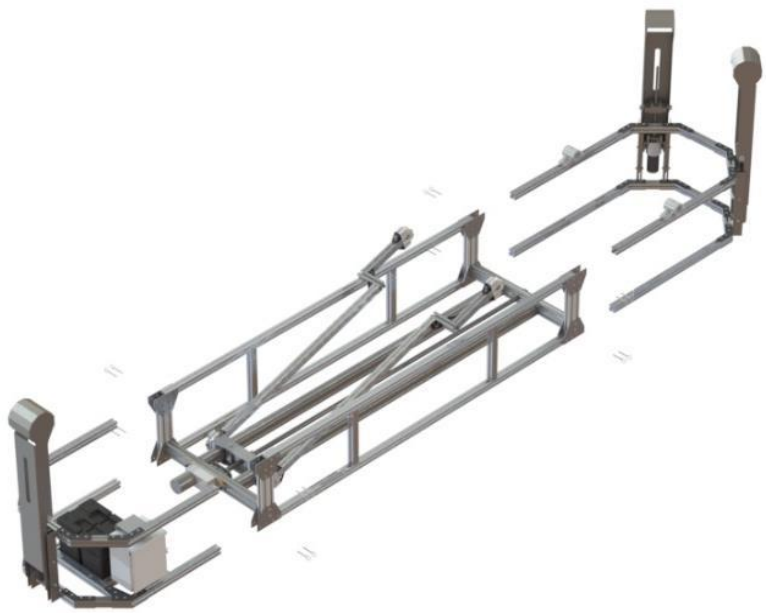


Figure 122: Stowed ground station exploded view.

The general construction of the ground station frame consists of a top and bottom exterior rail, eight vertical support rails, and trapezoidal end caps that consist of three aluminum extrusion rails. The trapezoidal end caps are fastened together using custom gussets on the top and bottom of the rail. These gussets were cut on the waterjet out of 0.125 inch thick aluminum pieces. To reduce costs, these were cut from the interior of the launch platform's stability rings mentioned in the launch platform section. All connections between ground station exterior rails will utilize 2 inch 1/4"-20 UNC 2A thread socket head cap screws and associated nuts to fasten the rails together. A trapezoidal end cap is shown in Figure 123.

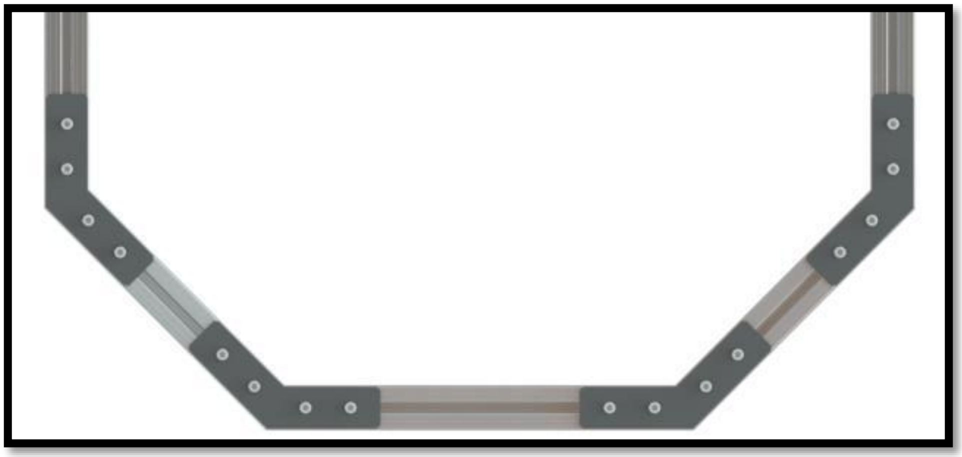


Figure 123: Trapezoidal end cap.

Front Module

The front module is a separable unit of the ground station that houses the AGSE battery pack, main electronics enclosure, and front stability system. The front frame is shown in Figure 124.

Figure 124: Ground station front end module.

The battery and main electronics enclosure were placed in the front frame to avoid exposure to motor exhaust from the rocket. A weather proof enclosure was also selected to protect the electronics during unexpected weather conditions or other environmental hazards. The batteries are mounted on an aluminum well that is supported by a t-slotted aluminum extrusion frame. The batteries will be secured in the well via a ratchet strap. The aluminum well is shown in Figure 125.

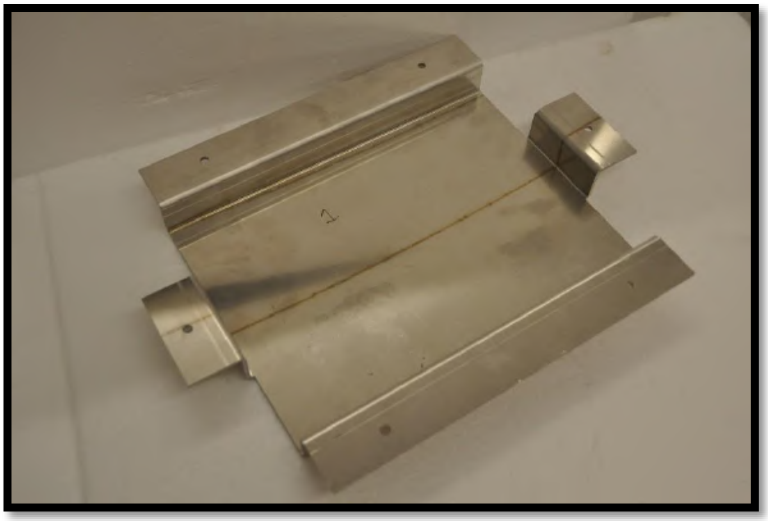


Figure 125: Ground station battery well.

The well will be fastened to the extrusion support structure using six 1.25 inch ¼”-20 UNC 2A thread button head cap screw. The electronics enclosure is also mounted using a bent aluminum component as shown in Figure 126.

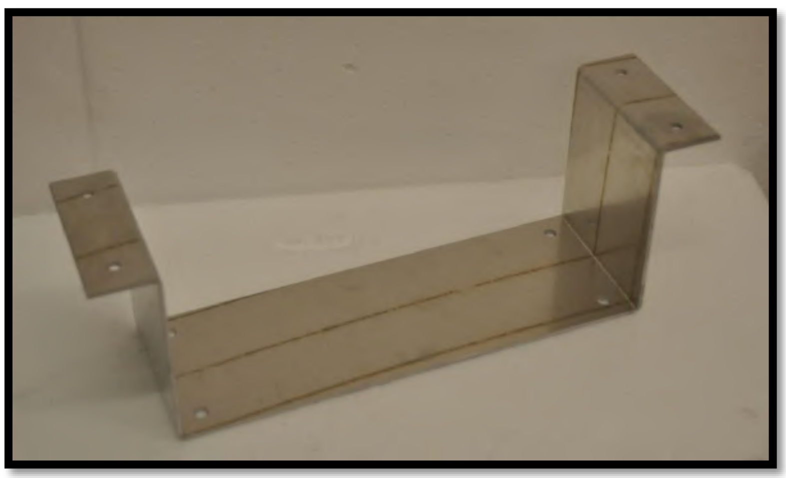


Figure 126: Ground station electronics enclosure mount.

The electronics enclosure will be fastened to the mount using four 9/16 inch 5/16”-18 UNC 2A thread socket head cap screws. The mount will be fastened to the front module using four 1.25 inch ¼”-20 UNC 2A thread socket head cap screws. Both the battery well and electronics enclosure mount were cut on a water jet and then bent on a CNC press break.

Middle Module

The middle module is another separable unit of the ground station that houses the vehicle erection system. The middle frame module is shown below in Figure 127.

Figure 127: Ground station middle module.

The middle module is fastened together using two custom gussets. These were waterjet out of 0.125 inch thick aluminum pieces. To reduce costs, the 0.125 inch thick components will also be cut from the interior of the launch platform's stability rings mentioned in the launch platform section. These gussets sandwich the station rails and interface with the vehicle erection system. One custom gusset will be used on the top of the module. This gusset, shown in Figure 128, uses six 2.25 inch ¼"-20 UNC 2A socket head cap screws and associated nuts to fasten to the station rails.

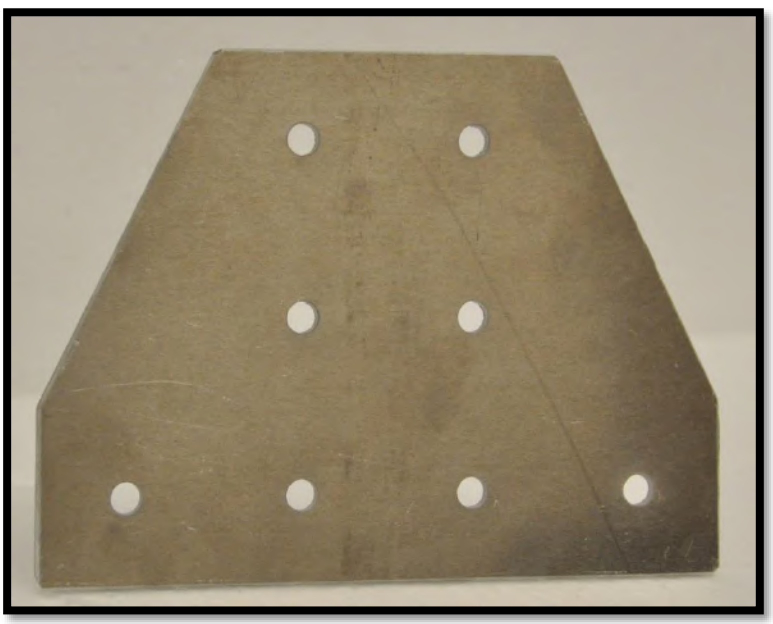


Figure 128: Middle module top gusset plate.

The second gusset, shown in Figure 129 is used on the bottom of the module. This gusset uses two 2.25 inch ¼"-20 UNC 2A thread socket head cap screws and two 2.25

inch 5/16”-18 UNC 2A socket head cap screws to fasten the gussets to the station rail and mount the vehicle erection system.

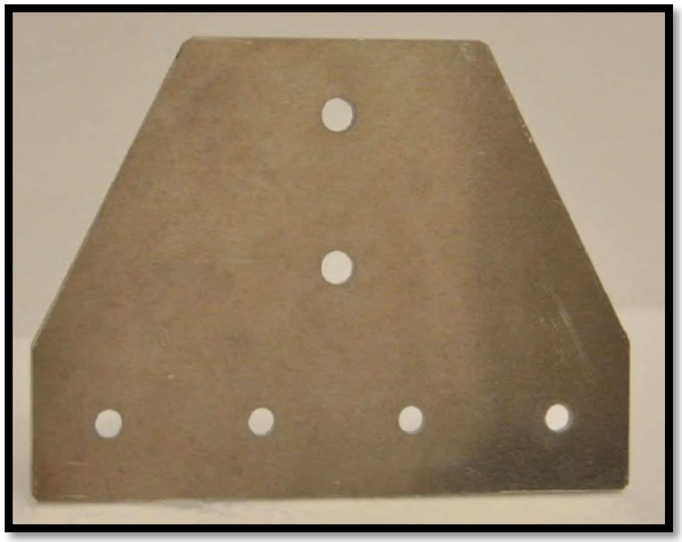


Figure 129: Middle module bottom gusset plate.

Rear Module

The rear module is the final separable unit of the ground station and houses the main pivot points for the launch platform and the rear stability system. The rear module is shown below in Figure 130.

Figure 130: Ground station rear module.

To integrate with the launch platform the rear module includes two special machined station rails. One of these machined station rails is shown in Figure 131.

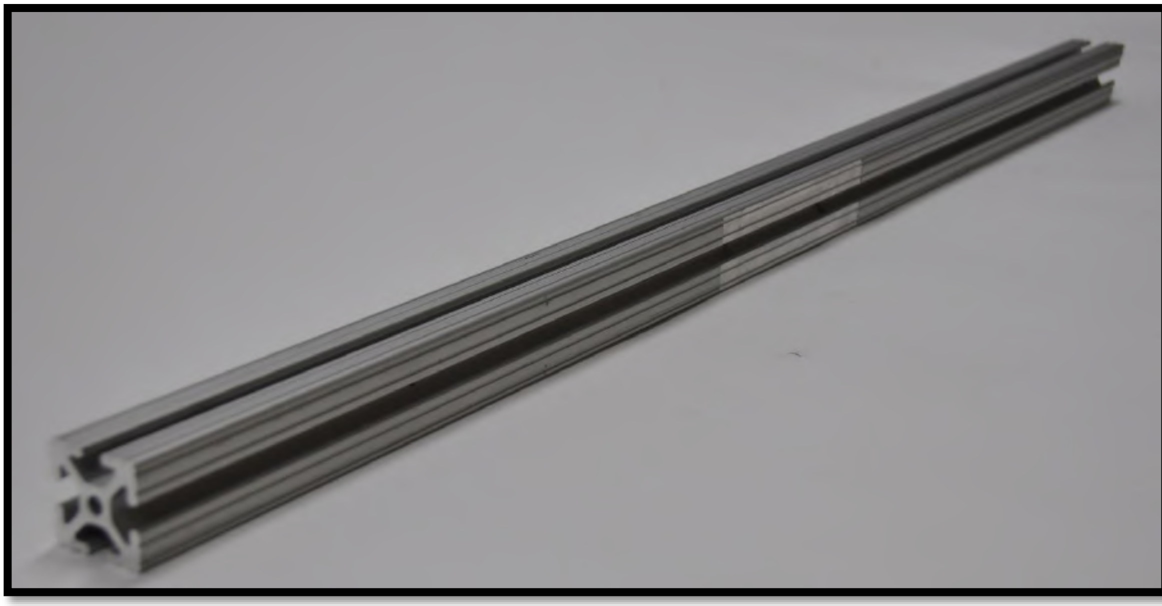


Figure 131: Rear module launch platform integration station rail.

The machined surface on the station rail is used to mount and locate bearings for the launch platform. The bearings used are sleeve bearings with a shaft diameter of 1.5 inches and a max load of 565 lb_f which is within the total load to be rotated. An example of the bearing is shown in Figure 132.

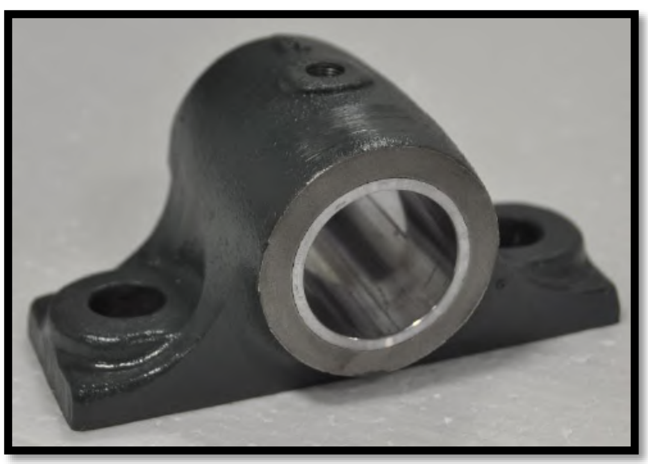


Figure 132: Vehicle rotational bearing.

As mentioned earlier, each modular section will separate via 8 quick pins. These pins will interface with a 3 inch t-slotted aluminum extrusion with gusset plates. This interface is shown below in Figure 133. All modular components will also have custom wiring harnesses that will include quick disconnects for all electrical connections.

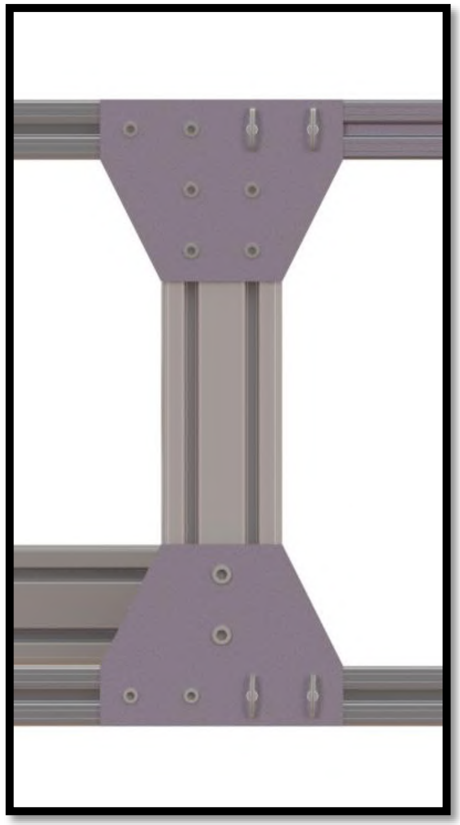


Figure 133: Support beams at module connection points.

Stability System

Outriggers were added to the ground station to increase the stability. The outriggers will also be used to raise and level the ground station once it has been placed on the launch field. The outriggers will raise the ground station after the payload is retrieved to provide clearance for the launch platform to articulate into launch position. The leveling of the ground station will be an automated process further explained from an electrical standpoint later in the document.

The ground station will have a total of three outriggers. This will provide three adjustable points of contact between the ground station and the ground. A three contact point system was selected because of its benefits in stability over a four point system. The outrigger assembly is shown in Figure 134.

Figure 134: Outrigger assembly.

The outriggers will consist of two primary assemblies, the outrigger leg and outrigger motor mount. The outrigger leg is shown in detail in Figure 135: Outrigger leg. The leg is constructed from two bent steel sheet metal components. The blanks for these will be cut with a waterjet out of 11 gauge steel and then bent on a CNC press brake.

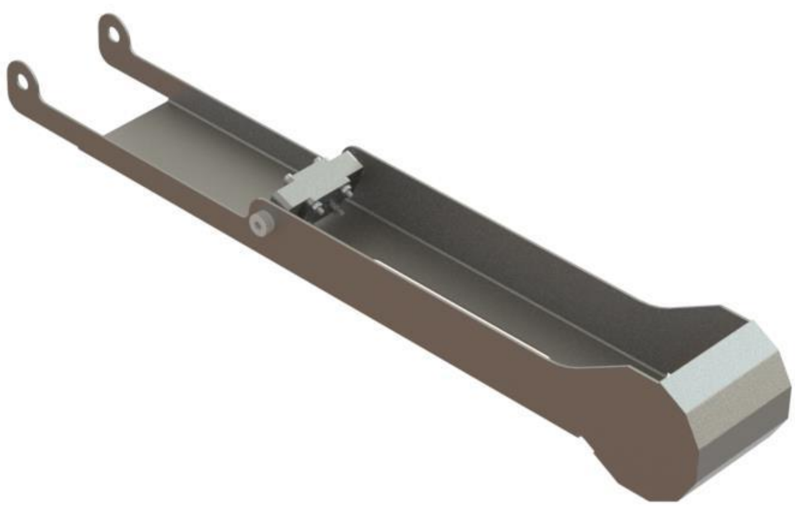


Figure 135: Outrigger leg.

The base of the outrigger leg is wrapped with a metal shoe that will provide a smooth surface as the outrigger slides across the ground during actuation. This shoe will be welded to the outrigger leg.

The outrigger will be actuated by a ½”-8 ACME lead screw. The screw will interface with the leg through a custom ACME nut mount, shown in Figure 136. This nut mount will be mounted on two ½ inch long ¾ inch shoulder socket head cap screw with a 5/8”-11 UNC 3A thread. Two ¼ inch steel plates will be bolted on to the nut mount with four 2 inch 1/4”-20 UNC 3A socket head cap screws. These plates will be used in conjunction with a spacer to retain the ACME nut in the mount.

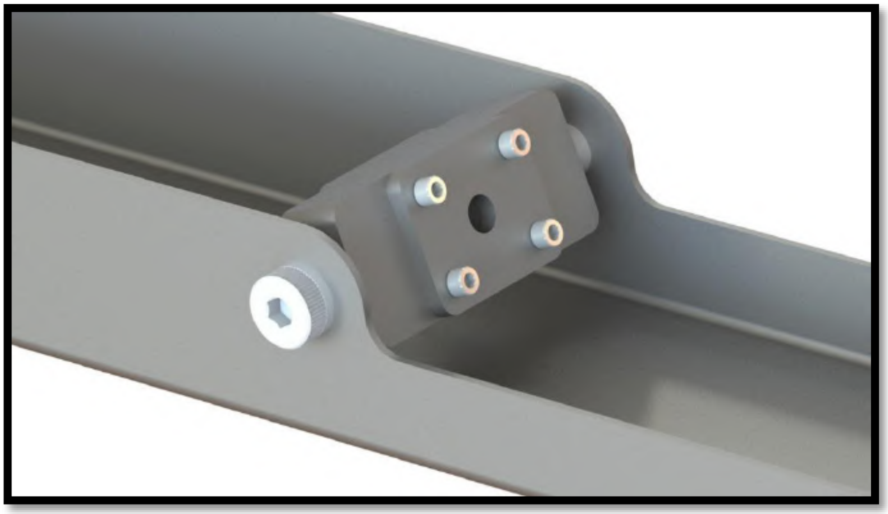


Figure 136: Outrigger nut mount.

The outrigger motor mount will consist of a three piece weldment as shown in Figure 137. This mount will be made out of a ¼ inch steel plate that will be cut with a waterjet and then will be bent on a CNC press brake. Two ¾ inch steel rods will then be welded to the bent plate to act as pivot points for the motor mount.

Figure 137: Outrigger motor mount.

The outrigger motor mount will also house a thrust bearing assembly to handle the high thrust loads the outrigger will experience. This bearing assembly will transfer the loads from the screw directly to the motor mount rather than through the gearbox.

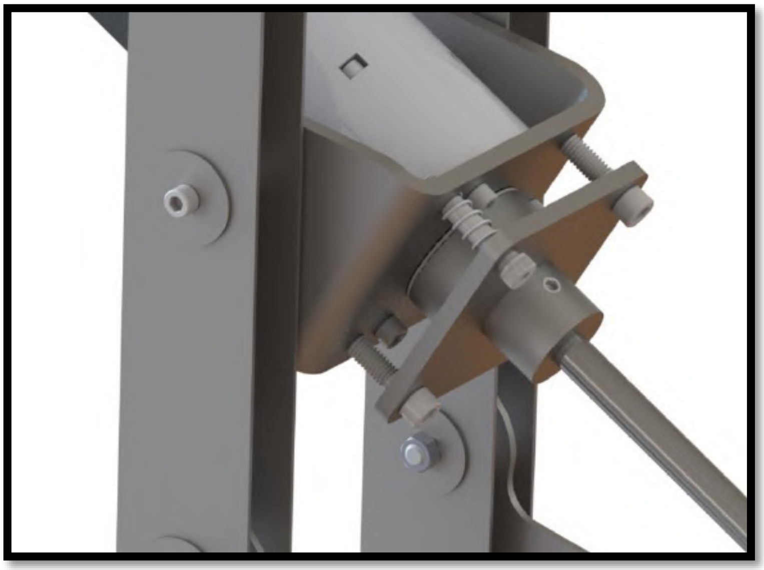


Figure 138: Outrigger thrust bearing assembly.

The thrust bearing assembly will be placed at the interface point between the ACME screw and the motor. The bearing assembly consists of a custom machined coupler and a steel retaining plate. The custom machined coupler, as shown in Figure 139, will be used to couple the ACME screw to the gearbox and provide a flange for the bearings to run against.

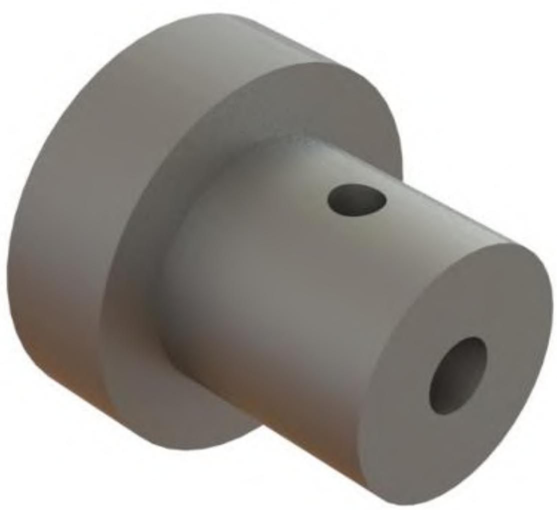


Figure 139: Outrigger thrust bearing coupler.

The thrust bearing coupler will couple with the motor using a ½" long 1/8" machine key. This will allow for an axial degree of freedom, transferring all axial loads to the thrust bearing assembly rather than the gearbox assembly. The coupler will be connected to the ACME screw using a 3/8 inch long 5/16”-18 UNC 3A set screw.

The steel retaining plate will also provide a surface for the bearings to run against and will transfer loads to the motor mount. The 0.25 inch plate will be kept in alignment by using two 1.125 inch 5/16”-18 UNC 3A socket head shoulder bolts. The plate will also provide a preload on the bearings using two 1.375 inch 5/16”-18 UNC 3A socket head cap screws. Two springs are also included in the assembly to keep the plates spaced evenly.

The thrust collar that will be used for the outrigger thrust assembly is shown in Figure 140.

Figure 140: Outrigger thrust collar.

The outrigger assembly will interface with the ground station via two vertical steel extrusion uprights. As shown in Figure 141 the motor mount will be retained using two 3/4" inch ¼”-20 UNC 2A socket head cap screws with custom washers. The leg will be attached using a ¾” steel sleeve with a 1.375” inch 5/16”-18 UNC 3A socket head cap screw with associated nut and custom washers. The outriggers will be fastened to the ground station using four 1.375 inch 5/16”-18 UNC 3A socket head cap screws.

Figure 141: Outrigger ground station interface.

The motor selected to actuate the outriggers is shown in Figure 142. The motor is an AndyMark CIM Motor with a 4 stage GEM gearbox and will be mounted to the motor mount using three 0.75 inch ¼”-20 UNC 3A socket head cap screws.

Figure 142: Outrigger actuation motor.

Finite Element Analysis was performed on the outrigger leg to obtain a minimum factor of safety of 2. Radial and axial fixed geometry boundary conditions were applied to the two mount points on the outrigger leg. The lower end of the outrigger leg was fixed with a boundary condition normal to the shoe at the points where it would contact the ground. The load was applied to the face of the outrigger nut mount where the nut would press against. Two load configurations were analyzed and the results are summarized in the Table 50.

Configuration	Leg angle	Load (lb_f)	Factor of safety
1	2	1068.90	2.461
2	19	1158.74	2.146

Table 50: Outrigger leg analysis configuration setup and results.

The boundary conditions for the analysis of the outrigger leg are shown in Figure 143.

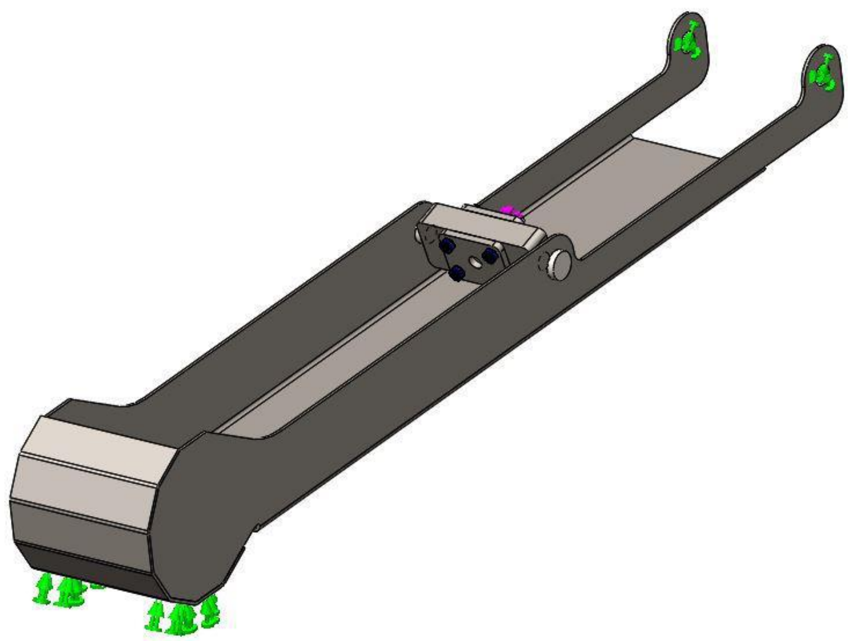


Figure 143: Outrigger leg analysis boundary conditions.

The load setup on the outrigger nut mount is shown in Figure 144.

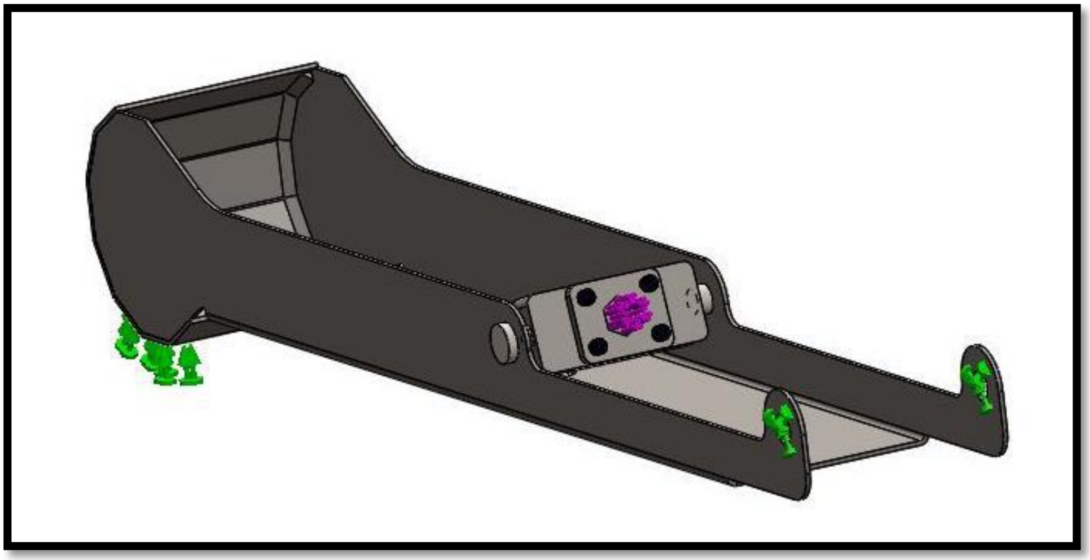


Figure 144: Outrigger nut mount load setup.

The stress plot from the analysis of configuration 2 is shown in Figure 145.

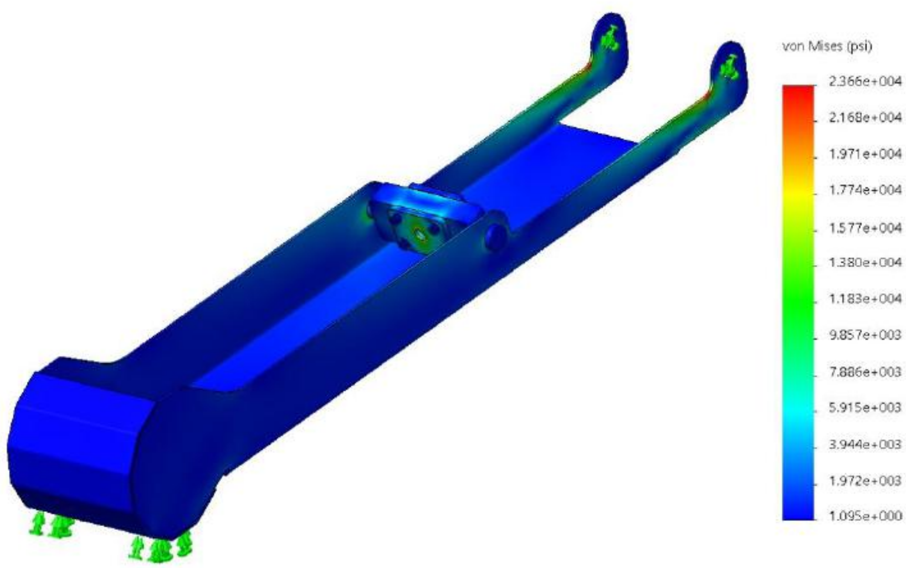


Figure 145: Outrigger leg configuration 2 stress plot.

The factor of safety plot from the analysis of configuration 2 is shown in Figure 146.

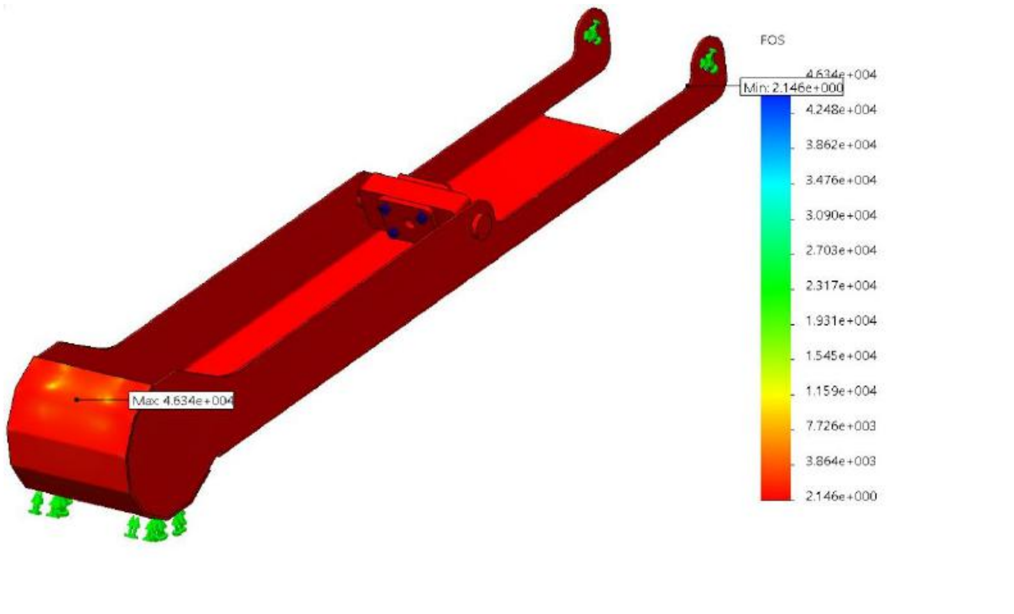


Figure 146: Outrigger leg configuration 2 factor of safety plot.

As shown in Figure 146 the minimum factor of safety for outrigger leg was 2.416.

The factor of safety plot from the analysis of configuration 1 is shown in Figure 147.

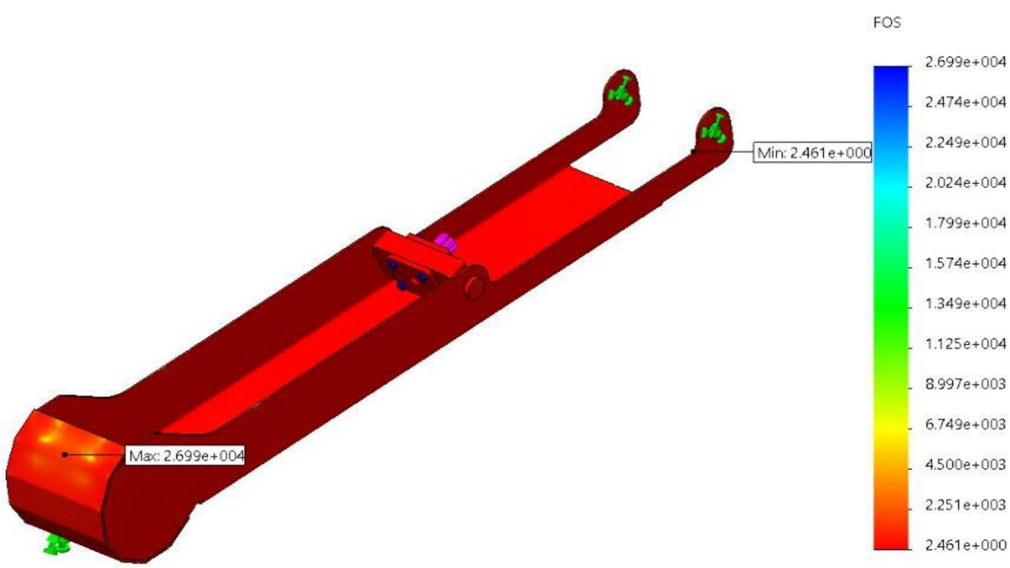


Figure 147: Outrigger leg configuration 1 factor of safety plot.

3) Payload Capture and Containment

Overview

The purpose of this system will be to grab the payload from the ground, raise it up to the rocket's level, and then insert the payload into its designated section in the rocket. To achieve this, an arm was designed that mounts onto a side rail of the AGSE. The payload will be placed on the ground underneath the AGSE so the arm will be able to start facing the rocket. The payload arm is shown in its vertical and diagonal position Figure 148 and Figure 149 respectively. The general dimensions of the payload arm are shown in Table 51.

Height (in)	Length (in)	Width (in)	Mass (lb_m)
18.250	15.975	6.625	13.362

Table 51: General dimensions of payload arm not including length of shafts.

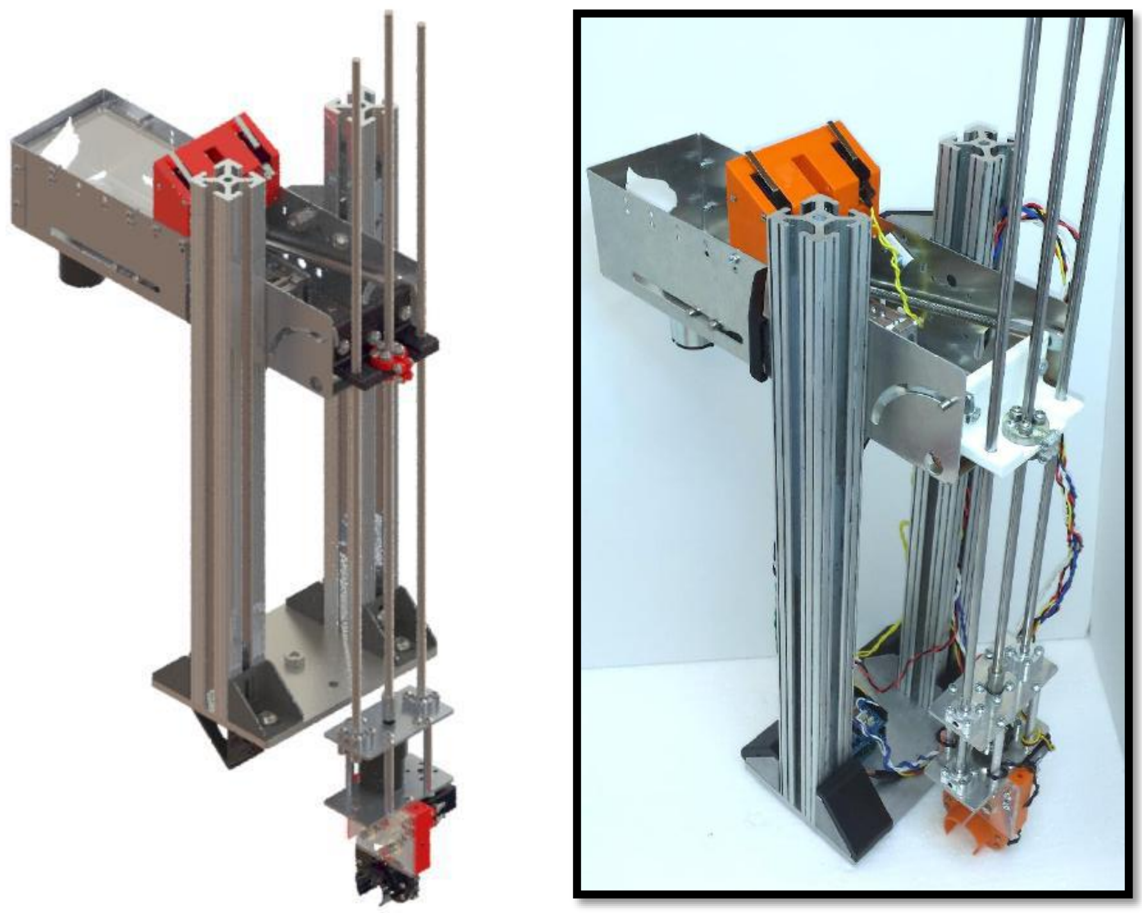


Figure 148: Payload arm in vertical position.

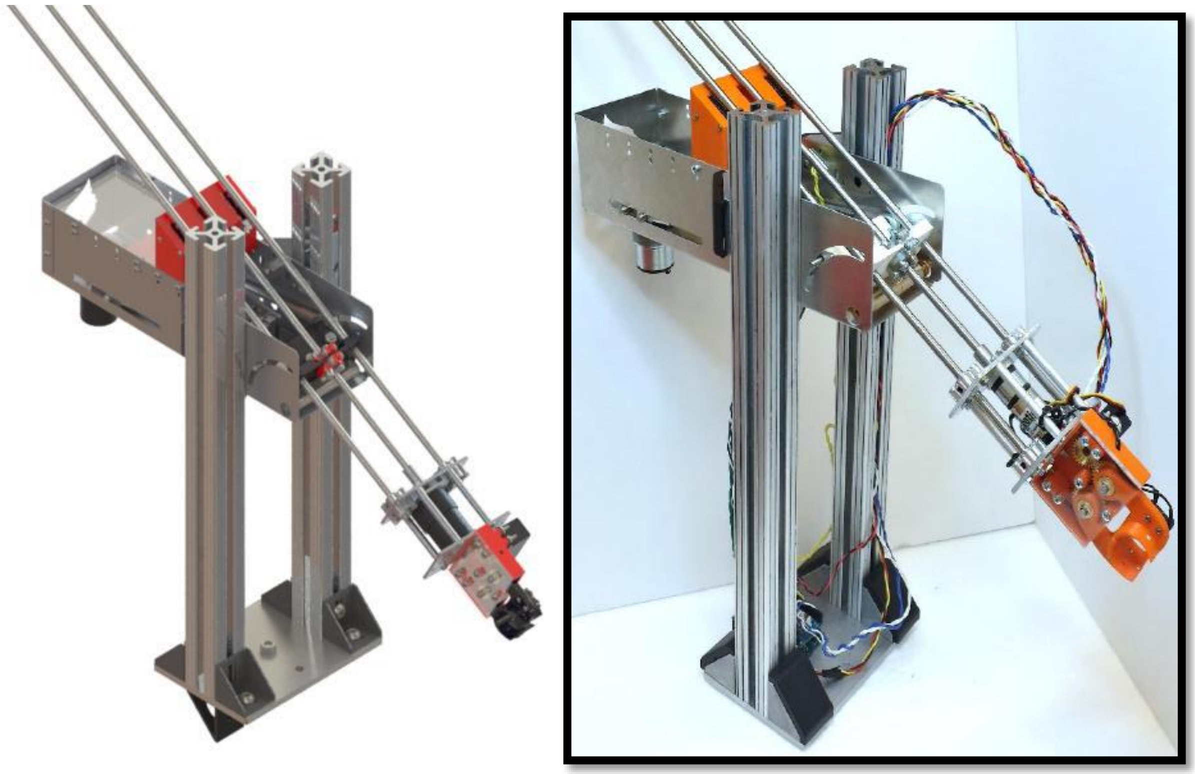


Figure 149: Payload arm in diagonal position.

Structural Design & Construction

Gripper Assembly

The gripper assembly is responsible for holding the payload and for driving the payload vertically and diagonally with the help of a motor. Figure 150 shows the gripper assembly.

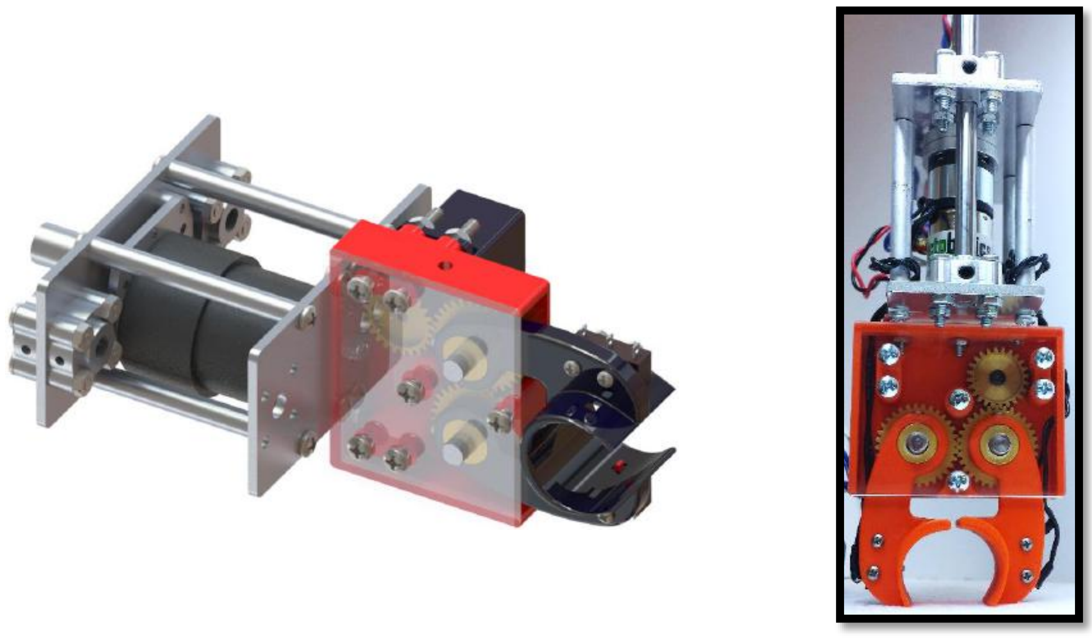


Figure 150: Gripper assembly.

Originally, a 10RPM 12VDC motor with maximum torque of 368 oz-in was going to be used to drive the gripper assembly but after doing some tests, which are described later, it was discovered that it was too slow. Instead, a 624RPM 12VDC motor is being used. The motor is connected to a 1/8 inch aluminum plate via #6-32 UNC screws. This plate has two hubs mounted to it to hold the support shafts and four standoffs. Another plate is at the bottom of the motor to connect the grippers and servo.

Figure 151: View of motor attachment plates.

The motor's shaft has a coupler that connects to a 0.25 inch steel shaft that moves the gripper assembly. To add support to the assembly, two other 0.25 inch steel shafts mount on each side of the motor. Set screw hubs hold these shafts in place. The hubs mount onto the top side of each plate using #6-32 UNC screws.

Underneath the bottom plate is where the arms that will hold the payload are located. A 3D printed ABS enclosure was used to mount the gears and servo. To be able to see inside the enclosure in case something goes wrong, a clear acrylic cover was cut out. The acrylic cover is attached via four #6-32 UNC screws that also hold the servo on the back side. The gears for the payload arms are shown in Figure 152.

Figure 152: View of gears used to move payload arms.

To open and close the payload arms, a Hitec HS-5485HB servo is being used which mounts on the back side of the 3D printed enclosure. The servo has a maximum torque of 89 oz-in. A brass gear is attached to the servo which in turn drives two other brass gears. The gears are store bought and their specifications are shown in Table 52.

Gear	Servo	Left Arm	Right Arm
Pitch Diameter (in)	0.75	1.00	1.00
Pitch	32	32	32
Teeth	24	32	32
Pressure Angle (deg.)	20	20	20

Table 52: Gear specifications.

The center distance, c, between the gears was calculated using

$$c = \frac{d_1 + d_2}{2} \tag{26}$$

where d_1 is the pitch diameter of the driving gear and d_2 is the pitch diameter of the driven gear. Twenty degree pressure angle gears were chosen due to their higher load capacity compared to other standard pressure angles.

The two arm gears attach to a 0.25 inch diameter D-shaft using a #10-32 UNC set screw. The payload arms slide over an extrusion on the gears and are held in place using the same set screw used for the connecting the gears and shafts. The curved part of the arms that hold the payload are dimensioned to be the same as the outer diameter of the inner tube of the payload. The payload arms were 3D printed out of Vero plastic. Vero plastic was chosen over ABS due to having better material properties as shown in Table 53.

Material	Vero Black	ABS
Tensile Strength (psi)	9450	5221
Elastic Modulus (psi)	435000	203052
Flexural Strength (psi)	16000	7541
Elongation at Break (%)	10	4

Table 53: Vero Black compared to ABS plastic.

To verify that the payload is held within the arms, a push button is placed on one side of each arm. The arms have a slot for the pin of the button to go through. Two #2-56 UNC screws and nuts attach the buttons to the arms. When the system gets activated, the arms close until both sensors are activated which indicates that the payload has been grabbed.

Threadless Ball Screw System

To move the gripper assembly, the motor on it is connected to a 0.25 inch diameter shaft. The shaft will be connected on one end to the motor on the gripper assembly and on the other end it will be connected to the threadless ball screw system. The reason for choosing this system is that it is unique compared to a traditional threaded rod and ball screw system. Secondly, the system is cheaper since it is mostly 3D printed.

Figure 153: Threadless ball screw assembly.

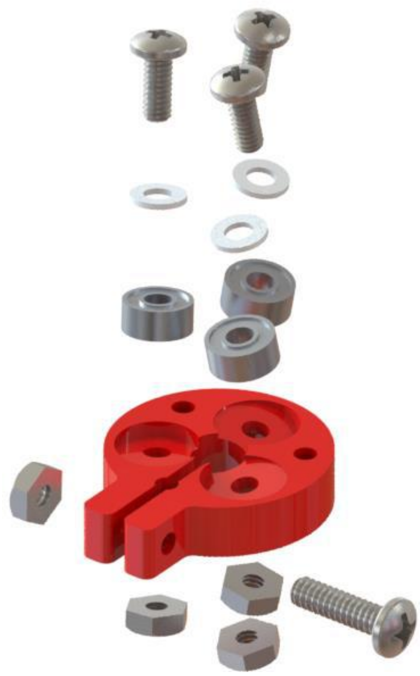


Figure 154: Exploded view of threadless ball nut.

The system works by using three bearings which center the shaft that goes through the middle of the threadless nut, shown in red. The bearings are angled such that they simulate a thread pitch. As the shaft rolls over the bearings, it follows the pitch of the bearings like a threaded rod. The bearings have a point contact on the shaft which causes a high force to keep the shaft in line. A screw is used on one side to add a preload to the shaft. The theoretical thread pitch, P, can be calculated using

$$P = \pi D \tan(\theta) \tag{27}$$

where D is the diameter of the shaft and θ is the bearing angle relative to the top surface of the threadless nut. The threadless ball nut contains three holes angled at an angle of 10 degrees where the bearings are mounted. A #6-32 UNC screw and nut hold each bearing in place. A low friction PTFE nut goes between the inner race of the bearing and screw.

The threadless ball bearing system is starting to become common in 3D printing machines due to their low cost since a regular threadless shaft is cheaper. Two of these assemblies are placed on opposing sides of an L-shaped 3D printed bracket to provide more support. All of these parts were 3D printed out of Vero plastic. To insure that the gripper assembly can be held securely, a horizontal facing screw can be tightened to add a preload by squeezing the plastic nut so that the bearings apply a higher force upon the shaft. The reason is that otherwise the gripper assembly would not be able to rise due to its own weight.

Gripper Assembly Rotation

The aforementioned threadless ball screw system will mount on the end of the payload tower structure facing the rocket as shown in Figure 155 and Figure 156. The team emphasized high quality workmanship and this can be seen by how close the assembled product resembles the 3D model.

Figure 155: Threadless ball screw assembly mounted on U-shaped channel, 3D model.

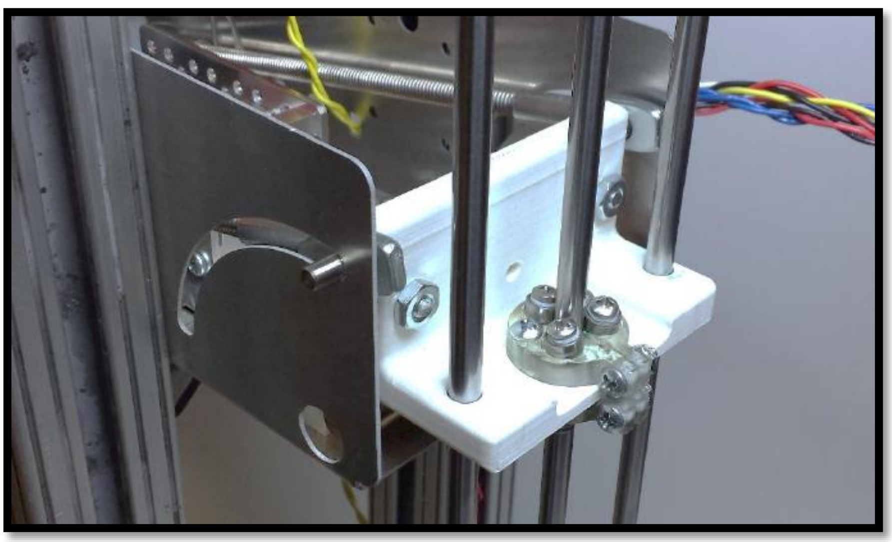


Figure 156: Threadless ball screw assembly mounted on U-shaped channel, assembled.

The L-bracket that the threadless nuts mount on attaches to the U-shaped channel in between the two towers using a mortise style hinge which is rated for a 40 lb load. Three #10-32 UNC flat head screws and nuts attach the hinge to the bracket as well as to the U-shaped channel. The U-shaped channel is made out of 32 gauge aluminum sheet metal that was cut out using a water jet. To limit the angle of rotation to 90 degrees, a curved slot was cut into the channel. The L-bracket has a though-hole near the top for a 3/16 inch shaft. The shaft goes through the curved slot in the channel on both sides.

Once the gripper assembly reaches the bottom of the payload arm towers, the system begins to rotate back until it reaches 60 degrees. At 60 degrees, the two support rods activate switches on an angled block. To accomplish the task of rotating, a belt system is being used, shown in Figure 157 and Figure 158. A similar belt system is used in photography to achieve shots where a steady horizontal camera movement is required. The belt, pulleys, and belt mounts used in the payload arm are the actual components used in some of these photography fixtures.

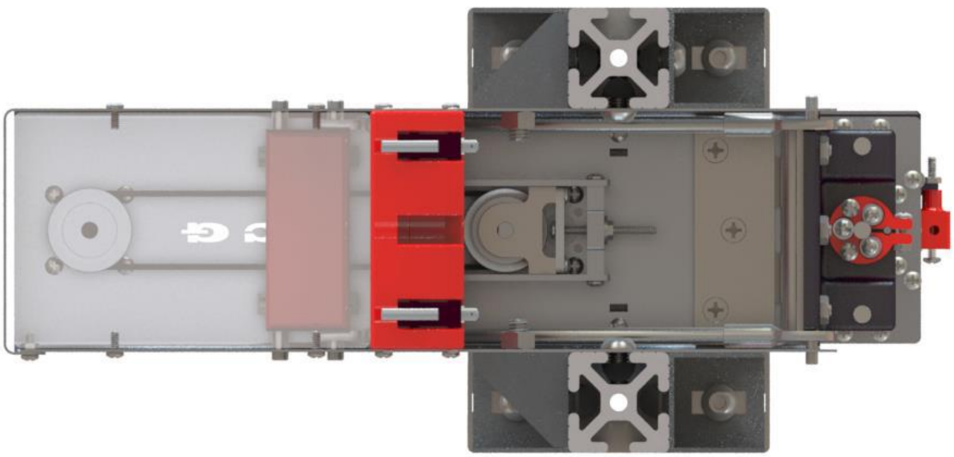


Figure 157: Top view of payload arm, 3D model.

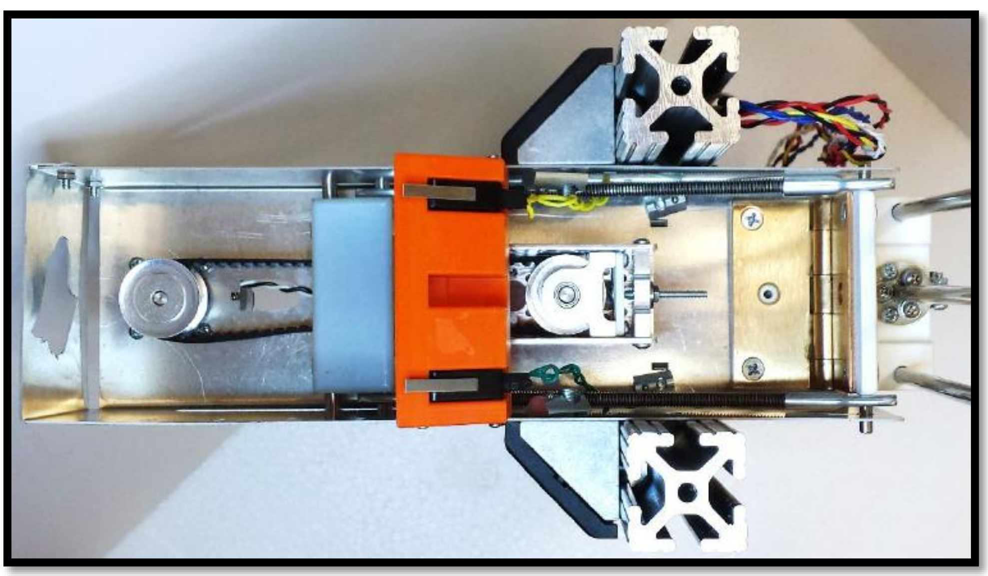


Figure 158: Top view of payload arm, assembled.

The timing belt is connected to two pulleys, one of which is driven by a 10 RPM 12 VDC motor with 303 oz-in of torque that is mounted underneath the U-channel and another which acts as the belt tensioner. To add tension to the belt, the second pulley is free to slide within a smaller U-channel, shown in Figure 159.

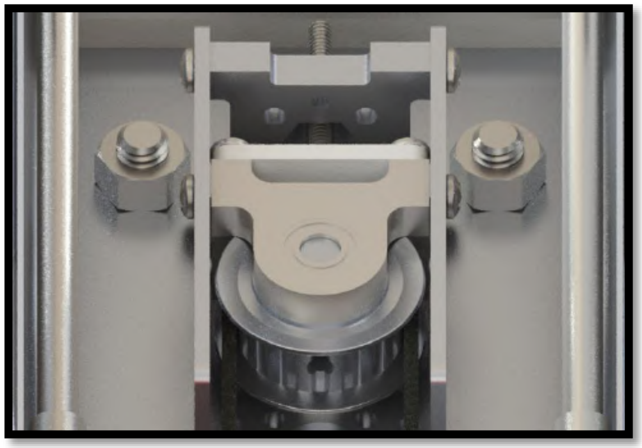


Figure 159: Belt tensioning pulley.

One bearing mount goes on each side of the pulley. A 0.25in diameter D-shaft goes through the bearings and the pulley so that the pulley can rotate. The bearing mounts are screwed into a 3D printed plate using #6-32 UNC screws. At the end of the smaller U-channel, a 0.25in thick 6061 aluminum end plate is attached using four #6-32 UNC screws. A 1.5in long #6-32 UNC screw connects the 3D printed plate and the aluminum plate. This screw is responsible for increasing or decreasing the tension on the timing belt. The smaller U-channel, end plate, timing belt, pulleys, and bearings are bought off the shelf from ServoCity.com. This allows the team to be sure that the parts interface smoothly.

The timing belt is clamped in between two 316 stainless steel belt mount plates using four #6-32 UNC screws. These same screws attach the belt mounts to a 3D printed slider as shown in Figure 160 and Figure 161. The back part of the U-channel where the slider is located will have a clear 1/8 inch acrylic cover to prevent something interfering with it.

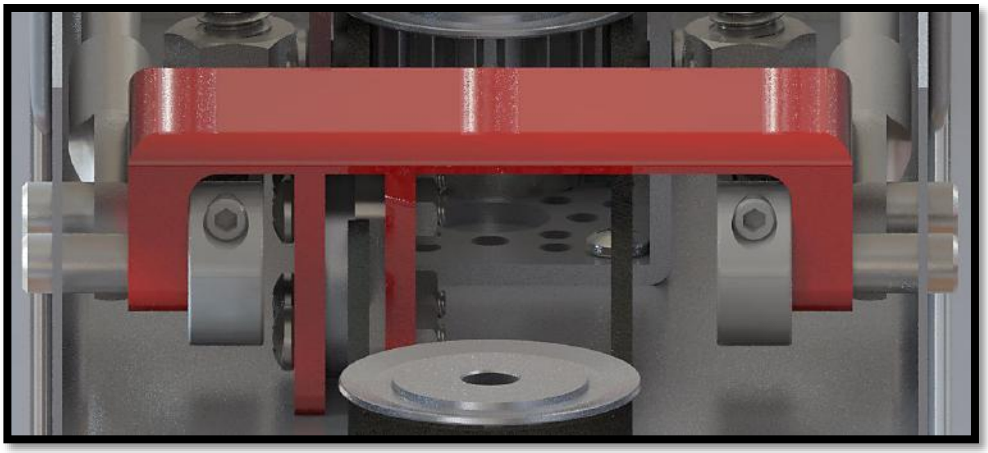


Figure 160: Slider mounted on timing belt.

Figure 161: Rear view of belt system.

The slider has flanges on each side where two 0.25 inch diameter shafts are located. Each shaft is held in place using an aluminum clamping collar. The shafts go through a slot on the sides of the main U-channel. The shafts keep the weight of the slider off the belt so that it will only experience a tension force in the direction of motion. The shafts also prevent the slider from rotating. Push rods are used to connect the slider with the L-bracket at the front of the payload arm. The ends of the push rods have an eye hook with a 0.25 inch hole. One end goes through the front shaft of the slider and the other end goes through the shaft on the top of the L-bracket. The push rods are placed on the sides of the U-channel.

Once the gripper assembly is rotated to 60 degrees, the timing belt stops moving. Next, the motor on the gripper assembly begins to rotate in the opposite direction which causes the payload to move towards rocket. The payload will travel 16 inches diagonally to reach the clips inside the rocket. Once inside the rocket, a hall-effect sensor will be used to detect when it has reached the clips that hold the payload. The motor will then stop and the payload arms will open up to release the payload. Finally, the motor will change its rotation direction and retract from the rocket.

Payload Arm Structure

The U-channel is mounted in between two 1.5 inch square t-slotted aluminum extruded posts. The posts are 18 inches tall to allow for the payload to come into the rocket from the top. The U-channel has two brackets that support it underneath and two brackets that support it from the side using socket screws and nuts.

A 0.25 inch thick 6061 aluminum plate will be used to mount the two towers holding the U-channel as shown in Figure 162.

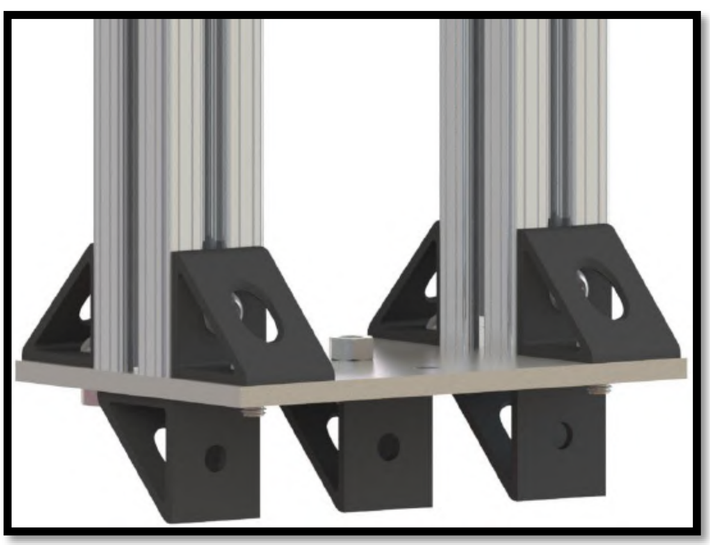


Figure 162: Payload arm mounting plate.

Four more brackets will be used to support the t-slotted aluminum extrusion towers on the front and back. Underneath the mounting plate, three more brackets will be placed that will be used to connect the entire payload arm assembly to the side rail of the AGSE launch platform.

The Arduino Uno that will be controlling the payload arm will be placed in a 3D printed case with a clear acrylic cover, yet to be made. The Arduino will be placed on top of the aluminum mounting plate as shown in Figure 163.

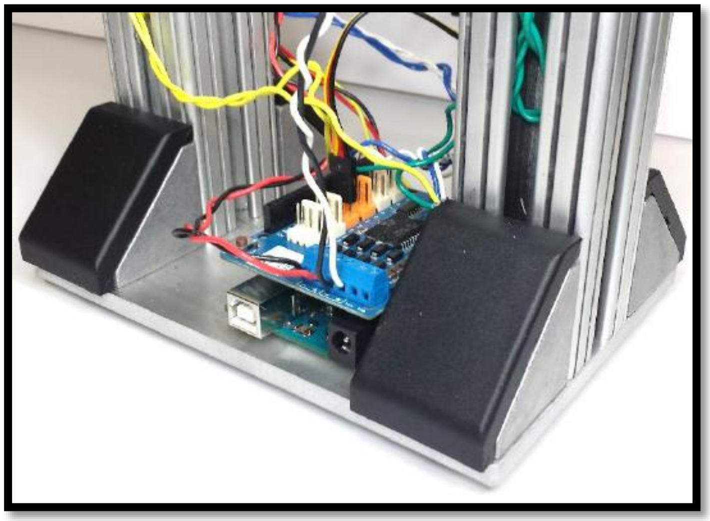


Figure 163: Location of Arduino on payload arm.

Cantilever Analysis

One of the main concerns with this system's design is that the shafts supporting the gripper assembly will deflect too much when it is extended diagonally to deposit the payload inside the rocket. A SolidWorks Simulation was performed to see how much deflection is expected in the shafts due to the weight of the gripper assembly. Figure 164 shows the constraints and loads that were applied to the shaft during the simulation.

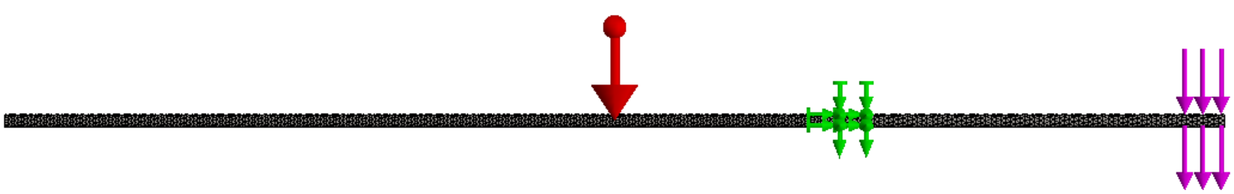


Figure 164: Constraints and loads on shaft.

The shaft was simulated as a cantilever beam since the threadless ball nuts will be supporting the shaft and the gripper assembly, shown in green in Figure 164. The shaft was analyzed at its maximum extended length of 16 inch and perpendicular to the gravity vector. In Figure 164, the red arrow represents the gravity vector and the purple arrows represent the force applied to the shaft due to the weight of the gripper assembly. The shaft was simulated to be made of steel with properties and loads applied shown in Table 54.

Elastic Modulus (Pa)	$210x10^9$
Poisson's Ratio	0.28
Yield Strength (MPa)	620
Density (kg/m^3)	7700
Gripper Assembly Mass (kg)	0.680
Applied End Load (N)	6.71

Table 54. Applied cantilever analysis constraints.

For the simulation, the entire weight of gripper assembly was applied as the end load on the shaft instead of distributing it among the three shafts. The reason for this is to see the worst case condition where the middle shaft is the only one carrying the load due to some unforeseen problem. The shaft was simulated at horizontal since this would give a worst case scenario answer. Figure 165 and Figure 166 show the resulting plots from the simulation.

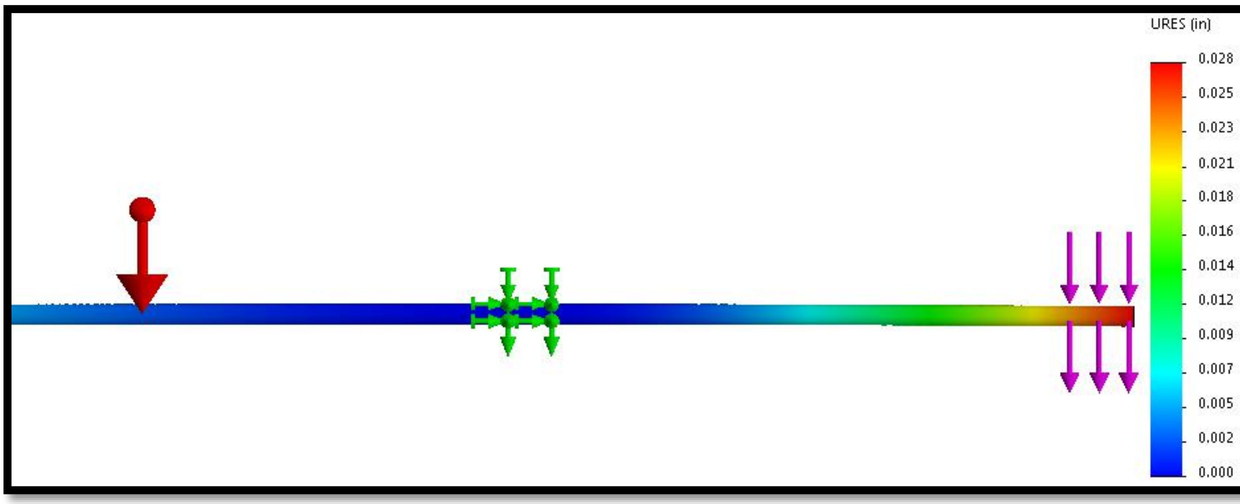


Figure 165: Vertical displacement plot.

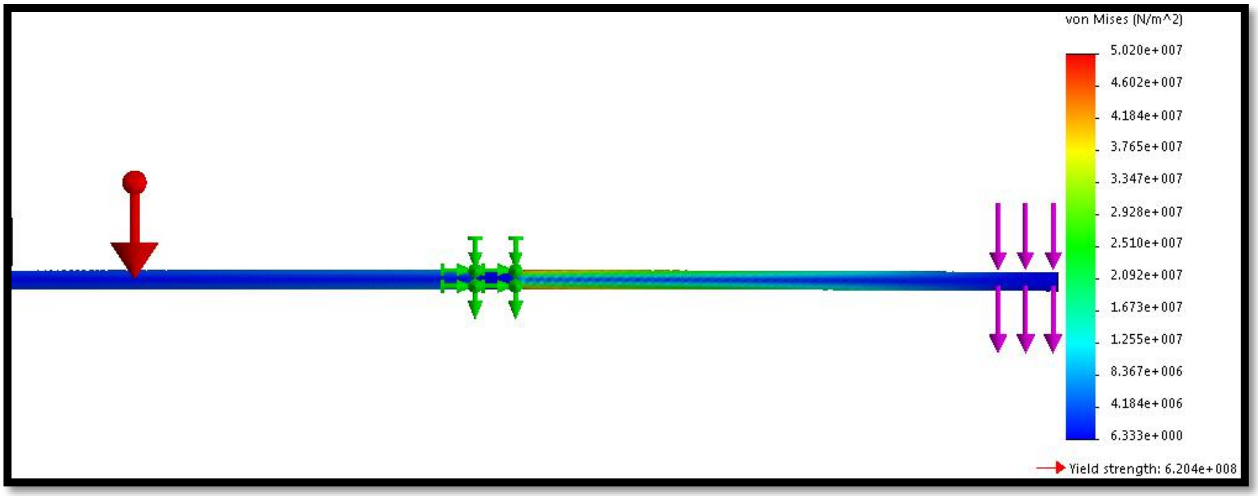


Figure 166: VonMises stress plot.

Assuming the worst case scenario where the entire weight of the gripper assembly is on one shaft and the gripper assembly is fully extended horizontally, the results shown in Table 55 were obtained.

Maximum vertical displacement (in)	Maximum VonMises stress (MPa)	Yielding factor of safety
0.028	50.2	12.4

Table 55: Results from cantilever analysis.

From the results, the team is confident that the vertical displacement caused by the weight of the gripper assembly on the shafts is negligible. When the payload arm was built, there was no measurable deflection on the rods as predicted.

Electronics

The payload arm operates on a series of checks to see if it is ready to go to the next step. An Arduino Uno is going to control the system with a motor shield attached to it. A general overview of how this system will operate is shown in Figure 167.

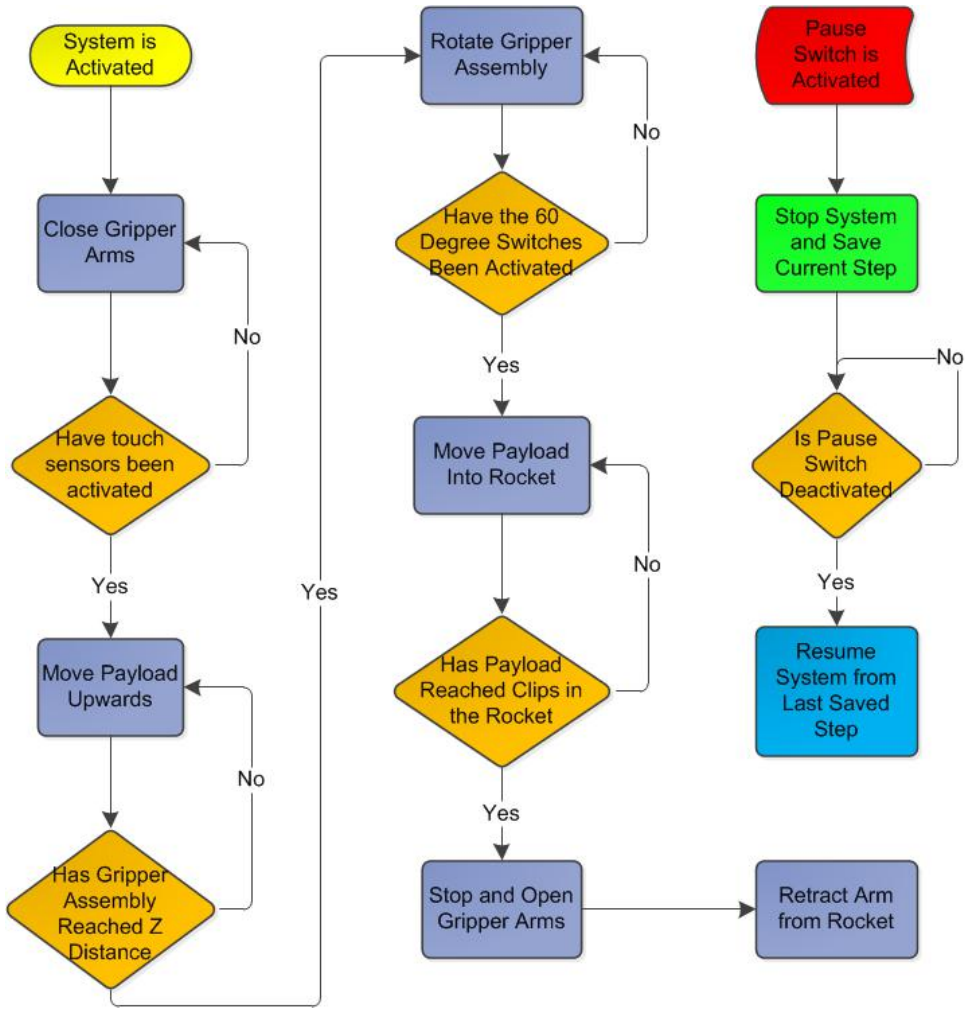


Figure 167: Flowchart for payload capture system.

One of the most important features in the system is that it must be able to completely stop what it is doing if the RSO decides to pause the team's launch. A pause switch will be connected to the entire AGSE including the payload arm. If system ever receives a signal that the pause switch has been activated, it will stop at its current position. The Arduino must then remember what it was doing and resume from this same place once the pause switch is deactivated. The payload arm systems must be able to hold in whatever position they are if this situation were to ever arise. The tests that have been conducted on this part are described in later sections.

To make sure that everything had a connection, every component was wired according to the diagram shown in Figure 168. With that diagram, it was guaranteed that the Arduino UNO had enough pins to control the system.

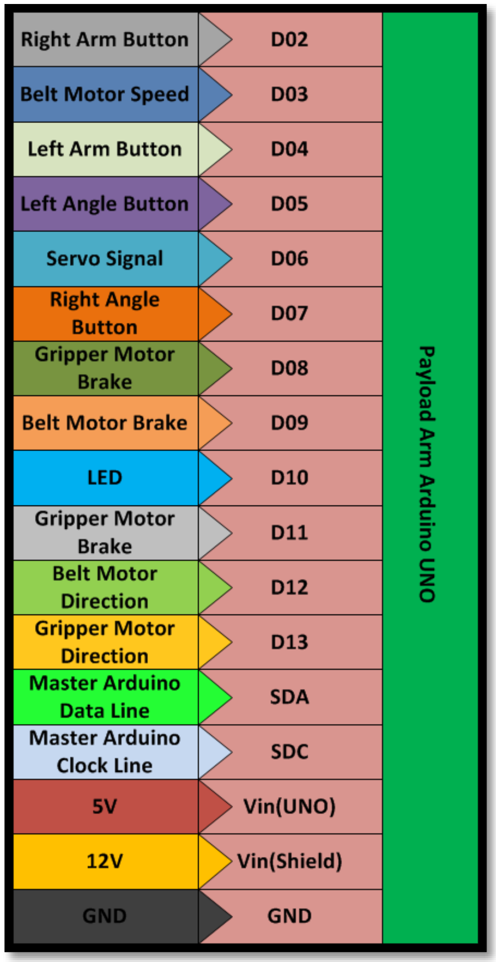


Figure 168: Payload arm Arduino connections.

To be able to drive the motors on the Payload Arm, a motor shield will be used which is shown in Figure 169. The shield is capable of driving two DC motors using the L298P full H-Bridge driver. The shield also keeps the same pin connections as the Arduino and it has connectors for servos. The specifications for the shield are shown in Table 56.

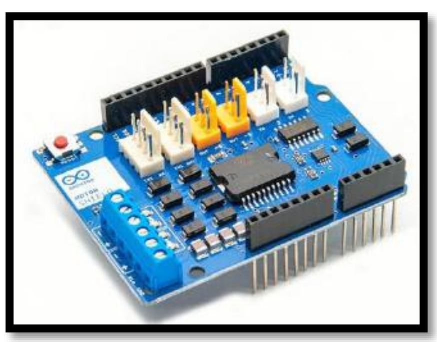


Figure 169: Arduino UNO motor shield.

Operating Voltage	5-12V
Motor Controller	L289P
Max Current Per Channel	2A

Table 56: Arduino UNO motor shield specifications.

The motors and servo are going to be the main source of power consumption from the Arduino so their specifications are shown in Table 57. As can be seen, the motor shield is easily able to drive both motors and servo.

Motor/Servo	RPM	Torque (oz-in)	Voltage (V)	Current (A)
Gripper Assembly	624	41.7	12	0.19
Belt System	10	368	12	.5
Servo	---	89	5	.4

Table 57: Motor and servo specifications.

Challenges

Table 58 shows the design challenges for the payload capture system and their chosen solutions.

Challenge	Solution
Detect when the payload has been captured the by the payload arm.	A touch sensor is located on each side of the gripper arms. When both have been activated, the system will know the payload is securely held.
Raise the payload a maximum of 40 inches from the ground at a low cost.	A threadless ball screw system is being implemented. A regular shaft will be more cost effective than a threaded rod at larger lengths.
Rotate the gripper assembly to be 60 degrees from the top of the AGSE rail.	A timing belt system will be implemented to rotate the assembly. This type of system is common in photography to move a camera at a steady rate.
Place the payload within the rocket in its allotted time.	The two DC motors that operate the payload arm have been chosen such that they are able to drive their components fast enough to accomplish their tasks.
Easily move the payload arm structure along the launch pad side rail to accommodate the location of the capsule bay on the rocket.	The payload arm will mount on a side rail using three brackets. The brackets will be able to be screwed anywhere on the side rail.

Table 58: Design challenges and solutions for payload capture system.

Verification Plan

To be considered successful, the payload arm must meet the requirements set forth in the statement of work.

Table 59 shows the verification plan to meet these requirements as well as any others set forth by the team.

Table 60 shows the tests that will be performed to verify the requirements.

Requirement	Method of completion	Method of verification
Each Maxi-MAV team must capture and contain a payload.	The team has designed and built an arm system to pick up a payload from the ground and place it inside the rocket.	Test 1, 2, 3, 4, 5, 6, 7, 8, 10
If the pause switch is enabled, all actions must stop immediately.	The Arduino controlling the system will constantly be polling for a signal from the pause switch and if it sees one all activity will be stopped.	Test 9
Each team will be given 10 minutes to autonomously capture, place, seal the payload within the rocket, erect the vehicle, and insert the igniter.	The motors moving the gripper assembly will be chosen to rotate fast enough to allow the system to complete its task within its allotted time.	Test 1, 2, 3, 4, 5, 6, 7, 8, 10
All AGSE systems shall be fully autonomous.	The payload arm will be completely controlled by an Arduino Uno.	Test 10.

Table 59: Verification plan for payload arm.

Tests	Success qualification	Status
1. Verify that the payload arm can detect when the payload is secured.	The system must correctly sense the payload whenever it is grabbed.	Passed
2. Verify that the payload can be held securely by the gripper assembly and then released	The payload is grabbed and does not fall out at least 5 times in a row until the release command.	Passed
3. Verify that the threadless ball screw system works correctly by running the	The gripper assembly must be able to move upwards without problems at least 5 times in a row.	Partially Passed

motor and shaft connected to it.		
4. Verify that the arm is able to rotate using the belt system.	The arm must successfully rotate 60 degrees at least 5 times in a row.	Passed
5. Verify that the arm is able to move towards and away from the rocket at 60 degrees.	The payload must be able to move across without deflecting more than a degree.	Passed
6. Verify that the payload can be pushed into the clips in the payload bay.	The payload must be held securely by the clips at least 5 times in a row. The payload arm must be able to retract without moving the payload.	In Progress
7. Verify that the payload arm is stable.	The payload arm must not wobble whenever it is in motion.	In Progress
8. Verify that the payload can be picked up and deposited inside the rocket in its allotted time.	The entire process must be at or less then the time given to the payload arm operation.	Partially Passed
9. Verify that the system can restart from a pause state.	The payload arm system must continue what it was doing before the pause switch was activated.	In Progress
10. Verify that the system can operate autonomously.	The system must operate successfully without any team member intervening while testing at least 5 times in a row.	In Progress

Table 60: Test plan for the payload arm.

Test 1: Verify that the payload arm can detect when the payload is secured.

The arms that hold the payload each have a miniature switch, shown in Figure 170. The button extrudes through a hole in the arms so that it is pushed in when the payload is grabbed.

Figure 170: View of switches on payload arms.

The switches are wired individually to the Arduino controlling the payload. To test that they worked, an LED was wired to the Arduino so that it would turn on whenever the buttons were pressed. The LED was able to be successfully turned on which indicated that the switches worked. Figure 171 shows the test setup used for testing the Payload Arm. In that image, the aforementioned LED in the breadboard can be seen turned on since the payload is captured.

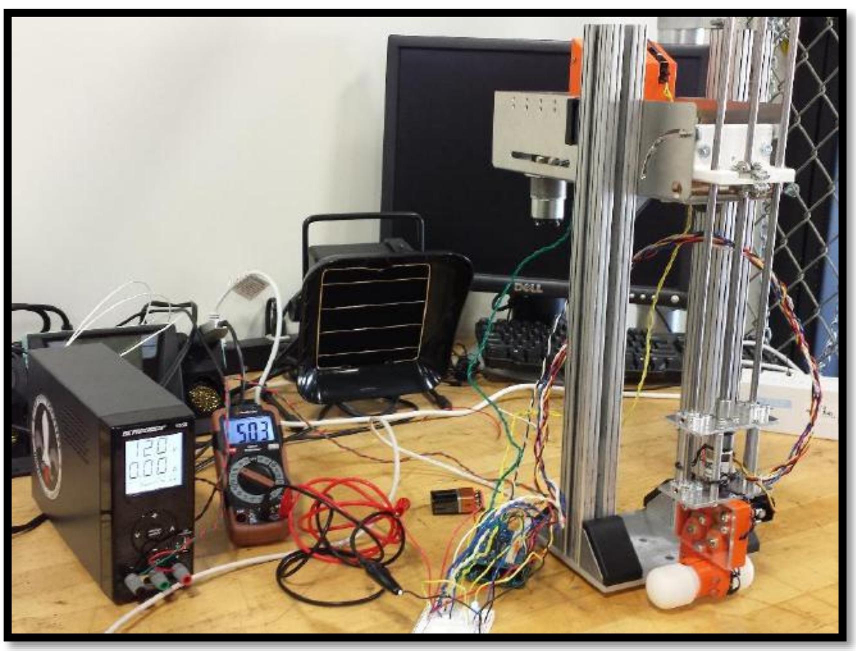


Figure 171: Payload arm test setup.

The payload was originally unable to activate the button, but after two iterations to the arms and some sanding, the payload was able to activate the switches. Therefore, this test is considered a success.

Test 2: Verify that the payload can be grabbed and held securely by the gripper assembly. To test that the payload could be held securely two separate functions ReleasePayload() and GrabPayload() were created for the releasing and grabbing the payload, respectively. This part of the code is shown below in Figure 172.

Payload_Arm

```
void ReleasePayload()
{
  if (GrabbedPayload == 0)
  {
    digitalWrite(ServoSignal,HIGH);
    for(pos = 0; pos < 70; pos += 1)  // goes from 0 degrees to 70 degrees
    {                                  // in steps of 1 degree
      myservo.write(pos);              // tell servo to go to position in variable 'pos'
      delay(15);                       // waits 15ms for the servo to reach the position
    }
    GrabbedPayload = 1;
    ReleasedPayload = 0;
  }
  else;
}

void GrabPayload()
{
  if(ReleasedPayload == 1)
  {
    digitalWrite(ServoSignal,LOW);
    for(pos = 25; pos >= 1; pos -= 1)  //goes from 25 degrees to 0 degrees
    {                                  // in steps of 1 degree
      myservo.write(pos);              // tell servo to go to position in variable 'pos'
      delay(15);                       // waits 15ms for the servo to reach the position
    }
    ReleasedPayload = 0;
    GrabbedPayload = 1;
  }
}
```

Figure 172: Grab and release payload functions.

Each function was individually run until the servo position values were dialed in. After dialing in the values, the payload was able to be securely held without falling out. Figure 173 shows the payload securely held at an angle of 60 degrees. The motor is providing a small amount of torque the entire time that the payload is held to make sure that it doesn't fall out.

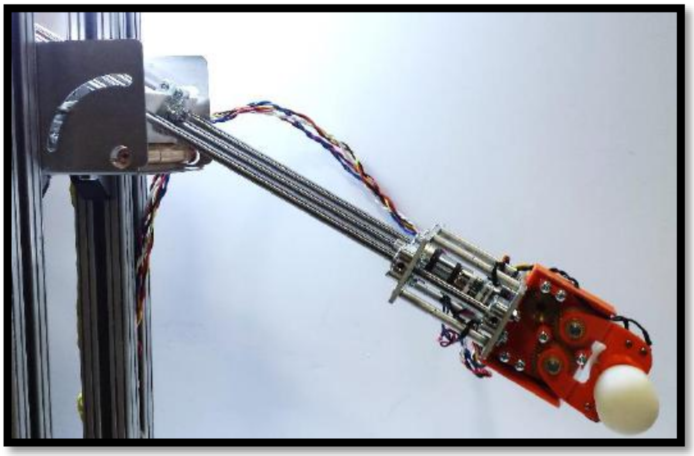


Figure 173: Payload held securely at 60 degrees.

The payload was then able to be released upon command several times. Since the payload was able to be held securely and released at least five times in a row, this test is considered a success.

Test 3: Verify that the threadless ball screw system works correctly by running the motor and shaft connected to it.

The threadless ball screw system doesn't have much data available online therefore this was a crucial component that needed to be tested. The 0.25 inch steel shaft for the motor was attached to the gripper assembly and then the other end was inserted into the ball screw system. At first the system did not move but it was discovered that the reason was not enough of a preload by the system. Once the screw and nut that adds a preload were tightened, the gripper assembly was able to successfully move.

Although the system was able to move, when the two steel support shafts were added to the system it stopped moving again. The reason for this is thought to be the weight because the system works when they are removed again. To remedy this, aluminum shafts will be bought instead due to their lower weight compared to steel. Since the system has been proven to work but it still requires a modification this test is considered to be Partially Passed.

Test 4: Verify that the arm is able to rotate using the belt system.

The belt system is responsible for rotating the payload to the required 60 degrees so that it can go into the rocket. The belt kept slipping from the pulleys but after inspecting it, the cause was found to be not enough tension on the belt. Once more tension was added, the belt did not slip anymore.

The motor driving the belt was at first wired to a power supply and the belt system was able to pull the payload back until it hit the 60 degree angle block. The motor was then wired to the Arduino and a function for controlling the motor was created so that it could easily be used. With the Arduino, the belt system was able to successfully pull back the payload multiple times. Due to this, the test is considered a Pass.

Test 5: Verify that the arm is able to move towards and away from the rocket at 60 degrees.

The payload bay's location within the rocket has required the payload to come in at 60degrees. To make sure that the belt system would stop at 60 degrees, two switches were mounted to a 60degree angled block. When the belt would be pulled back the support rods would hit the switches thus telling the Arduino that it had reached its desired angle. The switches were each individually tested using an LED similar to Test 1 before they had their wires soldered on.

Once the payload was at 60 degrees, the gripper assembly's motor was activated and the payload was able to move forwards and backwards without any complications. The system operated better at an angle then vertical. Due to this, the test is considered a Pass.

Test 6: Verify that the payload can be pushed into the clips in the payload bay.

To prevent the payload from moving around in the rocket, the payload arm will have to insert the payload into two clips in the payload bay. To do this, the plan is to have the motor moving the gripper assembly move forward and push the payload inside. Unfortunately, the payload bay has not been built to be able to conduct this test, therefore it is considered to be In Progress.

Test 7: Verify that the payload arm is stable.

The reason that the payload arm must be stable is to make sure that the payload can be correctly inserted into the rocket. As mentioned in Test 5, the payload arm operated tilted back at 60 degrees. Unfortunately, an issue arose when the payload arm was vertical. When the gripper assembly was extended down to the floor, it would twist whenever the motor was run. The reason for this is that the spinning of the motor created a counter torque which made the gripper assembly want to rotate. The solution to this was to add a block with holes for the shafts to slide through at the bottom of the payload base to prevent the rotation. Since the block is not an ideal solution, the 3D printed case for the Arduino will have a similar concept integrated into it so that it can prevent the shafts from twisting. Since this casing is yet to be made, this test is considered to still be In Progress.

Test 8: Verify that the payload can be picked up and deposited inside the rocket in its allotted time.

The gripper assembly will start out hovering above the payload as shown in Figure 174 with the arms open. The arms are angled such that they scoop up the payload. Several trials were run that verified that the payload was able to be picked up every time.

Figure 174: Gripper assembly hovering above payload.

The 40 RPM motor that was originally chosen was found to be too slow when it was tested since it only moved the gripper assembly 3 inches in one minute. To remedy this, a 624 RPM motor was chosen to replace it. With this motor, the gripper assembly was able to move 36 inches in one minute. This motor is considered to be fast enough to move the payload the required distance. Since all the system steps have yet to be put together to verify that the process can be done within the allotted time, the test is considered to be Partially Passed.

Test 9: Verify that the system can restart from a pause state.

One of the requirements for the competition requires the team to be able to pause the system if the RSO wants to. The master Arduino will send a signal to the Payload Arm Arduino and tell it to stop. The motor shield that is going to be used has a brake pin that can be engaged to stop the motors from rotating so this will be used if the pause signal is detected. This part of the system has not been written into the code so this test is In Progress.

Test 10: Verify that the system can operate autonomously.

Since the goal of the project is to do everything autonomously, this test is the most important. Once all the other systems have been individually debugged, they will be combined. If all the parts are able to successfully operate without human intervention the Payload Arm will be considered launch ready. Until then, this test is considered to still be In Progress.

4) Launch Platform

Overview

The launch platform must perform the following functions in order of importance to be considered a success:

1. Allow the vehicle to leave at a safe exit velocity.
2. Maintain vehicle alignment during payload insertion.
3. House the ignition system for the vehicle.
4. Mount to the ground station in a consistent manor.
5. Attach to the vehicle erection system in a repeatable manor.
6. Be reusable.
7. Be transportable by a single or a series of passenger vehicles

The overall dimensions of the launch platform are shown in Table 61.

Overall height (in)	Rail length (in)	Overall width (in)	Overall thickness (in)	Overall mass (lb_m)
127.00	119.89	30.98	22.63	106.94

Table 61: Launch platform general dimensions.

Figure 175: Launch platform.

Changes since CDR

The changes made to the launch platform since CDR are shown in Table 62.

Change	Justification for change
Top plate of the launch platform base was modified to remove motor retainer clearance holes.	The motor retainer clearance holes were removed to protect the rocket from potential damage while being loaded into the launch platform.
Fin guide was changed to a sheet metal component.	The change was made to save on manufacturing costs and time during manufacturing and assembly.
Added machined slots to guide rails for ring alignment.	Provides an alignment feature for constant placement of each connecting ring.

Table 62: Changes made since CDR.

Design

The launch platform consists of three t-slotted aluminum extrusions which guide the vehicle until the vehicle has reached a designated safe velocity. The rails will be coated with a thin layer of talcum powder to reduce the frictional losses between the vehicle and the rails. The team has previously used graphite power to reduce friction with the rail, however talcum powder was selected because it is non-conductive and is cost efficient. The gap between the guide rails and the vehicle is 0.025 inches.

Figure 176: Launch platform base.

The guide tower rests upon a base, shown in Figure 176, made from three machined 0.375 inch thick steel triangular plates with each plate serving a specific purpose. The bottom most plate, shown in Figure 177, is where three 18.375 inch aluminum extrusions that stabilize the primary guide rails and is the base mounting plate for the ignition system. These aluminum extrusions are mounted to the bottom plate using three 5 inch 5/16”-16 UNC 2A cap screws that thread into the extrusions. Three corner brackets are also used to fasten the extrusions to the bottom plate. Each bracket has two end fed slotted framing fastener with an 11/16 inch 5/16”-18 UNC 2A flanged button head cap screw to fasten the bracket.

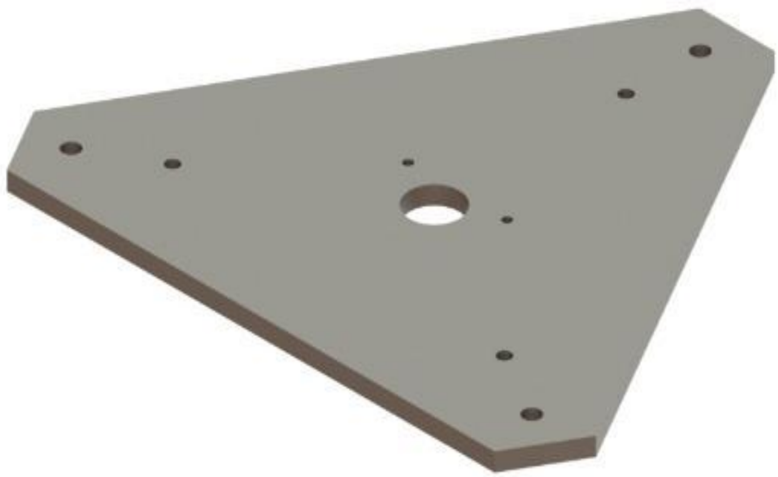


Figure 177: Platform bottom plate.

The middle plate, shown in Figure 178, is the plate in which the guide rails mount.

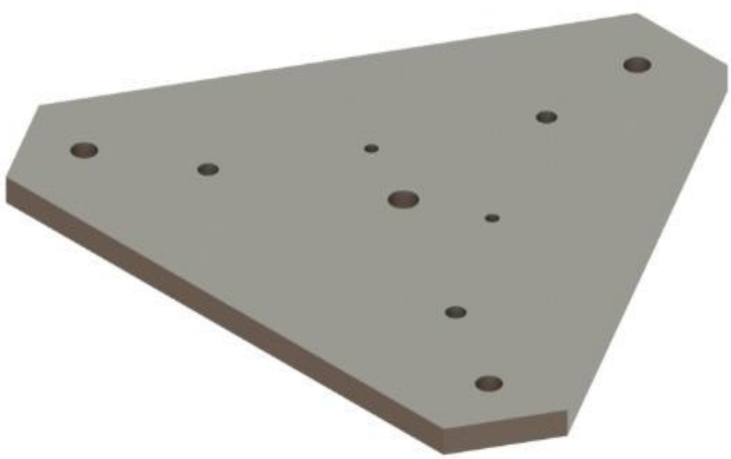


Figure 178: Middle base plate.

The guide rails mount the same way as the support rails with the same threaded fasteners and corner brackets. The rails then are attached via rectangular connecting plate that is fastened to both support and guide rail. The rectangular connection plate uses two end fed slotted framing fastener with a 1/2 inch 5/16”-18 UNC 2A flanged button head cap screw to fasten the plate.

The uppermost plate, shown in Figure 179, is where the vehicle rests pre-flight. This is constrained by two sets of plates that connect and stabilize the support and guide rails.

Figure 179: Uppermost base plate.

To ensure correct vehicle position during payload insertion, an alignment plate, shown in Figure 180, will hold one of the fins in the correct orientation and only allows for translation along the axis of the launch platform. The fin alignment plate is fastened using two 3/8 inch ¼”-20 UNC 2A button head cap screws.

Figure 180: Vehicle alignment plate.

The guide tower consists of three rails that split into two groups for transportation reasons. To ensure proper alignment, at the conjunction between each plate, a connecting rod and a fastening plate are mounted on three sides of the extrusion, shown in Figure 180. The fastening plates utilize two end fed slotted framing double fastener with two 1/2 inch 5/16”-18 UNC 2A flanged button head cap screw to fasten to the rails. The connecting rod is a

9.76 inch rod with the bottom 4.76 inches being threaded and the upper portion being the same diameter as the t-slotted extrusion.

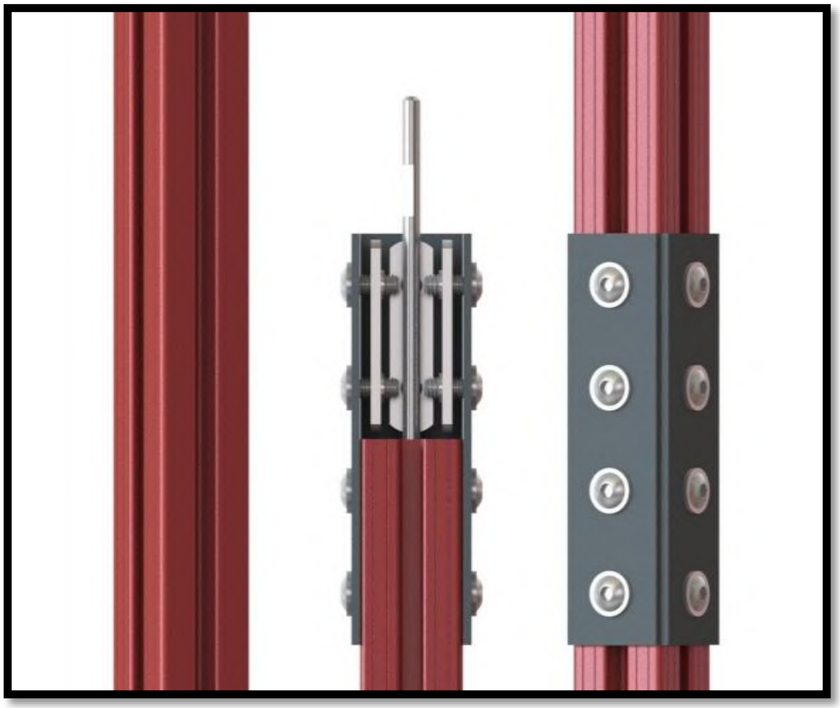


Figure 181: Tower connection joint.

To maintain structural rigidity during vehicle erection and provide the mounting locations for the ground station and the vehicle erection system, three ring assemblies are used. To avoid any incidental contact between the vehicle's fins, the amount of gap between the fins and the inner diameter was set to 0.75 inches nominally and a parallel view is shown in Figure 182. These rings connect to three t-slotted aluminum extrusions which are 6.79 inches long. The aluminum extrusions are attached to each ring using an end fed slotted framing double fastener with two 1/2 inch 5/16"-18 UNC 2A flanged button head cap screw.

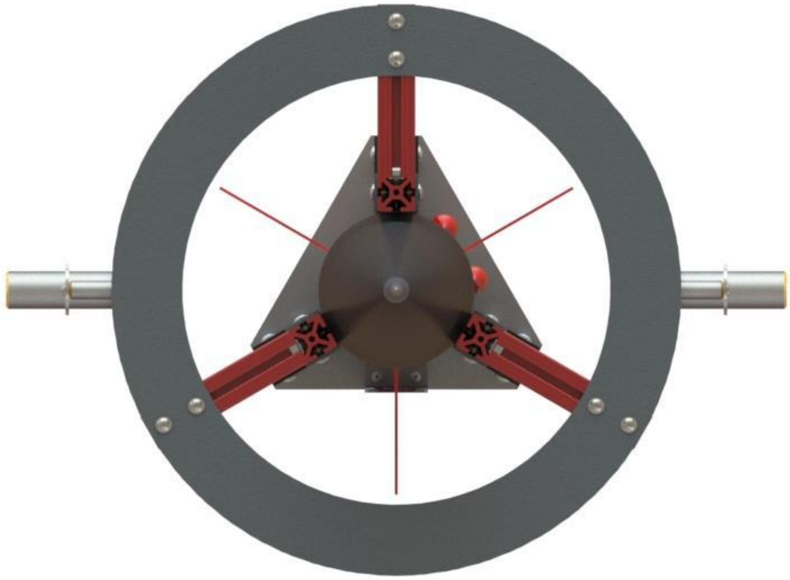


Figure 182: Worst case alignment.

The bottom most stability ring assembly, shown in Figure 183, doubles as the method of attachment to the ground station. This assembly consists of two rings with an inner diameter of 17.00 inches and an outer diameter of 22.63 inches. The placement of this ring assembly is 23.78 inches from the bottom of the station.

Figure 183: Bottom stability ring.

The connecting shaft is a solid piece that is a mounting block and a shaft machined as one piece with a shaft diameter of 1.5 inches. To ensure proper alignment, two ¼ inch dowel holes will be part of the connecting shaft, shown in Figure 184, and the tower rings. The connecting shaft will be fastened to each ring using two ¾ inch ¼-28 UNC 3A button head cap screws.

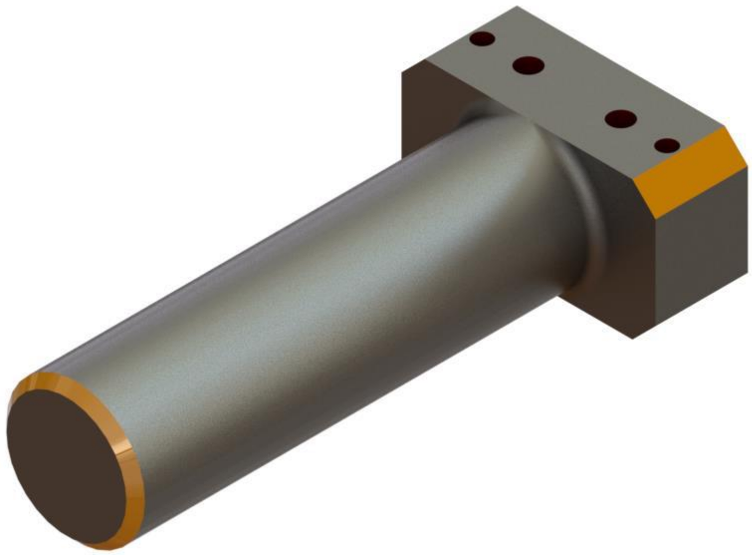


Figure 184: Vehicle connection shaft.

The secondary ring assembly, shown Figure 185, houses the connection point between the platform and the vehicle erection system. The ring assembly is identical except for the connecting part has a shaft size of ¾ inches, and the spacing between it and the lower ring is 40.35 inches.

Figure 185: V.E.S. connection ring.

The connecting shaft ends in a tapped hole to accommodate a 0.140 inch thick nylon washer, this washer keeps the arm that connects the V.E.S. to the launch platform attached to the platform. A close-up of the washer and screw are shown in Figure 186. These shafts will also be held in proper alignment via two ¼ inch dowels through both the connection shaft and the rings. The articulating arm connection shafts will use the same fasteners and the ground station connection shafts.

Figure 186: V.E.S. and platform connection joint.

The ring assemblies are attached to each rail using a 1.5 inch 5/16"-18 UNC 2A socket head cap screw. A corner bracket, each with two end fed slotted framing fastener with an 11/16 inch 5/16"-18 UNC 2A flanged button head cap screw, is also used to fasten the rings to the rails. The rings are located using a machined slot in the guide rails as shown in Figure 187.

Figure 187: Ring interface locating feature.

The vertical placement of the connecting ring assemblies will be discussed further in the technical description of the V.E.S..

The height of the launch tower was determined using

$$h = \int_0^{t_e} V dt \tag{28}$$

where V is the velocity as a function of time, and t_e is the time at which the vehicle has hit the required exit velocity. To determine t_e the following free body diagram (F.B.D.) was constructed and shown in Figure 188.

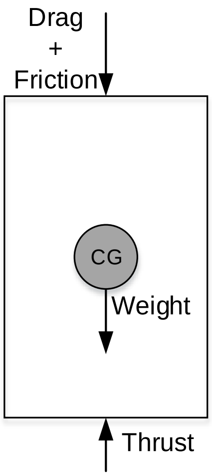


Figure 188: Vehicle takeoff F.B.D.

The sum of forces could be determined to determine the acceleration as a function of time.

$$+\uparrow \sum F = ma \qquad (29)$$

where F is equal to the sum of forces, m is the total mass of the vehicle and a is the acceleration of the vehicle. The sum of forces is determined using

$$+\uparrow \sum F = T - mg - F_d - F_f \qquad (30)$$

where T is the motor thrust, g is the acceleration due to gravity, F_d is the force due to drag, and F_f is the frictional force due to the guide tower. F_d is determined via

$$F_d = \frac{1}{2}\rho C_d A V^2 \qquad (31)$$

where ρ is the air density, C_d is the drag coefficient which will be taken from the OpenRocket simulation, A is the reference area, and V is the vehicle velocity. The mass of the vehicle is determined using

$$m = m_w - b_r t \qquad (32)$$

where m_w is the “wet” mass of the vehicle with a full motor, b_r is the burn rate of the motor propellant, and t is time after ignition. Equations (29) through (32) can be combined to determine the acceleration of the vehicle and the resulting equation is shown below.

$$a_i = \frac{T_i - (m_w - b_r t)g - F_f - \frac{1}{2}\rho C_d A V_{i-1}^2}{m_w - b_r t} \tag{33}$$

A fourth order Runge Kutta method will be used to calculate the vehicles velocity as a function of time using the following the following incremental based slopes

$$k_1 = a_i(V_{i-1}) \tag{34}$$

$$k_2 = a_i\left(V_{i-1} + \frac{h}{2}k_1\right) \tag{35}$$

$$k_3 = a_i\left(V_{i-1} + \frac{h}{2}k_2\right) \tag{36}$$

$$k_4 = a_i\left(V_{i-1} + \frac{h}{2}k_3\right) \tag{37}$$

where h is the time step size. The vehicle velocity is then determined via

$$V_i = V_{i-1} + \frac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{38}$$

To verify the validity of this analysis, flight data from a previous team launch vehicle was analyzed and compared. The vehicle used in the comparisons is the same one from the 2012 – 2013 academic year. This vehicle was chosen due to having accelerometer based altitude data Table 63 shows the necessary parameters needed to run the simulation.

Vehicle name	Mass (kg)	C_d	Area (m^2)	Motor	Launch pad height (m)
Dis-Reefer	16.6015	0.31	0.0213	L-995-R	3.048

Table 63: Trail 1 parameters.

Figure 189 shows the recorded flight data during the competition launch from the vehicle's primary Raven altimeter.

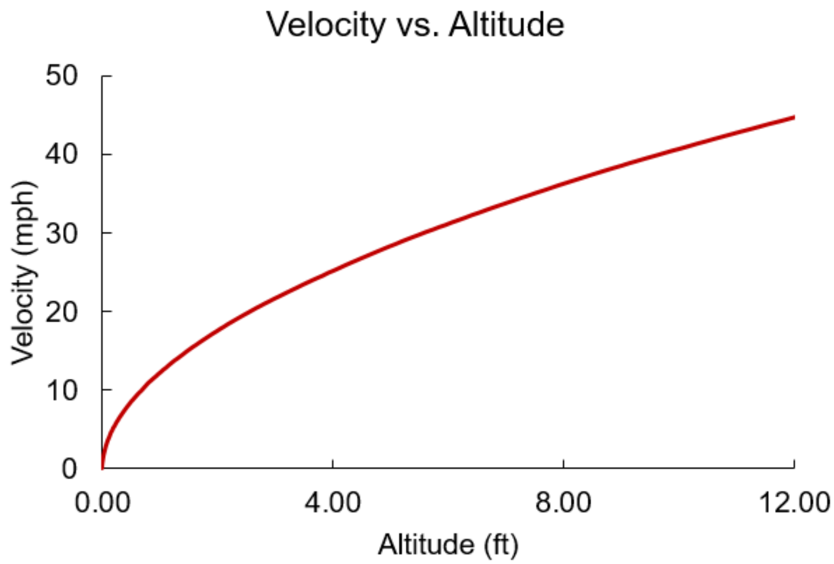


Figure 189: Velocity vs. altitude in tower.

The flight data was then compared to the predicted flight profile shown in Figure 190.

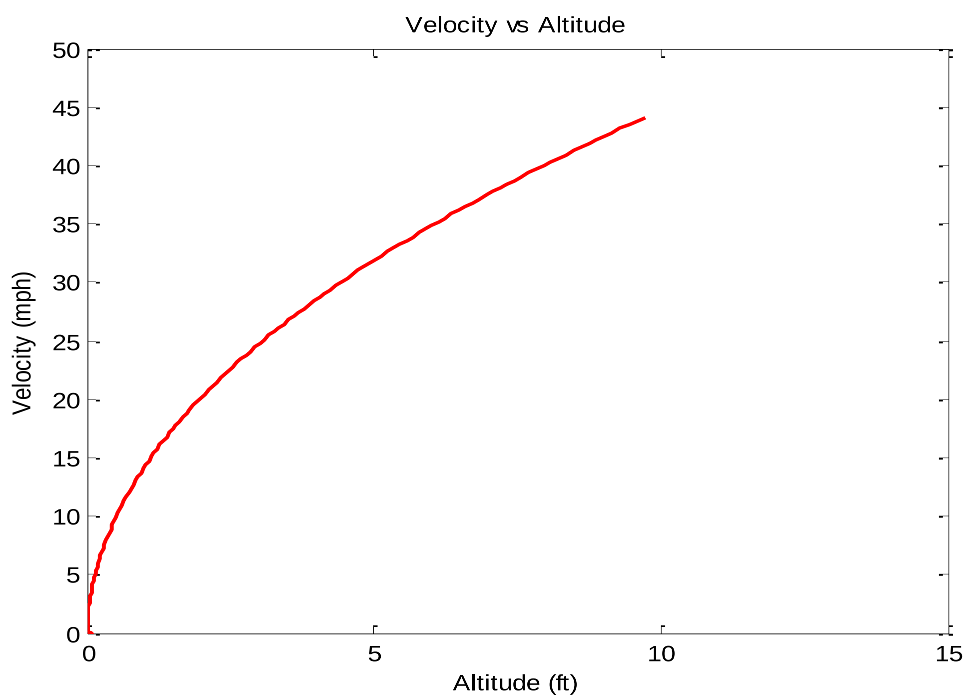


Figure 190: Predicted velocity vs. altitude in tower.

The exit velocities and percent error are shown in Table 64.

True velocity (mph)	Predicted velocity (mph)	Percent error
40.712	44.6263	9.61%

Table 64: Predicted vs. actual exit velocity.

The analysis was not able to take into account frictional forces which is a potential cause for the percent error. To accommodate this error when sizing the launch platform for the current competition, the desired exit velocity was determined using

$$V_e = V_{e\,required} * (1 + P.E.) \tag{38}$$

where $V_{e\,required}$ is the required exit velocity and P.E. is the previously mentioned percent error. The required exit velocity of the vehicle was chosen to be the same exit velocity that the previous team launch vehicles, this was done due the success of those vehicles during ascent which gives a high level of confidence of its continued success.

Required exit velocity (mph)	Error adjusted exit velocity (mph)
41.4	45.4

Table 65: Error adjusted exit velocity.

Figure 191 shows the predicted flight profile until rail exit.

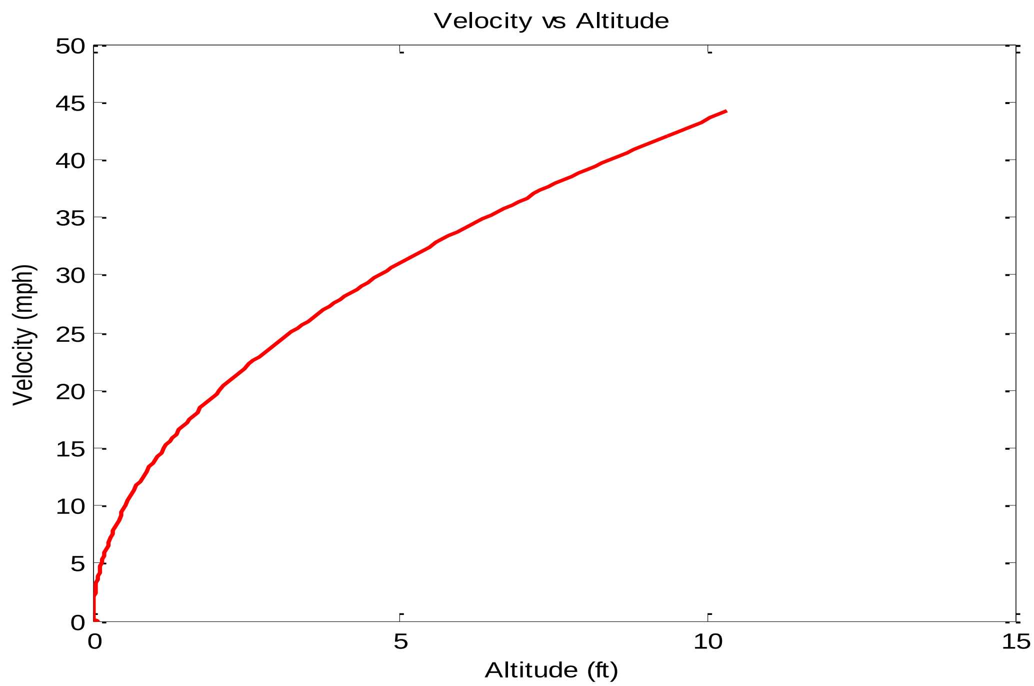


Figure 191: Predicted flight profile.

With the accounted velocity, the total height that the vehicle is to be guided is shown previously in Table 61.

Construction

The t-slotted aluminum extrusions were be cut using a horizontal band saw. The pieces were then planed and cut to length using a manual mill. The stability rings were cut using the waterjet shown in Figure 192.

Figure 192: Waterjet cutter.

CNC technology will be used to create the connection shafts.

Challenges

The design challenges and chosen solutions are shown in

Design Challenge	Solution
Accurate placement of the vehicle so that the payload capture and containment systems are able to function properly.	At the base of the platform there will be a fin alignment guide. This guide will hold the fins such that the vehicle cannot rotate away from the proper alignment. The launch platform itself will be horizontal and thus the vehicle should not slide axially along the platform.
Mount to both V.E.S. and Ground Station.	Stability ring assemblies double as mounting points.
Able to support the vehicle during V.E.S. actuation.	The vehicle will always be in a position that gravity would pull it towards the base of the platform.
Be able to protect sensory equipment during ignition/takeoff.	The sensors will be mounted on the bottom of the ring assemblies, protecting them from exhaust.
Be transportable by passenger vehicle.	The platform breaks down into two separate sections along the guide rails for transportation.

Table 66: Launch platform design challenges.

5) Vehicle Erection System

Overview

The vehicle erector must be capable of meeting the following requirements to be consider a success:

1. Erect the vehicle from a horizontal position to a position five degrees from vertical.
2. Hold vehicle steady during pre-launch procedures including erection of the vehicle, installation of igniter, and arming of recovery systems.
3. Upon power failure, system pause, or other motion halting action maintain vehicle orientation at the time of action.
4. Hold vehicle steady during launch.
5. Be reusable.

Changes since CDR

The changes since CDR are shown in Table 67.

Change	Justification for change
Added thrust bearing setup	The axial load from the ball screw was originally only supported by the gearbox which was not rated for thrust loading.

Table 67: Vehicle erector changes since CDR.

Design

The design of the vehicle erector will consist of a track, carriage, and articulating arm linkage system. The entire vehicle erector system is shown in Figure 193.

Figure 193: Vehicle erection system.

The track will consist of two parallel t-slotted aluminum extrusions that will provide linear guides for the carriage as shown in Figure 194.

Figure 194: Vehicle erector track assembly.

The track extrusions were sized by analyzing the loads and associated deflections over the length of the track. The deflection of the track was calculated using equation

$$y = \frac{W(L - x)^3 x^3}{3EIL^3} \quad (39)$$

where W is the load, x is the position of the load on the track, L is the length of the track, I is the moment of Inertia of the cross section, and E is the modulus of elasticity.

The load on the track varies based on the position of the carriage. The deflection was modeled over the entire travel of the carriage to find the point of maximum deflection. The results of the deflection analysis are shown in Table 68.

Modulus of elasticity ($\frac{\mathbf{lb_f}}{\mathbf{in^2}}$)	Moment of inertia ($\mathbf{in^4}$)	Max deflection (in)
10,200,000	1.8042	0.0079

Table 68: Track deflection results.

The maximum deflection was calculated using a minimum safety factor of 2. The calculated maximum deflection is an acceptable deflection for the track. The carriage will be designed such that this deflection does not prevent the carriage from traveling the full length of the track.

The main parallel track extrusions will be mounted to two cross extrusions which will then be mounted to the ground station. The parallel track extrusions will be bolted to the cross bars using four 2 inch 5/16"-18 UNC 2A thread socket head cap screws. One cross extrusion will serve as the mount point for the vehicle erection system motor and the second will serve as a mount for the bearing support at the opposite end of the power screw. Bearing support cross extrusion is shown below in Figure 195.

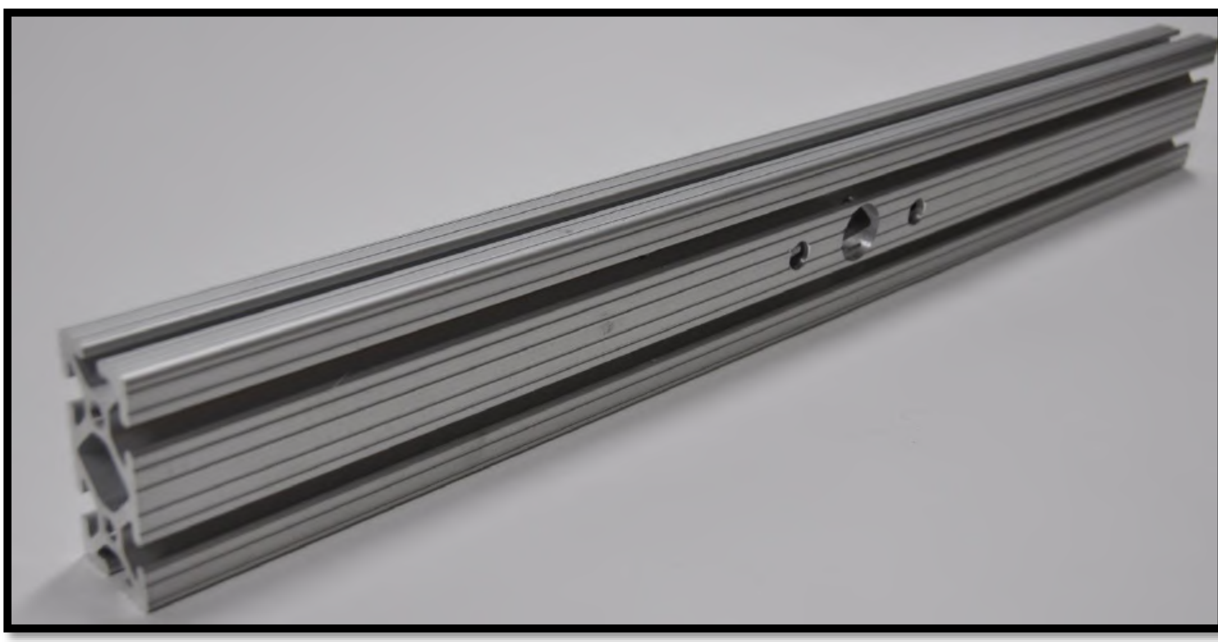


Figure 195: Bearing support cross bar.

The carriage will be actuated by a one inch ACME screw. The ACME screw was sized by analyzing the stresses. An oversized screw was selected based on availability from suppliers.

The power screw will be powered by an Ampflow brushed DC - E30-150-G gearmotor as shown in Figure 196.

Figure 196: Ampflow brushed DC-E30-150-G gearmotor.

The motor will be mounted to the track system via the motor mount plate shown in Figure 197.

Figure 197: Track motor mount plate.

The motor mount plate will be bolted to the track crossbar using two 2.5 inch 3/8”-16 UNC 2A thread socket head cap screws. The motor will be mounted to the plate using 4 counter bored ¾ inch ¼”-20 UNC 2A thread socket head cap screws. Alignment of the motor will be controlled by the two bearing holes in the plate.

As mentioned earlier, the ball screw will be supported by a ball bearing on the opposite end from the motor. The bearing is shown in Figure 198. The bearing will be mounted using two 2 inch 7/16”-14 UNC 2A thread socket head cap screws with associated nuts. The ball screw will also be supported by a brass bearing sleeve. The brass bearing sleeve will support the screw across the cross section of the track cross bar.

Figure 198: Power screw support ball bearing.

The thrust load bearing assembly shown below in Figure 199 will be used to handle the axial loads the ball screw will experience. This bearing assembly will transfer the loads from the screw directly to the track structure rather than through the gearbox.

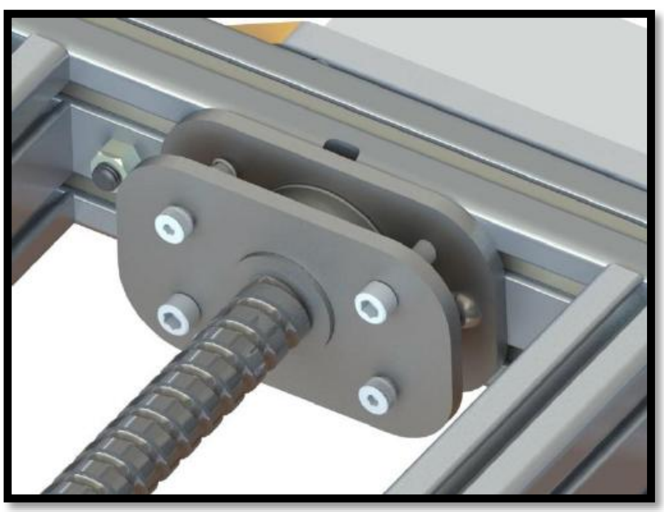


Figure 199: V.E.S. thrust bearing assembly.

The thrust bearing assembly will be placed at the interface point between the ball screw and the motor. The bearing assembly consists of a custom machined coupler and two steel plates. The custom machined coupler, as shown in Figure 200, will be used to couple the ball screw to the gearbox and provide a flange for the bearings to run against.

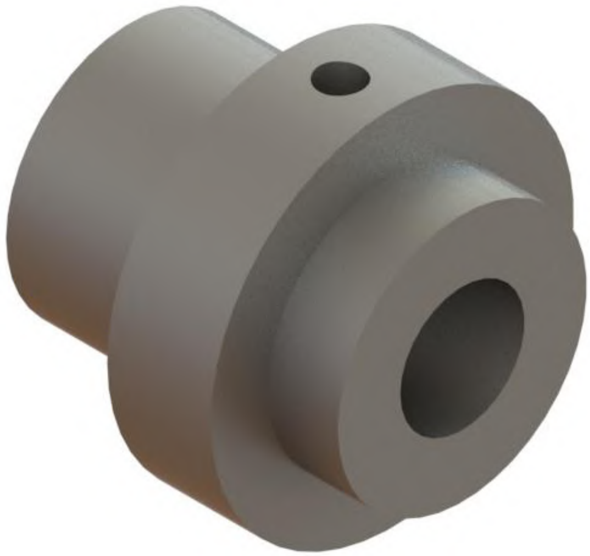


Figure 200: V.E.S. thrust bearing coupler.

The thrust bearing coupler will couple with the motor using a ¾ inch long ¼ inch machine key. This will allow for an axial degree of freedom, transferring all axial loads to the thrust bearing assembly rather than the gearbox assembly. The coupler will be connected to the ball screw using a 3/8 inch long 5/16”-18 UNC 3A set screw.

The two steel plates will also provide a surface for the bearings to run against and will transfer loads to the track structure. The plates will be kept in alignment by using two 1.125 inch 5/16”-18 UNC 3A socket head shoulder bolts. The plates will also provide a preload on the bearings using two 1.375 inch 5/16”-18 UNC 3A socket head cap screws. Two springs are also included in the assembly to keep the plates spaced evenly. The bearing assembly will be attached to the track structure using two 9/16 inch 5/16”-18 UNC 3A socket head cap screws through one of the steel plates.

The thrust collar that will be used on the vehicle erection system is shown in Figure 201.

Figure 201: V.E.S. thrust collar.

The carriage assembly is shown in Figure 202.

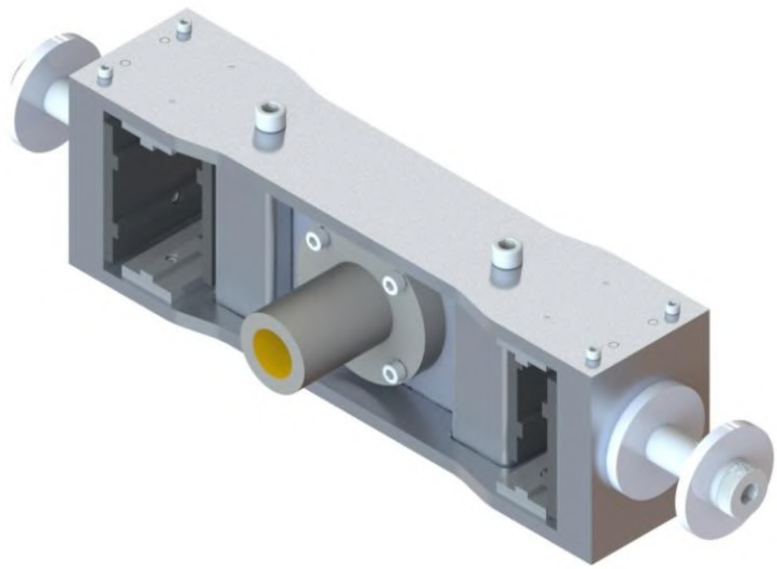


Figure 202: Vehicle erector carriage assembly.

The carriage will be made of out seven unique machined components. The top and bottom plates on the carriage are identical and provide symmetrical connections to the other components. The bottom plate is shown in Figure 203.

Figure 203: Carriage bottom plate.

A vertical mounting plate interfaces with the power screw and transfers the load from the screw to the carriage. The vertical mounting plate is shown in Figure 204.

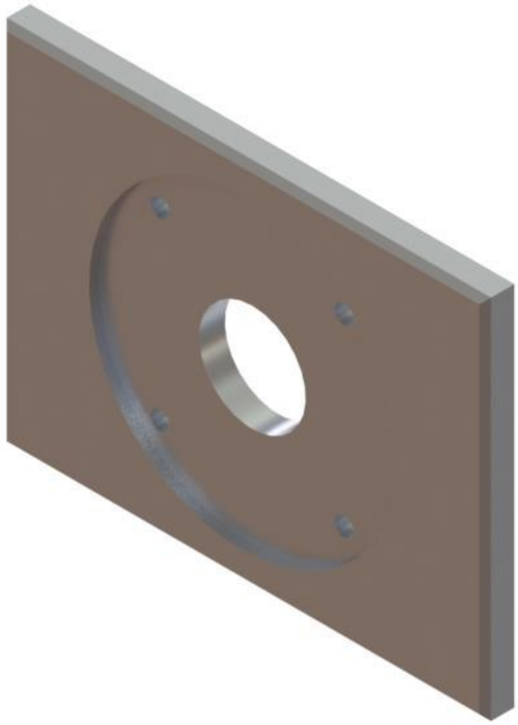


Figure 204: Carriage vertical mount plate.

The power screw nut will be aligned by the round well in the center of the mount plate. The nut will be fastened to the vertical mount plate via four 1 inch ¼”-20 UNC 2A thread socket head cap screws. Two vertical uprights are used to transfer loads from the vertical mounting plate to the top and bottom plates. A vertical upright is shown in Figure 205.

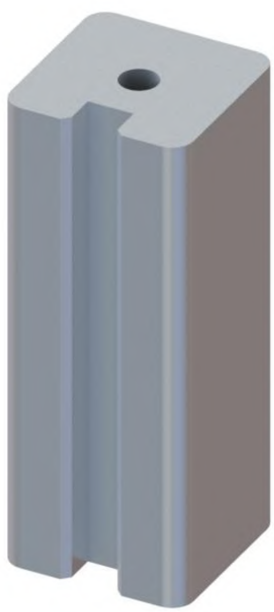


Figure 205: Carriage vertical upright.

Two vertical side plates also connect the top and bottom plates and are used to interface the carriage with the articulating arms. A vertical side plate is shown in Figure 206.

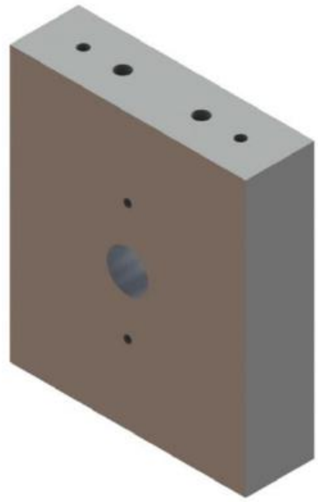


Figure 206: Carriage vertical side plate.

The articulating arms are connected to the side plates via a ¾ inch diameter 2 inch long shoulder bolt with 5/8”-11 UNC 3A thread. Nylon linear guide pads are used to interface the carriage with the track. The guide pads will provide a low friction contact point between the carriage and the track to reduce the total load required to actuate the carriage. The guide pads also help maintain the orientation of the carriage as the pads will seat into the t-slots of the track extrusions.

The vertical uprights will be fastened to the top and bottom plates via two 1 inch 3/8”-16 UNC 2A thread socket head cap screws. The side plates will be fastened to the top and bottom plates via four 1 inch #8-32 UNC 2A thread socket head cap screws. The vertical mounting plate will be secured in machined slots in the vertical uprights. The vertical mounting plate will be secured additionally by a slot in both the top and bottom plates.

The geometry of the carriage was selected to reduce the possibility for the carriage to jam inside the track system. The loads on the carriage are all centralized on a neutral axis to prevent rotational load from being applied to carriage. A rotational load could potentially jam the carriage. The width of the carriage also allows for a wide articulating connection between the vehicle erector and the launch platform. This wide articulation connection will provide more stability for the launch platform prior to, during, and post launch.

In order to validate the design of the carriage, a Finite Element Analysis was performed. To reduce the complexity of the model, the nylon guide pads were removed from the model and symmetry was used across the vertical center of carriage. The guide pads were removed under the assumption that they would always be in compression and would not see loads that would net failure. Fixed geometry boundary conditions were applied to the cross-sectional areas where the guide pads would sit. The horizontal guide pad locations received fixed geometry in the Y axis direction and vertical guide pad locations received fixed geometry in the Z axis direction. Fixed geometry in the X axis direction was applied to the threaded holes in the center carriage plate where the power screw nut will be attached. Three loading cases were analyzed and the results are summarized in Table 69.

Configuration	Vehicle angle (deg)	Load bar angle (deg)	Load (lbf)	Factor of safety
1	0	14.0	223.8	3.403
2	45	47.0	37.97	3.863
3	85	68.0	10.37	N/A

Table 69: Carriage analysis configurations setup and results.

A full analysis was not run for the third configuration because of the low load calculated for this position. Therefore the factor of safety was assumed to be higher than 2 and was not included in the table above.

Detailed results from the analysis of configuration 1 are shown below and a followed by a factor of safety distribution for configuration 2. For all simulations on the carriage assembly the loads were applied through a simulated load bar as shown in Figure 207.

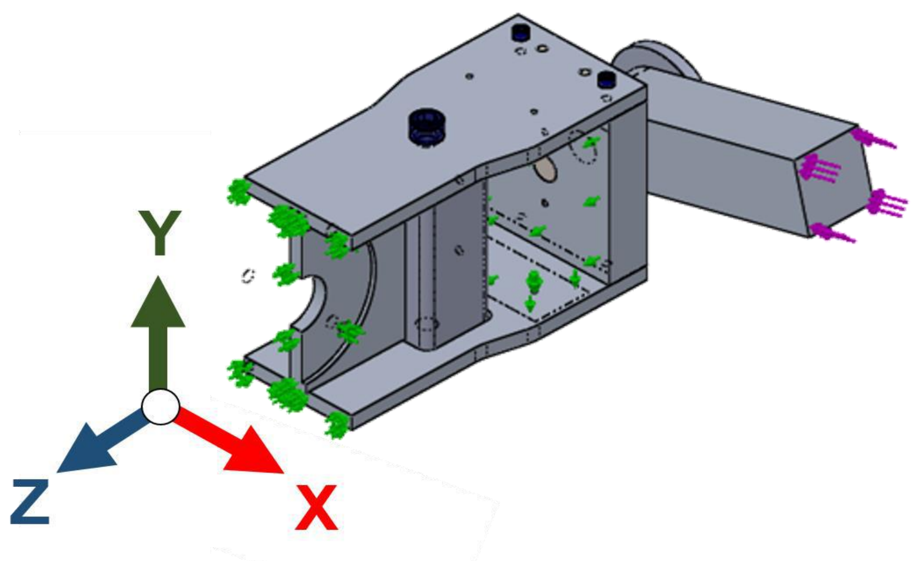


Figure 207: Carriage boundary conditions for configuration 1.

A stress distribution plot for configuration 1 is shown in Figure 208.

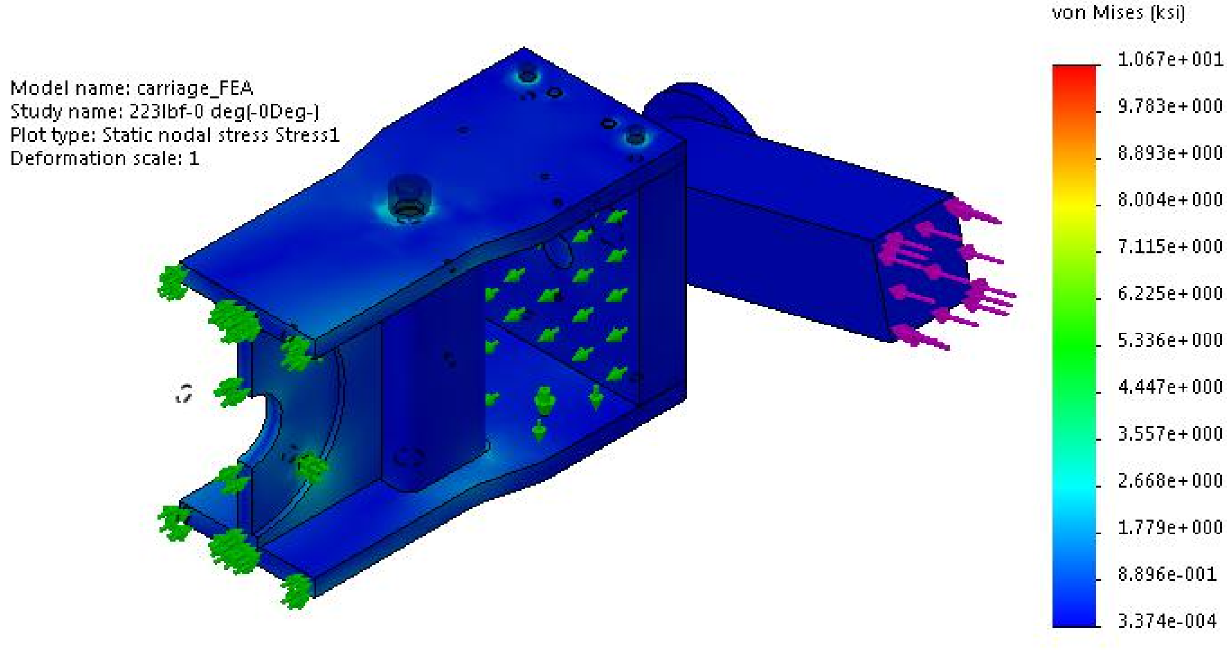


Figure 208: Carriage stress distribution for configuration 1.

The factor of safety distribution for configuration 1 is shown in Figure 209.

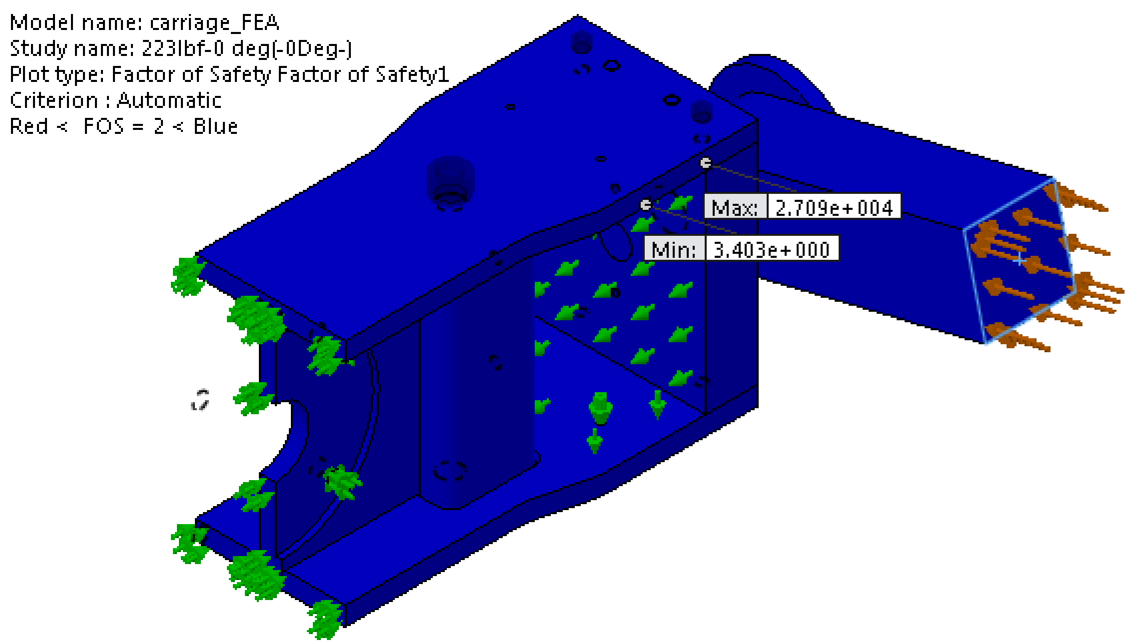


Figure 209: Carriage factor of safety distribution configuration 1.

As shown in Figure 209 the minimum safety factor was 3.403.

The factor of safety distribution for configuration 2 is shown in Figure 210.

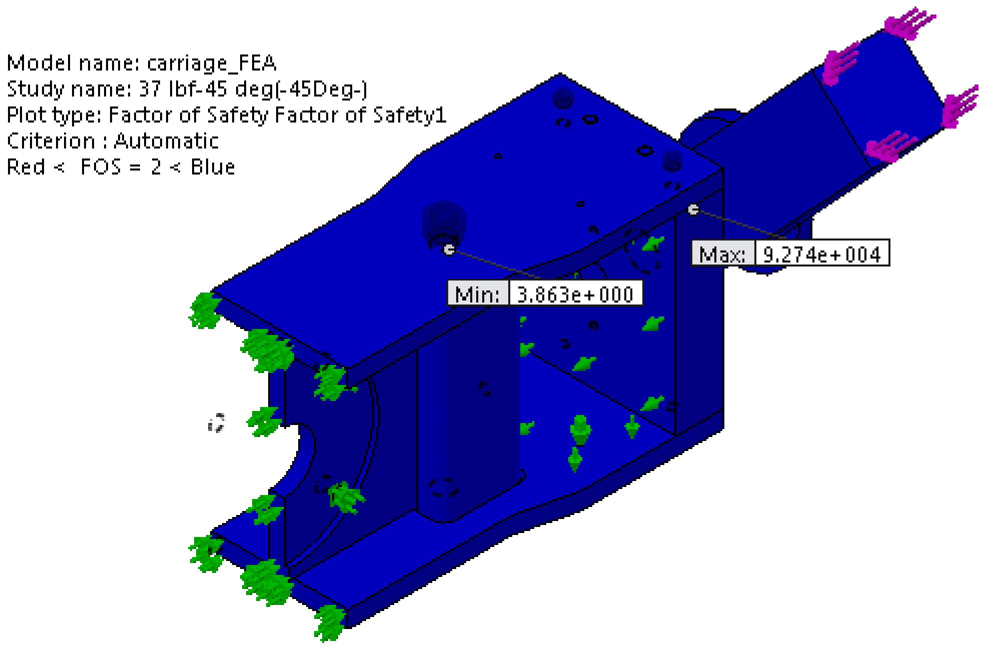


Figure 210: Carriage factor of safety distribution configuration 2.

The articulating arms will be made out of t-slotted aluminum extrusion. One articulating arm is shown in Figure 211.

Figure 211: Articulating arm assembly.

Two articulating arms will be used in the vehicle erection system to balance the load of the launch platform. The geometry of the arms was selected based on their connection points and surrounding components. The connection points for the articulating arms were optimized using custom iterative processing code as discussed later. Cross members could not be added between the articulating arms because of potential interference with the carriage and vehicle fins. The entire launch platform cross section must be kept clear when launch platform is in the loading or launch position. This clearance is required so the vehicle can be loaded and launched.

The articulating arm components will be bolted together using two 2 inch 5/16”-18 UNC 3A socket head cap screws. Corner brackets will add additional support using two end fed slotted framing fasteners with an 11/16 inch 5/16”-18 UNC 2A flanged button head cap screw per bracket. An exploded view of this connection is shown in Figure 212.

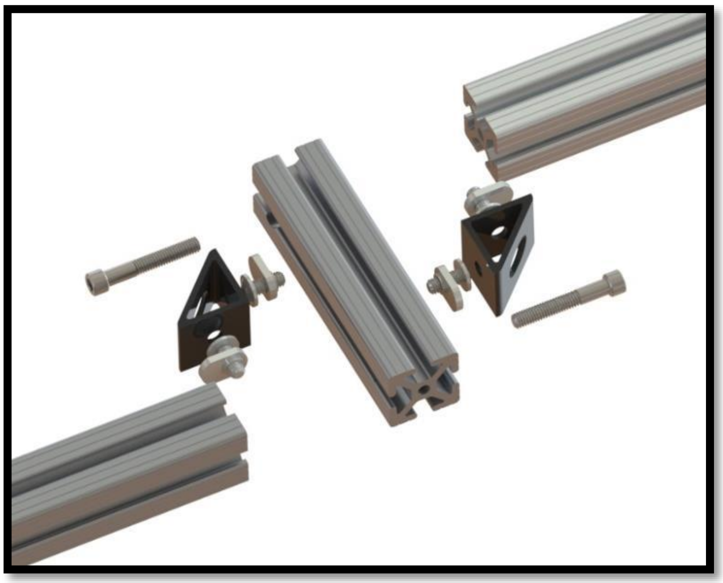


Figure 212: Articulating arm joint connection.

The end caps of the articulating arms are made of two larger aluminum extrusions with a brass bearing. These will be fastened to the articulating arm components using two 90 degree corner brackets. These brackets will interface with the end caps using a 1.5 inch 5/16”-18 UNC 2A thread button head cap screw. The brackets will interface with the articulating arm components using an end fed slotted framing fastener with an 11/16 inch 5/16”-18 UNC 2A flanged button head cap screw. A completed end cap is shown in Figure 213.

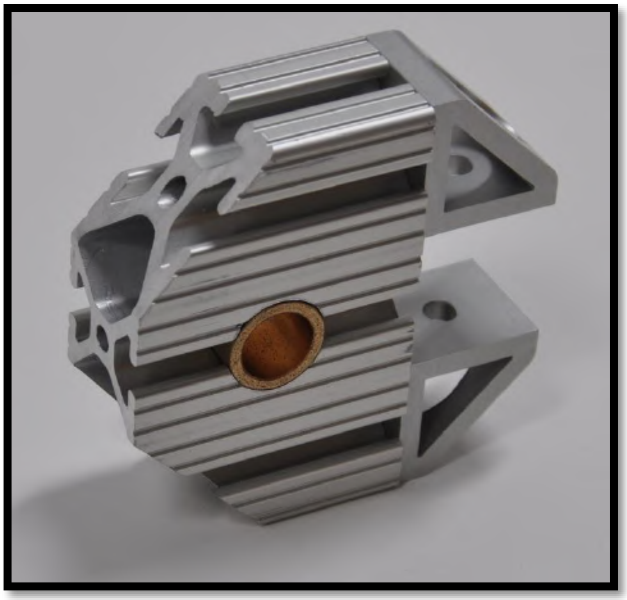


Figure 213: Articulating arm end cap.

Geometry Selection

The geometry of the vehicle raising system is shown in Figure 214.

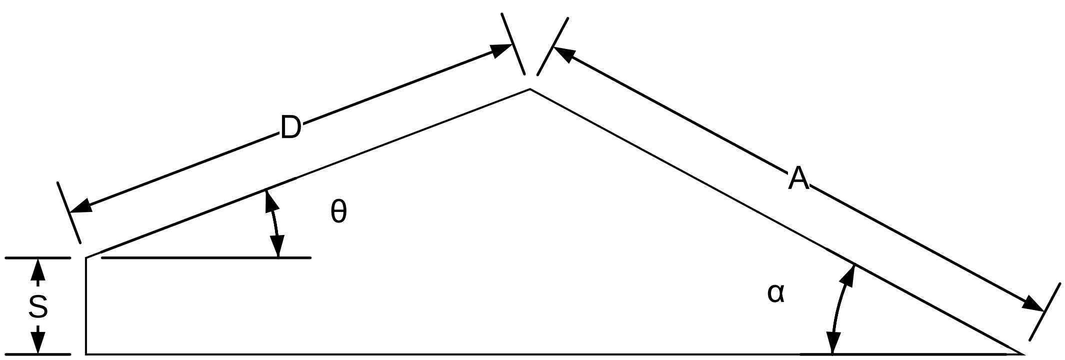


Figure 214: Vehicle erection system geometry.

S is the vertical distance from the power screw track system to the platform pivot point, D is the distance from the pivot point to the attachment point to the arms which raise the vehicle, A is the length of the arms, θ is the angle the vehicle makes relative to the ground, and α is the angle the arms make relative to the ground. Equation (1) shows the relationship be α, D, S, A, and θ.

$$\alpha = \sin^{-1}\left(\frac{\sin(\theta)\,D + S}{A}\right) \tag{1}$$

Because not all combinations of D, S, and A will result in a real solution for α, an iterative approach was used to determine all valid combinations of D, S, and A. Table 70 shows the min, max, and step size used to generate the potential solutions.

Parameter	A	D	S
Min (in)	28.000	40.350	11.000
Max (in)	80.000	77.850	14.000
Step size (in)	0.125	0.125	0.125

Table 70: Constraints to generate solutions.

For each combination of D, S, and A, α was calculated and checked if it was a real or imaginary solution. If real, the value was reported for further calculations. The distance the carriage is relative to the pivot point was calculated using

$$X=D\cos(85)+A\cos\left(\frac{\sin^{-1}(85)D+S}{A}\right)-\left(D+A\cos\left(\frac{S}{A}\right)\right) \qquad (2)$$

The total geometry including forces is shown in Figure 215.

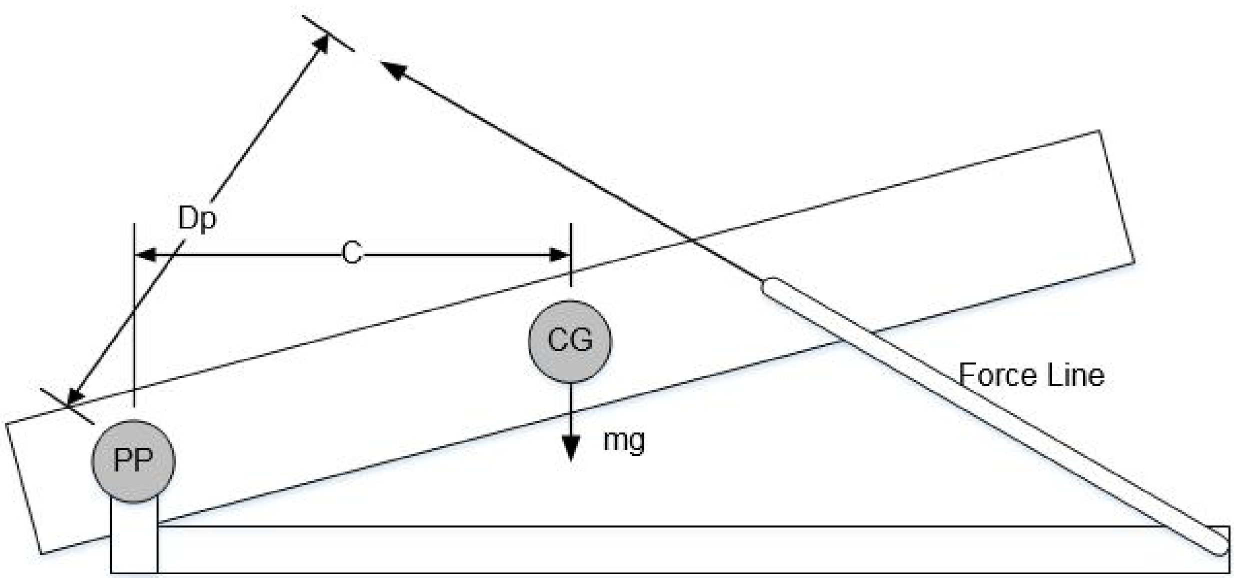


Figure 215: Total system description.

where C is the horizontal distance from the systems pivot point to the center of mass, D_p is the perpendicular distance from the systems force line to the pivot point. The sum of moments about the pivot point was calculated by

$$+\circlearrowleft \sum M_{PP} = F_a D_p - mgC \qquad (3)$$

where F_a is the force that the arms are putting on the platform, m is the total mass to be raised, and g is the acceleration due to gravity. The minimum raising force was then calculated via

$$F_a = \frac{mgC}{D_p} \tag{4}$$

D_p was calculated using

$$D_p = \sin(\alpha + \theta) D \tag{5}$$

The horizontal center of gravity distance was calculated via

$$C = C_0 \cos \theta \tag{6}$$

Combining equations (3) through (7), the raising force was determined using

$$F_a = \frac{mgC_o \cos \theta}{\sin(\alpha + \theta) D} \tag{7}$$

The initial opening force calculations were performed in addition to the carriage travel distance and plotted against each other in Figure 216. This is useful to see the different force vs. travel relationships available to further determine the optimum solution.

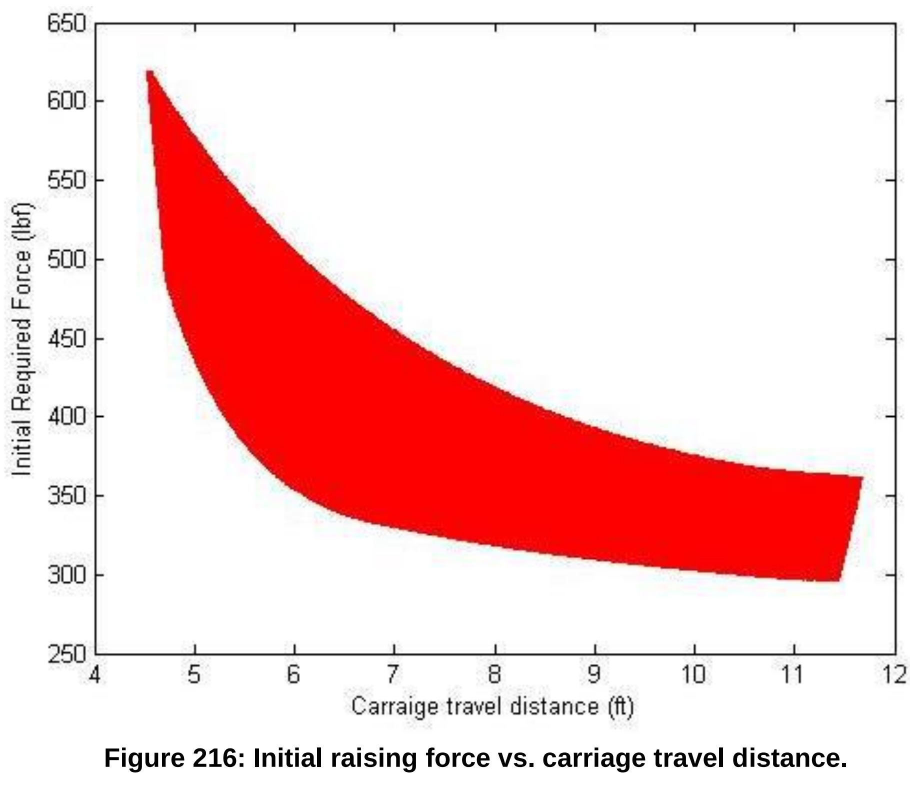


Figure 216: Initial raising force vs. carriage travel distance.

The options were sorted using the following rules in order of importance:

1. The placement of the attachment points must not interfere with the vehicle's capture and containment system.
2. The carriage travel length must be less than seven feet.

Using these criteria, the values for D, S, and A were chosen and shown in Table 71.

D (in)	A (in)	S (in)
40.350	58.375	14

Table 71: Optimized selections.

For this set, the amount of force the screw must provide to the carriage was calculated using

$$F_s = F_a \cos\alpha + F_f \tag{39}$$

where f_f is the frictional force of the carriage on the support rails, which was calculated using

$$F_f = \mu F_a \sin\alpha \tag{40}$$

The required input torque to the power screw was then determined using

$$T = \frac{F_s l}{2\pi v} \tag{41}$$

where l is the screw lead and v is the screw efficiency, typically 90% for ball screws. Table 72 shows the calculation parameters.

μ	m (lb_m)	C_o	L (in/thread)
0.35	150.82	28.72	0.5

Table 72: Calculation parameters.

Figure 217 shows the required raising force vs. vehicle angle.

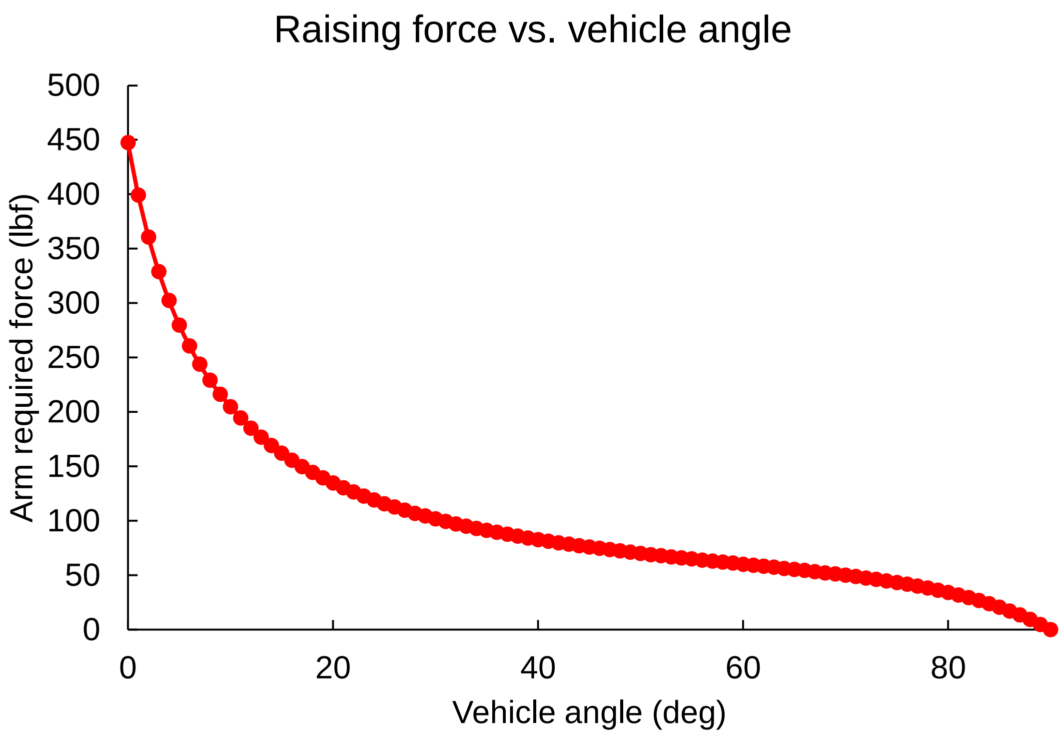


Figure 217: Raising force vs. vehicle angle.

Figure 218 shows the screw drive force vs the vehicle angle.

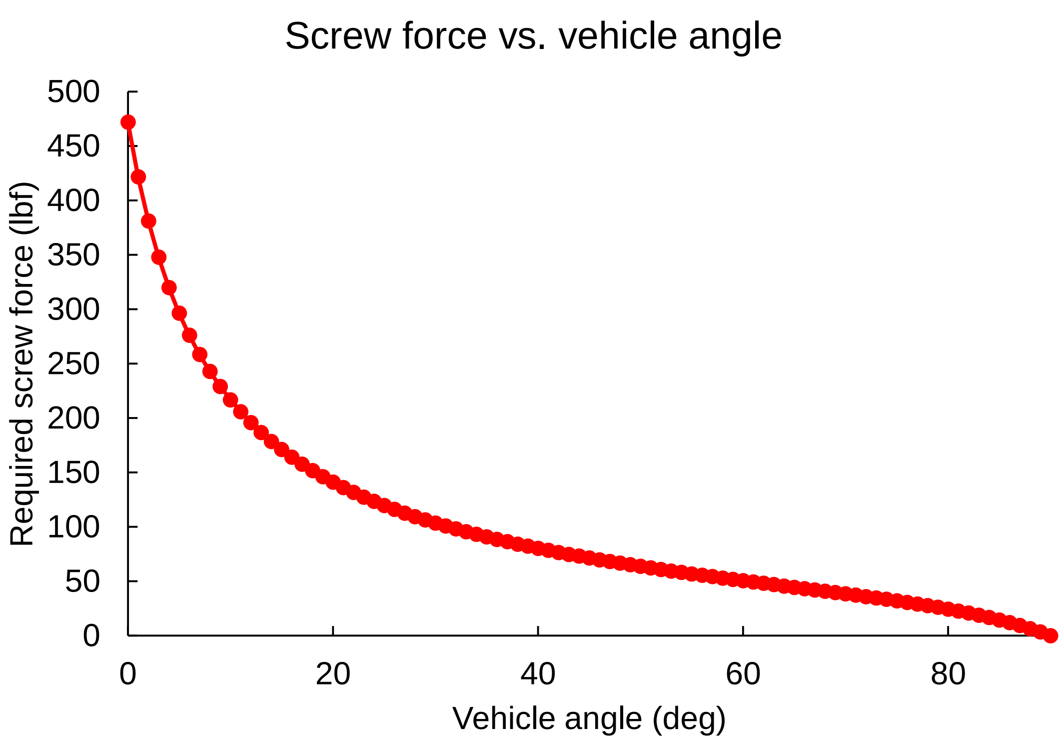


Figure 218: Screw drive force vs. vehicle angle.

Figure 219 shows the required motor torque vs. vehicle angle.

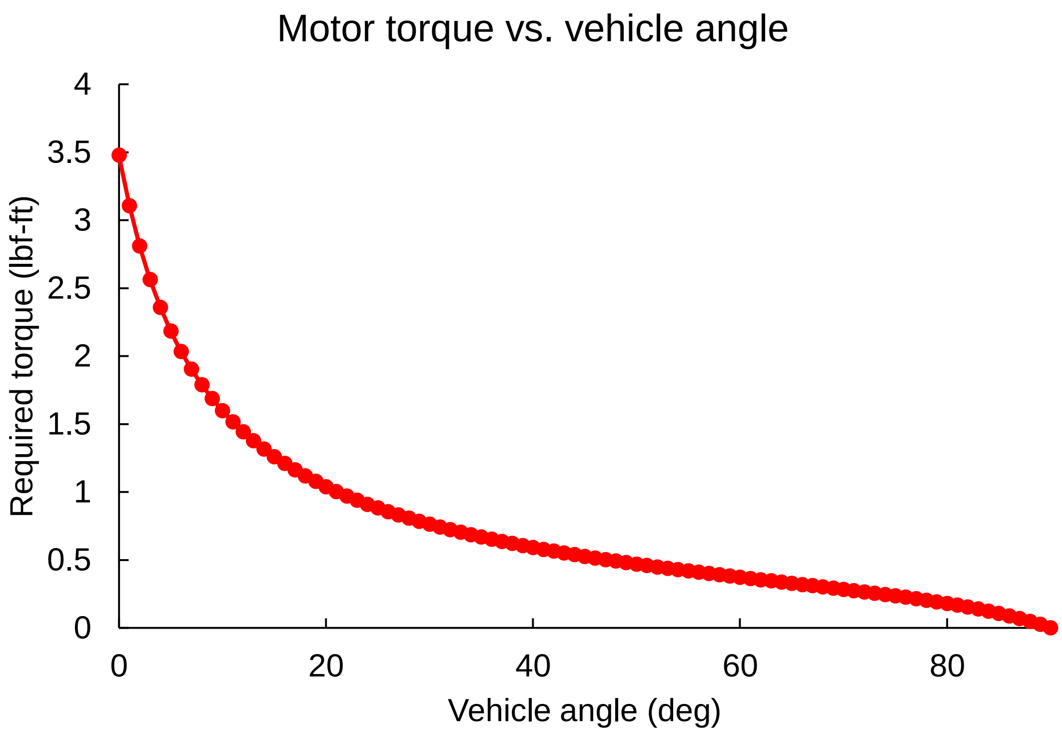


Figure 219: Required motor torque vs. vehicle angle.

6) Ignition Station

Overview:

The ignition station must perform the following functions in order of importance to be considered a success:

1. House the igniter without damage during activation of the V.E.S.
2. Raise the igniter to the top of the interior of the motor.
3. Hold the igniter in position until motor ignition and liftoff has been achieved.
4. Be reusable after liftoff.

The overall station dimensions are shown in Table 73.

Overall height (in)	Overall thickness (in)	Overall width (in)	Overall mass (lb_m)
4.00	3.00	4.20	0.98

Table 73: Ignition system overall dimensions.

Changes since CDR

The changes since critical design review are shown in Figure 221.

Change	Justification for change
Extrusion wheel has been simplified into one 3D printed piece.	To simplify design and maximize cost effectiveness.
The extrusion wheel groove has been modified.	The extrusion wheel groove is formatted to the augmented igniter to ensure full enclosure Figure 232 and Figure 233.
Acrylonitrile Butadiene Styrene (ABS) plastic is replacing all titanium and nylon parts.	uPrint three dimensional (3D) printer is more available and reliable.
Nylon bushings are changed to 3D-printed ABS printed bushings.	Cost effective and allow for a tighter fit since it is meshing with the same material.
Diameter of dowel rod.	Within safety threshold set by Cesaroni Technology Incorporated.

Table 74: Ignition station changes since critical design review.

Design

The design of the ignition station obtains the same cable extruder platform from the critical design review. However, the main improvement was the incorporation of a groove in the extrusion wheel as shown below in Figure 220.

Figure 220: Updated extrusion wheel.

Obtaining the correct groove was determined by the blockage percentage. When the sets of extrusion wheels are pressed together a seal is created and the groove forms a slot, shown below in Figure 221.

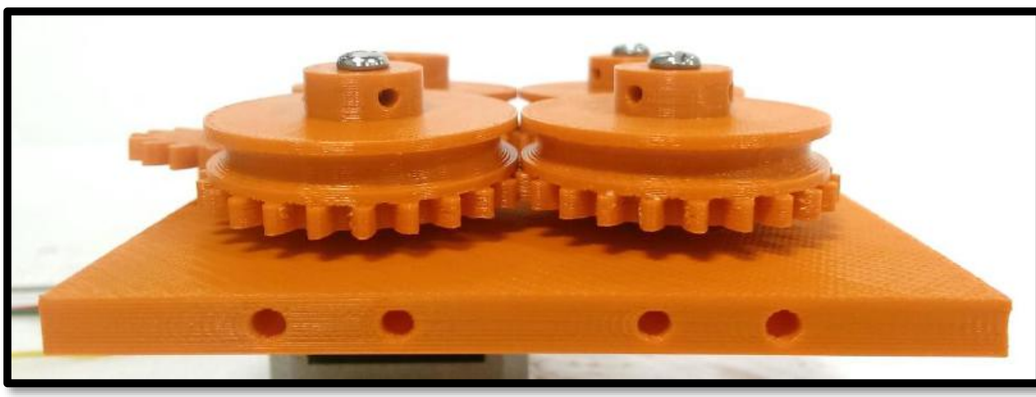


Figure 221: Top view of ignition station assembly.

After consulting with a Cesaroini Technology Incorporated technician, the following two safety requirements were proposed for the L-935 impulse max motor.

1. Make sure it travels a total distance of 24.30 inches up into the motor to ensure maximum probability of ignition.
2. Less than ten to twenty percent of the nozzle diameter (0.625 inches) should be blocked.

Taking into account these safety factors a new extrusion groove was designed. This groove is constructed using simple geometry and blockage percent below in Table 75. The face of both sets of extrusion wheels will be pressed flush during rotation and enclose the augmented igniter.

Material	Diameter (in)
Igniter Wire	0.042
(1/8”) Dowel Rod	0.13
Shrink Tubing	0.02
Aluminum Tape	0.004
Total	0.196
Radius	0.098

Table 75: Augmented igniter material diameters.

Determining the blockage percentage is calculated by first finding the theoretical value from the area of the nozzle inlet of the motor and the experimental value from the area of the augmented igniter as shown in equation (42).

$$A=\pi r^2 \tag{42}$$

The theoretical value was determined by using the nozzle radius of the L-935 impulse max motor. The experimental value was to be determined by using the total radius of the augmented igniter, which can be found in Table 75. Verification of the safety requirements for blockage percentage in a Cesaroni L-935 impulse max motor is shown in equation (43).

$$\text{Blockage \%}=100-\frac{\text{Theoretical Value-Experimental Value}}{\text{Theoretical Value}}*100 \tag{43}$$

The blockage was calculated to be 9.84 percent, which meets the criteria for this particular motor.

The ignition station is powered by a stepper motor that is connected to a single extrusion wheel that disperses power through a simplified gear box procedure. The procedure consists of four drive gears and an idler gear, shown in Figure 222, which transfers power to the lower drive gears.

Figure 222: Idler gear.

The idler gear and the four drive gears are mounted on a plate printed out of ABS plastic, shown below in Figure 223.

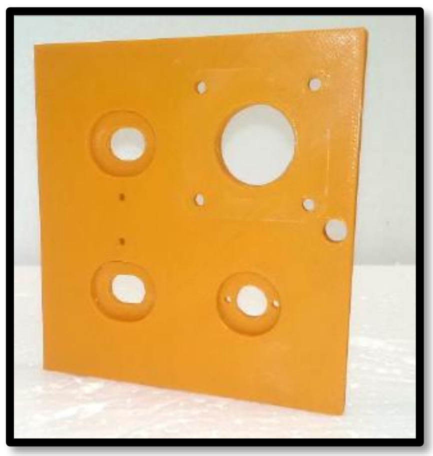


Figure 223: Back view of mounting plate.

As shown in Figure 223, on the back view of the mounting plate, there are countersink holes. The holes house three 3D printed bushings, shown in Figure 224, that support a 5mm diameter steel shaft while providing the correct amount of spacing for all drive gears to mesh and rotate smoothly. The assembly with the bushings installed into the mounting plate is shown in Figure 225.

Figure 224: Bushing.

Figure 225: Assembly of bushings and mounting plate.

In order to keep the two drive wheels that will not be directly meshed with the stepper motor meshed, a spring tensioner is applied to keep constant tension on the extrusion wheels which will transfer over to the augmented igniter. The spring tensioner has been 3D printed using ABS plastic on the uPrint and shown below in Figure 226.

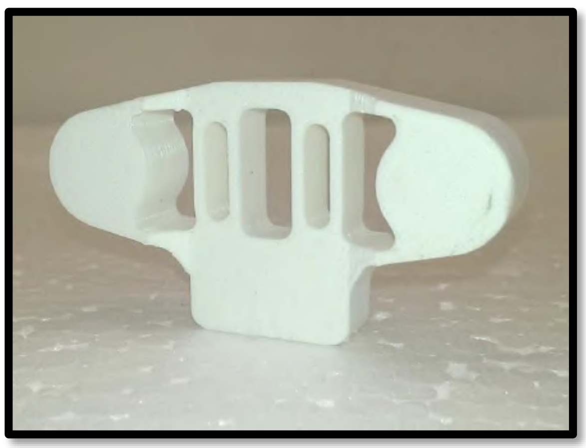


Figure 226: Spring tensioner.

The main concept of the spring tensioner has not changed since the preliminary design review. Constant alignment and the vertical stature of the shafts are maintained at all times. Two shoulder screws are used to hold the tensioner on the back side of the mounting plate shown in Figure 227.

Figure 227: Assembly of spring tensioner onto mounting plate.

Due to the possibility of wire-less signals during competition, the igniter is to be wrapped in aluminum tape to shield the wire and to create an augmented igniter assembly.

In order to create the augmented igniter, the igniter will be laid flat on a hard surface which is demonstrated as step one in Figure 228. For demonstrating purposes an e-match will replace an igniter wire in the example pictures of how to construct the augmented igniter.

Figure 228: Step one in assembly of augmented igniter.

Step two requires a 0.125 inch diameter dowel rod that will be placed on top of the e-match so that it is in contact with both strips of the e-match. Step two is shown below in Figure 229. Note that a 24.30 inch piece of dowel rod will be connected to the igniter on competition day to insure the best chance of reaching the inserting distance.

Figure 229: Step two in assembly of augmented igniter.

Step three requires aluminum tape to be wrapped around both the E-match and dowel rod to constrain the two parts together while also creating a faraday cage to shield the igniter from any wire-less signal during competition, as shown in Figure 230.

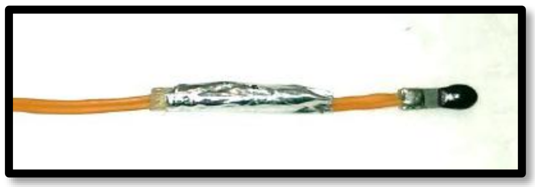


Figure 230: Step three in assembly of augmented igniter.

Step four requires shrink tubing to be placed over the entire assembly to further constrain the assembly and allow for a greater coefficient of friction between the augmented igniter and the extrusion wheels. Figure 231 demonstrates this procedure by use of a heat gun.

Figure 231: Step five in assembly of augmented igniter.

The cross-section of the augmented wire is shown below in both a virtual and microscopic view of the augmented igniter cross-section as seen in Figure 232 and Figure 233.

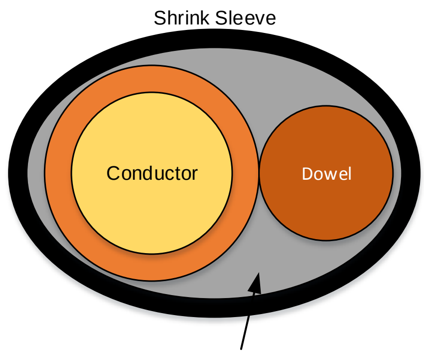


Figure 232: Virtual cross-section of augmented igniter.

Figure 233: Microscopic view of augmented igniter cross-section.

Testing

In order for the launch sequence to start an igniter must be inserted into the rocket's motor. For this to happen successfully, the requirements detailed in Figure 223.

Requirement	Method of completion	Method of verification
Ensure that gears operate smoothly.	Drive gears mesh correctly.	Inspect teeth under microscope and check that the augmented igniter is enclosed between a set of drive gears (test 1).
Confirming that augmented igniter is seeded correctly inside a set of drive gears.	Each set of drive gears maintain surface contact throughout a full rotation.	Check the gap between a set of drive gears so that the augmented igniter is fully enclosed (test 2).

Table 76: Verification plan on ignition station.

Test 1:

The first test consist of the construction of the drive gears and determining if the gear themselves will turn properly. To pass this test the gears were looked at underneath a microscope to see if the gear teeth were printed correctly. This test was proven useful and is shown in Figure 236. The first prototype (extrusion wheel on the top half of Figure 236) was printed on a MakerBot Replicator, which is shown below in Figure 234. Figure 236 clearly shows deformation and nonsymmetrical teeth around the entire gear. This is not ideal due to the fact that the drive gears will not grip one another and the possibility of slippage occurring increases exponentially.

However, on the lower half of Figure 236 the final design of the extrusion wheel was printed on an uPrint as seen in Figure 235. The overall design is clearly enhanced by the uPrint due to its even passes and a more advanced smart extruder than the MakerBot Replicator. 3D-printer and allows for accurate molding of the teeth on the drive gears that result in smooth meshing between all gears.

Figure 234: MakerBot Replicator 3D-printer.

Figure 235: uPrint 3D-printer.

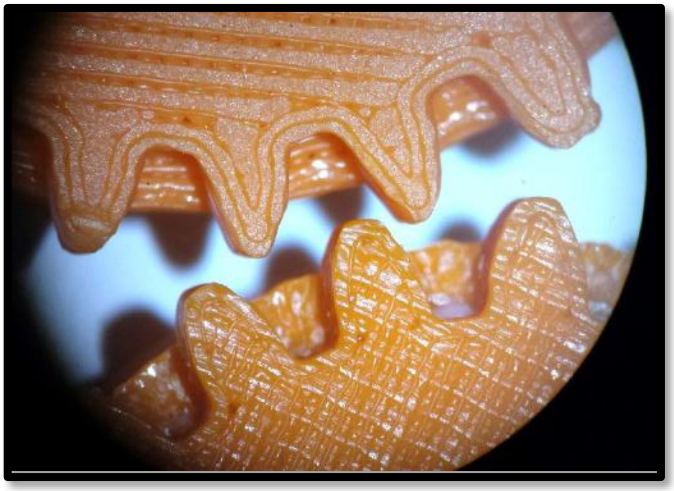


Figure 236: Microscopic view of old and new extrusion wheels.

Test 2

During this test a set of extrusion wheels are be meshed together in order to determine the interlocking accuracy of the gears. Each piece is first visually inspected to determine the mate between the two extrusion wheel surfaces. As seen in Figure 237, the first inspection was passed.

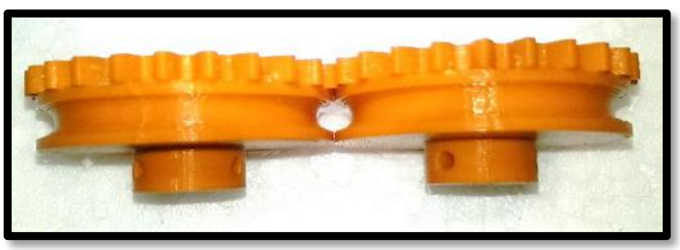


Figure 237: First visual inspection of meshing between extrusion wheels.

The next step was to administer a microscopic inspection to validate that the gears would mesh correctly. The inspection also ensured that the groove between the two extrusion wheels were symmetric to seal the augmented igniter. Figure 238 proves the extrusion wheels mate throughout a full rotation assuring that the groove and teeth of the gears will coincide.

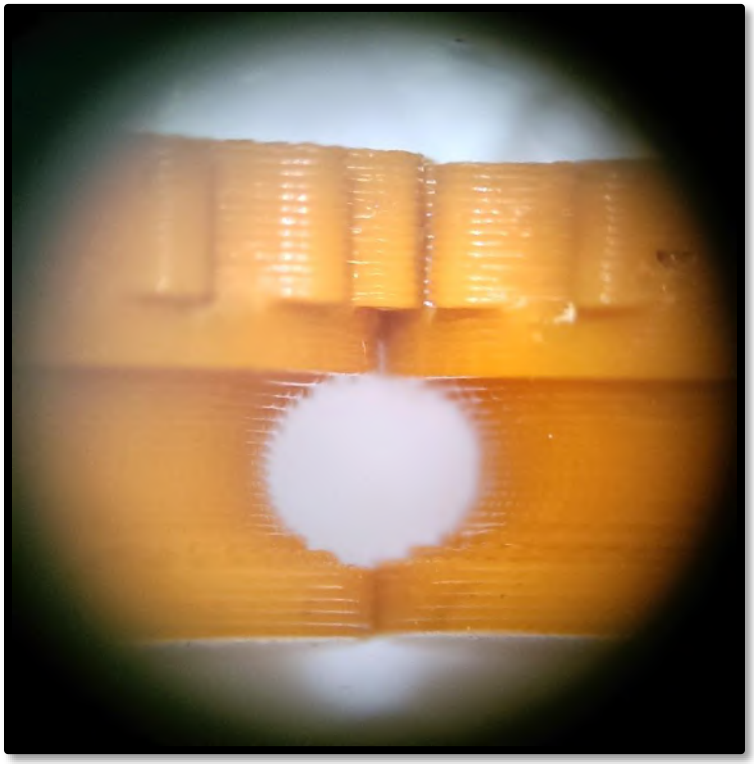


Figure 238: Second visual (microscopic) inspection of meshing between extrusion wheels.

7) Fabrication

Instead of describing the manufacturing of components for each subsection, it was determined that analyzing components based on the type of component, needed precision, and required manufacturing type, would be a better method of describing the manufacturing processes. These classifications are shown in Table 77.

Component classification	Definition
Flat plates	Flat parts with tolerance requirements that can exceed 0.005 inches.
Precision components	Components with tolerances requirements to be within 0.005 inches.
Printed components	Plastic printed components.

Table 77: Definition of components.

Flat plates

Many fastening plates used in the design of the AGSE do not require tight tolerances to function properly and have complex geometries that would make them difficult or expensive to machine. These parts are classified as flat plates. An example of one is shown in Figure 239.

Figure 239: Flat plate example.

Components classified as flat plates will be produced using the waterjet located at Firstbuild. The waterjet advertises a tolerance of +/- 0.008 inches and all parts have been designed with this in mind. Figure 240 shows the waterjet cutter which will be used. It has a cutting area of 48”x 96”.

Figure 240: The waterjet.

To take advantage of the high material efficiency potential of the cutting method, nesting software was used to minimize material usage. An example is shown in Figure 241.

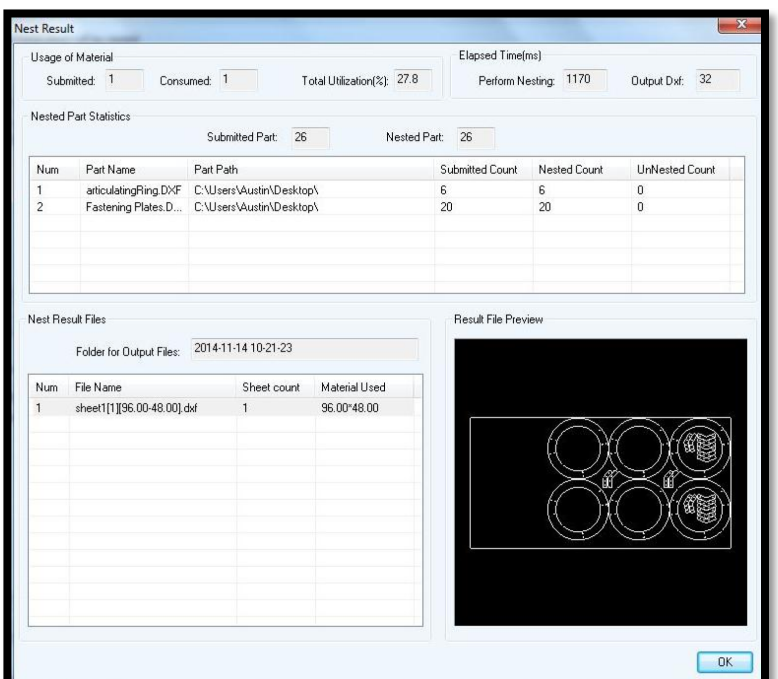


Figure 241: Nesting software.

Parts cut using the waterjet do not have flat exterior edges and thus two edges which have been cut cannot mate accurately. Figure 242 shows that the edge of the part isn't flat as only a part of the face is being cut by the mill's cutting tool.

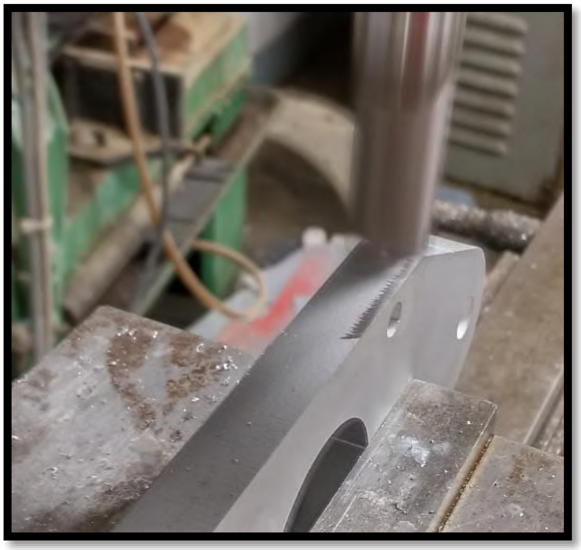


Figure 242: Modification of a waterjet part.

Due to the speed of a waterjet and the high material efficiency, the outside portion of precision components will be waterjet if the outside faces do not need precision and any mating faces can be machined to dimension as shown in Figure 243.

Figure 243: Machining a mating face.

Many precision components will have their first manufacturing process be performed along with flat plates. To determine if the component will be started using this process, the below flow chart is used.

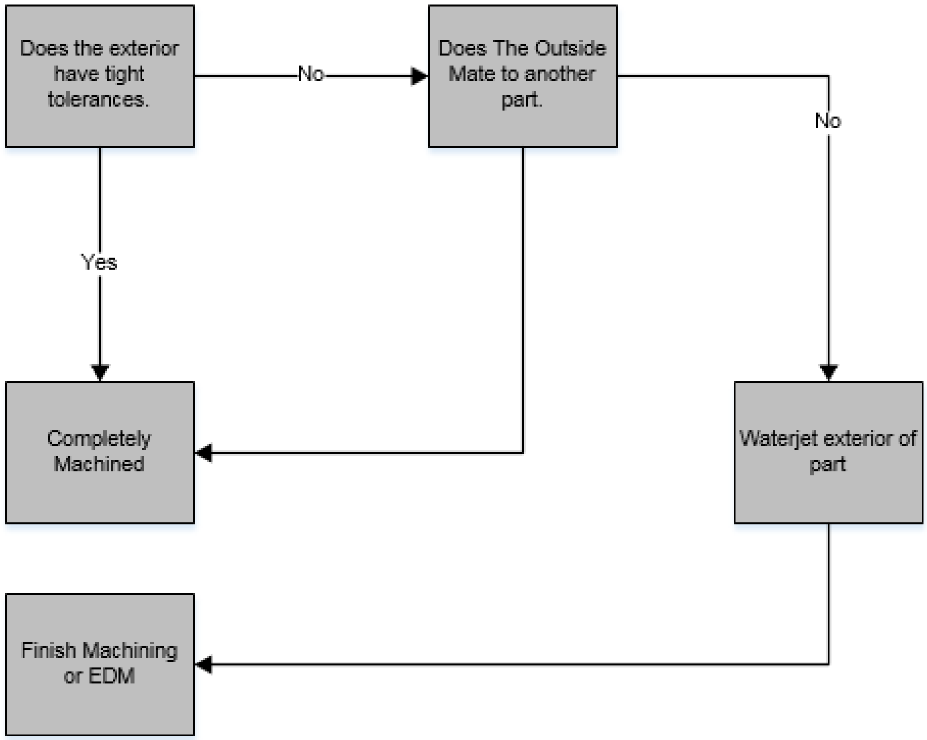


Figure 244: Flowchart depicting whether or not a part can start with a looser process.

Precision components

The final fabrication process of all precision components will be a machining operation done on one of the following: manual mill, manual lathe, CNC mill, CNC lathe, or wire EMD machine. The team has access to the manual mill and manual lathe on campus, CNC mill access at Firstbuild, Atlas machine and tool has donated machine time for the CNC lathe, and SAMTEC has donated time for the wire EDM.

The team will perform simple operations themselves, more complicated setups will be done at Firstbuild and complex machining operations will be performed by ATLAS Machine and Tool. Below are images of machined precision components.

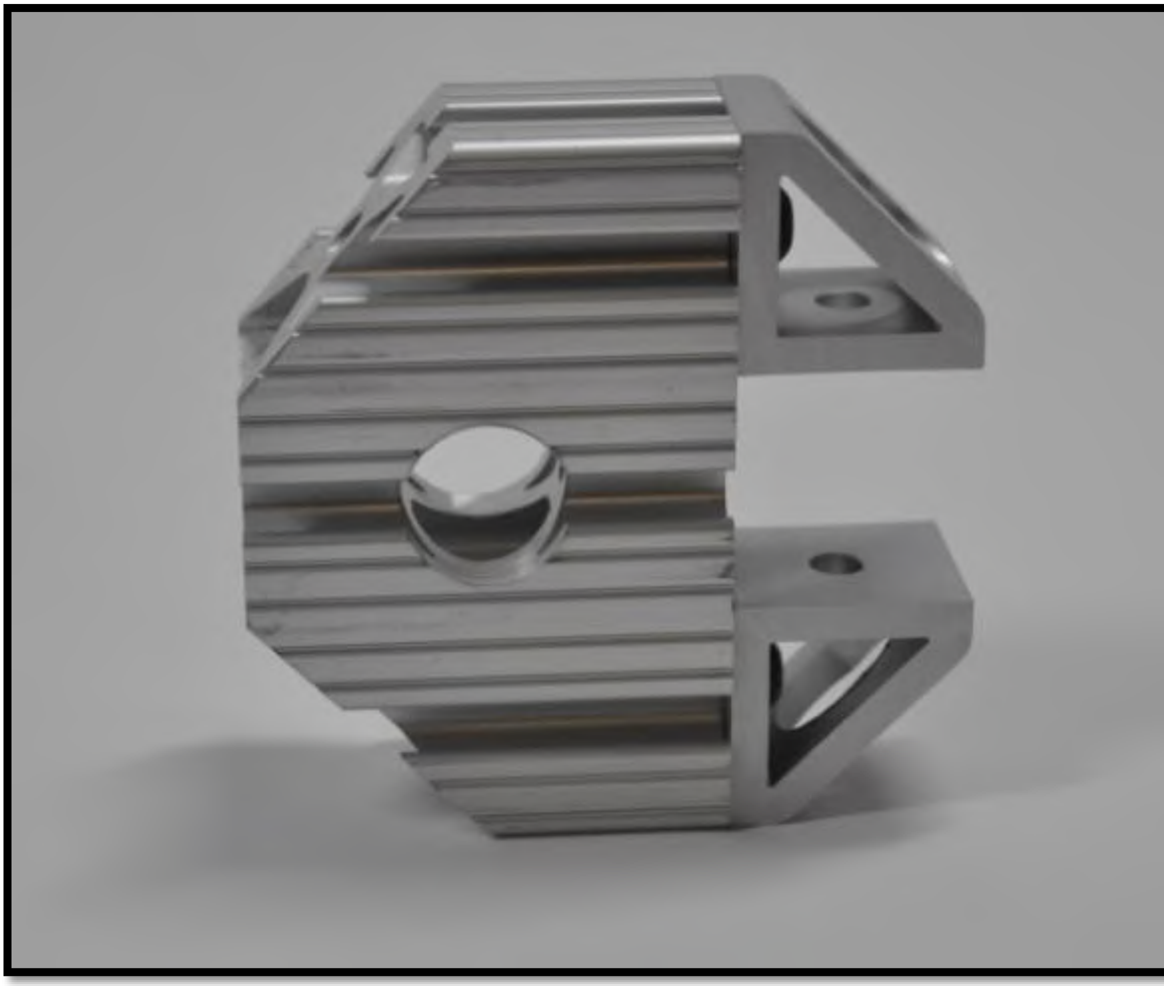


Figure 245: Arm connection component.

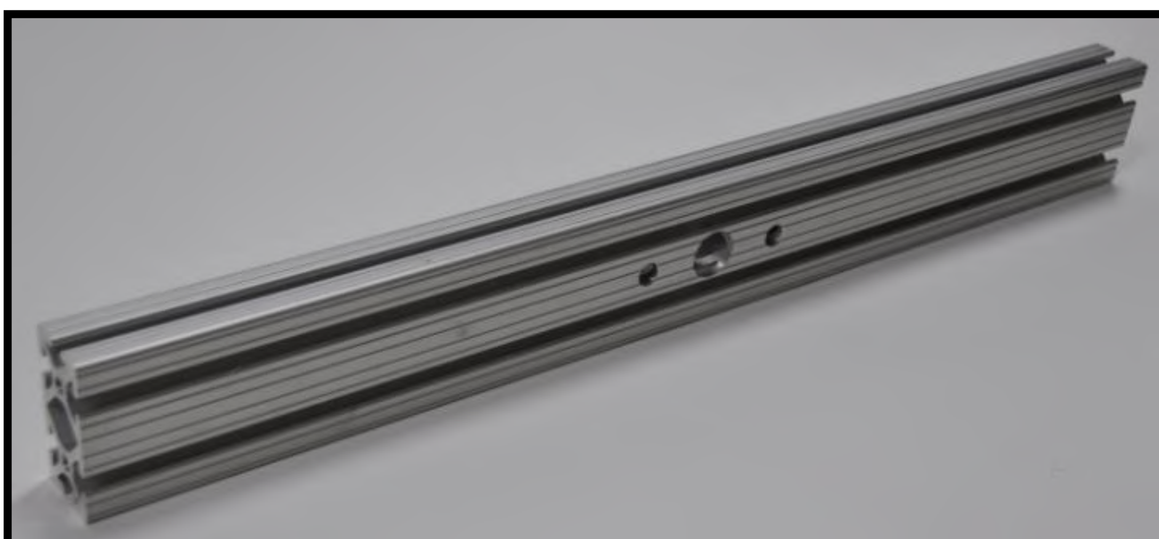


Figure 246: Rear track support for vehicle erection system.

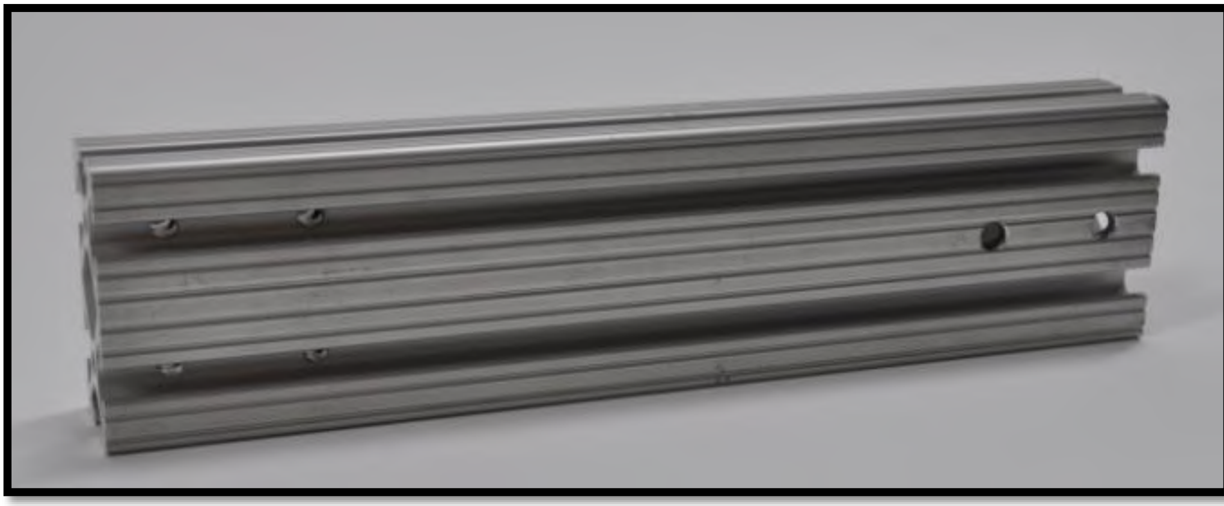


Figure 247: Ground station support beam.

Printed components

Printed components are components that meet the following requirements.

1. Complex geometry – defined as geometry that would require custom tooling or would require more than a 3 axis cutting machine.
2. No load, low load, or large deflections are desired.

Examples of printed components are shown below.

Figure 248: Spring tensioner.

Figure 249: Threadless ball screw nut.

Figure 250: Gripper arm.

8) Safety and Environmental

All failure modes and effects for the AGSE have been analyzed and are detailed in the risk mitigations charts found in Appendix III on page 347. Below the top five critical risks have been analyzed in more detail.

1. **Unstable launch platform**
   Probability: 3, Moderate
   Severity: 1, Catastrophic

   Outcome: An unstable launch platform can jeopardize a successful flight. Should the launch platform become unstable, the launch vehicles flight path will be unpredictable and could jeopardize the safety of launch personnel and spectators.

   Mitigation: Prior to any launches all personnel will be required to maintain the minimum safe distance from the pad as established by NAR in the Minimum Distance Table. The AGSE also includes stability outriggers that increase the footprint of the ground station therefore increasing stability. These outriggers have additional travel allowing for leveling on uneven terrain.

2. **Carriage jam**
   Probability: 2, Likely
   Severity: 1, Catastrophic

   Outcome: Should the vehicle erector carriage jam the vehicle erector will be unable to complete the task of raising the rocket. Jamming could also lead to damage to the vehicle erection system, including cross threading or stripping of the threads on the actuation ball screw.

   Mitigation: The carriage's final geometry was selected as it best distributed the load from the articulation arms to the track. The geometry provides a wide base that evenly distributes. Loading was also focused on the neutral axis of the carriage to avoid torqueing of the carriage during loading. The track that the carriage rides on has been analyzed for the expected loading and has been adequately sized to handle the expected loads with an acceptable deflection. Also, following each launch the vehicle erection system will be cleaned to remove any foreign debris that may jam the carriage.

3. **Movement of pivot or articulating points**
   Probability: 5, Improbable
   Severity: 1, Catastrophic

Outcome: Should the pivot or articulating points move from their desired positions the launch platform may jam, resulting in a mission failure. The launch platform could also fall, potentially damaging the vehicle and injuring personnel.

Mitigation: All fasteners will be properly tightened during assembly and will be checked prior to each launch. Machined surfaces were also added to accurately position these critical connections and to lock the components into position. All personnel will also be required to maintain a minimum safe distance from the AGSE during operation.

4. **Igniter is not fully installed into the motor**
   Probability: 2, Likely
   Severity: 1, Catastrophic

   Outcome: Should the ignitor not be fully inserted into the motor, a catastrophic failure of the rocket motor may occur during ignition. This would result in the loss of the vehicle and potential damage to surrounding equipment, including the AGSE. Also, this could result in personnel injury.

   Mitigation: To avoid tangling while inserting the ignitor, the ignitor will be augmented with small dowel rods. These dowel rods will be sized correctly to avoid choking the motor with the augmentation installed. Additional feedback mechanism will be interfaced with the control electronics to confirm the ignitor has been fully installed.

5. **Gyroscopic sensor failure**
   Probability: 2, Likely
   Severity: 1, Catastrophic

   Outcome: Should the gyroscopic sensor fail, the launch platform will fail to level and could result in an unstable launch platform. This would result in an unpredictable flight path for the launch vehicle if still launched. A sensor failure could also result in unexpected motion from the ground station resulting in damage to the AGSE and personnel injury.

   Mitigation: Testing has been performed on a sub-scale level and will be completed at the full scale level to ensure the gyroscopic sensor performs as expected. Prior to launch all sensors will be calibrated to ensure correct performance during the autonomous procedures. These checks are included in the pre-launch check sheets to ensure these checks are completed. During operation all personnel will be required to maintain a minimum safe distance away from the AGSE.

Secondary interlocks will also be implemented in to the control algorithms of the AGSE to prevent undesired motion.

9) Electronics Systems

Overview

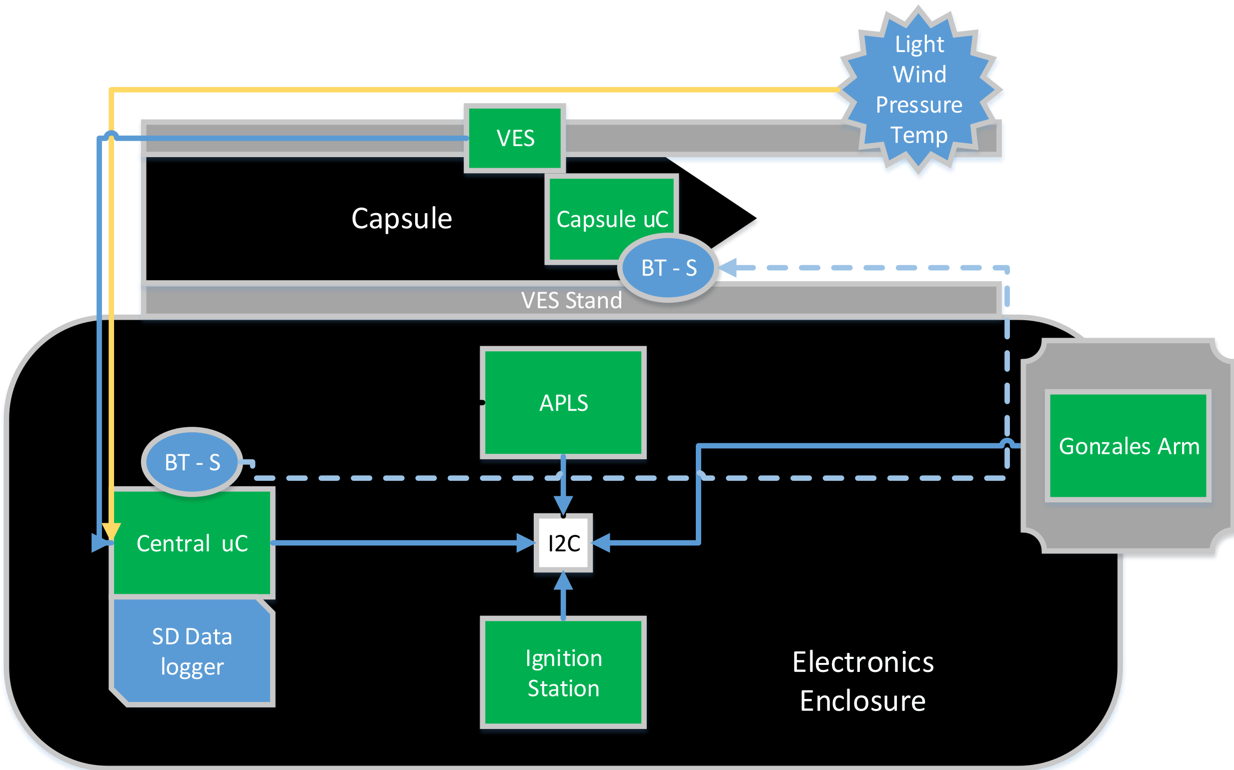


Figure 251: System connections.

As shown in Figure 251, the ground station provides the integration for all other subsystems and communications. It includes an Arduino Uno as a central microcontroller that is connected to the other subsystems via I2C network (solid blue lines), Bluetooth (dotted blue lines), and GPIO interface (solid yellow lines). The central controller initiates all subsequent processes including: station power, device boot sequence, software halt procedures, weather data collection, wireless communication and logging system status to SD card for later review. The Gonzales Arm is contained in a separate structure attached to the ground station but is still connected to the central uC through I2C.

Automatic Platform Leveling System (APLS) Controls

Overview

The Automatic Platform Leveling System (APLS) controls three outrigger motors to raise and level the launch station. Using a LIDAR distance module, the AGSE can measure absolute distance from the ground. Once raised, the system utilizes digital motion processor (MPU-6050) to measure the launch platform's orientation. After orientation is initialized, the microcontroller directs the motors to correct the roll followed by the pitch of the station to achieve level. To simplify the leveling process, one outrigger has been deemed the "reference". The other two outriggers will orient themselves to level with respect to the position of the reference.

Objective

Autonomously level the AGSE within 1 degree of level (with reference to pitch and roll).

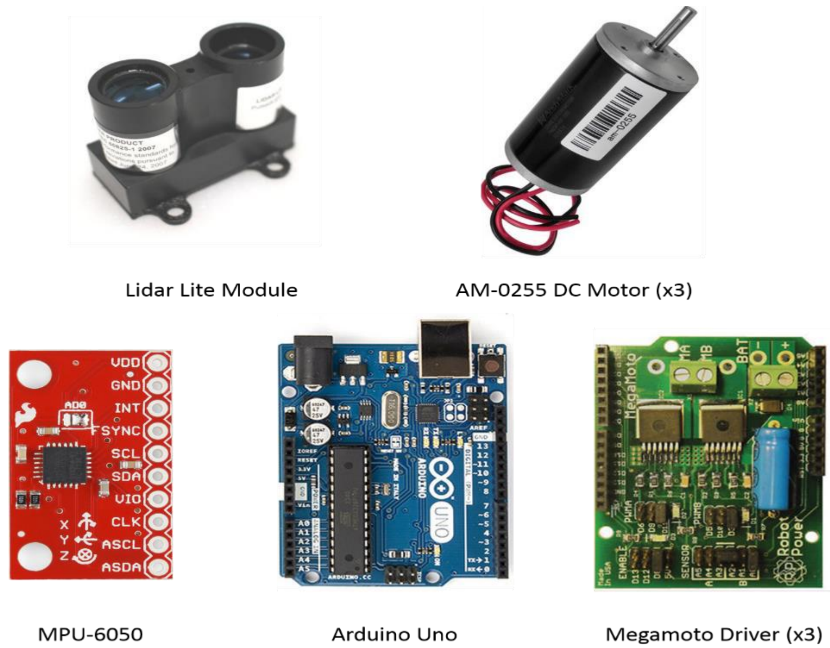


Figure 252 : APLS components.

Hardware Implementation

The APLS prototype components are shown in Figure 252. The system is implemented through the connection and communication architecture shown below in Figure 253. The LIDAR and MPU-6050 communicate through I2C protocol to the Arduino. The motor shields connect via stackable GPIO headers. The motor drivers are wired directly to the 12V motors through on-board screw terminals.

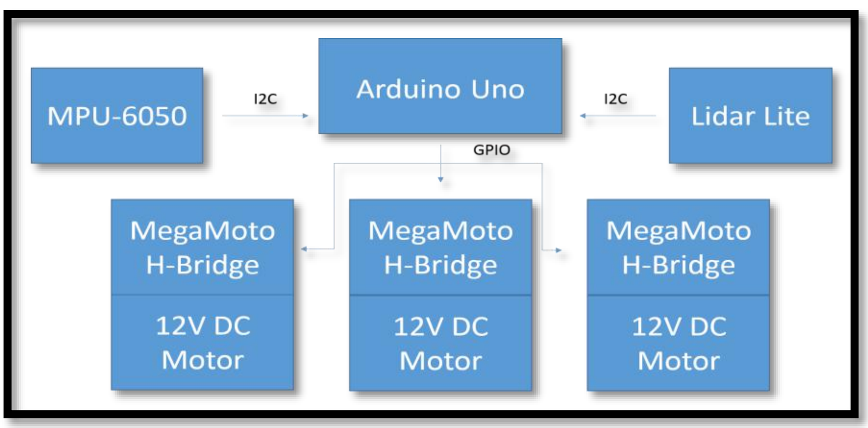


Figure 253 : APLS connection overview.

LIDAR

Communication with the LIDAR module is accomplished via I2C bus. By utilizing the LIDAR technology, distances are measured without dependence on Earthly references such as ultrasonic sensors. Per the LIDAR lite module's specifications, the module is rated to 40 meters. With the ground station standing approximately 10 inches off of the ground, the sensor is within the 40m range. The ground clearance will be able to be measured within +/- 0.025m of the distance. The LIDAR module is the only indication of clearance changes during the leveling phase of launch preparation. The LIDAR module will be placed as close to the reference outrigger as the design allows. This will ensure that the platform will be at the correct height after the leveling sequence.

MPU-6050

The MPU-6050 is a digital motion processor which integrates both accelerometer and gyroscopic sensors onto one DIO. This integration combines the gravitational acceleration of the accelerometer with the angular movement of the gyroscope. The internal data is measured by the integrated ADC of the digital motion processor, providing 16-bits of resolution for measuring the ground station's orientation.

Megamoto & Motors

The microcontroller uses PWM signal to control direction and speed of the connected motor drivers; the respective driver amplifies the PWM signal up to 12V to drive the DC motor in forward or reverse. As inspection of the schematic in Figure 254 illustrates, the shield stacking is possible through manipulation of open header jumpers.

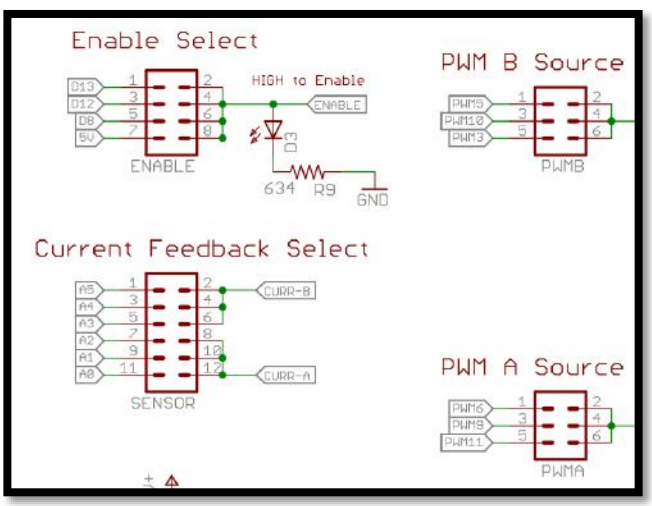


Figure 254: Megamoto specifications (from schematic).

The "Enable Select" allows for up to three unique "on/off switches" for selecting the shield that will correct the tilt in the station. In addition to the shield selection control, the "PWM A" and "PWM B" sources can be set differently for each layer of motor driver. The distinction in signal source allows the motors to be driven simultaneously in opposite directions. Energizing multiple motors at once allows correction of two axes at the same time, rather than using one motor at a time for single axis control. This is an option to reduce the process time.

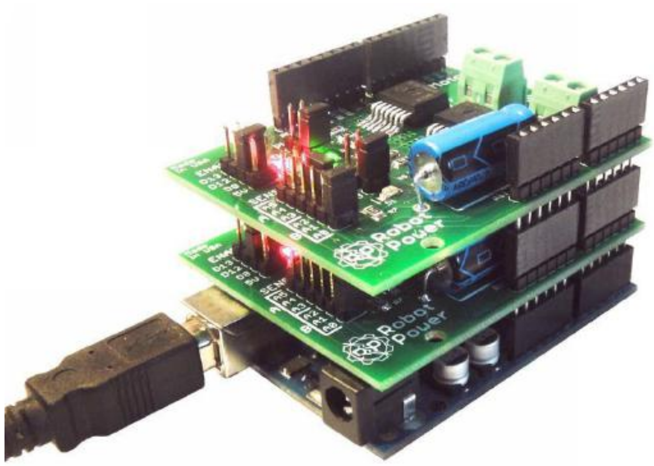


Figure 255: MegaMoto h-bridge stack.

The stacked motor drivers connect to the GPIO pins of the APLS microcontroller (shown in Figure 255). An H-bridge configuration is required for each DC motor to allow bi-directional operation of the motor. The AM-0255 DC motors are driven by the h-bridges and install into the outrigger lead screws.

Figure 256: Objectives of APLS.

Processes and Software

As the outline in Figure 256 broadly states, the APLS does not begin its routine until the payload has been obtained by the Gonzales arm. In Figure 257 the step-by-step process for the APLS is described.

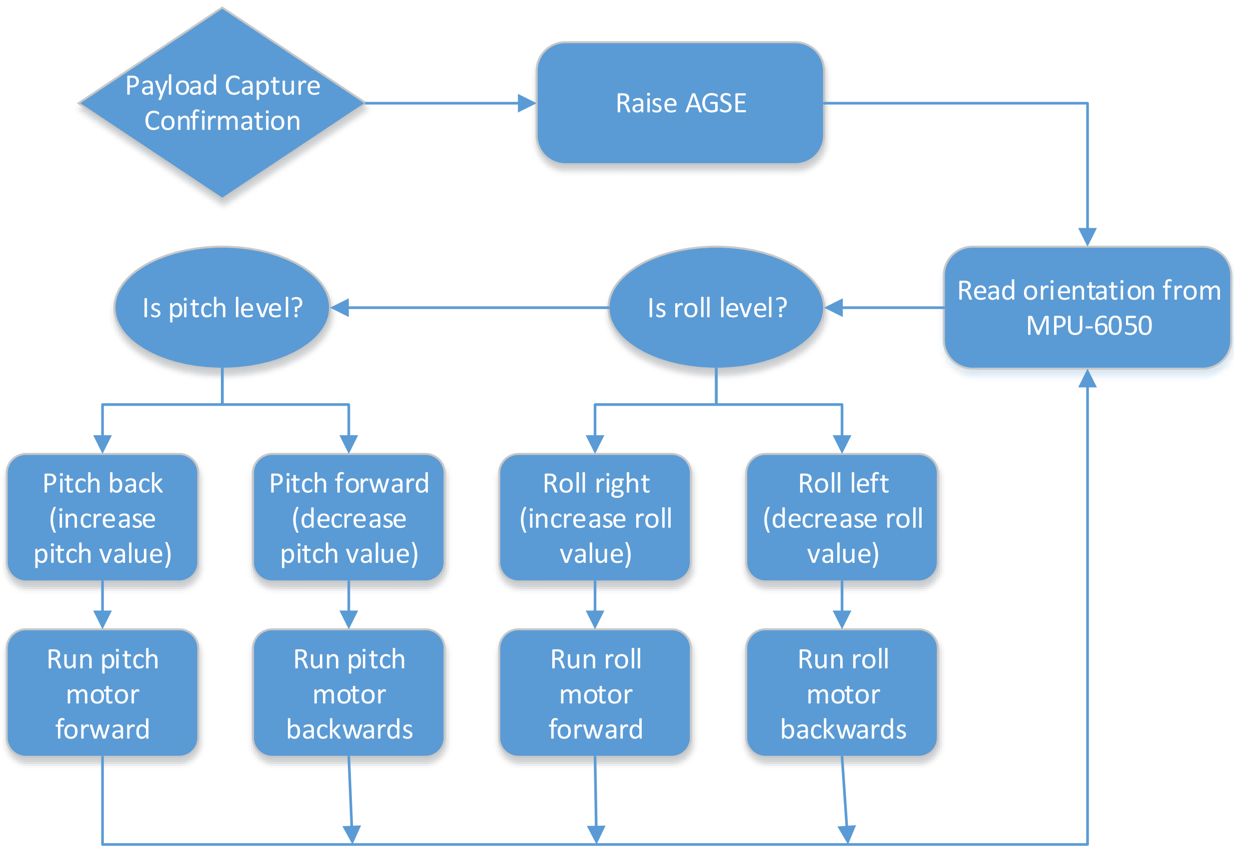


Figure 257: APLS logic flow chart.

Following the payload containment, the initial measurement for tilt of the AGSE is processed. The raw orientation data is then digitized and sent via I2C to the APLS controller. Using the data from the accelerometer readings, angle values for the platform can be found.

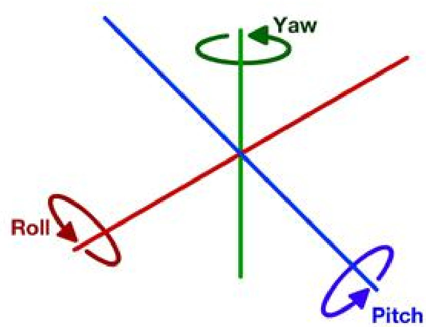


Figure 258: Roll, pitch, and yaw axis.

The angles for roll and pitch are illustrated above in Figure 258. Though yaw is a measureable data point, the processes for leveling only depend on the pitch and roll of the station. Both are converted from the measured data using equation (44) and equation (45) below.

$$\Phi\ (\text{Roll}) = \arctan\left(\frac{A_x}{\sqrt{A_y^2 + A_z^2}}\right) \tag{44}$$

$$\rho\ (\text{Pitch}) = \arctan\left(\frac{A_y}{\sqrt{A_x^2 + A_z^2}}\right) \tag{45}$$

Each motor will have control over specific changes in the orientation of the pad to correct the positioning of the gyroscope. There will be one specified roll motor and one pitch motor. The third is designated as a reference motor and will only be active during the raising/lowering of the entire ground station. The system will level by first engaging the roll motor in the appropriate direction. After the system has achieved a reading within 1 degree the pitch motor will then follow the same process.

Completed Testing

Verification 1: MPU6050 data acquisition

The sensing circuit and software of the APLS have been tested. The YPR (yaw, pitch, and roll) values were measured through the use of the MPU libraries of the Arduino Uno and output to a simulated test bench.

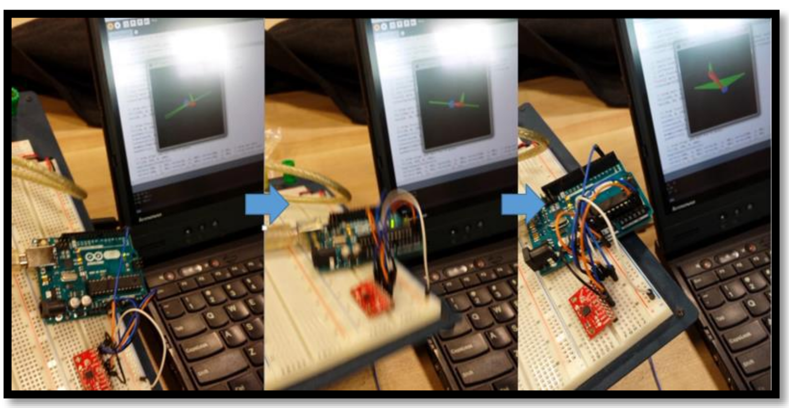


Figure 259: MPU-6050 orientation test bench.

The test bench, shown above in Figure 259, used the open source program called *Processing* to give live visual feedback of the MPU-6050 to the on-screen diagram. Through the simulated testing, we were successfully able to update our orientation measurement at a baud rate of 9600bps through the Uno to our test bench.

Verification 2: APLS Raising/Lowering

Using the isolated subscale system, the algorithms were tested for raising and leveling the AGSE as stated in Figure 256. To test the APLS, the subscale prototype was initialized in a standing position and lowered it as shown below. Using a DC power supply and Adafruit stepper motor, we controlled all motors to run in reverse to test the mechanics of the system. The platform successfully lowered as shown below in Figure 260 below.

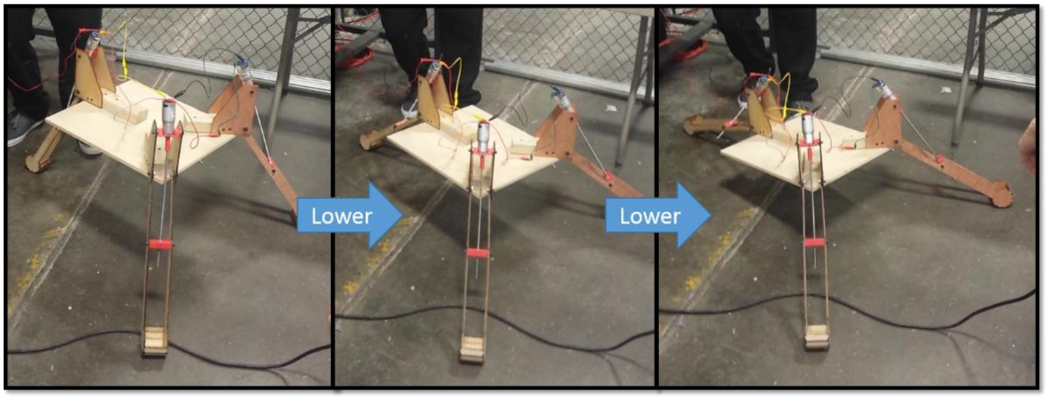


Figure 260: Lowering test.

Verification 3: APLS leveling capabilities

To test the leveling capabilities we initialized the subscale prototype with boxes under the outriggers to simulate uneven ground. The system began approximately 10° off center and achieved level (within +/- 0.1°) within 90 seconds. The stock iPhone leveling app was used to verify the leveling status of the system.

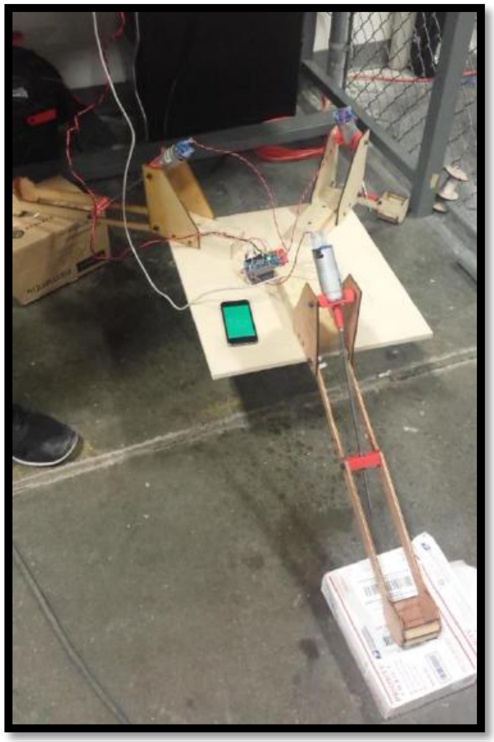


Figure 261: Leveling test setup.

Planned Testing

We will give a simulated confirmation that the payload has been captured. The APLS must automatically raise the system 24 inches from the ground verified with a LiDAR sensor. The next test will be the leveling process. To test the leveling procedure, we will start the AGSE in an arbitrary offset position. We can then simulate the “system raised confirmation” to the station to initiate the leveling procedure. We expect the system to level the AGSE in 90 seconds.

When the leveling procedure is finalized, the APLS is dynamically tested by placing the outrigger system on a variable tilt surface. The system is expected to perform the leveling procedure at consistent intervals throughout the competition. Once the system is leveling consistently, the APLS will be integrated into the larger system. Minor changes are expected in the systems performance once the system is fully integrated due to testing with the isolated system.

The next steps of testing will involve verifying the speed of the motors to raise and lower the system as needed. The no load speed is expected to reach the stated 118 rpm for the motor. The speed will change with the final weight of the AGSE as the motors must move the entire station upward to a level position after the payload has been captured by the arm. To analyze the practical speed of the APLS motor setup, the resistance of the station will be simulated with weight that will be added to an isolated outrigger setup.

Vehicle Erector System (VES) Controls

Overview

The Vehicle Erection System is a simplified, single axis version of the APLS. It utilizes the MPU-6050 chip and requires only pitch measurements to erect the launch vehicle. The system provides an amplified power signal from the microcontroller to a motor that will erect the rocket to within 5 degrees from vertical. Similar to the APLS, the system is accurate to +/-.5 degrees. The testing, algorithm, and sensing hardware is common between the APLS to increase efficiency in testing and accelerate implementation.

Hardware Implementation

We are going to use the Sabertooth motor controller (Dimension Engineering). The controller implements soft current limiting and thermal protection for the driver. It can be controlled through 1000us-2000us pulse train from the Arduino. The components are as follows:

Motor driver: Sabertooth 60A motor driver

Figure 262: Sabertooth 60A motor driver.

The Sabertooth is designed for power-intensive tasks and projects. Out of the box, the Sabertooth can supply DC brushed motors with up to 60A each (with peak currents of 120A per channel). Overcurrent and thermal protection protect the system against accidental stalls. The operating mode is set with the onboard DIP switches. Our chosen mode is as shown in the following:

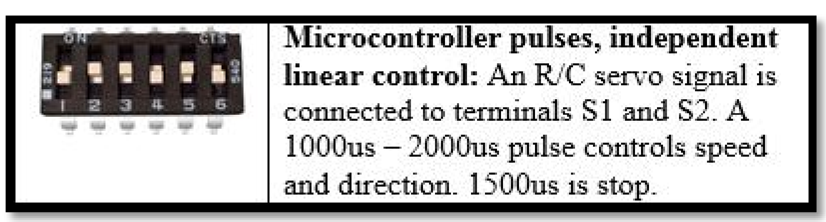


Figure 263: Pulse train operation.

Sabertooth features screw terminal, and has a built in 5V 1A Switch-mode BEC that can supply power for our microcontroller.

Motor: AmpFlow brushed DC-E30-150-G

Figure 264: VES gearmotor.

(Discussed above with the mechanical features of the VES)

Controller and sensor

The MPU-6050 and the Arduino Uno are common with the APLS.

Software Processes

Upon receiving the activation character (ASCII "G") from the central controller the system will begin taking measurements of its current angle. The system will continuously check its current angle and drive the motor until it is within 1 degree of vertical. Once this is achieved, the system will no longer attempt to change the angle of the rocket. This safeguard ensures that there is no unpredictable interference with other systems. Figure 265 shows each state of the V.E.S.

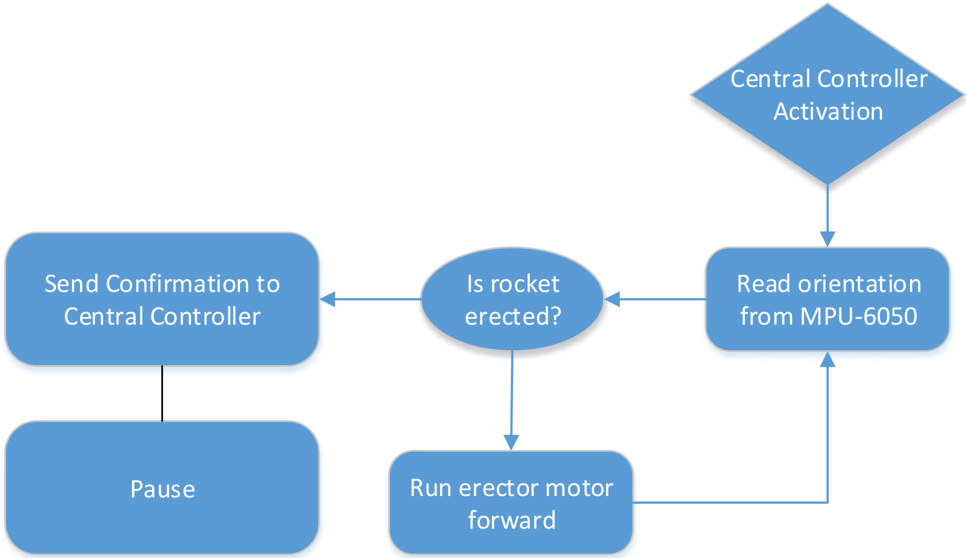


Figure 265: VES control processes.

Testing

The testing involved with the VES is common with the APLS.

Igniter Installer Controls

The operational flow chart below depicts the possible ignition station states. At any time, (not just during the activated state) the station can enter the "Process Halted state" if the interrupt is activated. The ignition station will not begin movement unless the interrupt pin is logic high and the igniter is enabled (via igniter enable switch) by the field safety officer.

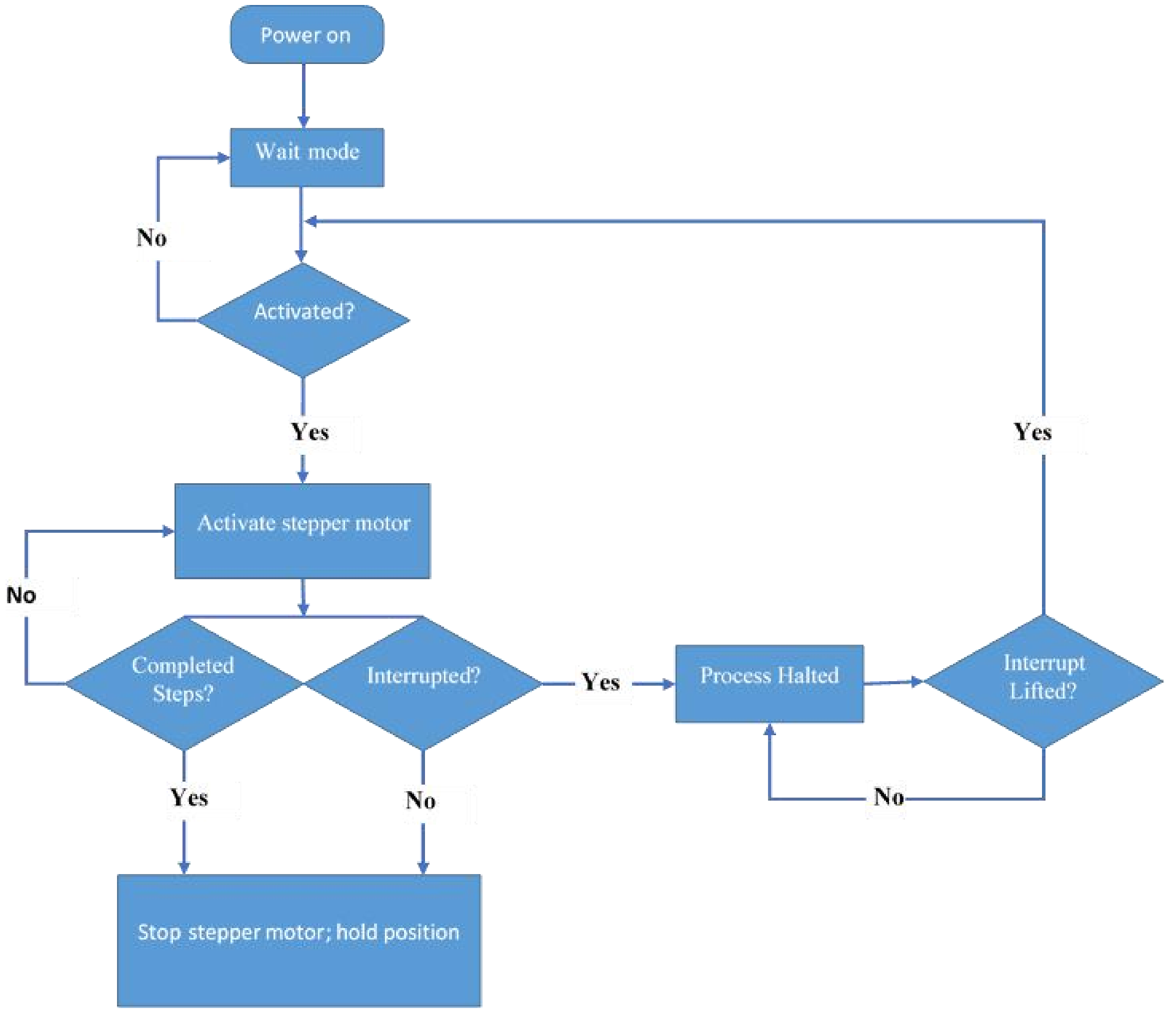


Figure 266: Operational flow chart.

The components used in controlling the ignitions station are as follows: the Arduino Uno microcontroller, Adafruit motor shield, and stepper motor (each component is described in more detail below). The igniter station software utilizes the "*Adafruit_MotorShield.h" and* "*wire.h"* libraries to interface with the stepper motor and the central controller, respectively.

Arduino Uno

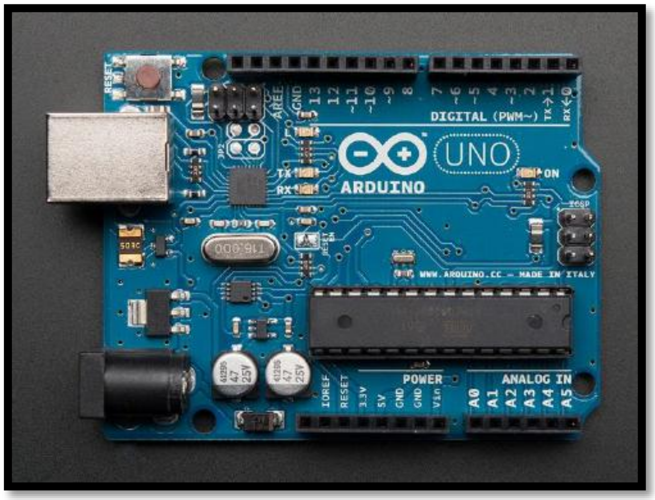


Figure 267: Arduino Uno microcontroller.

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button.

Adafruit motor shield

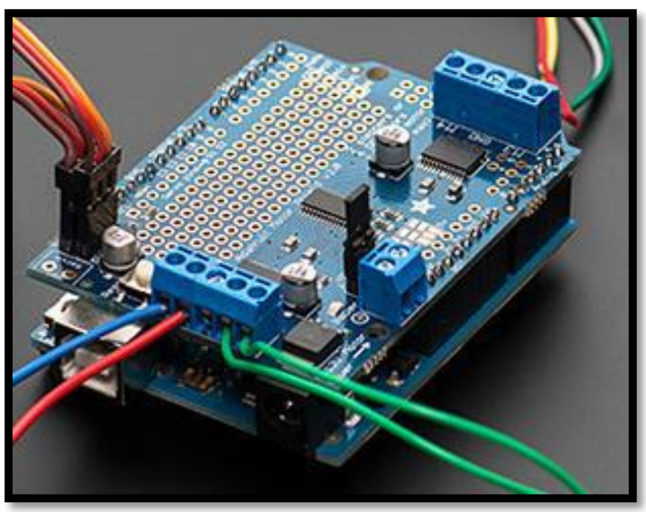


Figure 268: Corresponding motor shield.

The Adafruit motor shield contains the following connections and components: two 5V servos, four bi-directional DC motors with individual 8-bit speed selection, two stepper motors (unipolar or bipolar) with single coil, double coil, interleaved or micro-stepping, four H-Bridges: L293D chipset provides 0.6A per bridge (1.2A peak) with thermal shutdown protection, 4.5V to 25V and 2-pin terminal block to connect external power.

Nema-17 Size 200 stepper motor

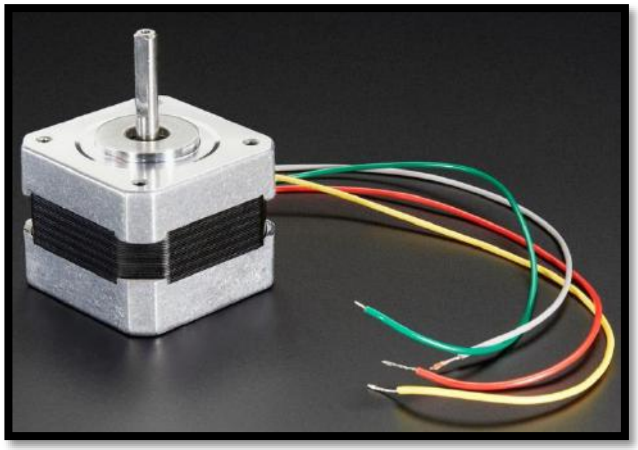


Figure 269: Stepper motor.

The Adafruit stepper motor has 200 steps per revolution (1.8 degrees/step). The bipolar stepper requires 2 full H-bridges for control. The shaft is a 5mm diameter drive shaft, 24mm long, with a machined flat section. It is 12V rated voltage at 350mA max current.

The internal communications of the igniter station are outlined in Figure 270.

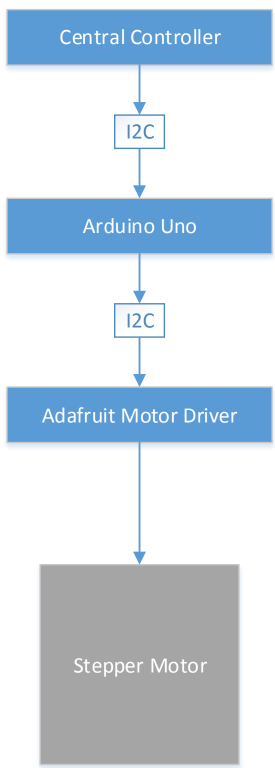


Figure 270: Component communications.

The Arduino will receive an activation character (ASCII "G") from the Central Controller through I2C. The Adafruit Motor Shield, connected to the Arduino through I2C, drives the stepper motor to install the igniter into the motor.

Performance Characteristics

The circumference of the drive wheel is calculated using

$$C=2\pi r \tag{46}$$

where r is the radius of the drive wheel. The number of revolutions needed to complete installation is determined via

$$N=\frac{L}{C} \tag{47}$$

where L is the total distance the igniter must move. The amount of time required is then calculated using

$$t=\frac{N}{\omega} \tag{48}$$

where ω is the rotational speed of the motor.

Table 78 shows the resulting number of turns and amount of time needed to raise the igniter into the proper position.

r (in)	L (in)	ω (rpm)	N	t (s)
0.75	26	60	5.517	5.517

Table 78: Performance evaluations.

To accurately control the system, the number of total turns must be known. The number of turns is calculated using

$$N_s=\frac{L}{D} \tag{49}$$

where D is the distance traveled per motor step which is calculated using

$$D=F_cC \tag{50}$$

where F_c is the fraction of the circumference that the wheel travels per motor step.

F_c is determined using

$$F_c = \frac{A_s}{360} \tag{51}$$

where A_s is the angle traveled per motor step.

Table 79 shows the resulting control values for the motor steps.

A_s (˚)	D (in)	N_s	F_c
1.8	0.024	1104	0.005

Table 79: Control values.

Testing

Status	Verification
Power on in wait mode.	LED indication light active on Arduino Uno. LED sustains illumination for 1 minute. Verified after three consecutive successful power cycles.
Stepper motor movement.	LED indication light blinking on Arduino Uno. LED sustains blinking for duration of stepper motor movement. Verified after three consecutive successful cycles.
Stepper motor movement speed.	Confirm speed is 60 RPM with stopwatch and taped flag passing marker. Verified after three consecutive successful attempts.
Igniter travel distance.	Physical measurement of yellow taped mark on igniter is visible above housing.
Abort functionality.	Verify interrupt state by halting at any point during insertion.

Table 80: Test plan.

The igniter installer controls have been tested using a 12 volt power supply. The stepper motor stayed within allotted current draw (1000 mA) and produced the necessary speed (60 RPM) to install the igniter within the time constraints allotted for the igniter station. The motor shafts do not spin freely while position is set.

Test Description	Supply Voltage (V)	Current Draw (mA)	RPM
Static Power Test (no interrupt)	12.1	300	75
Static Power Test (interrupt active)	12.1	300	75
Test Duration = 400 steps / 2 full rotations no load	12.1	170	75
Test Duration = 800 steps / 4 full rotations no load	12.1	170	75
Test Duration = 1600 steps / 8 full rotations no load	12.1	170	75

Table 81: Tests results.

Testing has been conducted verifying the use of the interrupt pin as a hardware stop. If the interrupt pin is not above the 3V threshold, the Arduino will not execute any code to move the igniter. After an interrupt is cleared, the stepper motor resumes running until the remaining number of steps have been completed and the igniter is fully installed.

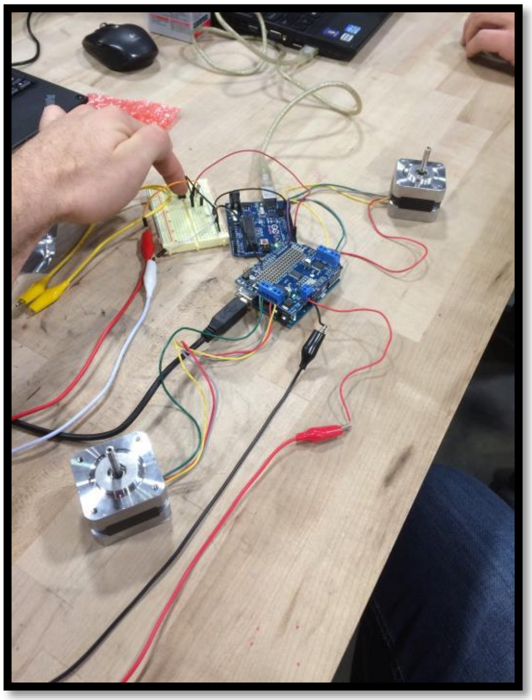


Figure 271: Igniter installation interrupt pin testing.

Tests were performed to retract the igniter to starting position in the event of a hardware interrupt during installation. Pending final testing on the fully assembled system, it will be implemented into the software design as a safety measure to avoid a partially inserted igniter on launch day.

Bluetooth Communication Controls and User Interface

Communication

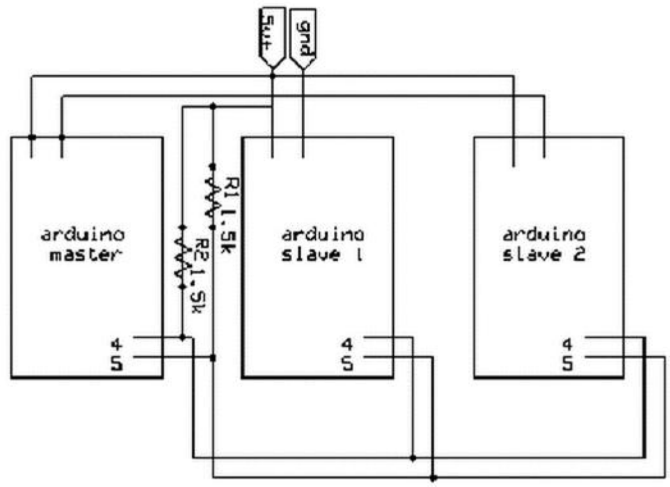


Figure 272: Example I2C network.

The AGSE communication operates as a distributed architecture. Multiple microcontrollers communicate by I2C in similar configuration to the setup shown in Figure 272. Each controller allocates analog pins A04 (SDL) and A05 (SDA) to communicate on the bus. Digital sensors, such as the pressure sensor and motion processor, have dedicated SDL and SDA pins. The I2C technology requires two pull-up resistors to function properly and ensure consistent communication.

The I2C bus will begin relaying subsystem information after the system pause is deactivated. Through the *wire* library available in Arduino, each subsystem is given a unique address to direct and filter communication. The library handles all bit-level communication operations with each ASCII character. To implement the protocol, the data and destination address are needed. Microcontroller communication is in the form of ASCII characters sent and received on the bus.

ASCII Character Sent	*Meaning,* Expected Action
“G”	*Go*; begin preset routine
“S”	*Stop;* halt routine (not a system pause or interrupt)
“C”	*Complete;* the subsystem announces completion of routine

Table 82. I2C commands.

As outlined in Table 82, a subsystem that receives a “G” character will be programmed to acknowledge the “Go” command and immediately begin the respective routine. The routine can halt for any of the following: system pause switch activated, routine complete, “S” (stop command), or loss of power to the system. All “Go” and “Stop” commands are from the central controller to the substation controller; the flow is reversed for the “Complete” command coming from each subsystem microcontrollers.

Wireless Communication Overview

The rocket capsule requires ground station communication for status updates and data transmission. The communication scheme will ensure transmission of payload capture signal (to close the payload bay doors) and launch data (up to 10m). To meet the transmission needs, Bluetooth communication was implemented by using two of the Bluetooth modules shown below in Figure 273.

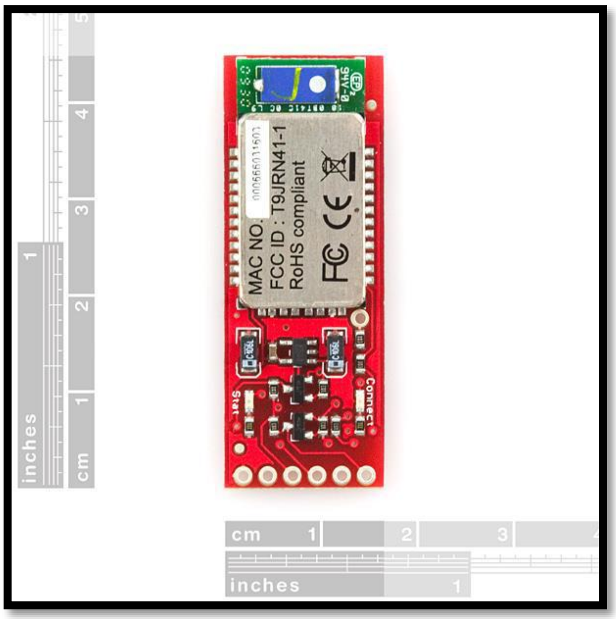


Figure 273. SparkFun Bluetooth mate gold.

Both transceivers are the Bluetooth Mate Gold model shown above in Figure 273. Each module transmits and receives data between the AGSE microcontroller and the capsule microcontroller.

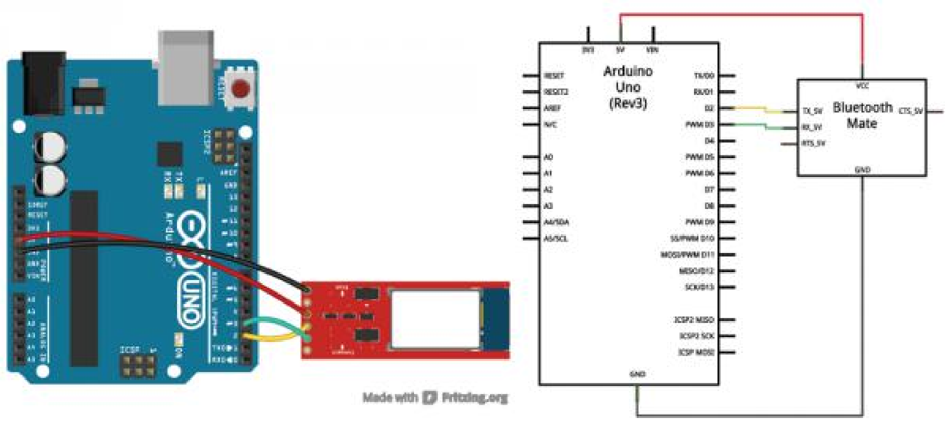


Figure 274: Uno hardware hookup.

Operation

The capsule and station become connected once the AGSE is powered. To accomplish this, the capsule module operates as a "slave" on the Bluetooth network (and the AGSE operates as the master, respectively). The capsule module operates in "slave" mode because it will be powered before the AGSE module. The sequence is outlined in Table 83 below.

Step 1	The capsule is powered on when installed into the rocket.
Step 2	The rocket is installed into the AGSE.
Step 3	The AGSE is powered on, starting the "master" Bluetooth module.

Table 83: Bluetooth launch day events.

As outlined in Figure 275 below, the capsule waits for the AGSE to be powered to connect. The "master" module then connects to the "slave" module in the capsule. With the capsule module in "slave" mode and the AGSE module in "Auto-discovery Master mode," our connection will connect automatically upon power up.

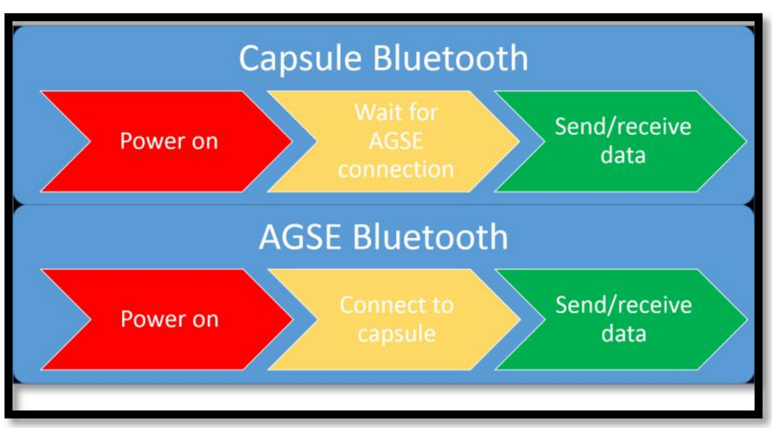


Figure 275: Bluetooth startup operation.

If the connection is lost, the slave returns to a “waiting for connection” status. The AGSE Bluetooth module has a 60 second time-out where the ground station will restart and reconnect to the waiting capsule. The “Auto-discovery Master mode” connection stays active until the AGSE is powered down or the capsule goes out of range during liftoff.

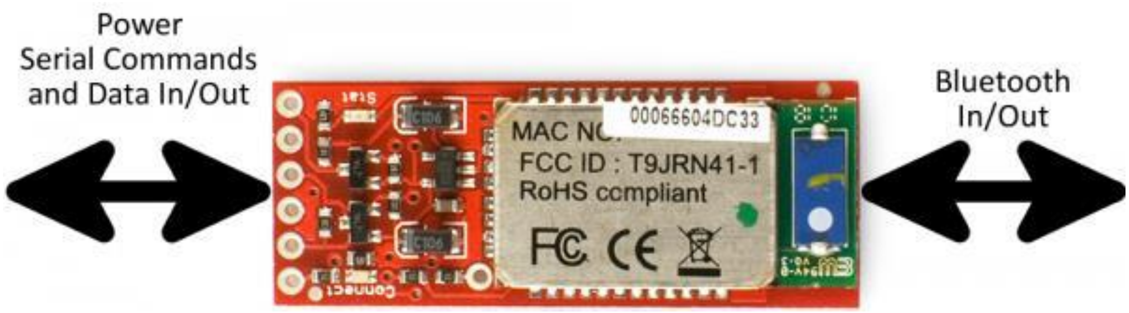


Figure 276: Data pipe operation.

The Bluetooth modules serve only as “data pipes” illustrated above in Figure 276. When the AGSE microcontroller sends data to the serial bus, the data is mirrored to the Bluetooth device. The Bluetooth is transmitted automatically and received by the capsule receiver. The capsule receiver receives the Bluetooth data and prints that data to the Rx line of the capsule microcontroller. The process remains the same for a return transmission.

Bluetooth Module Software

The RN41 Bluetooth module is preloaded with factory firmware that makes the communication functionality accessible through a serial terminal as shown below in Figure 277. Using this interface with the “AT command” document provided by the manufacturer, the modules the AGSE and capsule connected modules are set as “master” and “slave,” respectively.

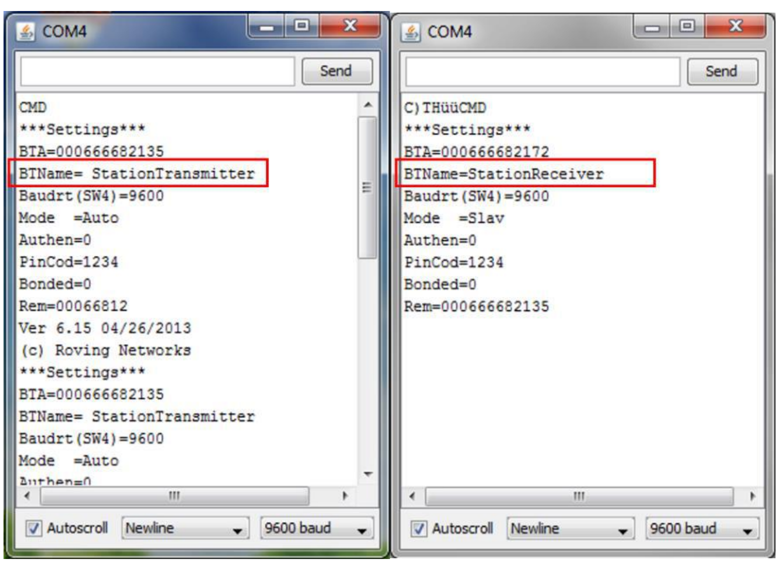


Figure 277: Bluetooth serial interface (unique names).

Through the provided command set, the AGSE Bluetooth module is set to "master mode auto-discovery." In auto-discovery mode, the connections are acquired automatically. The last firmware function used is the "SY" command to set the transmit/receive power output. The device has the ability to attenuate the output power in order to conserve battery life. The AGSE and capsule devices are set for maximum range during testing and we do not expect to change that setting for competition operation. The Arduino communicates with the Bluetooth device like a serial communication port. The "data pipe" architecture transmits serial data wirelessly and automatically.

Testing

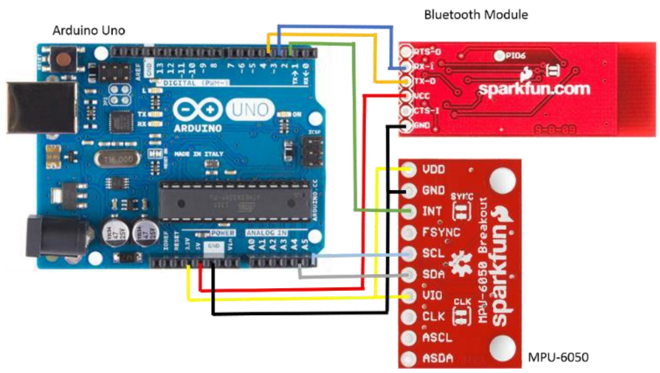


Figure 278: Bluetooth orientation transmitter.

Verification 1: Proof of concept

The Bluetooth communication has been verified to receive and transmit serial data. The pair of transceivers wirelessly transmitted data from one microcontroller to another. The initial test included two identical Arduinos, two identical Bluetooth modules, and one MPU-6050 (to generate data to transmit). The transmitter setup (Figure 278 above) read the orientation data from the MPU-6050 and broadcast the data through Bluetooth. A receiver setup (Figure 279 below) received the broadcasted data from the transmitter and relayed the information to the serial monitor of a laptop. We manually connected and communicated wirelessly.

Verification 2: Transmission through fiberglass

The second test of Bluetooth communication was to verify that the devices could transmit more that 3m while installed in the fuselage of the rocket. To perform this test, the device was installed in an enclosed section of the launch vehicle. The test was performed in the Firstbuild facility shop. The stream of accelerometer data was initiated and recorded on a received on the station counterpart. The system was reliable to 10m. The data could be received at greater distances, but would experience interference.

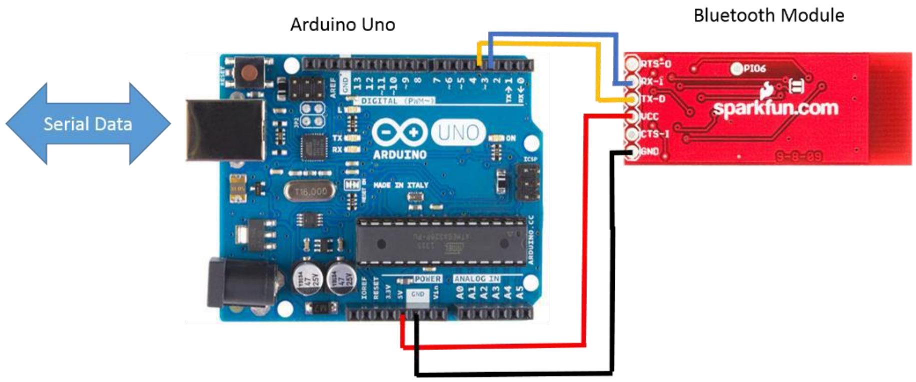


Figure 279: **Bluetooth receiver.**

Verification 3: Remote monitoring with cell phone

After verifying that two identical systems were functional, we tested the compatibility with a third party Bluetooth terminal app on a Galaxy S4 smartphone. A cell phone screenshot (shown in Figure 280 below) was taken of a cell phone that was able to pair with the Bluetooth transmitter. The data shown in the screenshot are YPR values from the MPU-6050. In line of sight, the module successfully transmitted up to 10m in a warehouse. This is less than the distance required for AGSE internal communication.

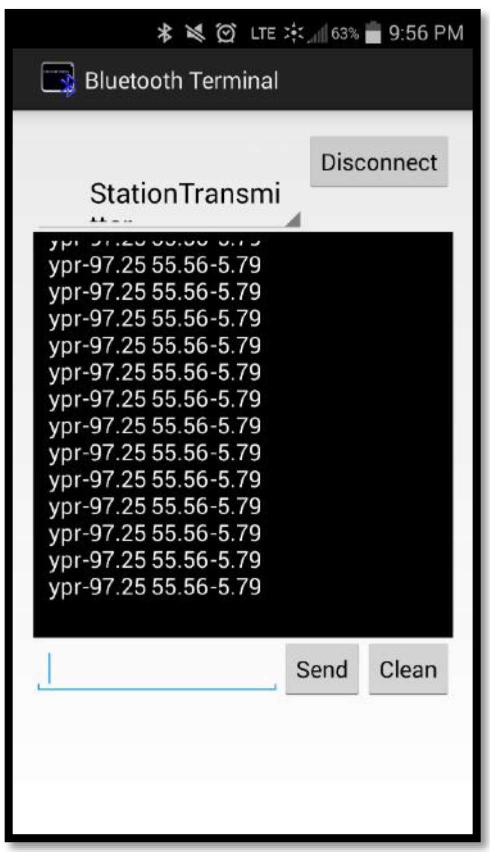


Figure 280: Cell phone screenshot.

Verification 4: Subscale flight

The communication dropped out before liftoff during the first subscale launch in Memphis, TN. This was due to the fact that the module was being configured in auto-discovery mode. The more current setup allows for automatic connection between the transceivers. The functionality will be tested in the next full scale launch of the rocket on March 28, 2015. Constant communication is expected to be maintained between the modules. The module is predicted to communicate post launch for a maximum distance of 10m into liftoff. This will be verified by time stamp in the transmitted orientation data to map the loss of connection.

User interface

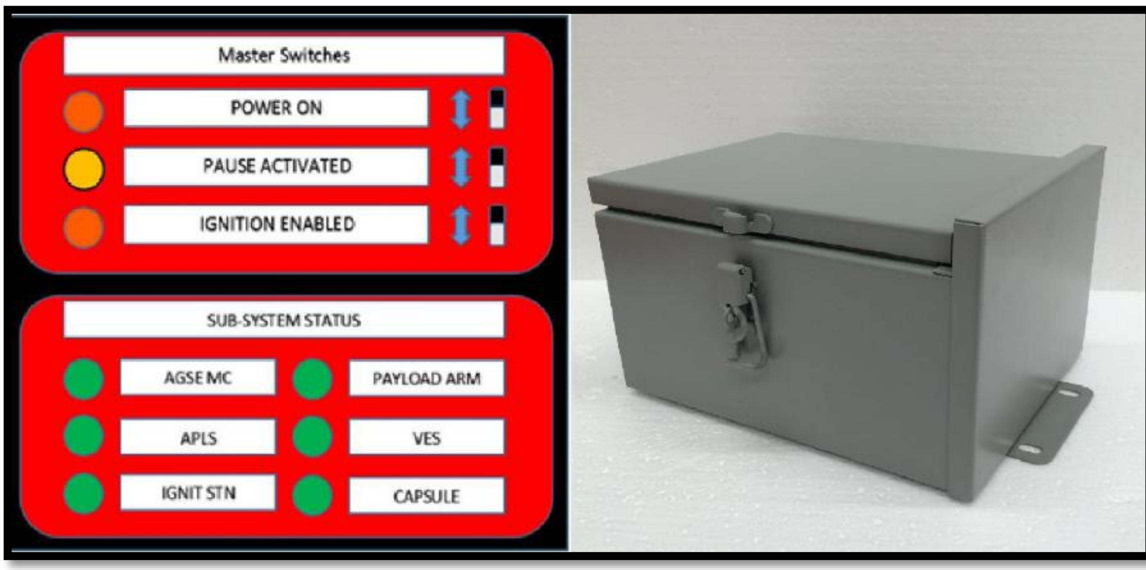


Figure 281: AGSE user Interface (left) and master control box (right).

As shown above in Figure 281, the user interface (that will be located on the right face of the master control box) provides the launch staff access to control the AGSE activities. The interface includes master boot, pause (status), and ignition toggle switches. As outlined in Figure 282, the boot switch will power on all controllers once AGSE setup is complete. When the switch is activated, all controls will boot. The master pause switch controls the amber status LED. The LED will be flashing at 1Hz when the system is powered and paused; the LED will be solidly lit when the system is in a non-paused state. The master switch will be wired to the interrupt pins of all subsystem's controllers. The hardware interrupt will be active when a low signal is measured on the interrupt pin of the Arduino. After boot and setup, the launch safety officer will toggle the pause switch to remove the low signal on the line. The pause switch will halt the system at any time the pause switch is active.

Figure 282: Boot setup sequence.

The third toggle available on the user interface of the AGSE is the igniter enable switch. The igniter enable switch will be wired to a digital input pin on the ignition station controller. When activated, the ignition enable switch will allow the station to begin the installation of the igniter. The activation of this enable switch will close a circuit to charge the igniter in a way that the igniter cannot energize without the approval of the field safety officer.

All systems go

The bottom set of green indicators on the user interface will identify that every system on the AGSE is functioning safely and ready to begin. The lights will be flashing when the safety tests are being performed and will be solidly lit green to show that the system has passed safety check and is "Go."

Testing

Verification 1: Wire rating (amps)

AWG gauge	Conductor Diameter Inches	Conductor Diameter mm	Ohms per 1000 ft.	Ohms per km	Maximum amps for chassis wiring
OOOO	0.46	11.684	0.049	0.16072	380
OOO	0.4096	10.40384	0.0618	0.202704	328
OO	0.3648	9.26592	0.0779	0.255512	283
0	0.3249	8.25246	0.0983	0.322424	245
1	0.2893	7.34822	0.1239	0.406392	211
2	0.2576	6.54304	0.1563	0.512664	181
3	0.2294	5.82676	0.197	0.64616	158
4	0.2043	5.18922	0.2485	0.81508	135
5	0.1819	4.62026	0.3133	1.027624	118
6	0.162	4.1148	0.3951	1.295928	101
7	0.1443	3.66522	0.4982	1.634096	89
8	0.1285	3.2639	0.6282	2.060496	73
9	0.1144	2.90576	0.7921	2.598088	64
10	0.1019	2.58826	0.9989	3.276392	55

Figure 283: American wire gauge rating sample.

Testing has been conducted to qualify gauge of wire used in the subscale system. This testing included the powering of a static APLS system (outlined in the APLS section), igniter installer (outlined in the igniter installer section). The APLS (subscale) was qualified first because it is one of the most power consuming systems. As for the full scale version of the launch pad, power testing will be conducted in a similar order to insure the power gets to the critical systems. Further success will qualify the full scale wire harnessing, connectors, and regulators used in the ground station. Each wire gauge is rated for a specific maximum amperage as shown in the sample set in Figure 283.

Verification 2: Communications test

The I2C bus has been tested for correct "call and response" to system commands. In testing the AGSE communications, three controllers were connected through I2C protocol and given simple "routines." The Arduino on the left of Figure 284 is the "master" controller that represents the central controller of the AGSE, while the remaining two represent the "slave" devices on the network. The master controller sends a command to slave 1 on the I2C bus that commands slave 1 to light its green LED. The master then sends another command to command slave 1 to turn off the green led. Once the process finished for slave 1 device, it was repeated for the second device. The model AGSE passed the test of communication. The master was able to deliver commands to the slaves. The slaves completed the assigned "routines" and would not move on until instructed by the master controller on the left.

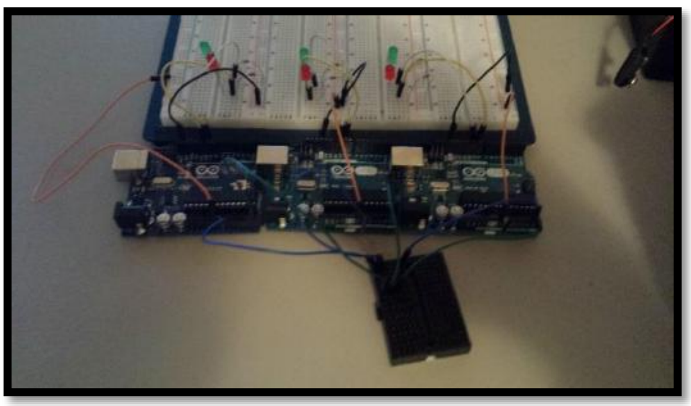


Figure 284: Communications testing.

Verification 3: Master Pause switch

The pause interrupt was tested to immediately pause the igniter installer subsystem. Upon activation of the master pause switch, the installer halted to a safe state and returned to normal operation. The test results were recorded in Table 84.

Test	Expected	Result	PASS/FAIL
Start subsystem in pause state	System does not begin operation, performs paused action	Stepper does not complete a step	PASS
Start subsystem in un-paused state	System begins operation upon activation	Stepper begins operation	PASS
Pause system after activation	System enters preset paused operation and remains until pause is deactivated. The system then returns to operation.	Stepper stops movement upon pause activation	PASS
Pause "TBD" amount of seconds after system activation	System pauses when pause is energized, returns to operation when pause is deactivated	Stepper stops operation when pause enabled and returns to operation when pause is lifted	PASS

Table 84: Hardware interrupt testing.

(PENDING) *Verification 4: Igniter enable switch*

The igniter enable switch will be tested to enable ignition system upon activation. No part of the instillation procedure can start until the enable ignition switch is activated. The test will consist of isolating the ignition system and simulating the dependent routines that lead up to ignition enable. If the installer begins it's routine before the enable is activated the test will be considered a failure. If the igniter installer fails to start once the enable is activated, the test will be considered a failure.

(PENDING) *Verification 5: Master boot switch*

The master boot switch will be tested to power on and boot all microcontrollers in the AGSE. Testing must simulate multiple power cycles to show that all controllers power on and boot without issue. The test will consist of powering the AGSE to the paused interrupt state. All systems must boot to a safe, predetermined state of pause to be considered successful.

Weather Station and SD Logger Controls

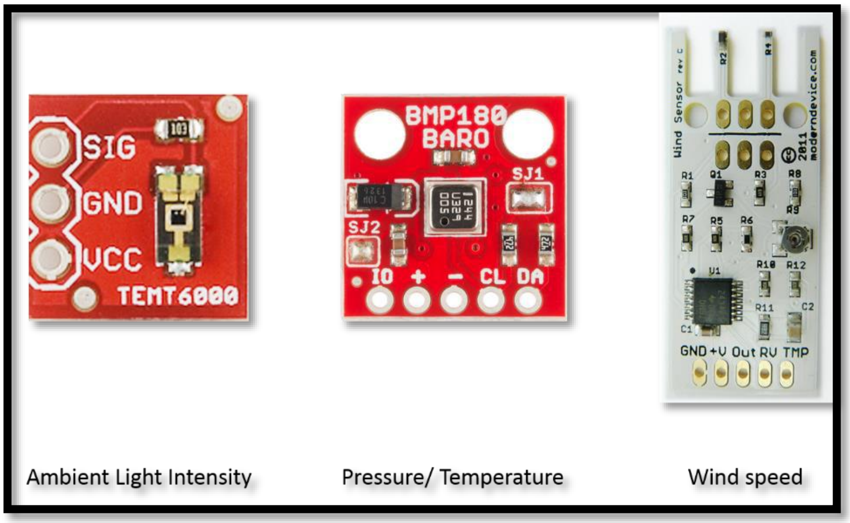


Figure 285: Weather cluster sensors.

The weather station is a cluster of three sensors. The cluster is installed into the swinging end of the VES launch rail. The cluster measures temperature, light, air speed, and pressure with sensors shown in Figure 285. The station software is a modular program that will measure and record each sensor, then write the data to SD card until the card is full. The program and sensors are ready to “drop-in” to the full scale AGSE. The cluster is described in more detail in the following sections.

Ambient light intensity

The light sensor (TEMT6000) outputs a light dependent voltage (0-5V) that represents the intensity of the ambient light. The 10K resistor provided on the SparkFun breakout board of the sensor relates the emitter current of the sensor to the output voltage. When the voltage is read, the data can be converted from a voltage to a current using the following version of ohm’s law:

$$I=\frac{V}{R} \tag{52}$$

The current is then converted to the illuminance coefficient provided from the datasheet in Figure 286.

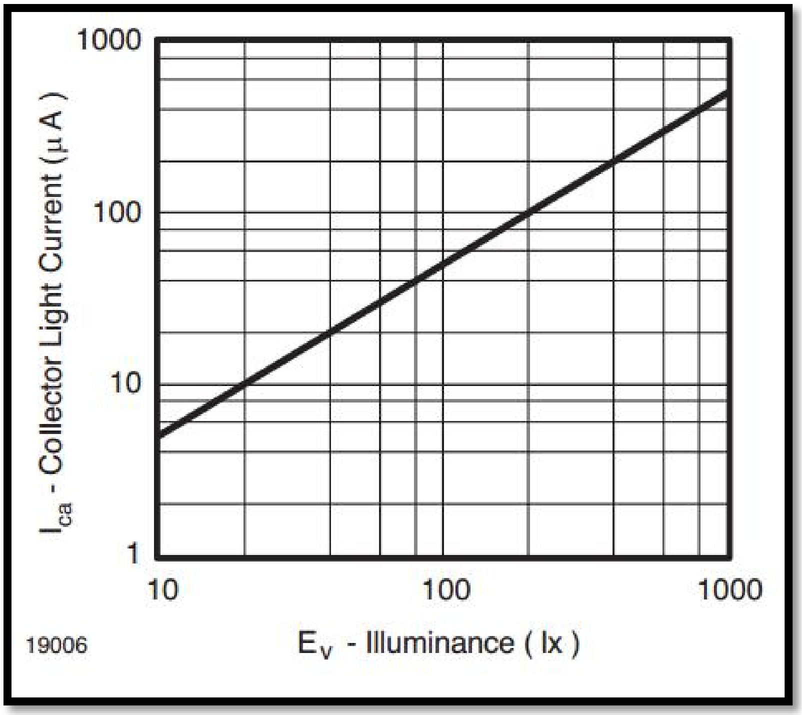


Figure 286: Collector light current vs. illuminance.

Using the above equations, the following lookup table relates the logged data to the voltage, emitter current and ambient light intensity.

V_{out} (V)	Logged Data (8-bit ADC)	Current (uA)	Illuminance (l_x)
5	255	500	1000
4	204	400	800
2	102	200	400
1	51	100	200
0.8	40.8	80	180
0.6	30.6	60	110
0.4	20.4	40	80
0.2	10.2	20	40
0.1	5.1	10	20
0.08	4.08	8	18
0.06	3.06	6	12
0.05	2.55	5	10

Table 85: Light intensity lookup.

The datasheet rates the sensor for operation in temperatures ranging from -40C to 85C. If the weather station were to move past the prototype stages of the competition and get sent to Mars, the sensor would need to have an allocated heating element to allow for stable operation in the Martian environment.

Pressure and Temperature

The second sensor is the Bosch BMP180. The BMP180 is a digital barometer/thermometer integrated circuit which measures the environment and relays the data through the I2C bus to the central controller. The sensor has a pressure range of 300-1100hPa. With the Martian atmosphere being recorded at 6hPa, the sensor would not be able to measure the atmosphere directly. The pressure sensor could be used to monitor a pressurized compartment on the ground station. The barometer requires no calibration because it is calibrated before it leaves the manufacturing plant. Similar to the light sensor, the BMP would require heating if sent on a mission to Mars.

Wind speed

To measure wind speed, the wind sensor (available from *Modern* Devices) was chosen. The wind sensor requires calibration on startup and outputs voltage from 0V to 5V depending on the air speed acting on it. The sensor must be covered with a wind blocker (i.e. cylinder) and adjusted to .5V at zero wind. The output relation for wind speed is show in Figure 287 below. The wind speed sensor would have to be heated like the other sensors to an offset of 21-23C.

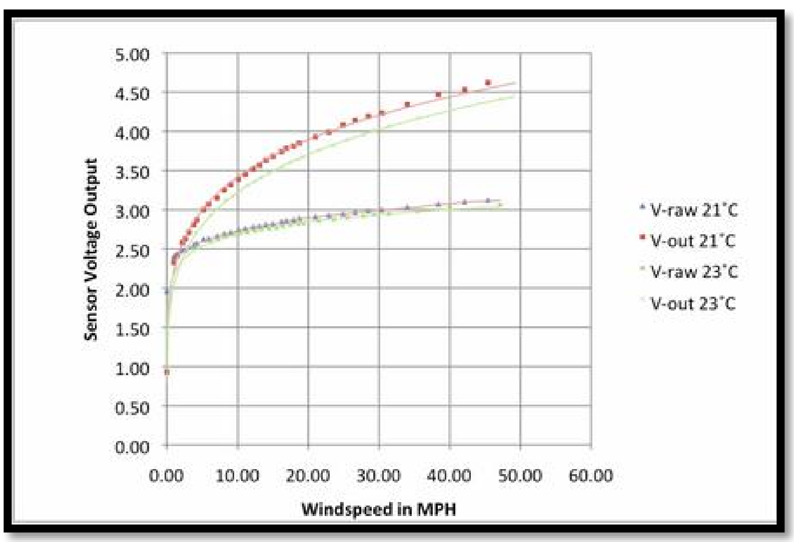


Figure 287: Wind speed look-up.

Design iterations

The weather station sensors have been tested on proto-board, as shown assembled in Figure 288 below, to simulate the competition goal. The sensors are wired up as they are designed to be on launch day. The wind and light sensors are being measured from inputs A0 and A1 on the Arduino and the pressure/temperature sensor is communicating through I2C as designed. The board is shown is installed on the top of an SD card shield (discussed in the next section). The test results of the weather cluster were logged onto SD card by the SD logger also discussed later.

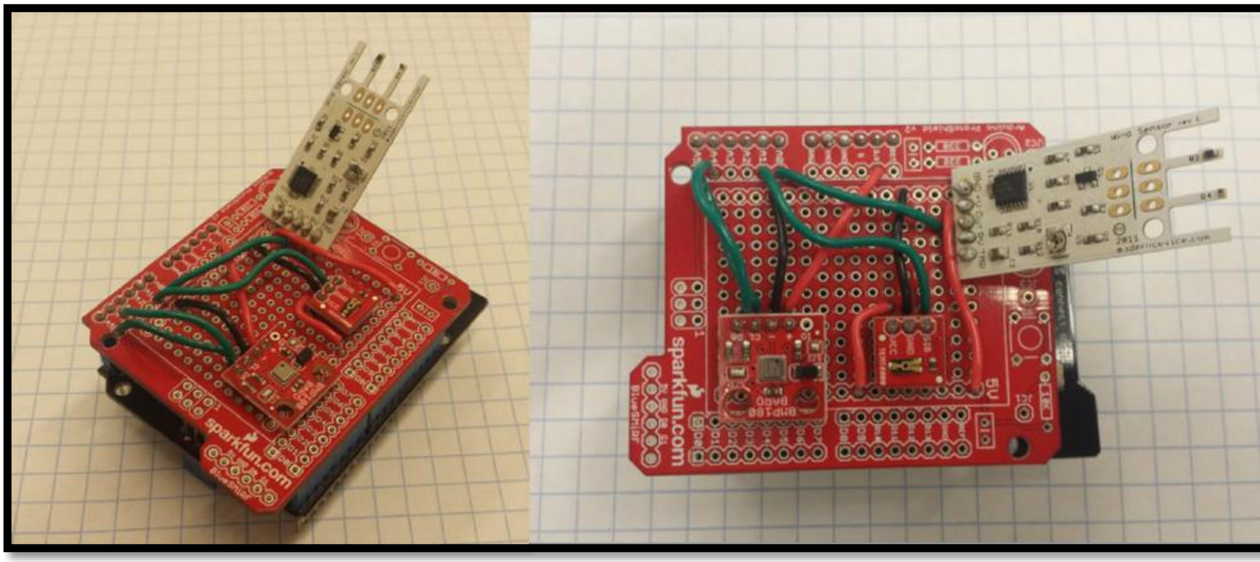


Figure 288: Weather cluster prototype board.

To assist in assembly and increase robustness of the circuitry, a custom PCB board was designed and laid out using Eagle CAD. The PCB will replace the prototype board above. The board, details shown in Figure 289, provides all connections for the sensors and controller to measure and communicate.

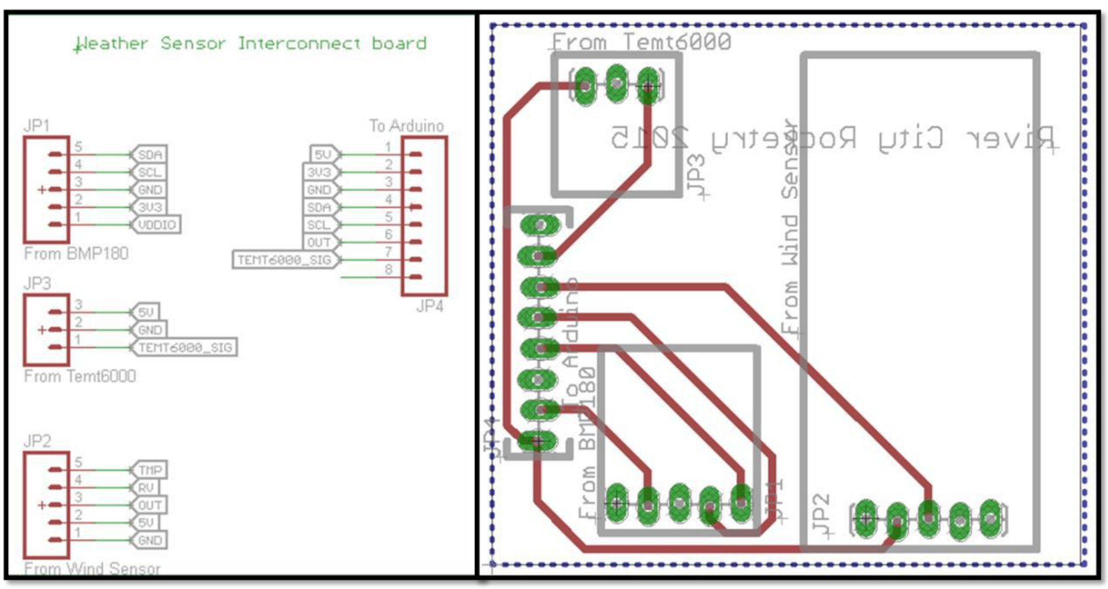


Figure 289: Weather station schematic (on left) and layout (on right).

Through functionality testing of the prototype weather station board, we have confidence in the functionality of the custom PCB above. The new board will use the same sensors, wiring, and software that has already been developed for the weather station.

SD Logger

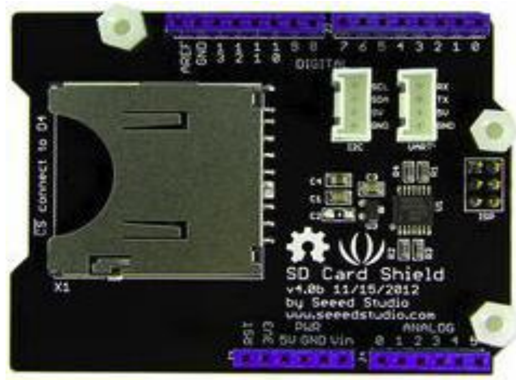
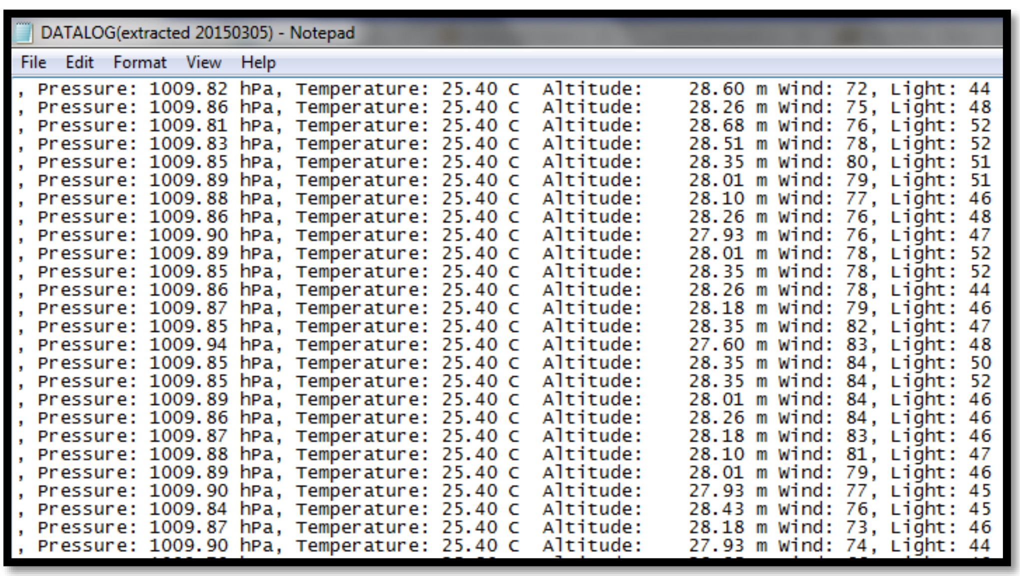


Figure 290. Seeed SD card shield V4.0.

A data logging SD card board (shown in Figure 290) is attached to the central controller through the SPI bus. The board is stacked directly to the central controller without external wiring or power. The shield requires the SPI bus on the Arduino Uno; it is accessed through digital pins D10-D13.

Using the shield as a data logger, data can be accessed after testing and weather station data can be logged with a time-stamp for post launch analysis. The Arduino IDE includes an "SD" library that will operate the Arduino as a data logger. Through integration of the SD library and sensor collection programming, the data is gathered from the sensors and saved into SD data file. The results of the test are shown below in Figure 291.



DATALOG(extracted 20150305) - Notepad

File Edit Format View Help

```
, Pressure: 1009.82 hPa, Temperature: 25.40 C  Altitude:    28.60 m Wind: 72, Light: 44
, Pressure: 1009.86 hPa, Temperature: 25.40 C  Altitude:    28.26 m Wind: 75, Light: 48
, Pressure: 1009.81 hPa, Temperature: 25.40 C  Altitude:    28.68 m Wind: 76, Light: 52
, Pressure: 1009.83 hPa, Temperature: 25.40 C  Altitude:    28.51 m Wind: 78, Light: 52
, Pressure: 1009.85 hPa, Temperature: 25.40 C  Altitude:    28.35 m Wind: 80, Light: 51
, Pressure: 1009.89 hPa, Temperature: 25.40 C  Altitude:    28.01 m Wind: 79, Light: 51
, Pressure: 1009.88 hPa, Temperature: 25.40 C  Altitude:    28.10 m Wind: 77, Light: 46
, Pressure: 1009.86 hPa, Temperature: 25.40 C  Altitude:    28.26 m Wind: 76, Light: 48
, Pressure: 1009.90 hPa, Temperature: 25.40 C  Altitude:    27.93 m Wind: 76, Light: 47
, Pressure: 1009.89 hPa, Temperature: 25.40 C  Altitude:    28.01 m Wind: 78, Light: 52
, Pressure: 1009.85 hPa, Temperature: 25.40 C  Altitude:    28.35 m Wind: 78, Light: 52
, Pressure: 1009.86 hPa, Temperature: 25.40 C  Altitude:    28.26 m Wind: 78, Light: 44
, Pressure: 1009.87 hPa, Temperature: 25.40 C  Altitude:    28.18 m Wind: 79, Light: 46
, Pressure: 1009.85 hPa, Temperature: 25.40 C  Altitude:    28.35 m Wind: 82, Light: 47
, Pressure: 1009.94 hPa, Temperature: 25.40 C  Altitude:    27.60 m Wind: 83, Light: 48
, Pressure: 1009.85 hPa, Temperature: 25.40 C  Altitude:    28.35 m Wind: 84, Light: 50
, Pressure: 1009.85 hPa, Temperature: 25.40 C  Altitude:    28.35 m Wind: 84, Light: 52
, Pressure: 1009.89 hPa, Temperature: 25.40 C  Altitude:    28.01 m Wind: 84, Light: 46
, Pressure: 1009.86 hPa, Temperature: 25.40 C  Altitude:    28.26 m Wind: 84, Light: 46
, Pressure: 1009.87 hPa, Temperature: 25.40 C  Altitude:    28.18 m Wind: 83, Light: 46
, Pressure: 1009.88 hPa, Temperature: 25.40 C  Altitude:    28.10 m Wind: 81, Light: 47
, Pressure: 1009.89 hPa, Temperature: 25.40 C  Altitude:    28.01 m Wind: 79, Light: 46
, Pressure: 1009.90 hPa, Temperature: 25.40 C  Altitude:    27.93 m Wind: 77, Light: 45
, Pressure: 1009.84 hPa, Temperature: 25.40 C  Altitude:    28.43 m Wind: 76, Light: 45
, Pressure: 1009.87 hPa, Temperature: 25.40 C  Altitude:    28.18 m Wind: 73, Light: 46
, Pressure: 1009.90 hPa, Temperature: 25.40 C  Altitude:    27.93 m Wind: 74, Light: 44
```

Figure 291: Weather cluster results.

Connections and Power Controls

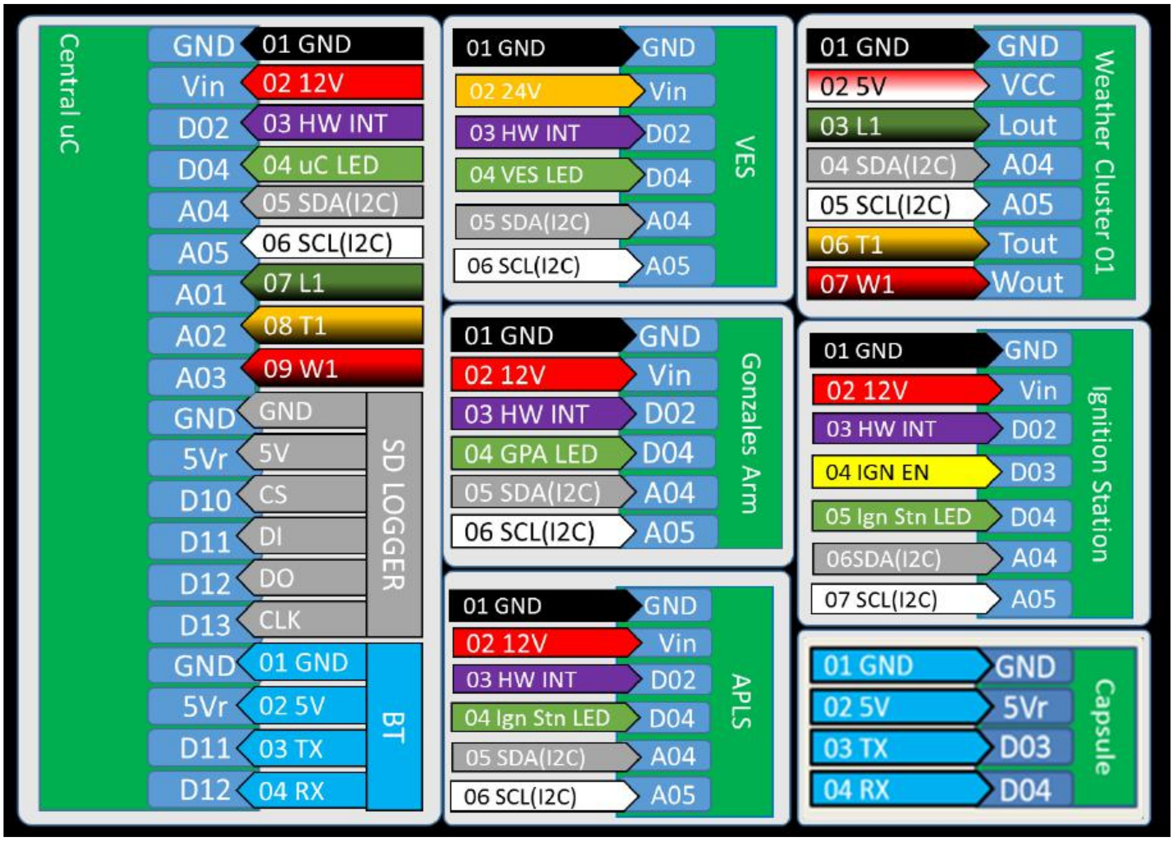


Figure 292: Wire harness and pin allocation.

The integration of electronic subsystems is physically done by means of connectivity. The wire harness outlined in Figure 292 conveys pin allocation and the external connections for each subsystem. The green boxes represent the Arduino Uno microcontrollers and weather cluster on the top right of the figure. The Bluetooth modules connect directly to the GPIO pins of the central controller and capsule controller. The SD logger interfaces with the central controller through the SPI bus available on the Arduino.

All appropriate systems share respective power, ground, and I2C communication bus connections. The hardware interrupt bus will be connected to each subsystem's controller (operation of the interrupt is discussed in the "user interface" section). The custom wire harness will contain removable disconnects for removal/installation of the electronics enclosure in between testing. The wire harness will be routed into the stations frame to minimize risk of physical damage. Each microcontroller has a hard line connection to the user interface as the respective status LED line.

Verification 1: Subscale wiring

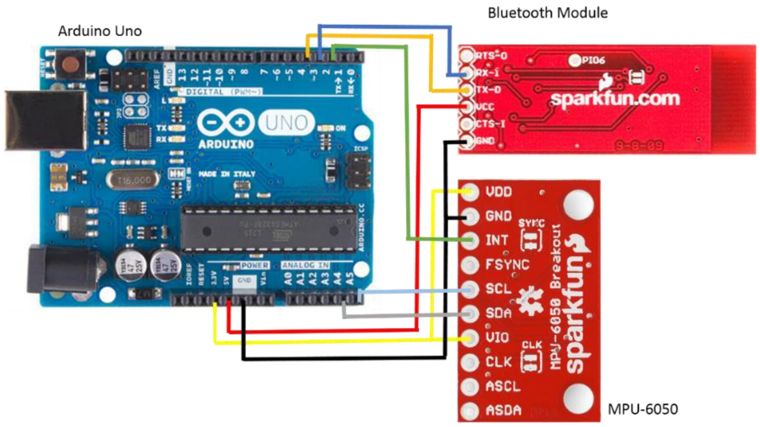


Figure 293: Subscale Bluetooth connections.

The first verification of our wiring harness was the subscale flight harness (shown above in Figure 293). The harness was constructed for subscale testing to connect the microcontroller, gyroscope, and Bluetooth module during the subscale launch. The harness that was implemented performed as designed. It provided sensor feedback from the MPU-6050 that was then transmitted through the harness to the allotted Bluetooth transceiver. The verification of the harness was a success.

Verification 2: APLS subscale wiring

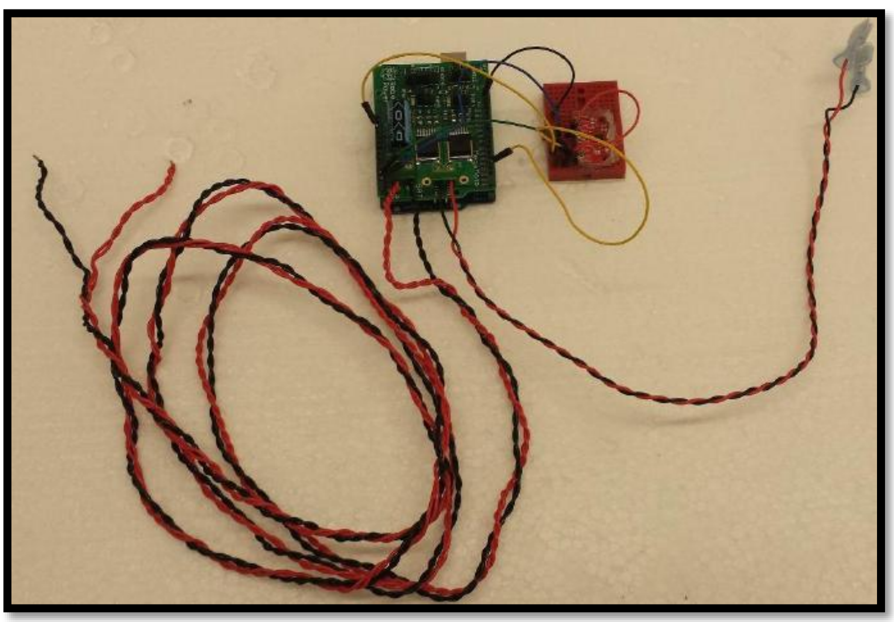


Figure 294: APLS subscale wiring.

To test the APLS subscale, a rough harness had to be made to verify the connections within. The harness components in Figure 294 include the power cable (bottom left), motor cable (on right), and sensor connections (in center between sensor and motor shield). The subscale wiring is a mission critical step in discovering design flaws in the shared connections of system components. With the connections verified for sensors and motors, the model can be scaled to full scale. The APLS functioned as designed with the pictured harness. The data was read from the motion processor, relayed to the microcontroller and converted to a corrective action by the motor.

(PENDING) Verification 3: Full scale Harness

After the success and learning opportunities of subscale builds, the full scale harness is ready to be prototyped and tested. The full scale harness includes all connections illustrated in Figure 292. The verification of the harness will verify the wiring's performance at length. It will verify that the ratings of the wiring are appropriate for the system when operating at the increased load of the full scale system.

AGSE Power Distribution

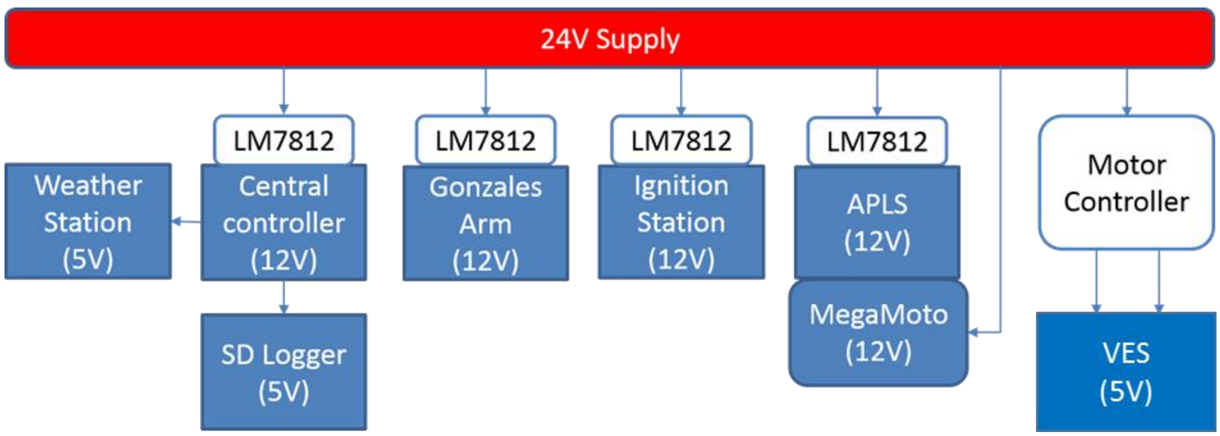


Figure 295: AGSE voltage lines.

Power is provided to the system by regulating the power contained in the dual car battery (24V) supply. The regulated line path is shown in Figure 295. All microcontrollers (excluding the VES) use a regulated 12V line provided by the commercially available 7812 IC (shown below in Figure 296); each subsystem relies on its own IC for a dedicated 12V line that can supply 1A for each microcontroller.

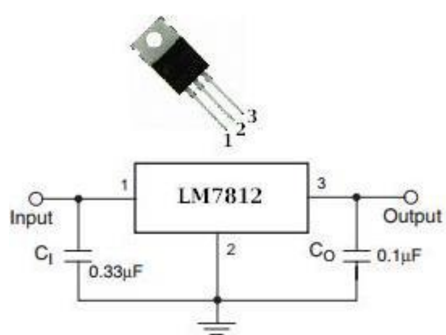


Figure 296: 12V regulator IC.

The power to the VES is regulated through the motor controller and provides the 24V needed to the VES motors. There is a dedicated 5V (regulated) line output by the motor driver that provides the power for the VES microcontroller. The three motors in the APLS will each be powered through the MegaMoto h-bridge controllers. The h-bridges will be directly powered from one of the 12V batteries.

10) Statement of Work Verification

Table 86 shows the requirements set forth by the statement of work and the teams proposed method of completion.

Requirement	Method of Completion
Teams will position their launch vehicle horizontally on the AGSE	The vehicle will be installed into in a horizontal position.
A master switch will be activated to power on all autonomous procedures and subroutines	There will be a toggle switch wired in line with the AGSE supply. A hardware toggle switch will have total capacity to disconnect entire system from power.
After the master switch is turned on, a pause switch will be activated, temporarily halting all AGSE procedure and subroutines. This will allow the other teams at the pads to set up, and do the same.	A secondary toggle switch will be implemented on the AGSE to halt all operations for safety and setup. This secondary toggle is wired in as a hardware interrupt. No system can be active while the toggle is activated.
Once the launch services official has inspected the launch vehicle and declares that the system is eligible for launch, he/she will activate a master arming switch to enable ignition procedures.	A third toggle switch will be implemented as an “igniter enable switch.” Power will be supplied to igniter installer microcontroller, but not to motors or igniter cable. The master arming switch activation allows the microcontroller to continue with automated igniter instillation.
The Launch Control Officer (LCO) will activate a hard switch, and then provide a 5-second countdown	Power supply for the igniter is electrically isolated and supplied by LCO and team. This will ensure LCO’s have complete control of abort process.
All AGSE systems shall be fully autonomous	All launch processes will be automated through self-contained microcontroller system. The processes ensuring safety of go/no-go toggle switch actuation which be controlled by appropriate launch staff.
The system must suffer no setbacks when the pause button is initiated	Through hardware interrupt, all systems pause to a known state. While the system is progressing it will log progress internally of each task into a tracking variable. In the case of a pause, the variable can be read and the system synchronized to the pre-pause state.
The system must complete all tasks within 10 minutes	The time requirement separated by sub-station and allocated for each. The time allotted for a sub-system is the driving design force of the subsystem.

The capture and containment system must be able to retrieve the payload from outside of the vehicle MOLD line and from the ground	Capture and containment system is designed to capture the payload from the ground (outside of the MOLD line) and install the payload into the rocket compartment.
No forbidden technologies will be utilized	Forbidden technologies are not utilized in the AGSE.
A master switch to power all parts of the AGSE, the switch must be easily accessible and hardwired into the AGSE	A fused power block will isolate all devices from power supply. The master power switch is capable of opening and closing the power circuit of the entire station.
A pause switch to temporarily terminate all actions performed by the AGSE. The switch must be easily accessible and hardwired into the AGSE	The secondary toggle switch will be implemented on the AGSE to halt all operations for safety and setup. The second toggle having all e-stop priority aside from the master switch.
A safety light that indicates that the AGSE is powered on. The light must be amber/orange in color. It will flash at a frequency of 1 Hz when the AGSE is powered on, and will be solid in color when the AGSE is paused while power is still supplied	The central microcontroller will have control of indicating power/pause status through an Amber LED panel indicator. The LED flashing at 1Hz will be implemented through PWM control from microcontroller with input from pause switch.
An all systems go light to verify all systems have passed safety verifications and the rocket system is ready to launch	LED and switch on AGSE User interface is installed to verify LCO's approval. The switch is activated by LCO. The activation energizes the LED to alert affected personnel that the system safety has been verified.

Table 86: AGSE SOW verification.

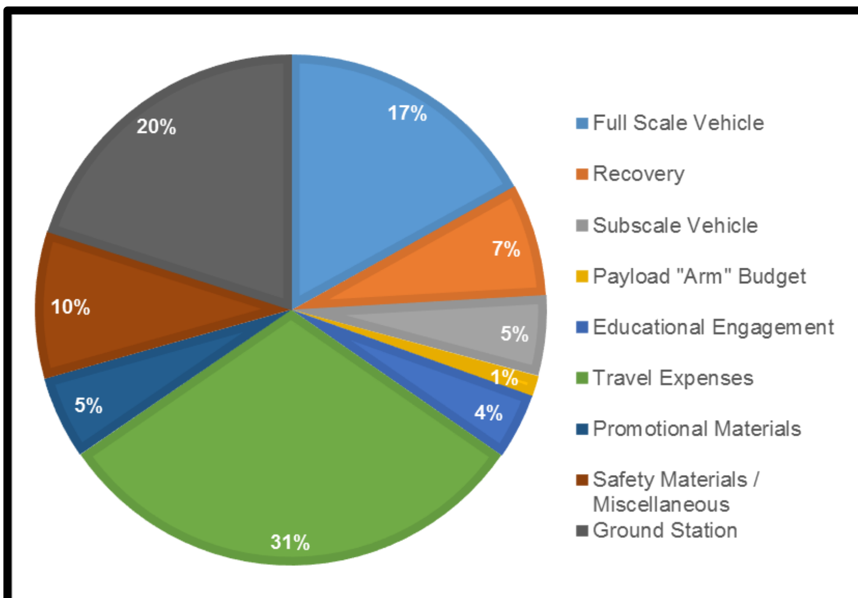
Section 5. Project Plan

1) Budget Plan

Overall Inflow Budget	
Supporter/Sponsor	**Total Investment**
Raytheon	$1,000.00
Samtec Material Donations	$1,500.00
FirstBuild Material Donations	$1,500.00
UofL ECE Department	$2,000.00
UofL ME Department	$2,000.00
UofL CECS Department	$1,000.00
UofL's Speed Dean's Office	$6,000.00
KSGC Grant	$10,000.00
Bagel	$2,000.00
Overall Cost	**$27,000.00**

Overall Outflow Budget	
Budget	**Total Cost**
Full Scale Vehicle	$3,175.09
Recovery	$1,322.21
Subscale Vehicle	$946.08
Payload "Arm" Budget	$243.99
Educational Engagement	$778.79
Travel Expenses	$5,750.00
Promotional Materials	$975.00
Safety Materials / Miscellaneous	$1,739.75
Ground Station	$3,742.03
Overall Cost	**$18,672.94**

On-Pad Budget	
Budget	**Total Cost**
Launch Vehicle	$3,308.68
Recovery	$287.79
AGSE	$4,455.92
Overall Cost	**$8,052.39**



Full Scale Vehicle Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
6" FG Von Karman Nosecone	1	$122.55	$122.55
6" FG Airframe Tubing (4 feet in length)	4	$185.02	$740.08
6" FG Coupler Tubing (1 foot in length)	5	$55.76	$278.80
1/8" Thick 24" x 36" Fiberglass	4	$35.78	$143.12
6" Plywood Bulkplate - 1/2" thick (Coupler)	6	$5.90	$35.40
6" Plywood Bulkplate - 1/2" thick (Airframe)	6	$5.90	$35.40
Cesaroni L910 - 2G CS	6	$199.66	$1,197.96
Pro 75 2G Hardware Set	1	$242.96	$242.96
1/4"-20 x 4' Threaded Rod (Aluminum)	4	$4.46	$17.84
1/4"-20 Hex Nuts (Aluminum) (pkg of 100)	1	$4.46	$4.46
4-40 Black Nylon Shear Pins (pkg of 100)	1	$5.42	$5.42
3/8"-16 for 2.5" OD Black-Oxide U-Bolt (Steel)	5	$1.55	$7.75
3/8"-16 Hex Nuts Black-Oxide (18-8 SS) (pkg of 25)	1	$7.11	$7.11
1/4" Flat Washer (Aluminum) (pkg of 100)	1	$6.80	$6.80
3/8" Flat Washer Black-Oxide (18-8 SS) (pkg of 100)	1	$8.49	$8.49
Servo	1	$40.00	$40.00
Hinges	2	$10.00	$20.00
Neodymium Magnets (1/8" x 1/16")	1	$8.99	$8.99
Momentary Contact Switch	2	$0.98	$1.96
Professional Paint Job for Competition	1	$250.00	$250.00
		Overall Cost	**$3,175.09**

Recovery Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Ripstop Nylon (59"x36")	13	$7.99	$103.87
1" Tubular Nylon (1 yard)	10	$1.25	$12.50
Nomex Cloth (1 ft)	3	$19.99	$59.97
TeleMetrum GPS Payload	1	$321.00	$321.00
Perfect Flight StratoLogger	4	$79.95	$319.80
Electric Matches	50	$1.25	$62.50
4FA Black Powder (1lb)	1	$24.40	$24.40
9V Duracell Batteries (x4)	3	$12.73	$38.19
Garmin Astro 320 GPS Unit	2	$189.99	$379.98
		Overall Cost	**$1,322.21**

Subscale Vehicle Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
3" FG Von Karman Nosecone	1	$46.01	$46.01
3" FG Airframe Tubing (4 feet in length)	3	$77.92	$233.76
3" FG Coupler Tubing (1 foot in length)	5	$13.16	$65.80
1/8" Thick 24" x 36" Fiberglass	3	$35.78	$107.34
3" Plywood Bulkplate - 3/16" thick (Coupler)	5	$1.64	$8.20
3" Plywood Bulkplate - 3/16" thick (Airframe)	5	$1.66	$8.30
1/4"-20 x 4' Threaded Rod (Aluminum)	2	$4.46	$8.92
1/4"-20 Hex Nuts (Aluminum) (pkg of 100)	1	$4.46	$4.46
4-40 Black Nylon Shear Pins (pkg of 100)	1	$5.42	$5.42
1/4"-20 for 1.5" OD Black-Oxide U-Bolt (Steel)	5	$0.85	$4.25
1/4"-20 Hex Nuts Black-Oxide (18-8 SS) (pkg of 50)	1	$7.07	$7.07
1/4" Flat Washer (Aluminum) (pkg of 100)	1	$6.80	$6.80
1/4" Flat Washer Black-Oxide (18-8 SS) (pkg of 100)	1	$6.11	$6.11
Standard Parachute Large	1	$25.00	$25.00
Standard Parachute Small	1	$7.50	$7.50
Perfect Flight StratoLogger	4	$79.95	$319.80
Electric Matches	15	$1.25	$18.75
4FA Black Powder (1lb)	1	$24.40	$24.40
9V Duracell Batteries (x4)	3	$12.73	$38.19
		Overall Cost	**$946.08**

Safety and Misc Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
3M 20-Pack Sanding Respirators	3	$19.97	$59.91
Latex Disposable Gloves (100 count)	1	$9.34	$9.34
Loctite Instant Mix 5 min epoxy	20	$4.70	$94.00
Rocket Poxy	2	$38.25	$76.50
Misc Hardware	1	$500.00	$500.00
Additional Parts Bank	1	$1,000.00	$1,000.00
		Overall Cost	**$1,739.75**

Payload "Arm" Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
15" Aluminum Channel	2	$11.99	$23.98
90deg Channel Bracket	6	$1.59	$9.54
10 RPM Gear Motor	1	$24.90	$24.90
90 deg Quad Hub Mount	2	$5.99	$11.98
6-32 Socket Head Machine Screw	3	$1.69	$5.07
Motor Mount D	1	$4.99	$4.99
Set Screw Shaft Coupler 6mm -0.25in	1	$4.99	$4.99
0.25in Clamping Hub	1	$7.99	$7.99
32P 32T Pinion	1	$12.99	$12.99
0.25in x2in D Shaft	2	$1.49	$2.98
Beam Gear Rack	1	$5.99	$5.99
0.25in Flat Bore Bearing	4	$5.99	$23.96
Multipurpose 6061 Aluminum	1	$56.67	$56.67
Servo	1	$24.99	$24.99
32P Gear	2	$5.99	$11.98
Servo Arm	1	$10.99	$10.99
		Overall Cost	**$243.99**

Promotional Materials Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Shirts	50	$8.00	$400.00
Stickers	500	$0.15	$75.00
Miscellaneous Kickstarter Rewards	N/A	N/A	$500.00
		Overall Cost	**$975.00**

Travel Expenses Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Hotel (Competition in Huntsville, AL)	N/A	N/A	$4,000.00
Hotel (Testing at Thunderstruck in Ash Grove, IN)	N/A	N/A	$500.00
Gas (Competition in Huntsville, AL)	N/A	N/A	$1,000.00
Gas (For all out of town testing)	N/A	N/A	$250.00
		Overall Cost	**$5,750.00**

Educational Engagement Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Orbit 1" 24V Electronic Valve	3	$12.97	$38.91
7/8" Tire Valve (pkg of 2)	2	$2.09	$4.18
1 NPT Pipe Size Threading Bushing (Brass)	3	$7.97	$23.91
2-1/2" Male x 1 NPT Female Bushing (PVC)	3	$2.80	$8.40
1/2" Tube ID x 1/2 Male Pipe Size Barbed Fitting (Brass)	3	$4.66	$13.98
1/2" ID x 10' Red Tubing (Flexible PVC)	1	$11.50	$11.50
7/32" to 5/8" Hose Clamp (pkg of 10)	1	$5.87	$5.87
1/4" Wide x 14 Yards Teflon Tape	1	$5.19	$5.19
2 Pipe Size x 4' Length (PVC)	1	$36.94	$36.94
2 Pipe Size Cap (PVC)	3	$0.94	$2.82
Plastic Pipe Cement	1	$4.55	$4.55
3/4 Male Adapter to Female Slip (PVC)	6	$0.30	$1.80
3/4 Pipe Size x 5' Length (PVC)	1	$3.25	$3.25
3/4 Pipe End Male x 1/2 Female Bushing (PVC)	3	$0.36	$1.08
1/2 Pipe Size x 4' Length (PVC)	1	$9.08	$9.08
2 Pipe End Male x 3/4 Female Slip Bushing (PVC)	3	$1.57	$4.71
6mm, SPDT-NO Push Button Sw itch	3	$6.18	$18.54
15" Length Red Nylon Cable Tie (pkg of 25)	1	$6.12	$6.12
9V Battery (pkg of 12)	1	$14.36	$14.36
9V Battery Snap, I-Style	6	$0.68	$4.08
24 GA 25' Stranded Wire (Black)	1	$3.18	$3.18
24 GA 25' Stranded Wire (Red)	1	$3.18	$3.18
Gnome Rocket Bulk Pack (pkg of 24)	2	$123.99	$247.98
1/2A3-4T Engine Bulk Pack (pkg of 24)	2	$57.79	$115.58
Scotch tape (pack of 3)	40	$4.74	$189.60
		Overall Cost	**$778.79**

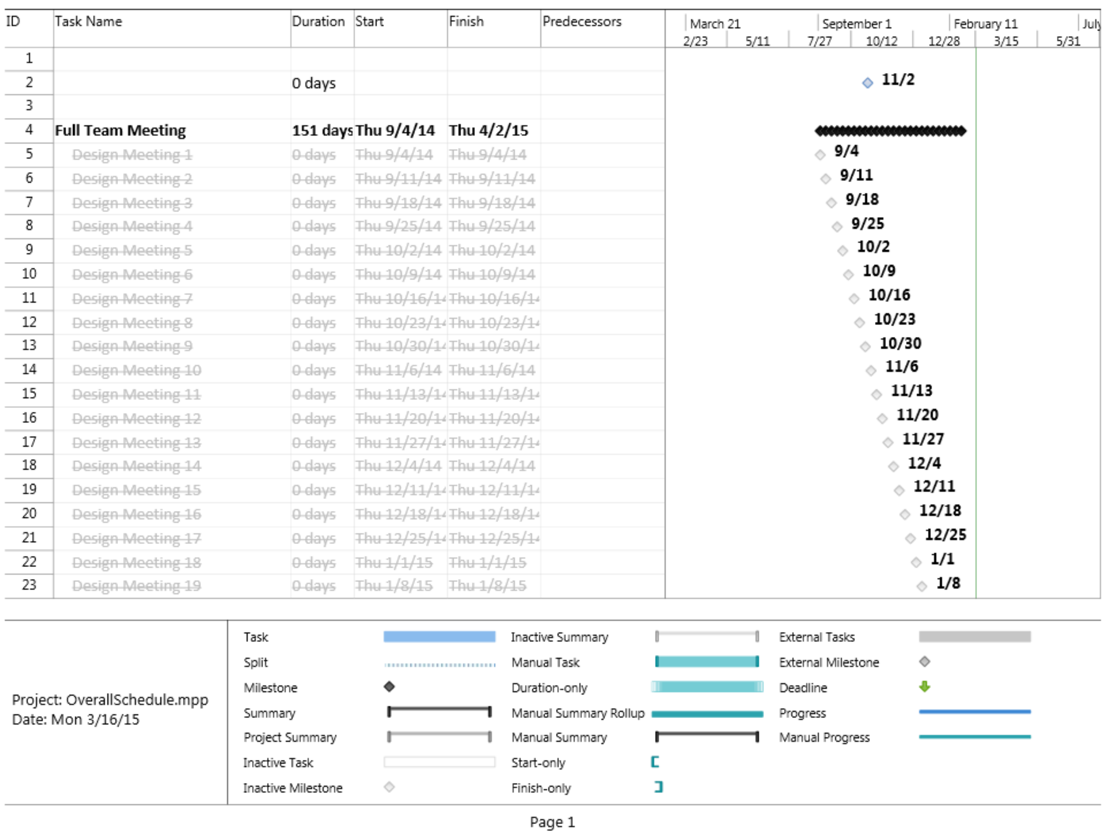
Ground Station Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
1515 Extrusion	360	$0.32	$115.20
1515 Extrusion	72	$0.32	$23.04
1515 Extrusion	36	$0.32	$11.52
Modified 10" Threaded rod	6	$3.88	$23.28
Stock Aluminum (0.25 inch)	1	$45.56	$45.56
Stock Aluminum Bar (0.375 thick)	1	$36.92	$36.92
5/16-18 Deep Hole Tap	1	$52.84	$52.84
Stock Aluminum Sheet (1/8 inch)	1	$147.34	$147.34
5/16-18 Button Head Screw (4inch length)	1	$11.63	$11.63
Anti-seize	1	$26.57	$26.57
5/16-18 Button Head Screw (0.375 inch)	3	$5.65	$16.95
5/16-18 Button Head Screw (1 inch)	3	$8.11	$24.33
Roll in T-nut w ith set screw	50	$1.58	$79.00
Double Slide in Economy T-nut	50	$0.53	$26.50
Inside Corner Gusset	24	$2.84	$68.16
2 Hole Flat Brace	12	$2.28	$27.36
End Piece 8020 Fastener	12	$1.12	$13.44
Aluminum Plate (0.25 thick)	1	$27.23	$27.23
Aluminum Plate (0.125 inch thick)	2	$24.17	$48.34
M3X0.5 screw s	1	$10.72	$10.72
1/8 inch Dow el Pins 0.5 inch long	1	$8.03	$8.03
#8-32 Button head screw s (0.75 inch long)	1	$5.91	$5.91
MSD Infused Nylon Rod (1 inch diameter)	2	$4.32	$8.64
Arduino	6	$30.00	$180.00
Motor Shield	2	$30.00	$60.00
Stepper Motor	4	$14.00	$56.00
Titanium Pow der	0.18221292	$300.00	$54.66
1515 Extrusion	581	$0.32	$185.92
1530 Extrusion	206	$0.59	$121.54
Fasteners	1	$181.86	$181.86
Computer	1	$240.00	$240.00
12 V Lead Acid Batteries	3	$70.00	$210.00
Motor	2	$200.00	$400.00
1/2 Inch Lead Screw (6ft length)	2	$95.39	$190.78
Stock Aluminum (0.5 inch thick)	1	$21.27	$21.27
Stock Aluminum (0.3125 thick)	1	$14.28	$14.28
Stock Aluminum (0.3125 thick)	1	$11.00	$11.00
Nylon pads	1	$21.95	$21.95
Nylon pads	1	$14.05	$14.05
Shoulder Bolt	1	$26.22	$26.22
PCB Fabrication	5	$130.00	$650.00
		Overall Cost	**$3,498.04**

2) Funding Plan

Louisville Cardinal: The Louisville Cardinal is the independent student newspaper at the University of Louisville. The newspaper is widely read and respected by the students at the university. In years past, River City Rocketry took the opportunity to sit down for interviews with the Louisville Cardinal. This has allowed students from all over the university to see what the team is doing and the progress they have made.

Registered Student Organization: In the Spring of 2012, River City Rocketry became a Registered Student Organization (RSO) at the University of Louisville. Since receiving RSO status, the team has been able to reach out to the Student Senate as well as several of the university's Student Councils to gain support and increase the knowledge of rocketry at UofL. The team has received very positive feedback and was elected "Best New RSO" in its first year as an RSO.

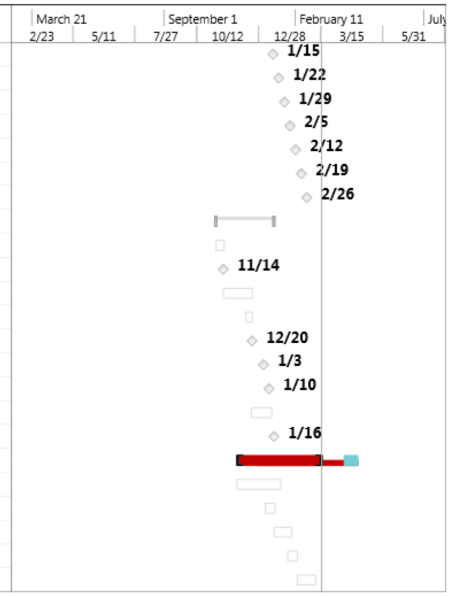
3) Timeline

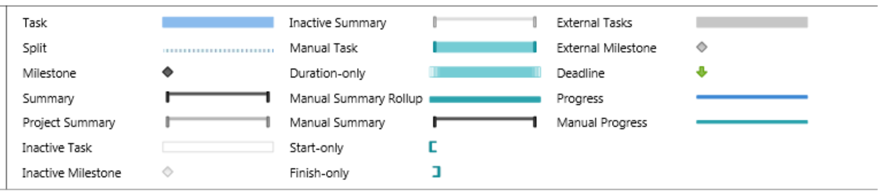


ID	Task Name	Duration	Start	Finish	Predecessors
1					
2		0 days			
3					
4	**Full Team Meeting**	**151 days**	**Thu 9/4/14**	**Thu 4/2/15**	
5	~~Design Meeting 1~~	~~0 days~~	~~Thu 9/4/14~~	~~Thu 9/4/14~~	
6	~~Design Meeting 2~~	~~0 days~~	~~Thu 9/11/14~~	~~Thu 9/11/14~~	
7	~~Design Meeting 3~~	~~0 days~~	~~Thu 9/18/14~~	~~Thu 9/18/14~~	
8	~~Design Meeting 4~~	~~0 days~~	~~Thu 9/25/14~~	~~Thu 9/25/14~~	
9	~~Design Meeting 5~~	~~0 days~~	~~Thu 10/2/14~~	~~Thu 10/2/14~~	
10	~~Design Meeting 6~~	~~0 days~~	~~Thu 10/9/14~~	~~Thu 10/9/14~~	
11	~~Design Meeting 7~~	~~0 days~~	~~Thu 10/16/1~~	~~Thu 10/16/1~~	
12	~~Design Meeting 8~~	~~0 days~~	~~Thu 10/23/1~~	~~Thu 10/23/1~~	
13	~~Design Meeting 9~~	~~0 days~~	~~Thu 10/30/1~~	~~Thu 10/30/1~~	
14	~~Design Meeting 10~~	~~0 days~~	~~Thu 11/6/14~~	~~Thu 11/6/14~~	
15	~~Design Meeting 11~~	~~0 days~~	~~Thu 11/13/1~~	~~Thu 11/13/1~~	
16	~~Design Meeting 12~~	~~0 days~~	~~Thu 11/20/1~~	~~Thu 11/20/1~~	
17	~~Design Meeting 13~~	~~0 days~~	~~Thu 11/27/1~~	~~Thu 11/27/1~~	
18	~~Design Meeting 14~~	~~0 days~~	~~Thu 12/4/14~~	~~Thu 12/4/14~~	
19	~~Design Meeting 15~~	~~0 days~~	~~Thu 12/11/1~~	~~Thu 12/11/1~~	
20	~~Design Meeting 16~~	~~0 days~~	~~Thu 12/18/1~~	~~Thu 12/18/1~~	
21	~~Design Meeting 17~~	~~0 days~~	~~Thu 12/25/1~~	~~Thu 12/25/1~~	
22	~~Design Meeting 18~~	~~0 days~~	~~Thu 1/1/15~~	~~Thu 1/1/15~~	
23	~~Design Meeting 19~~	~~0 days~~	~~Thu 1/8/15~~	~~Thu 1/8/15~~	

Figure 297: Overall project timeline. Page 1.

ID	Task Name	Duration	Start	Finish	Predecessors
24	~~Design Meeting 20~~	~~0 days~~	~~Thu 1/15/15~~	~~Thu 1/15/15~~	
25	~~Design Meeting 21~~	~~0 days~~	~~Thu 1/22/15~~	~~Thu 1/22/15~~	
26	~~Design Meeting 22~~	~~0 days~~	~~Thu 1/29/15~~	~~Thu 1/29/15~~	
27	~~Design Meeting 23~~	~~0 days~~	~~Thu 2/5/15~~	~~Thu 2/5/15~~	
28	~~Design Meeting 24~~	~~0 days~~	~~Thu 2/12/15~~	~~Thu 2/12/15~~	
29	~~Design Meeting 25~~	~~0 days~~	~~Thu 2/19/15~~	~~Thu 2/19/15~~	
30	~~Design Meeting 26~~	~~0 days~~	~~Thu 2/26/15~~	~~Thu 2/26/15~~	
31	~~CDR~~	~~52 days~~	~~Wed 11/5/14~~	~~Thu 1/15/15~~	
32	~~Design for subscale~~	~~8 days~~	~~Wed 11/5/14~~	~~Fri 11/14/14~~	
33	~~Part order for subscale~~	~~0 days~~	~~Fri 11/14/14~~	~~Fri 11/14/14~~	
34	~~Construction~~	~~26 days~~	~~Fri 11/14/14~~	~~Fri 12/19/14~~	
35	~~Ground testing~~	~~6 days~~	~~Fri 12/12/14~~	~~Fri 12/19/14~~	
36	~~Subscale Launch~~	~~0 days~~	~~Sat 12/20/14~~	~~Sat 12/20/14~~	
37	~~Secondary Subscale Launch~~	~~0 days~~	~~Sat 1/3/15~~	~~Sat 1/3/15~~	
38	~~Final Subscale Launch~~	~~0 days~~	~~Sat 1/10/15~~	~~Sat 1/10/15~~	
39	~~Write CDR~~	~~17 days~~	~~Fri 12/19/14~~	~~Mon 1/12/15~~	
40	~~CDR Due~~	~~0 days~~	~~Fri 1/16/15~~	~~Fri 1/16/15~~	
41	**FRR**	**76 days**	**Mon 12/1/1**	**Mon 3/16/1**	
42	~~Order full scale parts~~	~~40 days~~	~~Mon 12/1/14~~	~~Fri 1/23/15~~	
43	~~Finalize full scale design~~	~~10 days~~	~~Mon 1/5/15~~	~~Fri 1/16/15~~	
44	~~Construction~~	~~16 days~~	~~Fri 1/16/15~~	~~Fri 2/6/15~~	
45	~~Ground testing~~	~~10 days~~	~~Mon 2/2/15~~	~~Fri 2/13/15~~	
46	~~Full scale launch~~	~~17 days~~	~~Sat 2/14/15~~	~~Sun 3/8/15~~	



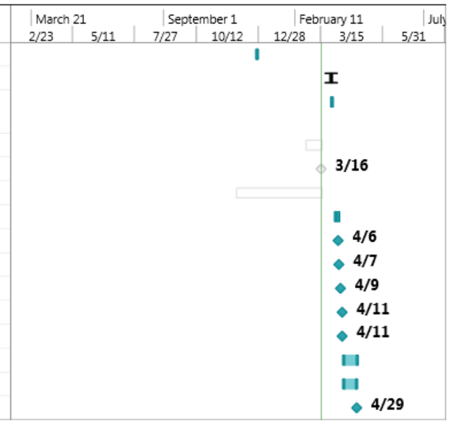


Project: OverallSchedule.mpp
Date: Mon 3/16/15

Page 2

Figure 298: Overall project timeline. Page 2.

ID	Task Name	Duration	Start	Finish	Predecessors
47	Ground test rocket	1 day	Fri 12/26/14	Fri 12/26/14	
48	Secondary full scale launch	1 day	Sat 3/28/15	Sat 3/28/15	
49	Backup secondary full scale launch	1 day	Sun 3/29/15	Sun 3/29/15	
50	~~Write FRR~~	~~14 days~~	~~Wed 2/25/15~~	~~Mon 3/16/15~~	
51	~~FRR Due~~	~~0 days~~	~~Mon 3/16/15~~	~~Mon 3/16/15~~	
52	~~FRR~~	~~76 days~~	~~Mon 12/1/14~~	~~Mon 3/16/15~~	
53	Pack for Huntsville	2 days	Fri 4/3/15	Mon 4/6/15	
54	Travel to Huntsville	0 days	Mon 4/6/15	Mon 4/6/15	
55	LRR	0 days	Tue 4/7/15	Tue 4/7/15	
56	Rocket Fair	0 days	Thu 4/9/15	Thu 4/9/15	
57	Launch	0 days	Sat 4/11/15	Sat 4/11/15	
58	Banquet	0 days	Sat 4/11/15	Sat 4/11/15	
59	PLAR	13 days	Mon 4/13/15	Wed 4/29/15	
60	Write PLAR	12 days	Mon 4/13/15	Tue 4/28/15	
61	PLAR Due	0 days	Wed 4/29/15	Wed 4/29/15	



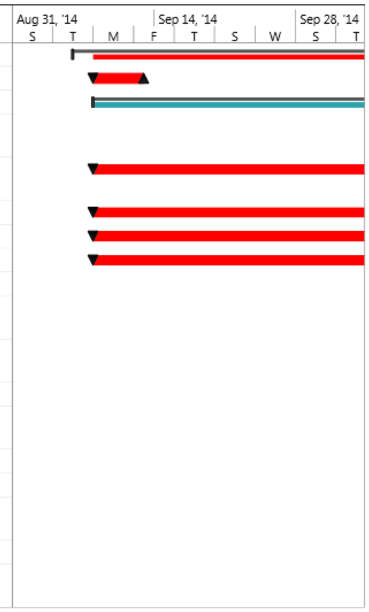
Project: OverallSchedule.mpp
Date: Mon 3/16/15

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

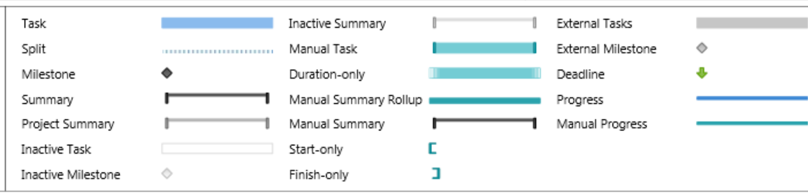
Page 3

Figure 299: Overall project timeline. Page 3.

ID	Task Name	Duration	Start	Finish	Predecessors
1	**AGSE**	**76 days**	**Sat 9/6/14**	**Fri 12/19/14**	
2	**Aquire and Inventory**	5 days	Mon 9/8/14	Fri 9/12/14	
3	**Concept Designs**	**75 days**	**Mon 9/8/14**	**Fri 12/19/14**	
4	ARM	2 days	Thu 12/18/14	Fri 12/19/14	
5	Launch Platform	75 days	Mon 9/8/14	Fri 12/19/14	
6	Vehicle Erection System (V.E.S.)	75 days	Mon 9/8/14	Fri 12/19/14	
7	Ground Station	75 days	Mon 9/8/14	Fri 12/19/14	
8	Ignition Station	75 days	Mon 9/8/14	Fri 12/19/14	
9	**Design Evaluation**	**21 days**	**Fri 12/19/14**	**Fri 1/16/15**	
10	ARM	3 days	Wed 1/14/15	Fri 1/16/15	
11	Launch Platform	3 days	Mon 1/19/15	Wed 1/21/15	10
12	Vehicle Erection System (V.E.S.)	21 days	Fri 12/19/14	Fri 1/16/15	
13	Ground Station	21 days	Fri 12/19/14	Fri 1/16/15	
14	Ignition Station	21 days	Fri 12/19/14	Fri 1/16/15	
15	**Fabrication**	**52 days**	**Fri 1/16/15**	**Fri 3/27/15**	
16	ARM	42 days	Fri 1/16/15	Sun 3/15/15	
17	Launch Platform	37 days	Fri 1/16/15	Fri 3/6/15	
18	Vehicle Erection System (V.E.S.)	50 days	Fri 1/16/15	Wed 3/25/15	



Project: AGSESchedule.mpp
Date: Mon 3/16/15



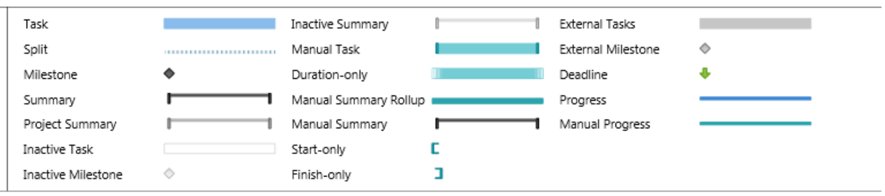
Page 1

Figure 300: AGSE timeline. Page 1.

ID	Task Name	Duration	Start	Finish	Predecessors
19	Ground Station	45 days	Fri 1/16/15	Wed 3/18/15	
20	Run wiring through ground station	4 days	Wed 3/18/15	Sun 3/22/15	
21	Outriggers	47 days	Fri 1/16/15	Fri 3/20/15	
22	Ignition Station	47 days	Fri 1/16/15	Fri 3/20/15	
23	Make final modifications to AGSE	0 days	Mon 4/6/15	Mon 4/6/15	
24	Construct jigs to prevent damage during transportation	4 days	Wed 4/1/15	Mon 4/6/15	
25	Pack using launch checklists to ensure everything gets packed	2 days	Fri 4/3/15	Mon 4/6/15	
26	LRR	0 days	Tue 4/7/15	Tue 4/7/15	
27	Correct punch list items	2 days	Tue 4/7/15	Wed 4/8/15	
28	Complete pre launch day procedures	1 day	Thu 4/9/15	Thu 4/9/15	
29	Launch	0 days	Sat 4/11/15	Sat 4/11/15	
30	PLAR	13 days	Mon 4/13/15	Wed 4/29/15	
31	Write PLAR	12 days	Mon 4/13/15	Tue 4/28/15	
32	PLAR Due	0 days	Wed 4/29/15	Wed 4/29/15	

Aug 31, '14 | Sep 14, '14 | Sep 28, '14
S T M F T S W S T

Project: AGSESchedule.mpp
Date: Mon 3/16/15



Page 2

Figure 301: AGSE timeline. Page 2.

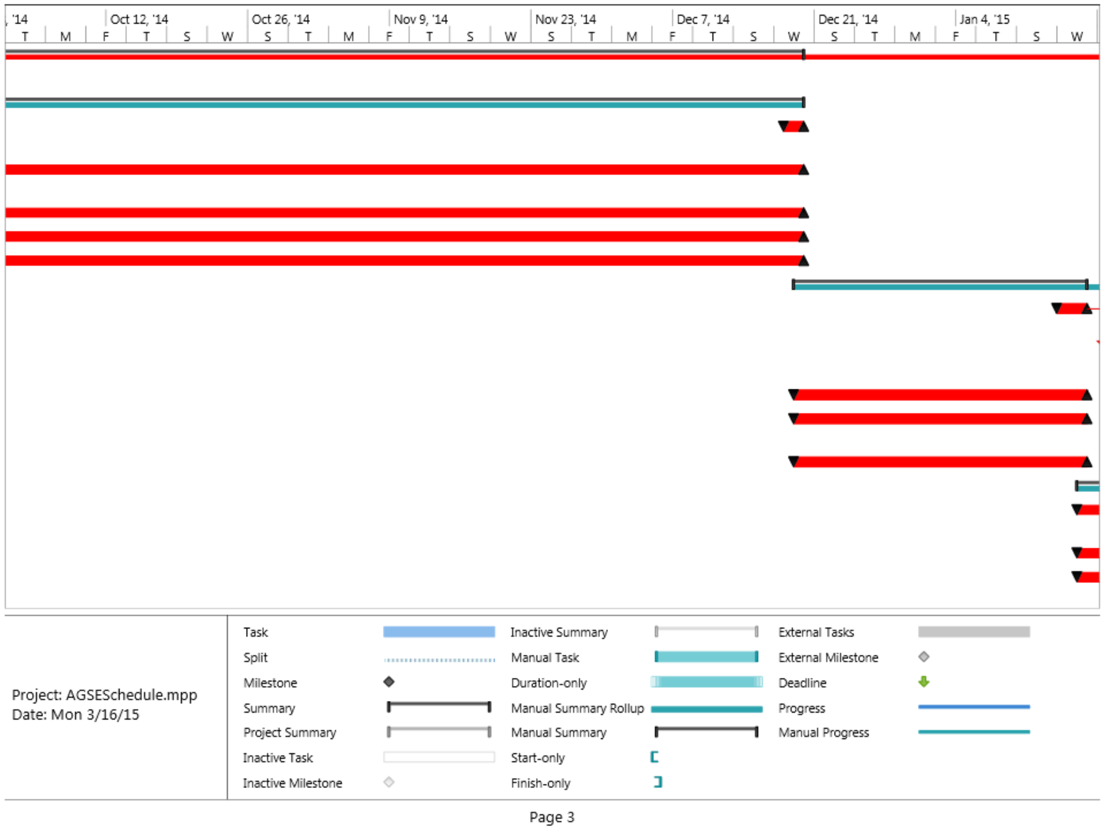


Figure 302: AGSE project timeline. Page 3.

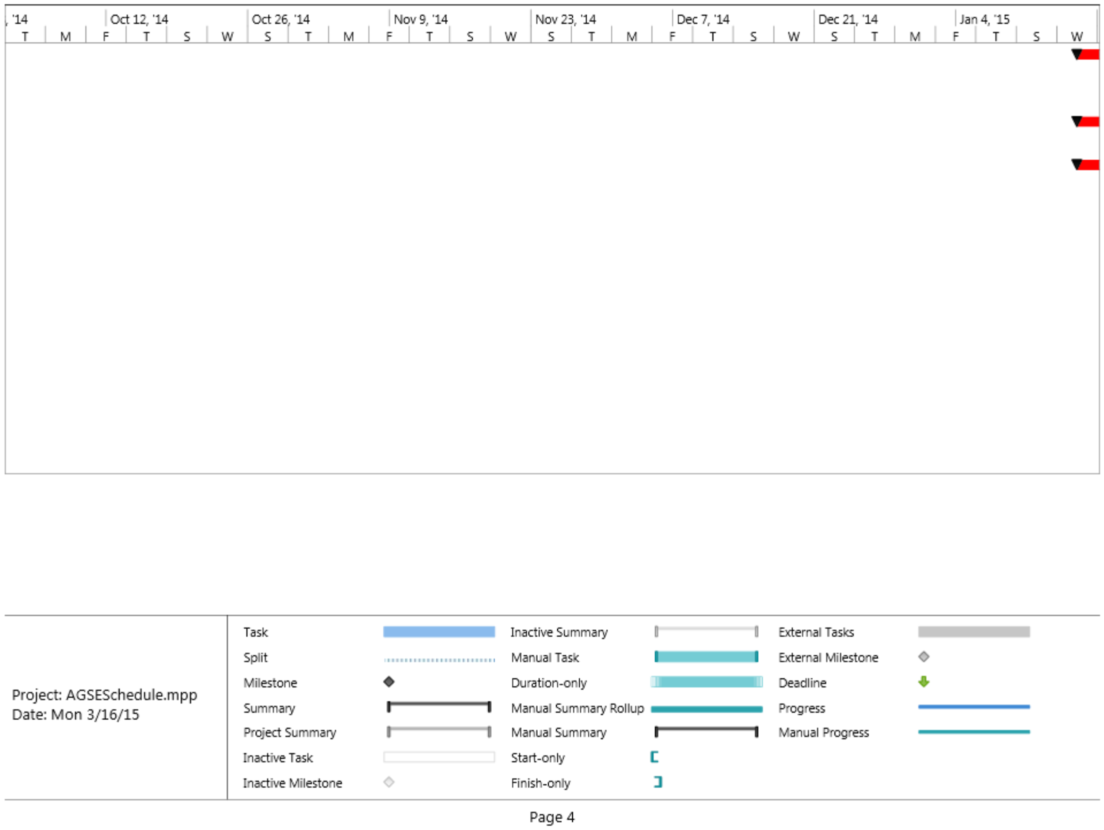


Figure 303: AGSE project timeline. Page 4.

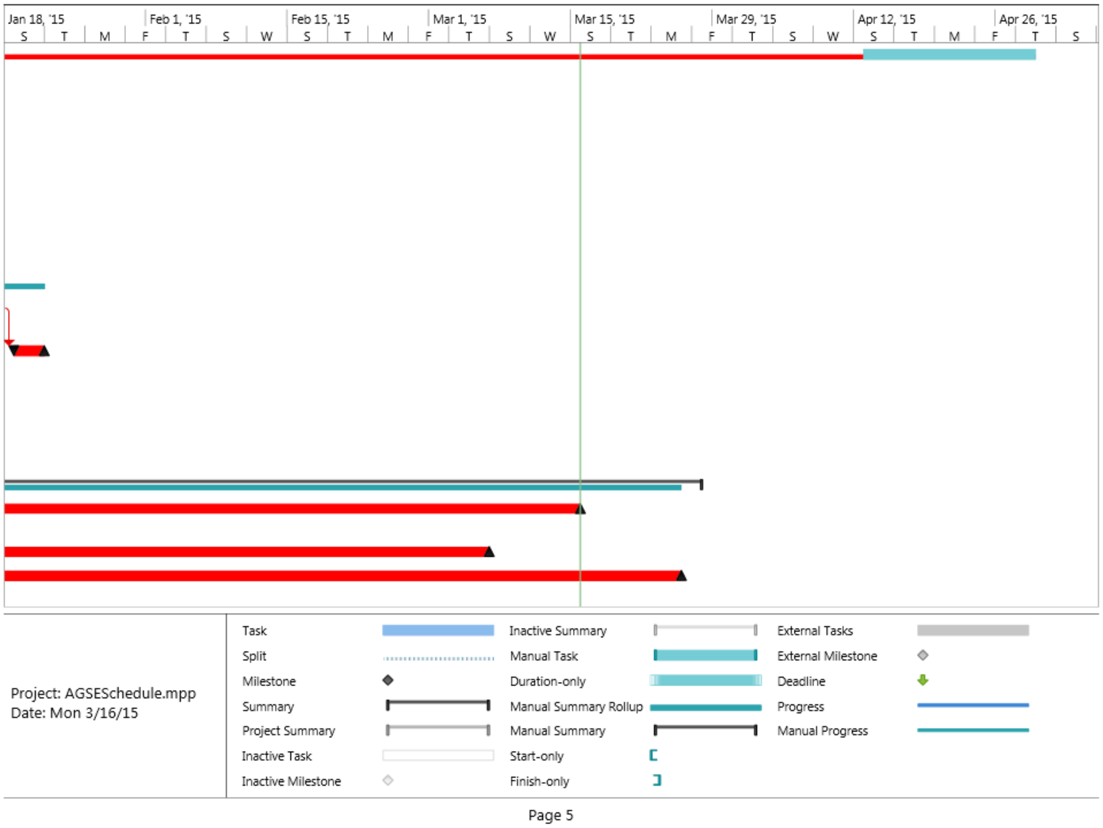


Figure 304: AGSE project timeline. Page 5.

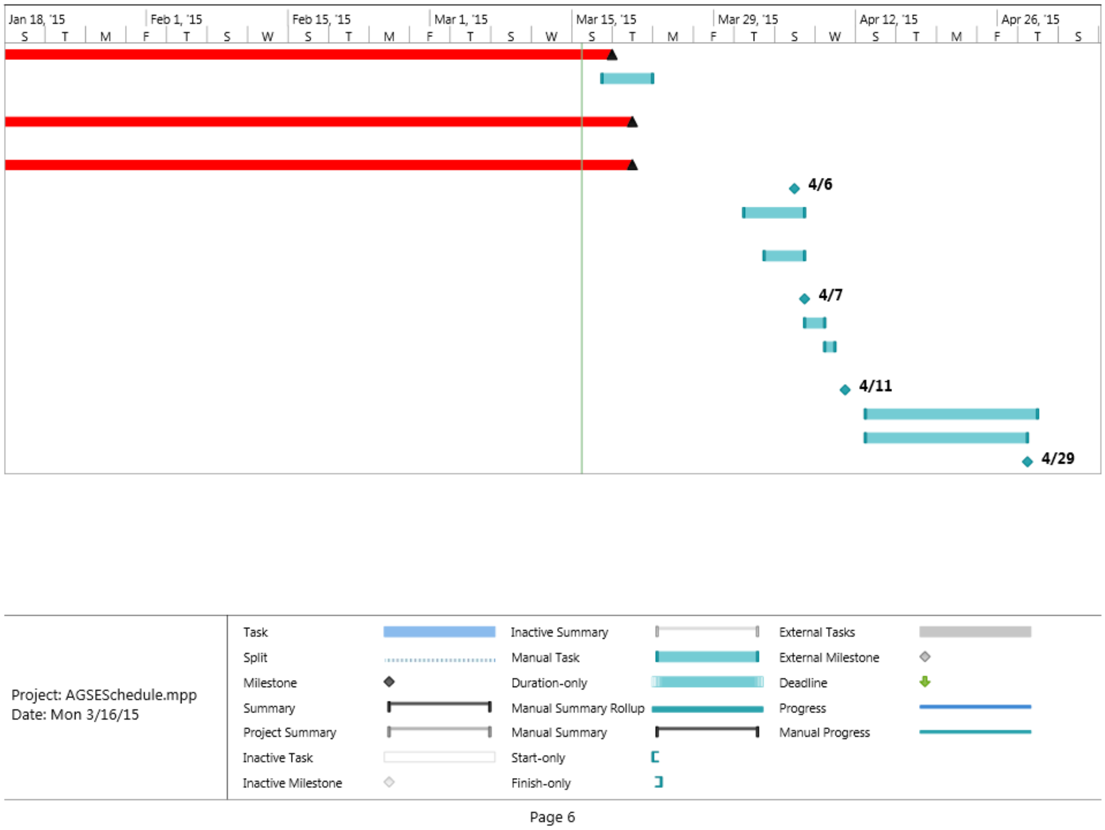
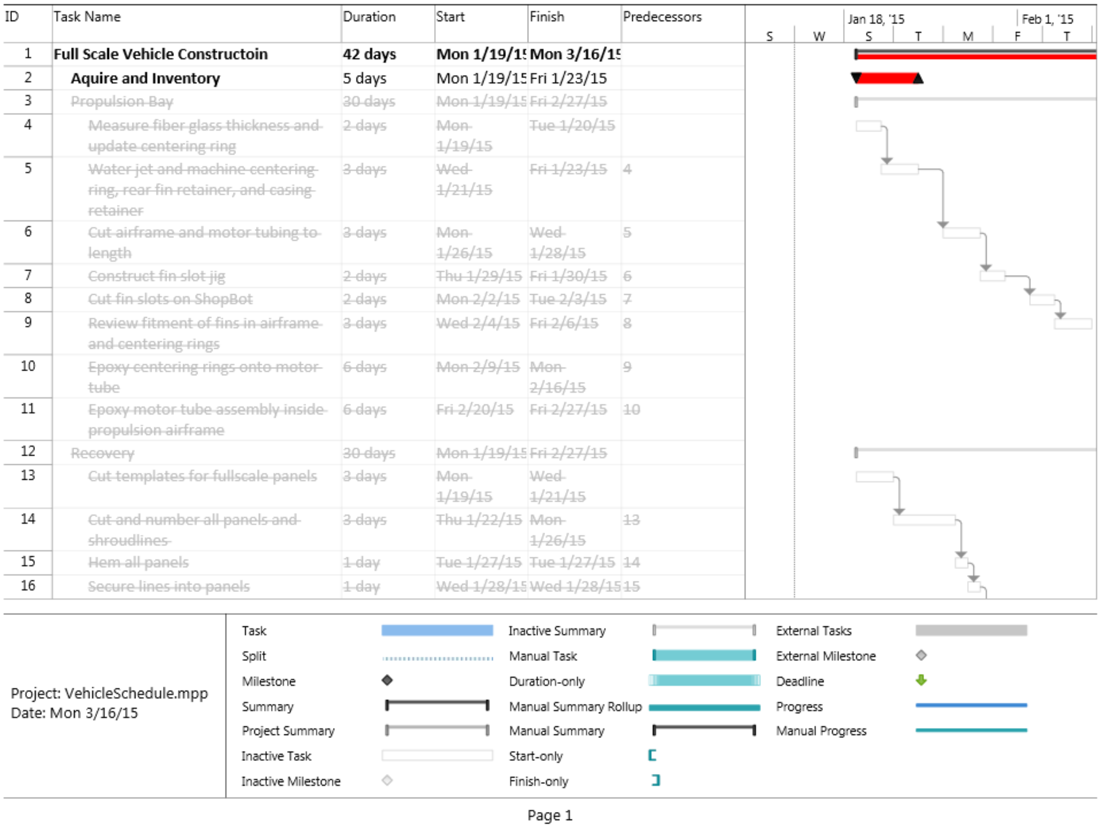


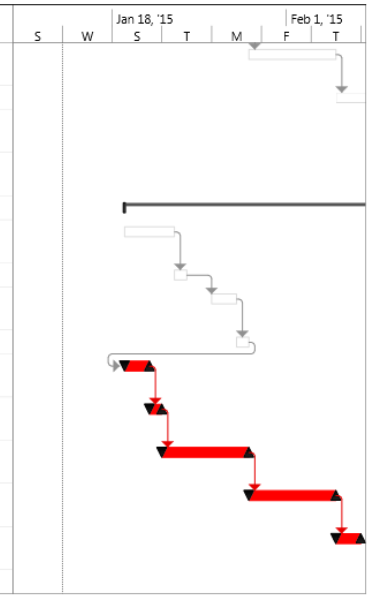
Figure 305: AGSE project timeline. Page 6.



ID	Task Name	Duration	Start	Finish	Predecessors
1	**Full Scale Vehicle Constructoin**	**42 days**	**Mon 1/19/15**	**Mon 3/16/15**	
2	**Aquire and Inventory**	5 days	Mon 1/19/15	Fri 1/23/15	
3	~~Propulsion Bay~~	~~30 days~~	~~Mon 1/19/15~~	~~Fri 2/27/15~~	
4	~~Measure fiber glass thickness and update centering ring~~	~~2 days~~	~~Mon 1/19/15~~	~~Tue 1/20/15~~	
5	~~Water jet and machine centering ring, rear fin retainer, and casing retainer~~	~~3 days~~	~~Wed 1/21/15~~	~~Fri 1/23/15~~	~~4~~
6	~~Cut airframe and motor tubing to length~~	~~3 days~~	~~Mon 1/26/15~~	~~Wed 1/28/15~~	~~5~~
7	~~Construct fin slot jig~~	~~2 days~~	~~Thu 1/29/15~~	~~Fri 1/30/15~~	~~6~~
8	~~Cut fin slots on ShopBot~~	~~2 days~~	~~Mon 2/2/15~~	~~Tue 2/3/15~~	~~7~~
9	~~Review fitment of fins in airframe and centering rings~~	~~3 days~~	~~Wed 2/4/15~~	~~Fri 2/6/15~~	~~8~~
10	~~Epoxy centering rings onto motor tube~~	~~6 days~~	~~Mon 2/9/15~~	~~Mon 2/16/15~~	~~9~~
11	~~Epoxy motor tube assembly inside propulsion airframe~~	~~6 days~~	~~Fri 2/20/15~~	~~Fri 2/27/15~~	~~10~~
12	~~Recovery~~	~~30 days~~	~~Mon 1/19/15~~	~~Fri 2/27/15~~	
13	~~Cut templates for fullscale panels~~	~~3 days~~	~~Mon 1/19/15~~	~~Wed 1/21/15~~	
14	~~Cut and number all panels and shroudlines~~	~~3 days~~	~~Thu 1/22/15~~	~~Mon 1/26/15~~	~~13~~
15	~~Hem all panels~~	~~1 day~~	~~Tue 1/27/15~~	~~Tue 1/27/15~~	~~14~~
16	~~Secure lines into panels~~	~~1 day~~	~~Wed 1/28/15~~	~~Wed 1/28/15~~	~~15~~

Figure 306: Vehicle project timeline. Page 1.

ID	Task Name	Duration	Start	Finish	Predecessors
17	~~Ground test all parachutes and verrify coefficient of drag~~	~~5 days~~	~~Thu 1/29/15~~	~~Wed 2/4/15~~	~~16~~
18	~~Construct deployment bags~~	~~5 days~~	~~Thu 2/5/15~~	~~Wed 2/11/15~~	~~17~~
19	~~Test proper deployment from bags~~	~~5 days~~	~~Thu 2/12/15~~	~~Wed 2/18/15~~	~~18~~
20	~~Ground test black powder charge sizing~~	~~7 days~~	~~Thu 2/19/15~~	~~Fri 2/27/15~~	~~19~~
21	**Fairing**	**22 days**	**Mon 1/19/1!**	**Tue 2/17/15**	
22	~~Cut airframe and coupler tubing to length~~	~~4 days~~	~~Mon 1/19/15~~	~~Thu 1/22/15~~	
23	~~Cut all bulkplates on ShopBot~~	~~1 day~~	~~Fri 1/23/15~~	~~Fri 1/23/15~~	~~22~~
24	~~Epoxy all bulkplates and coupler tubing inside airframe~~	~~2 days~~	~~Mon 1/26/15~~	~~Tue 1/27/15~~	~~23~~
25	~~Cut fairing assembly in half~~	~~1 day~~	~~Wed 1/28/1!~~	~~Wed 1/28/15~~	~~24~~
26	Machine foam inserts on ShopBot	2 days	Mon 1/19/15	Tue 1/20/15	25
27	3D print all fairing ABS components	1 day	Wed 1/21/15	Wed 1/21/15	26
28	Construct door and cache capsule assemblies	5 days	Thu 1/22/15	Wed 1/28/15	27
29	Install door and cache capsule assemblies	5 days	Thu 1/29/15	Wed 2/4/15	28
30	Epoxy foam inserts in fairing halves	2 days	Thu 2/5/15	Fri 2/6/15	29
31	Test fairing actuation	7 days	Mon 2/9/15	Tue 2/17/15	30



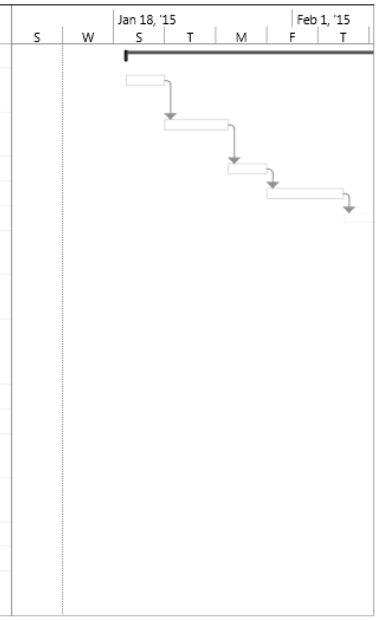
Project: VehicleSchedule.mpp
Date: Mon 3/16/15

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

Page 2

Figure 307: Vehicle project timeline. Page 2.

ID	Task Name	Duration	Start	Finish	Predecessors
32	**Avionics**	**30 days**	**Mon 1/19/1**	**Fri 2/27/15**	
33	~~3D print altimeter sleds, GPS mounts, and GoPro mount~~	~~3 days~~	~~Mon 1/19/15~~	~~Wed 1/21/15~~	
34	~~ShopBot wood and water jet fiberglass bulk plates~~	~~3 days~~	~~Thu 1/22/15~~	~~Mon 1/26/15~~	~~33~~
35	~~Assemble bulk plates~~	~~3 days~~	~~Tue 1/27/15~~	~~Thu 1/29/15~~	~~34~~
36	~~Cut and install all thread~~	~~4 days~~	~~Fri 1/30/15~~	~~Wed 2/4/15~~	~~35~~
37	~~Install and wire terminal blocks~~	~~4 days~~	~~Thu 2/5/15~~	~~Tue 2/10/15~~	~~36~~
38	~~Apply alminum tape to bulk plates~~	~~2 days~~	~~Wed 2/11/15~~	~~Thu 2/12/15~~	~~37~~
39	~~Final assembly of electronics into their appropriate bays~~	~~4 days~~	~~Fri 2/13/15~~	~~Wed 2/18/15~~	~~38~~
40	~~Ensure fitment of assemblies into their designated sections of airframe~~	~~7 days~~	~~Thu 2/19/15~~	~~Fri 2/27/15~~	~~39~~
41	**Test launch**	0 days	Sat 3/28/15	Sat 3/28/15	
42	~~Final Revisions beofre FRR Proposal~~	~~10 days~~	~~Mon 3/2/15~~	~~Fri 3/13/15~~	
43	Make final modifications to launch vehicle	0 days	Mon 4/6/15	Mon 4/6/15	
44	Pack using launch checklists to ensure everything gets packed	2 days	Fri 4/3/15	Mon 4/6/15	
45	LRR	0 days	Tue 4/7/15	Tue 4/7/15	
46	Correct punch list items	2 days	Tue 4/7/15	Wed 4/8/15	
47	Complete pre launch day procedures	1 day	Thu 4/9/15	Thu 4/9/15	



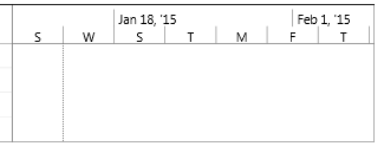
Project: VehicleSchedule.mpp
Date: Mon 3/16/15

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

Page 3

Figure 308: Vehicle project timeline. Page 3.

ID	Task Name	Duration	Start	Finish	Predecessors
48	Launch	0 days	Sat 4/11/15	Sat 4/11/15	
49	PLAR	13 days	Mon 4/13/15	Wed 4/29/15	
50	Write PLAR	12 days	Mon 4/13/15	Tue 4/28/15	
51	PLAR Due	0 days	Wed 4/29/15	Wed 4/29/15	



Project: VehicleSchedule.mpp
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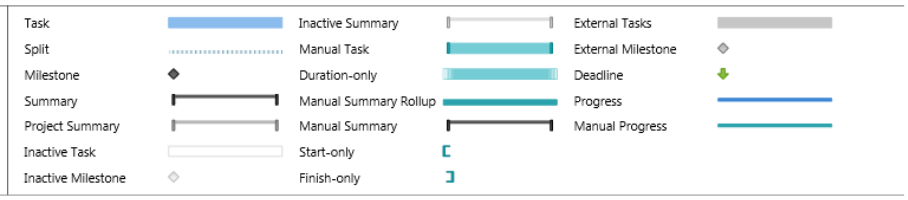


Page 4

Figure 309: Vehicle project timeline. Page 4.

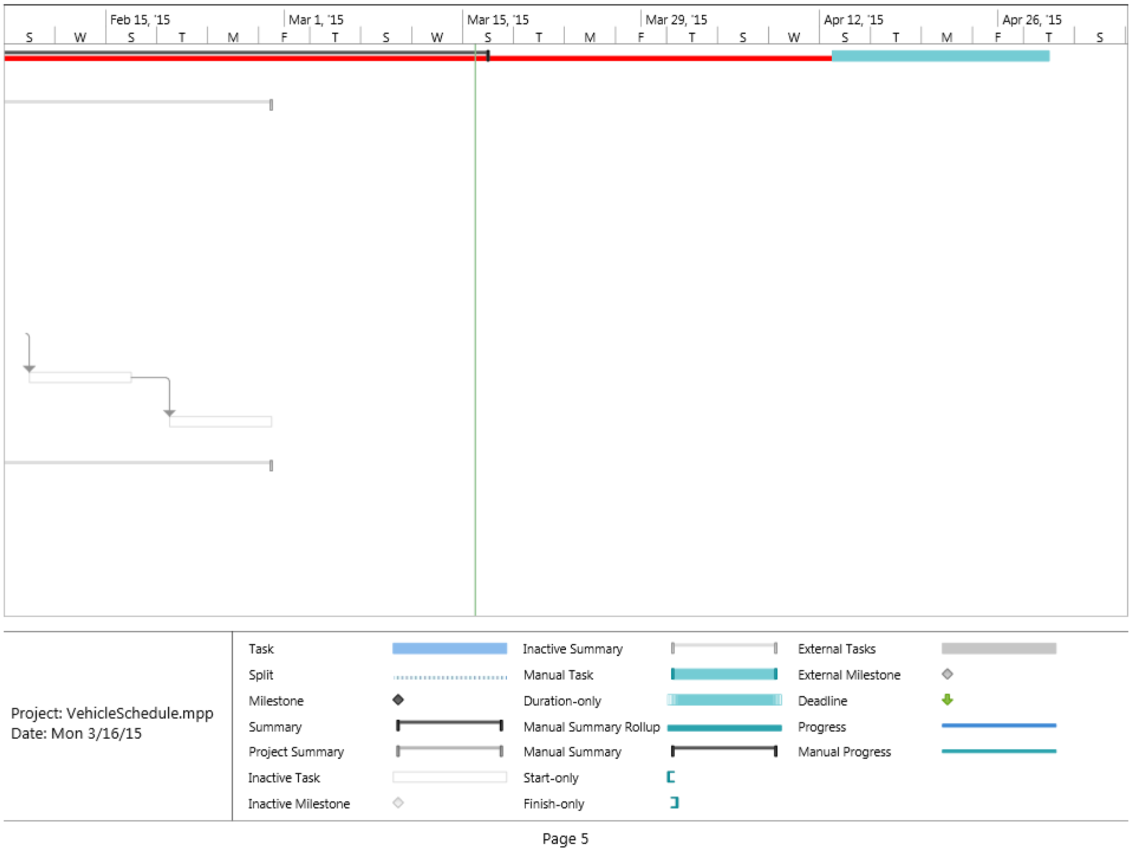


Figure 310: Vehicle project timeline. Page 5.

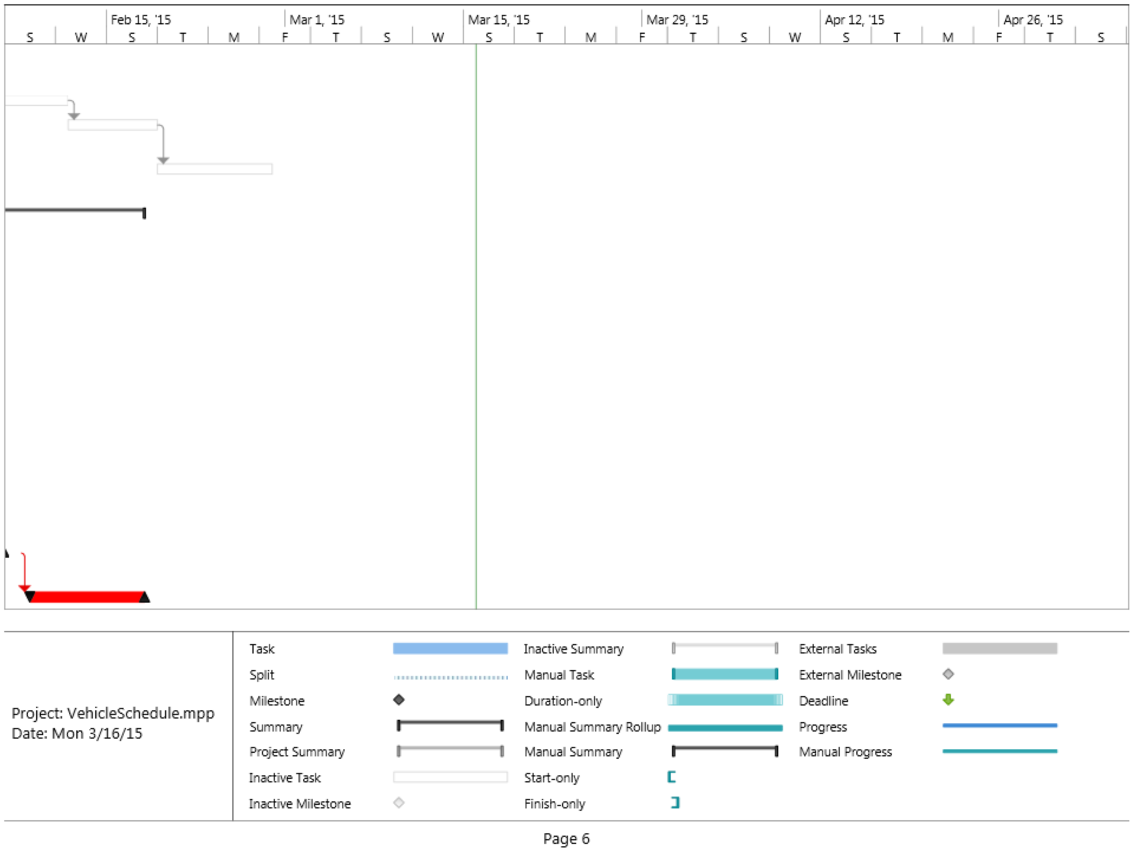


Figure 311: Vehicle project timeline. Page 6.

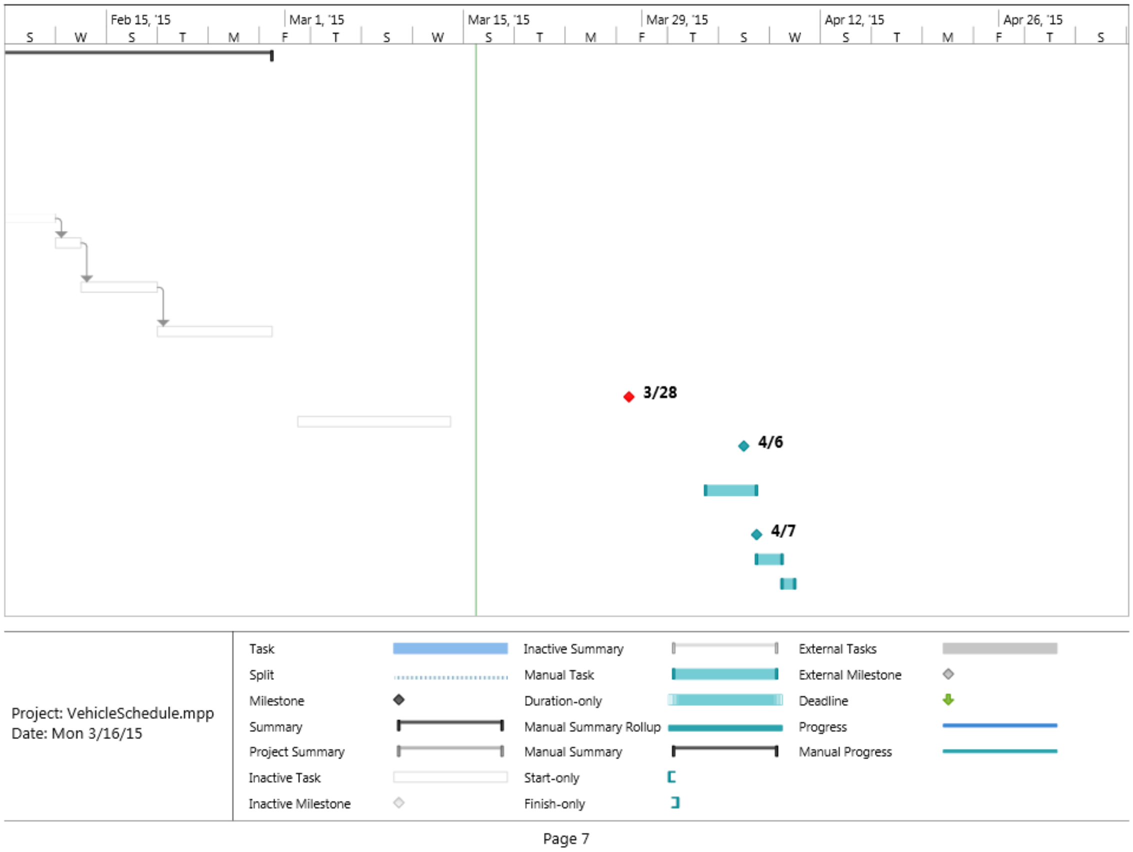


Figure 312: Vehicle project timeline. Page 7.

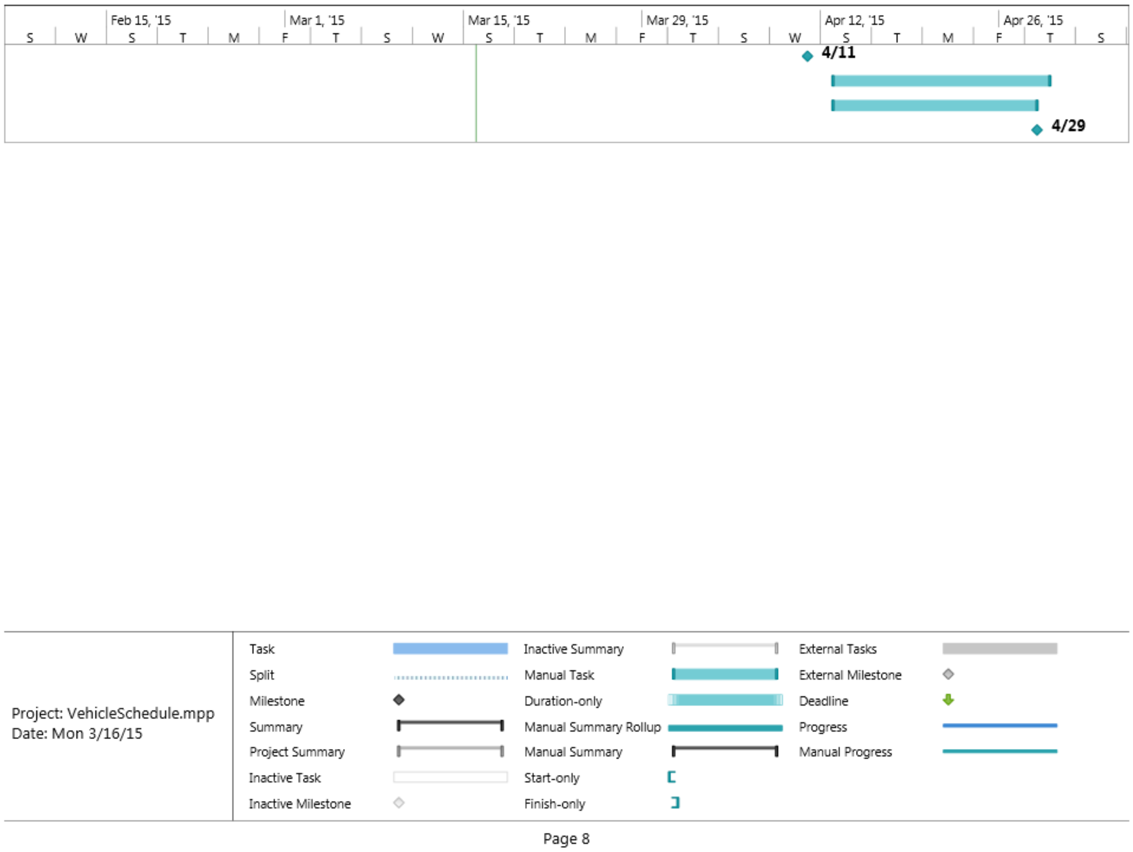


Figure 313: Vehicle project timeline. Page 8.

ID	Task Name	Duration	Start	Finish
1	~~CDR~~	~~52 days~~	~~Wed 11/5/14~~	~~Thu 1/15/15~~
2	~~Design subscale vortex ring~~	~~8 days~~	~~Wed 11/5/14~~	~~Fri 11/14/14~~
3	~~Size subscale parachute~~	~~4 days~~	~~Wed 11/5/14~~	~~Mon 11/10/1~~
4	~~Determine mounting hardware for subscale design~~	~~6 days~~	~~Wed 11/5/14~~	~~Wed 11/12/14~~
5	~~—Part order for subscale~~	~~8 days~~	~~Wed 11/5/14~~	~~Fri 11/14/14~~
6	~~Construction Parachute and deployment bag~~	~~26 days~~	~~Mon 11/10/14~~	~~Mon 12/15/14~~
7	~~Ground test vortex ring~~	~~26 days~~	~~Fri 11/14/14~~	~~Fri 12/19/14~~
8	~~Determine coefficient of drag~~	~~26 days~~	~~Fri 11/14/14~~	~~Fri 12/19/14~~
9	~~Subscale Launch~~	~~0 days~~	~~Sat 12/20/14~~	~~Sat 12/20/14~~

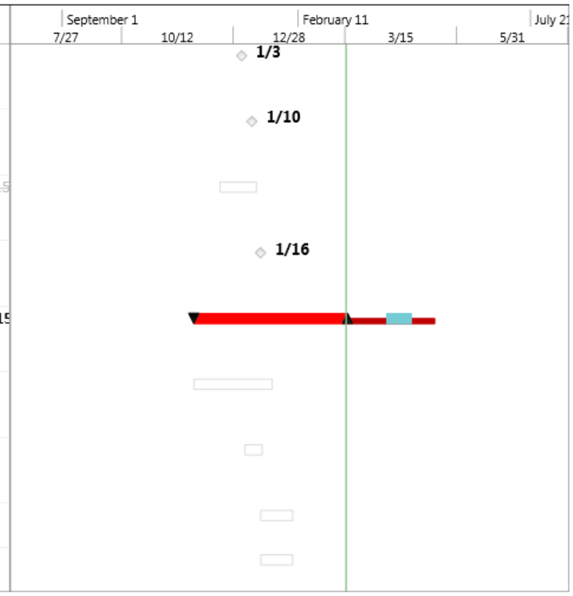
Project: RecoverySchedule.mpp
Date: Mon 3/16/15

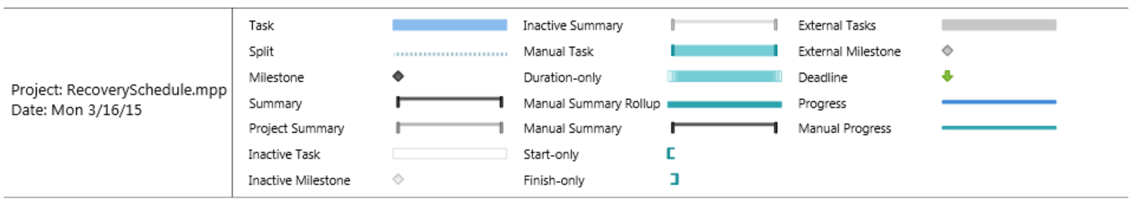
Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress

Page 1

Figure 314: Recovery project timeline. Page 1.

ID	Task Name	Duration	Start	Finish
10	~~Test flight~~	~~0 days~~	~~Sat 1/3/15~~	~~Sat 1/3/15~~
11	~~Final Subscale Launch~~	~~0 days~~	~~Sat 1/10/15~~	~~Sat 1/10/15~~
12	~~Write CDR~~	~~17 days~~	~~Fri 12/19/14~~	~~Mon 1/12/15~~
13	~~CDR Due~~	~~0 days~~	~~Fri 1/16/15~~	~~Fri 1/16/15~~
14	**FRR**	**76 days**	**Mon 12/1/14**	**Mon 3/16/15**
15	~~Order full scale parts~~	~~40 days~~	~~Mon 12/1/14~~	~~Fri 1/23/15~~
16	~~Finalize full scale design~~	~~10 days~~	~~Mon 1/5/15~~	~~Fri 1/16/15~~
17	~~Construction of full scale vortex ring~~	~~16 days~~	~~Fri 1/16/15~~	~~Fri 2/6/15~~
18	~~Construction of full scale cruciform parachute~~	~~16 days~~	~~Fri 1/16/15~~	~~Fri 2/6/15~~

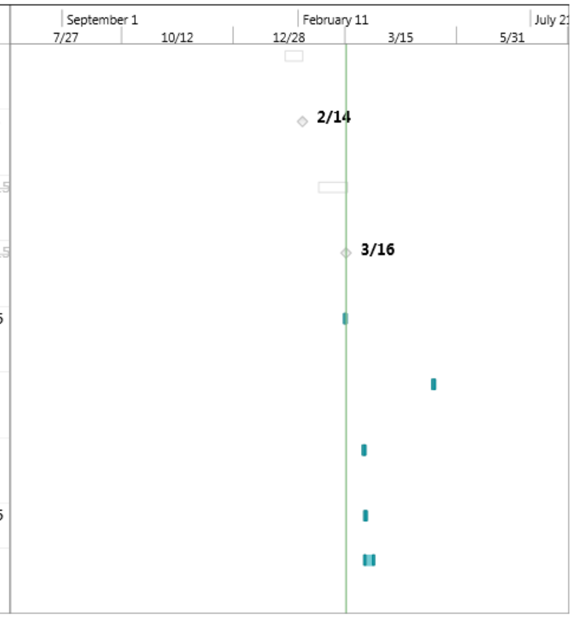




Page 2

Figure 315: Recovery project timeline. Page 2.

ID	Task Name	Duration	Start	Finish
19	~~Ground testing - verify predicted coefficient of drag for vortex ring~~	~~10 days~~	~~Mon 2/2/15~~	~~Fri 2/13/15~~
20	~~Full scale test flight~~	~~0 days~~	~~Sat 2/14/15~~	~~Sat 2/14/15~~
21	~~Write FRR~~	~~14 days~~	~~Wed 2/25/15~~	~~Mon 3/16/15~~
22	~~FRR Due~~	~~0 days~~	~~Mon 3/16/15~~	~~Mon 3/16/15~~
23	Ground test vortex ring	1 day	Sun 3/15/15	Sun 3/15/15
24	Verrify packing method	1 day	Fri 5/15/15	Fri 5/15/15
25	2nd Full scale test launch	1 day	Sat 3/28/15	Sat 3/28/15
26	Inspect parachutes for any damage from testing	1 day	Sun 3/29/15	Sun 3/29/15
27	Repair parachutes as needed	6 days	Sun 3/29/15	Fri 4/3/15



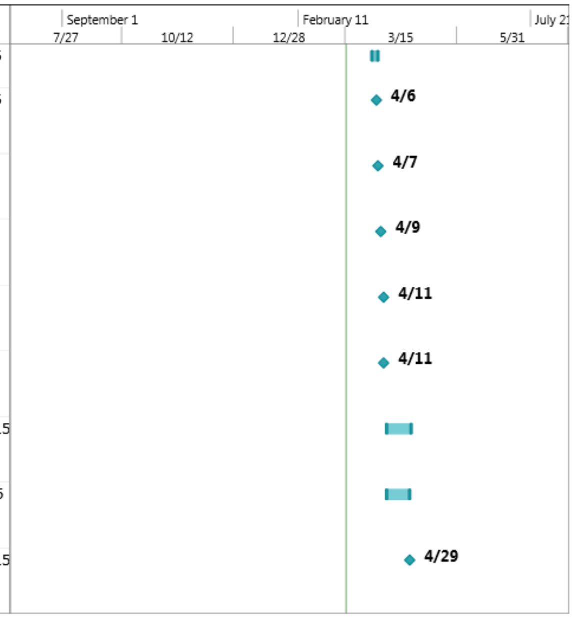
Project: RecoverySchedule.mpp
Date: Mon 3/16/15

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

Page 3

Figure 316: Recovery project timeline. Page 3.

ID	Task Name	Duration	Start	Finish
28	Pack parachutes for Huntsville	2 days	Fri 4/3/15	Mon 4/6/15
29	Travel to Huntsville	0 days	Mon 4/6/15	Mon 4/6/15
30	LRR	0 days	Tue 4/7/15	Tue 4/7/15
31	Rocket Fair	0 days	Thu 4/9/15	Thu 4/9/15
32	Launch	0 days	Sat 4/11/15	Sat 4/11/15
33	Banquet	0 days	Sat 4/11/15	Sat 4/11/15
34	PLAR	13 days	Mon 4/13/15	Wed 4/29/15
35	Write PLAR	12 days	Mon 4/13/15	Tue 4/28/15
36	PLAR Due	0 days	Wed 4/29/15	Wed 4/29/15



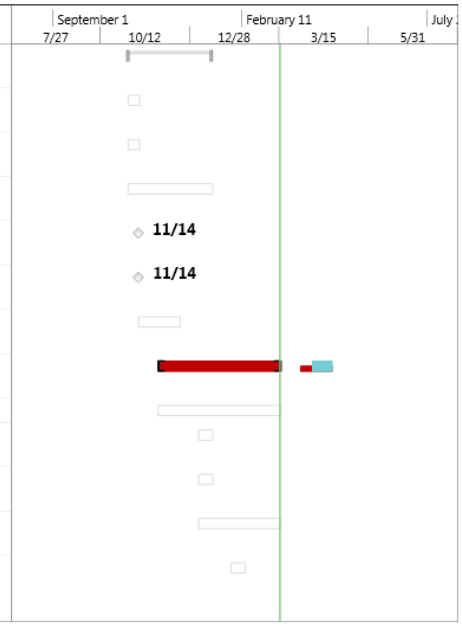
Project: RecoverySchedule.mpp
Date: Mon 3/16/15

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

Page 4

Figure 317: Recovery project timeline. Page 4.

ID	Task Name	Duration	Start	Finish	Predecessors
1	~~CDR~~	~~52 days~~	~~Wed 11/5/14~~	~~Thu 1/15/15~~	
2	~~Finalize design for subscale~~	~~8 days~~	~~Wed 11/5/14~~	~~Fri 11/14/14~~	
3	~~Identify all potential risks~~	~~8 days~~	~~Wed 11/5/14~~	~~Fri 11/14/14~~	
4	~~Update risk assessment matrix~~	~~53 days~~	~~Wed 11/5/14~~	~~Fri 1/16/15~~	
5	~~Lab safety training seminar~~	~~0 days~~	~~Fri 11/14/14~~	~~Fri 11/14/14~~	
6	~~Team safety compliance forms due~~	~~0 days~~	~~Fri 11/14/14~~	~~Fri 11/14/14~~	
7	~~Prepare subscale launc procedures~~	~~26 days~~	~~Fri 11/14/14~~	~~Fri 12/19/14~~	
8	**FRR**	**76 days**	**Mon 12/1/1**	**Mon 3/16/1**	
9	~~FRR~~	~~76 days~~	~~Mon 12/1/1~~	~~Mon 3/16/1~~	
10	~~Finalize full scale design~~	~~10 days~~	~~Mon 1/5/15~~	~~Fri 1/16/15~~	
11	~~Identify all potential risks~~	~~10 days~~	~~Mon 1/5/15~~	~~Fri 1/16/15~~	
12	~~Update risk assessment matrix~~	~~51 days~~	~~Mon 1/5/15~~	~~Mon 3/16/15~~	
13	~~Ground testing - validation of systems/risk mitigation~~	~~10 days~~	~~Mon 2/2/15~~	~~Fri 2/13/15~~	

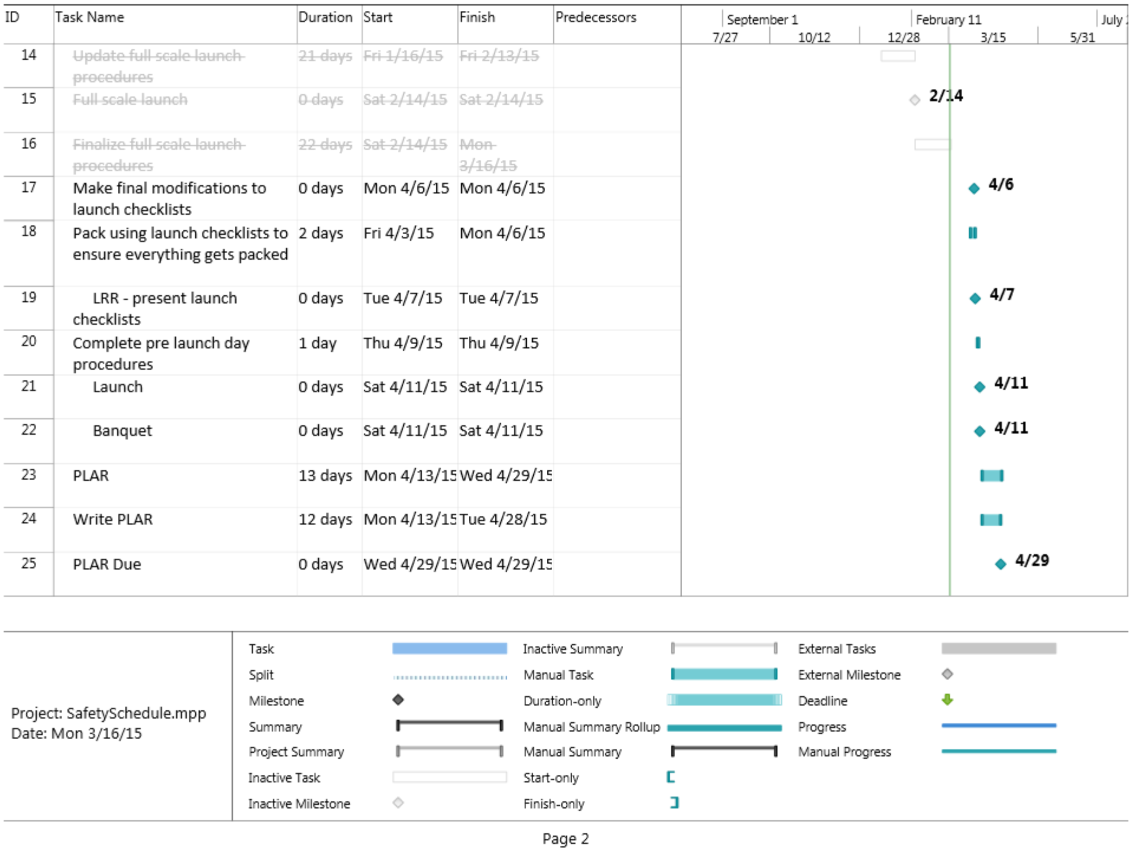


Project: SafetySchedule.mpp
Date: Mon 3/16/15

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

Page 1

Figure 318: Safety project timeline. Page 1.



ID	Task Name	Duration	Start	Finish	Predecessors
14	~~Update full scale launch procedures~~	~~21 days~~	~~Fri 1/16/15~~	~~Fri 2/13/15~~	
15	~~Full scale launch~~	~~0 days~~	~~Sat 2/14/15~~	~~Sat 2/14/15~~	
16	~~Finalize full scale launch procedures~~	~~22 days~~	~~Sat 2/14/15~~	~~Mon 3/16/15~~	
17	Make final modifications to launch checklists	0 days	Mon 4/6/15	Mon 4/6/15	
18	Pack using launch checklists to ensure everything gets packed	2 days	Fri 4/3/15	Mon 4/6/15	
19	LRR - present launch checklists	0 days	Tue 4/7/15	Tue 4/7/15	
20	Complete pre launch day procedures	1 day	Thu 4/9/15	Thu 4/9/15	
21	Launch	0 days	Sat 4/11/15	Sat 4/11/15	
22	Banquet	0 days	Sat 4/11/15	Sat 4/11/15	
23	PLAR	13 days	Mon 4/13/15	Wed 4/29/15	
24	Write PLAR	12 days	Mon 4/13/15	Tue 4/28/15	
25	PLAR Due	0 days	Wed 4/29/15	Wed 4/29/15	

Figure 319: Safety project timeline. Page 2.

4) Educational Engagement

In previous years, the University of Louisville River City Rocketry Team has managed to reach out to many students and adults in the local community. Schools from across the state of Kentucky were able to get a hands on experience with engineering and rocketry working side-by-side with members of the team. The team strove to maintain relationships built with organizations in the community while continuing to reach people in new ways. The focus was not on how many people could be reached, but the quality of education that was brought to each and every individual.

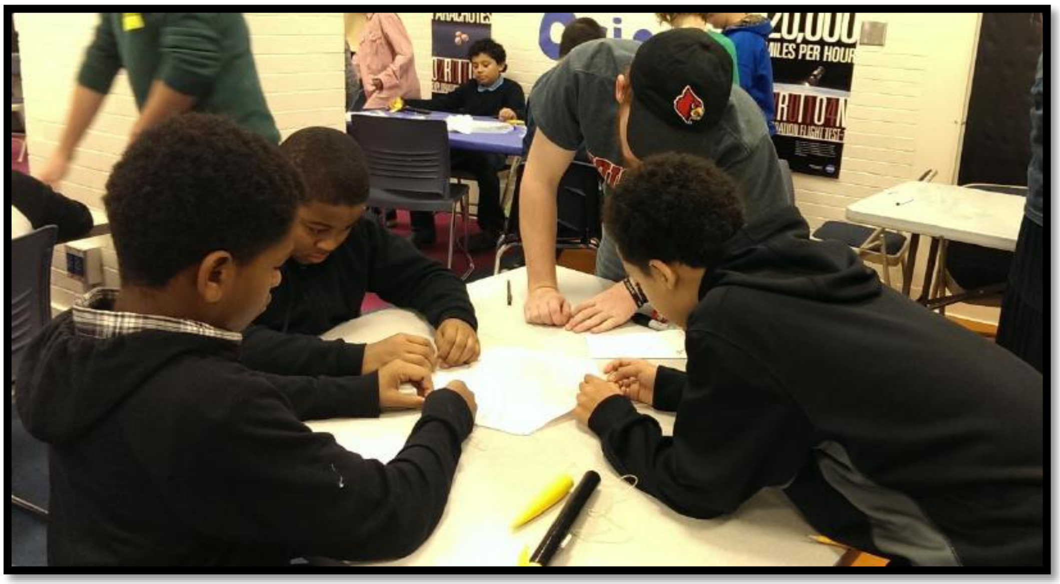


Figure 320: Ross assisting students in assembling their parachute.

Curriculum

The team has developed a variety of new programs that have been incorporated into this year's outreach program. Included is a list of the different activities in which the team has participated in this season.

Last year the team added a six week aerospace program that was a huge success. Due to the high demand by schools to have the program offered at their schools, the team continued to offer this program. With the incorporation of robotics into NASA's competition and the large increase in the electrical and programming team, the team offered a similar program that incorporated robotics and basic programming. The curriculum for the aerospace and engineering programs are detailed below.

6 Day Aerospace Program Curriculum

Figure 321: A young engineer building a paper rocket at E-Expo.

Day 1: The Space Race and Mercury and Gemini Program History:
This lesson introduces the cold war, the relationship between the United States and the U.S.S.R. and how it propagated the space race. The beginning of space history is discussed, including the missions and objectives from the Mercury and Gemini programs. America's achievements are highlighted such as Alan Shepard becoming the first American in space and John Glenn becoming the first American to orbit the Earth. Rocketry concepts are taught including rocket stability, principles of aerodynamics, Newton's Laws, and basic rocket building techniques. The day concludes with the building and launching of paper rockets.

Day Two: Apollo Program History:
This lesson examines in detail the most monumental program in the history of manned spaceflight. The students will learn about the 17 Apollo missions, including the fatal fire of Apollo 1, mankind's giant leap of Apollo 11, the "successful failure" of Apollo 13, and the rest of the historic moon landings. Core concepts taught during this lesson are:

- Thrust-to-weight ratio.
- Improved rocket building techniques (Advanced paper rocket activity).

Figure 322: Emily helping students prepare their rocket for launch.

Day Three: Shuttle Program, ISS, and Curiosity Rover History:
This lesson examines in detail the movement of NASA from making deep space missions, to mastering low-earth-orbital techniques. The space shuttle was also analyzed from a standpoint of reusability. The International Space Station is followed with a look into what it takes to sustain life in low earth orbit. Finally, a brief look at the Curiosity Rover mission demonstrates how we land a probe on another planet. Students had the opportunity to do the following:

- Understand the use of composites vs. metals in aerospace applications.

- Design a payload that would fit inside the space shuttle cargo bay.
- Design a space station with the fundamental elements for sustaining life.
- See simulations of extra-terrestrial landing techniques for unmanned missions.
- See videos from inside the International Space Station.

Day Four: OpenRocket Simulation:

The class had the opportunity to model the Estes rocket that they built in the fifth day of the program. A worksheet is prepared with all of the parameters to accurately simulate the rocket. The simulation software allows the students to learn how to use the same program that the University of Louisville River City Rocketry Team uses to simulate their rocket. This stresses the importance of precisely predicting flight trajectories and altitudes. The following concepts are discussed:

- Understanding how math is applied through software simulations.
- Mass balance.
- Stability margin acceptability.
- The relationship between position, velocity, and acceleration curves and flight events.

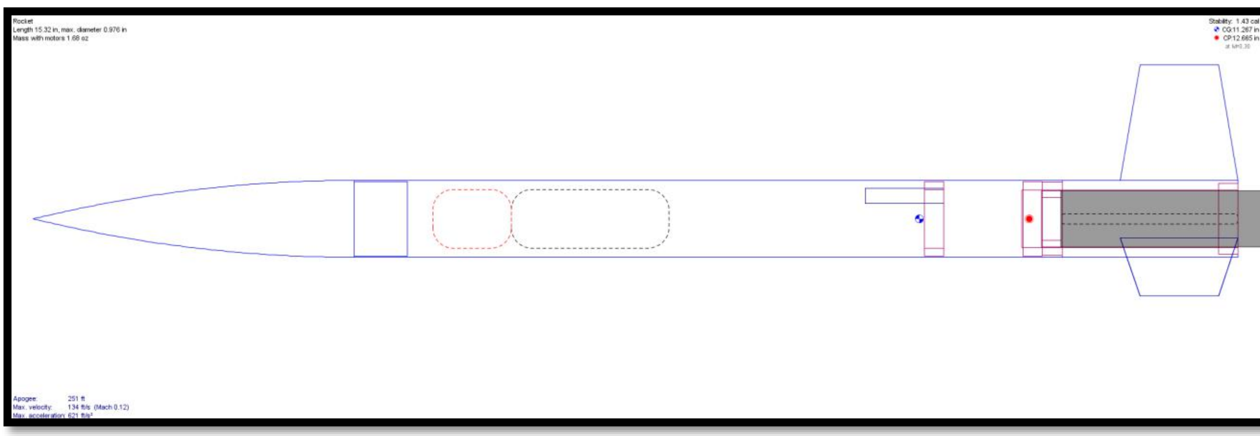


Figure 323: OpenRocket simulation created by students.

Day Five: Rocket Construction:

Each student has the opportunity to construct and launch their own rocket. Rockets are small Estes model rockets using black powder motors. Each student is be carefully supervised. The students are led through a visual walkthrough of rocket assembly. The following concepts are taught:

- Proper measurement and construction techniques.
- Fin installation.
- Launch lug mounting.
- Shock cable and parachute organization.

Day Six: Final Construction/Rocket Launch:

The students are taken through a safety briefing by a member of the University of Louisville River City Rocketry Team. Any remaining construction work on the rockets is completed during this session. The students are taught how to pack parachutes, load motors, install igniters and develop a pre-launch checklist. Finally, the students launched their rockets.

Figure 324: Carlos helping a student prep her rocket for launch.

Figure 325: A middle school student launching her rocket.

<u>Six Week Exploring Rocketry and Engineering Program</u>

The goal of this program is to not only talk about rocketry, but to introduce students to the variety of disciplines of engineering that are involved. We want them to understand that there is more to it than just the mechanical aspects. The first three weeks, the team rotates through, allowing each discipline, mechanical, electrical, and computer engineering, to teach a lesson. The last half of the program is spent bringing the concepts together by simulating, building, and launching a rocket. Specific day by day plans are further described below.

Day One: Programming

Team members give an hour presentation to teach students of the importance of programming in today's world. We give an in depth look at the history of programming, discussed the basics of how programming works, and talked about the evolution and innovation of programming and how it can change the world that we live in.

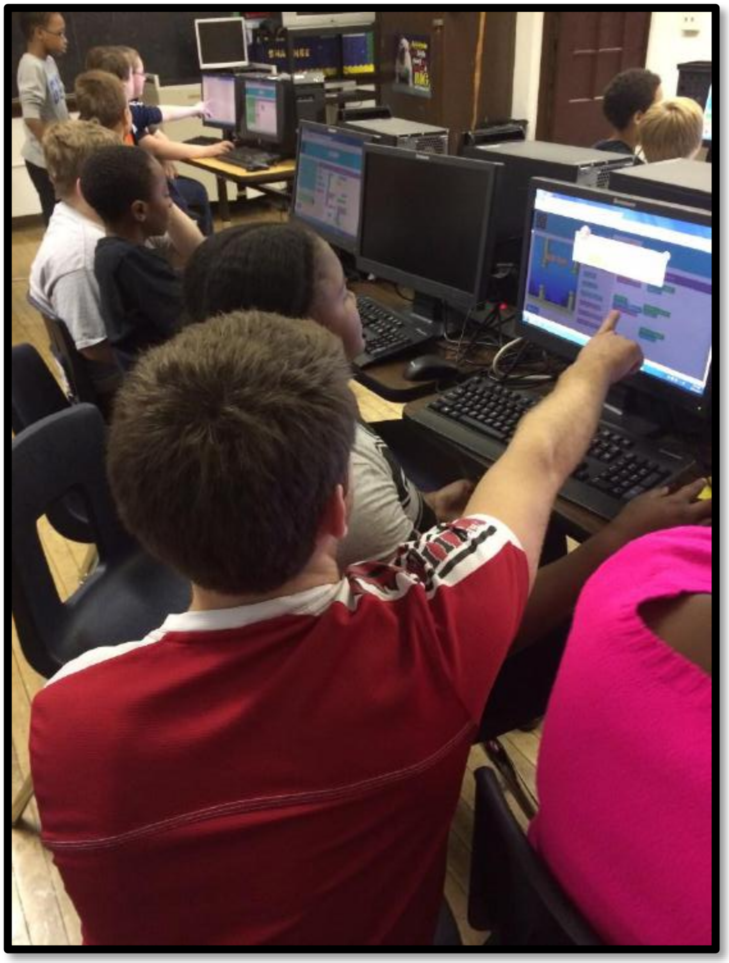


Figure 326: David teaches students how to program a game on code.org.

Students spend a second hour in the programming lab. Here students get the opportunity to utilize online tools from code.org to teach the students how to program on their own. Students are able to build, test, and manipulate their own custom game programs.

Day Two: Satellites

Team members give a presentation to teach students about satellites. We introduce the students into what defines a satellite. The students interact with the team members listing and describing various applications for satellites, and how they function to perform a defined task. We also involve the students in a history of the first satellites all the way up to the most recent Rosetta satellite and Philae lander.

The team stresses the importance of interpreting data from a satellite, and describes how certain satellites transmit data. A team member created a program that took an imported black and white image, recognized the black pixels from the white ones and assigned a coordinate to it. The program breaks down the entire image into various coordinate systems ranging from (A,1) to (J,10). Each coordinate system is a piece of the uploaded image. These coordinate systems are printed on individual pieces of paper for the students to fill out. Coordinates referencing a black pixel are shown in a table. Students then color in their respective coordinate systems, and at the end of the activity each student's completed coordinate system is taped together to form the original image.

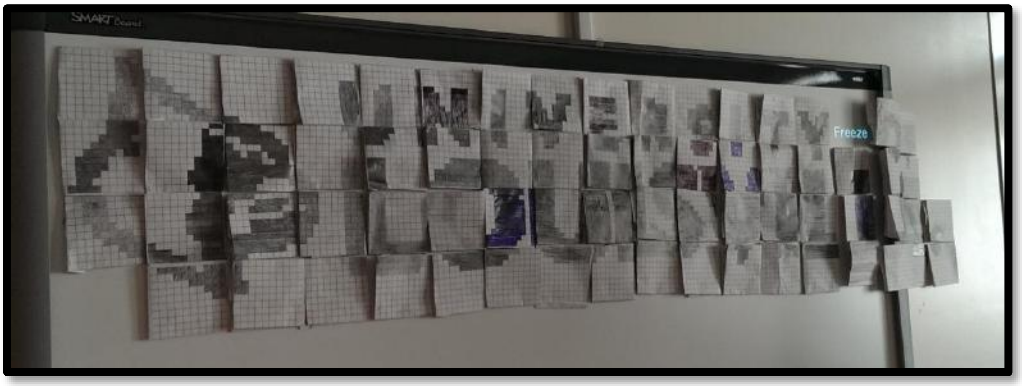


Figure 327: The satellite message that students decoded.

The activity shows how a satellite sends data back in a series of information points. It also stresses the idea that not every data signal is completely correct. The students are able to see various inconsistencies in the final image, whether it be due to the wrong block being filled out, or someone forgetting a particular coordinate. The students are given an understanding as to how and why people are needed to review every set of data from a satellite to interpret, determine if there are unexpected artifacts in the signal, and lay out the completed interpreted signal.

Day 3: Circuits

Team members gave a presentation to teach students about electronics and circuitry. We introduce the students to the basics of electronics with a PowerPoint presentation and an interactive activity. The students interact with the team members listing and describing various components that make up your average circuit board, and how they perform. We also involve the students in a history of circuitry to give the students an appreciation for where we've come to in this technologically advanced world.

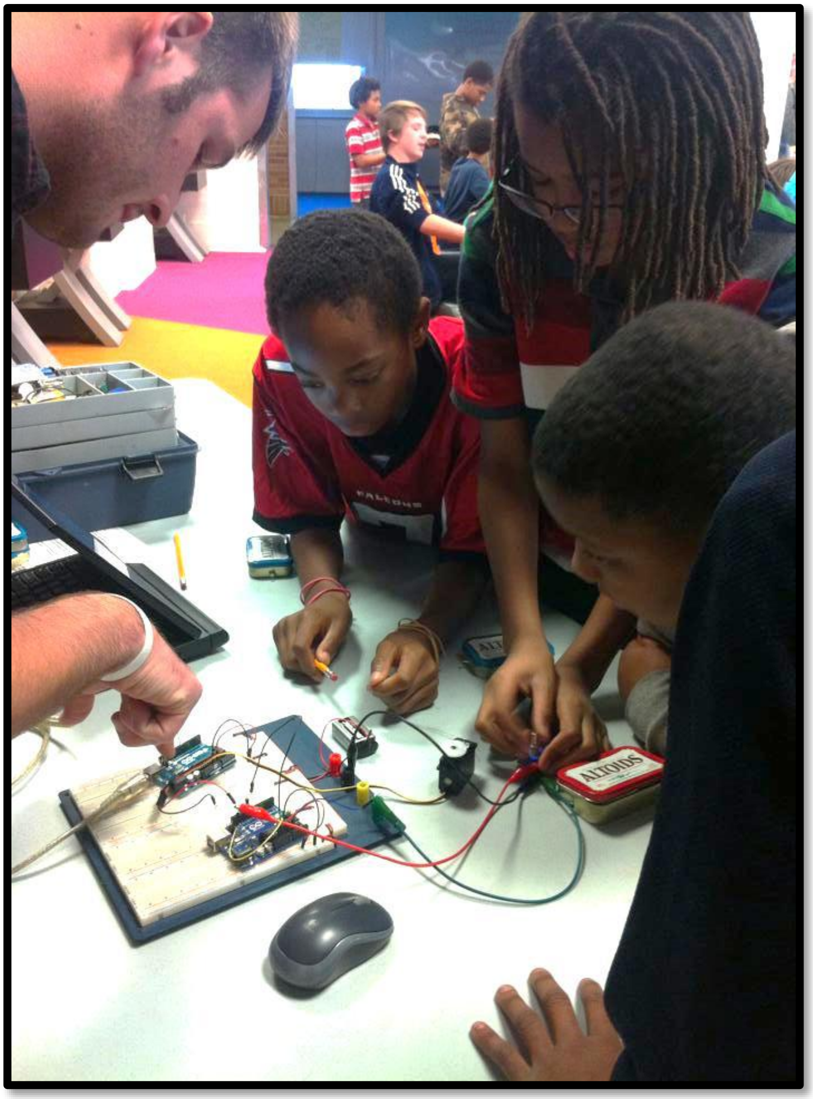


Figure 328: Sherman shows students a circuit that he built and how it works.

The primary focus is to help the students understand how various components work together to complete a certain task. The activity designed for this course is a great tool to do just that. The team helps each student build their very own “Altoid Flashlight.” Together, students are able to build a functioning circuit with a 9V battery, a resistor, an LED, and a toggle switch. They learn the ins and outs of the circuit and are able to ask questions throughout the experiment to gather a better understanding of their custom system.

After the activity, team members set up a bread-board circuit that allows students to manipulate the circuitry to control various small motors. They are able to be hands on with various components to see how varying the voltage and current through a system can have an effect on the output of the system.

Day 4: OpenRocket Simulations

The team gives a presentation to the students on what it takes to build a high powered rocket. We stress the importance of simulation and how it can affect your design. We walk students through the basics of individual components of a rocket. Each primary component is talked about in great detail to give the students a firm understanding of the complete system. The team brings in last year's subscale launch vehicle to act as a "dissectible patient" so the students could look at both the internal and external components of what goes into a high powered launch vehicle.

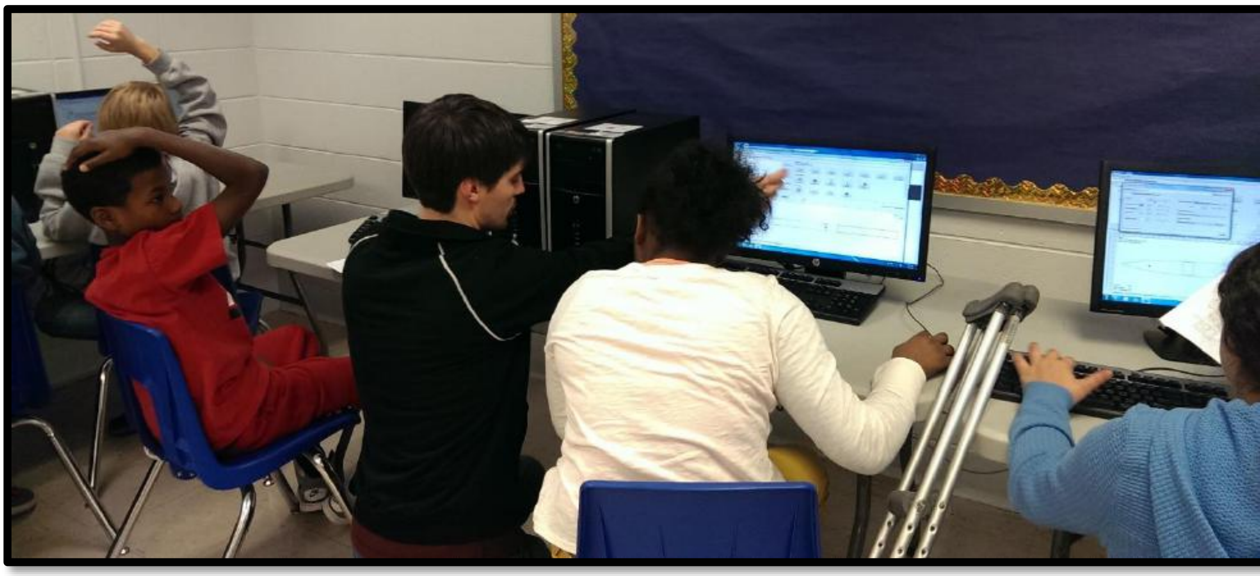


Figure 329: Gregg helps student with her OpenRocket simulation.

When the students have an understanding of all the pieces of a rocket, we introduce them to the OpenRocket simulation software. We walk them through the user interface, how to add components, motors, and how to simulate a flight. The team members teach the students the importance of a stable launch vehicle and how the center of gravity and center of pressure of a launch vehicle plays an important role in determining the rocket's flight. Once the student's know how to run the program, they are given a list of variables to use to simulate the rocket's they build the following week. They are able to estimate their rocket's flight path and altitudes. Afterwards, they were tested to see who could design a rocket to fly the highest!

Day 5: Rocket Construction

Day 6: Rocket Launch

See previous program for details on rocket construction and launch.

<u>Lego Mindstorm Programming</u>

Students work on building and programming Lego Mindstorm robots for a local competition. The groups all work at different paces, so each group is assisted based on where they are at. We work with some groups on the mechanical design of the robots, while other groups are taught the fundamentals of programming the robots. The students write their programs, test them, and continue to tweak the programs until the robot did what they wanted it to do.

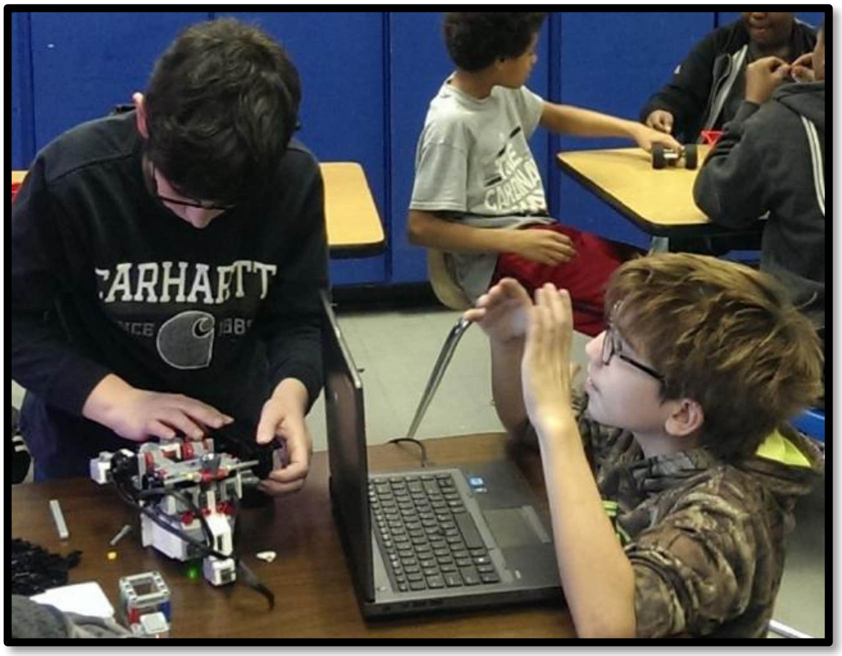


Figure 330: Students discuss designs and modifications to their program.

Outreach Opportunities

<u>Engineering Exposition (E-Expo)</u>
Since 2006, the J.B. Speed School of Engineering Student Council has hosted the larges student-run event on the University of Louisville's campus called Engineering Exposition. The event is geared towards celebrating strides in engineering as well as getting the local youth interested in the field. During the event, the professional engineering societies on UofL's campus set up educational games and scientific demonstrations for the elementary and middle school students to participate in.

The University of Louisville River City Rocketry Team will host its third annual water bottle rocket competition for middle school students. Teams from local middle schools can participate in teams of up to three students to design and build their own water bottle rockets out of two liter bottles and other allowable materials. Workshops will be held with schools interested to teach the students about the components of a rocket and aerodynamics in preparation for the competition. The students will get to show off their rockets at the E-Expo event throughout the day and will conclude the day with the competition. Teams will compete for awards in highest altitude, best constructed rocket, and landing closest to the launch pad. This event has been a huge success in the past and many schools have voice interest in continuing their involvement so we are looking for our best turn out yet this year.

Figure 331: Three students launch a water bottle rocket that they built themselves while at the annual E-Expo.

In addition to the water rocket competition, the team will host a paper rocket station for people of all ages. This has been the most popular station at the exposition in the past and are looking to continue to build up that reputation.

Unfortunately due to snow, this event was partially cancelled. We are looking to schedule a makeup day to host the water rocket competition as well as an open house for students to learn about the team, rocketry, and to get the opportunity to build and launch paper rockets. There are currently 42 teams registered for the competition, with each team comprising of two to three middle school students. We also typically expect around 400 grade school students at the open house. While the entire event cannot be completely rescheduled, we are looking into options to give as many students the opportunity to learn about rocketry.

<u>Boy Scouts and Cub Scouts:</u>
In the past, the University of Louisville River City Rocketry Team has worked with local Boy Scout and Cub Scout troops to assist the earning of the Space Exploration merit badge. The team has assisted in developing a program that meets the requirements to earn the merit badge. The scouts get to learn about the history of space, current space endeavors, and build and launch an Estes rocket. The team has plans to continue to work with these groups throughout the year. While cub scouts are not eligible to earn

their merit badge, we still enjoy getting to teach them about rocketry. This year, we have had the pleasure of working with three scouts troops in educating the kids about the fundamentals of rocketry, while also giving them the opportunity to build and launch their own paper rockets.

Big Brothers Big Sisters Partnership:

Big Brothers Big Sisters is active in the Louisville community and is constantly striving to bring opportunities to underprivileged kids. The team recently put on a program with a group of kids that had not yet been paired with a mentor through the program. Through this event, we have established a relationship with Big Brothers Big Sisters and are looking forward to bringing more programming to the students involved in this organization.

Figure 332: A thought provoking "little brother" grills the team on the fundamentals of rocketry.

Louisville Mini-Maker Faire

Every year Louisville hosts a mini-maker faire. The team took the project out to show off to anyone attending the event. We worked with small children as well as adults with experience in the field. This gave us an opportunity to talk to the community about our project and what our rocket does. People were given the opportunity to ask questions about anything about the rocket, what it does, and how it works.

First Lego League Competition

The competition was an all-day event and the team did several activities throughout the day. Throughout the majority of the day, the team had a display set up so that when students were in between events, we could talk to them about the previous year's rocket and rover. This was a good way to show the students how programming can be applied into something beyond their Lego Mindstorm robots.

During the competition period, team members assisted in the judging process. We helped to judge a portion of the competition called core values. In this, we tested the students in a variety of ways to see how well they worked together as a team and how dedicated they were to their project. The first way this was tested, is that the students were given a task of building a structure out of spaghetti and marshmallows. The students were free to design whatever they wanted in the allotted time frame. Afterwards, they were asked why they built what they built, how they measured its success, and why they came to some of the conclusions that they did. This was important to show the student the importance of being able to work together as a team and qualities of a successful team.

Figure 333: Justin judging core values at the FLL competition.

At the end of the day, while all of the teams were waiting for the final results of the competition, the team gave a presentation to all of the students, parents, and educators present. Here we were able to talk about what we do as a team and relate that to the students' projects. We discussed the how we still use the same design process that they do: design, test, design improvement, test, and work to completion. We also discussed opportunities to continue programming and the possibilities in the aerospace industry.

<u>Women in STEM</u>

The event was all about encouraging young girls in engineering. A documentary was shown about women in space and what these women have been able to accomplish. We talked about how STEM used to be very difficult for women to engage in, and looked at some of these women that broke down those barriers. The team member discussed her experiences in STEM including involvement and leadership position on the NASA student launch team. She also talked about her experiences working with Raytheon Missile Systems, challenges she faced during that, and how these challenges were overcome. She tried to encourage the girls to pursue careers in engineering. The variety of options in engineering was exposed to the girls, showing them how diverse the field is from mechanical, computer, biomedical, to chemical engineering. At the end of the session, the girls had the opportunity to ask questions to the team member. The team member fielded questions such as "what classes did you take when you were in high school to prepare yourself for a career in STEM?"

Progress

The team has already been extremely active throughout the season with regards to educational outreach. While we have not yet reached our goal of 1000 students engaged due to the cancelation of E-expo, we are pleased with the quality of programs and the number of students we have been able to reach.

Participant's Grade Level	Education		Outreach	
	Direct Interactions	**Indirect** Interactions	**Direct** Interactions	**Indirect** Interactions
K-4	42	0	0	0
5-9	367	0	392	0
10-12	0	0	50	0
12+	0	0	0	0
Educators (5-9)	25	10	44	0
Educators (other)	5	0	24	0
Total Outreach	**959**			

Table 87: Educational outreach totals for the season.

We continuously strive to inspire students across our community to discover a passion for STEM and to pursue lifelong learning. The community has supported our school team tremendously and we understand the importance of giving back to the community. Just because our season is coming to a close, doesn't mean that we stop working with the youth of our community. We continue to offer programs throughout the summer in an effort to encourage as many students as possible.

Section 6. Appendix I – Subscale Launch Procedures

Safety Checklist: Stability and Propulsion

To be checked and initialed by S&P Safety representative.

Stability and Propulsion Representative Signatures:

1. ______________________________ *2.* ______________________________

Prior to leaving for launch site:

Sustainer Propulsion Bay Assembly Checklist:

Required Equipment:

- *Gorilla Glue*
- *Grease*
- *Lower Sustainer Stand*
- *K360 motor*
- *Motor retainer*

Required PPE:

- *Nitrile Gloves*

1. ___ The team mentor will be responsible for preparing motor within casing.
   ⚠CAUTION: Protective gloves are to be worn when applying grease to the motor.
2. ___ Slide motor casing fully into the motor mount tube.
3. ___ Attach motor retention ring. Do not over-torque.
4. ___ Set completely assembled bay on stand; do not rest on fins.
5. ___ Inspect each fin fillet for any signs of cracking or fatigue.
   Note: If any damage is identified, **immediately** inform both of the team captains and the safety officer. The rocket will be deemed safe to fly or a corrective action will be decided upon and implemented.

⚠ DANGER The motor is not allowed to be handled by personnel without proper certifications. Individuals handling the motor need to ensure assembly is stored in a safe and secure place void of moisture and open flames.

Safety Checklist: General Preparations

To be checked and initialed by River City Rocketry team member.

River City Rocketry Team Member Signatures:

1. ___________________________ *2.* ______________________________

Prior to leaving for launch site:

Required Equipment:

- *Clear black powder capsules (x4)*
- *E-matches (x4)*
- *Drill*
- *1/8" drill bit*
- *Electrical tape*
- *Scissors*
- *Black powder*
- *Paper towels*

Required PPE:

- *Safety glasses*

Black Powder Charge Preparation

1. ___ Drill a 1/8" hole in the bottom of each of the clear black powder capsules.
   ⚠**CAUTION**: Safety glasses are to be worn while drilling.
2. ___ Unwind one e-match.
3. ___ Feed wire from the e-match through the hole in the base of a capsule. Ensure the pyrotechnic end of the e-match is inside the capsule.
4. ___ Wrap electrical tape to secure the e-match in place and to ensure that black powder will not leak from the capsule.
   ⚠**WARNING** If the capsules are not completely sealed, black powder will leak when the capsules are filled. Leakage could potentially result in ejection charges being too small or failing altogether, causing a catastrophic failure in recovery.
5. ___ Fill capsules with black powder up to line on container. Fill excess space with a piece of paper towel to ensure black powder remains in contact with the pyrotechnic tip of the e-match no matter the orientation of the capsule.
6. ___ Repeat steps 2 through 4 four times.
7. ___ Store modified capsules and e-matches in explosives box.

DANGER E-matches are explosive. The black powder charges and leads must be kept clear from batteries and any open flames in order to avoid accidental firing.

GPS Preparations

Required Equipment:

- *GPS unit*
- *GPS charger*
- *Aluminum tape*

1. ___ Check GPS unit for full charge. If not fully charged, charge GPS units.
2. ___ Ensure that nosecone bulk plate has complete coverage of aluminum tape.
   WARNING Ensure that the entire inside of the GPS bay is properly shielded in order to protect from interference with the avionics bay. In the incident that interference occurs, pyrotechnic devices may be actuated prematurely, causing potential harm to personnel and mission failure.

<u>Launch Day Procedures:</u>

Nosecone GPS Installation

Required Equipment:

- *GPS unit*
- *M3 screws (x2)*
- *Socket cap screws (x4)*
- *Metric socket set*
- *GPS tracking device*
- *¼ -20 nuts (x2)*
- *Washers (x2)*

1. ___ Turn on GPS unit.
2. ___ Check GPS unit for contact with tracking device.
3. ___ Securely mount GPS to GPS sled in lower sustainer using two M3 screws.
4. ___ Insert GPS sled onto threaded rods in GPS.
5. ___ Install bulk plate for the nosecone onto threaded rods. Insure that it is fully seated on the coupling of the nosecone.
6. ___ Secure bulk plate to nosecone using two ¼ - 20 nuts and washers.

Safety Checklist: Recovery

To be checked and initialed by Recovery Safety representatives.

Recovery Representative Signatures:

1. ______________________________ *2.* __________________________________

Prior to leaving for launch site:

Parachute Packing

Required Equipment:

- *50" main parachute*
- *15" drogue parachute*

1. ___ Inspect canopy and lines for any cuts, burns, fraying, loose stitching and any other visible damage.

   Note: If any damage is identified, **immediately** inform both of the team captains and the safety officer. The rocket will be deemed safe to fly or a corrective action will be decided upon and implemented.
2. ___ Lay parachute canopy out flat.
3. ___ Ensure shroud lines are taut and evenly spaced and not tangled.
4. ___ Fold parachute.
5. ___ Repeat steps 1 through 4 for each parachute.

   ___ 50" main parachute packed

   ___ 15" drogue parachute packed

Avionics Bay:

- *Precision flathead screwdriver*
- *Standard Phillips head screwdriver*
- *Avionics bay altimeter sled*
- *StratoLogger altimeter (x2)*
- *4x40 shear pins (x14)*
- *Battery holster cover (x2)*
- *Duracell 9V battery (x2)*
- *Battery clips (x2)*
- *Multimeter*
- *Wire*
- *Wire strippers*
- *¼ -20 nuts (x2)*
- *Washers (x2)*

1. ___ Verify proper shielding on both bulk plates for the avionics bay.

   WARNING Ensure that the entire inside of the avionics bay is properly shielded in order to protect from interference. In the incident that interference occurs, pyrotechnic devices may be actuated prematurely, causing potential harm to personnel and mission failure.
2. ___ Verify StratoLogger altimeters are properly programed in accordance with file in team Dropbox folder.
3. ___ Verify 9V batteries has a minimum charge of 8V.
4. ___ Attach batteries to battery clips and install into holster.
5. ___ Attach battery holster cover using two 4-40 shear pins.
6. ___ Mount StratoLoggers onto standoffs on sustainer altimeter sled using 4-40 shear pins.
7. ___ Ensure screw switches are turned off and wire screw switches to switch terminal on StratoLogger.
8. ___ Wire battery to +/- terminal on StratoLogger.
9. ___ Wire drogue terminals on StratoLogger to terminal blocks on the upper bulk plate.
10. ___ Wire main terminals on StratoLogger to terminal blocks on the lower bulk plate.
11. ___ Install altimeter sled into avionics bay.
12. ___ Secure bay using two ¼ - 20 nuts and washers.

Safety Checklist: Overall Final Assembly Checklist

Final Assembly Representative Signatures:

1. ____________________________ *2.* ________________________________

Required Equipment:

- *4-40 aluminum Philips head screws (x8)*
- *Phillips Head Screwdriver (large)*
- *Flat Head Screwdriver (Large)*
- *Small Screwdriver Set (Small)*
- *4-40 shear pins (x4)*
- *Tape*

1. ___ Attach lower airframe to propulsion bay using four 4-40 aluminum Philips head screws.
2. ___ Attach avionics bay to lower airframe using two 4-40 shear pins.
3. ___ Attach upper airframe to avionics bay using two 4-40 metal pins.
4. ___ Attach nose cone to upper sustainer using two 4-40 shear pins.
5. ___ Tape motor igniter to the outside of the lower sustainer in a place easily seen by the field RSO.
6. ___ A final visual inspection will need to be performed to ensure all systems are go.

Safety Checklist: Clear to Leave for Launch Pad:

All sections of the safety checklist preceding the "at the launch pad checklist" must be complete prior to leaving for the launch pad. A signature of completion is required for launch.

*General Pre-Launch Day Preparations:*___________________________________

*Stability and Propulsion:*____

Recovery: ____

Overall Final Assembly: ____

Signatures indicating the rocket is a "Go" for launch:

Team Captain: ____

Team Co-Captain: ____

Safety Officer Signature: ____________________________________

Safety Checklist: At Launch Pad Checklist

Required Equipment:

- *Pen or pencil*
- *Level 2 Certification card.*
- *Propulsion Bay Stand*
- *Precision Philips head screwdriver*

1. ___ Verify flight card has been properly filled out and permission has been granted by RSO to launch.
2. ___ Place rocket on launch pad.
3. ___ Tilt and rotate the launch pad in desired direction, or in direction ruled necessary by RSO. Use level to ensure desired launch angle. Use turnbuckles for fine adjustments.
4. ___ Ensure proper connection has been made with ground station electronics.
5. ___ Arm both Stratologgers by fully seating the screw on both screw switches.
6. ___ Before leaving launch pad area, double check for signs that all electronics are still operating correctly.
7. ___ Clear launch pad area and do not return until range has been reopened by the RSO.

Safety Checklist: During and After Flight (DAF):

Flight Events:

First Event: Nosecone separation from rocket – deployment of drogue parachute.

Observer Signature: ___________________________ *Time:* ______

Second Event: Ejection of lower airframe from rocket – deployment of main parachute.

Observer Signature: ________________________ *Time:* ______

Landing:

Observer Signature: ________________________ *Time:* ______

Miscellaneous:

Video Recorder Signature: ________________________________

Photographer Signature: _________________________________

Retrieval:

Rapid Retrieval Team Member #1: _________________________

Rapid Retrieval Team Member #2: _________________________

Rapid Retrieval Team Member #3: _________________________

Required Equipment:

- *Stopwatch or phone timer.*
- *Small Phillips head screwdriver*
- *Camera*

1. Rapid Retrieval team members are to be within close vicinity to a vehicle ready to move within a few seconds notice.
2. Start stopwatch upon liftoff and call out time in 5 second intervals until T-10 seconds until first event. Continue to call out times until T-10 seconds to second event.
3. Maintain line of sight with rocket at all times. Indicate any observed anomalies out loud to alert spectators.
4. While retrieving rocket, disarm all rocket recovery systems first.
5. Prior to touching the rocket or parachute, take photo documentation of how the rocket landed.

6. Before disturbing the rocket, note any damages and anomalies with root causes. Document these for later examination.
7. Disassemble the rocket looking for any signs of wear, damage, or fatigue. Note what repairs will have to be made, if any.

After Flight Checklist: To be checked and initialed by Recovery Safety representative.

Recovery Representative Signatures:

1. ___________________________ *2.* ______________________________

1. ___ Inspect all shroud lines for any damage, or burn marks.
2. ___ Inspect all shroud attachment points for damage.
3. ___ Inspect entire canopy for any damage, or stretching.
4. ___ Inspect deployment bag for damage.

Damage found on shroud lines? Y / N

*Notes:*____

Damage found on attachment points? Y / N

*Notes:*____

Damage found on deployment bag? Y / N

*Notes:*____

Tearing or stretching found on canopy? Y/N

If yes, sketch approximate location below:

Damage Notes:

____

____

____

Repair Plan:

____

____

____

Altitude Achieved: _______________

Motor Used: ____________________

Location: ______________________

Temperature: ___________________

Pressure: ______________________

Wind Speed: ___________________

Event #1 Success: Y or N

Event #2 Success: Y or N

Captain Approval: 1. ____

2. ____

Section 7. Appendix II – Full Scale Launch Procedures

Safety Checklist: Electrical and Computer Systems

To be checked and initialed by River City Rocketry team member.

River City Rocketry Team Member Signatures:

1. ______________________________ *2.* ______________________________

Launch Day Procedures:

1. ___ Master power in off position.
2. ___ System pause switch in on position.
3. ___ Ignition enable in off position.
4. ___ Check that pause switch is not active.
5. ___ Check that capsule Bluetooth is active.
6. ___ Turn master power on.
7. ___ Ensure that 24V power supply is active.
8. ___ Ensure 12V power supply is active.
9. ___ Check that system is in pause state.
10. ___ Check that ignition igniter is not enabled.
11. ___ Ignition station powered.
12. ___ Central uC powered.
13. ___ Capsule uC powered.
14. ___ APLS powered.
15. ___ VES powered.
16. ___ Gonzales arm powered.
17. ___ Check AGSE Bluetooth active.

Safety Checklist: AGSE Payload Arm

AGSE Payload Arm Setup: To be checked and initialed by AGSE Safety representative.

AGSE Safety Representative Signature: ______________________________

Required Equipment:

- *AGSE Payload Arm*
- *3/16 Hex Key*

Prior to leaving for launch site:

1. ___Check all 3D printed components for any cracks. If any are present, replace with one of the backup parts.

At launch site:

1. ___ Make sure the arm is lined up with the rocket's payload bay.
2. ___ Make sure the payload arm is securely attached to the AGSE side rail.
3. ___ Lower the gripper assembly right above the payload with the arms in the open position.
4. ___ Make sure Arduino is connected to main computer and is sending/receiving data.

Post-flight Inspection:

1. ___ Verify all components are still attached and undamaged. If any parts are damaged make sure to write it down below so that it can be replaced before the next launch.

Safety Checklist: Launch Platform

To be checked and initialed by AGSE Safety representative.

Launch Platform Assembly:

AGSE Representative Signatures:

1. ______________________________ *2.* ______________________________

Required Equipment:

- *Upper launch platform section*
- *Lower launch platform section*
- *3/16" T-handled Allen Wrenches*
- *Fasteners*
- *Pivot point bearings (2x)*

Prior to leaving for launch site:

1. ___ Ensure launch platform is clean and free of debris.

At launch site:

1. ___ Attach upper launch platform section to lower launch pad section.
2. ___ Slide section of airframe into launch pad. If section of airframe does not freely slide up and down the entirety of the launch pad, troubleshooting may be necessary.

   ⚠WARNING Launch pad is not to be cleared for launch until the section of airframe moves freely. If the airframe gets hung up on the launch pad, too much friction will be seen by the rocket, risking a successful flight.
3. ___ Slide bearings over pivot points.
4. ___ Place launch platform on ground station.
5. ___ Verify mounting location for launch platform.
6. ___ Fasten bearings to ground station.
7. ___ Attach articulating arms to launch platform using a washer and a socket head cap screw.
8. ___ Connect launch platform power and data lines.

Safety Checklist: Ground Station

To be checked and initialed by AGSE Safety representative.

Ground Station Assembly:

AGSE Representative Signatures:

1. ______________________________ *2.* __________________________________

Required Equipment:

- *Front ground station section*
- *Middle ground station section*
- *Rear ground station section*
- *Articulating arms*
- *T-handled Allen Wrenches*
- *Additional fasteners*

Prior to leaving for launch site:

1. ___ Ensure outrigger ball screws are clean and free of debris.
2. ___ Ensure outrigger ball screw nuts are clean and free of debris.
3. ___ Verify outriggers are able to actuate over their full travel distance using motor bench-top testing unit.
4. ___ Verify that all fasteners on the ground station assembly are tight.

At launch site:

1. ___ Attach front ground station section to middle ground station section.
2. ___ Attach rear ground station section to middle ground station section.
3. ___ Connect ground station power and data lines.
4. ___ Actuate carriage over full travel to check for jamming issues.
5. ___ Attach articulating arms to carriage.
6. ___ Actuate outriggers to ground position.

Safety Checklist: Igniter Installation

To be checked and initialed by AGSE Safety representative.

Igniter Installation Assembly:

AGSE Representative Signatures:

2. ______________________________ *2.* ______________________________

Required Equipment:

- *Igniter station*
- *T-handled Allen Wrenches*
- *Fasteners*
- *Igniter*
- *Aluminum tape*
- *Dowel rods*
- *Heat shrink tubing*
- *Heat gun*

Prior to leaving for launch site:

1. ___ Assemble wheel extrusion sub-assemblies.
2. ___ Attach drive motors to mounting plate.
3. ___ Attach spring tensioner sub-assemblies to side plates.
4. ___ Mount wheel extrusion assembles to motor shaft.
5. ___ Insert secondary shaft and wheel extrusion assembles.
6. ___ Mount side plates.
7. ___ Mount assembly to base of launch platform.

Note: For the next three steps, reference document on constructing augmented wire.

8. ___ Augment igniter with dowel.

   ⚠WARNING Leading edge of chained dowels must NOT have sharp or hard edges. Sharp or hard leading edges could damage motor grains during insertion, resulting in a false signal, potentially causing the motor to ignite unintentionally.
9. ___ Augment igniter with aluminum tape.
10. ___ Shrink sleeve dowel assembly.

At launch site:

1. ___ Connect igniter station power and data lines.
2. ___ Verify that igniter station motors are both fully operational.
3. ___ Thread igniter into system.

Safety Checklist: Stability and Propulsion

To be checked and initialed by S&P Safety representative.

Stability and Propulsion Representative Signatures:

2. ____________________________ *2.* _______________________________

Prior to leaving for launch site:

Sustainer Propulsion Bay Assembly Checklist:

Required Equipment:

- *Gorilla Glue*
- *Grease*
- *Lower Sustainer Stand*
- *CTI3147-L935-IM-P motor*
- *Motor retainer*
- *Dead blow*
- *¼-20 bolts (x6)*

Required PPE:

.

- *Nitrile Gloves*

4. ___ The team mentor will be responsible for preparing motor within casing.
   ⚠CAUTION: Protective gloves are to be worn when applying grease to the motor.
5. ___ Inspect forward fin tabs for signs of cracking or fatigue.
6. ___ Install three fins by tapping into place with a dead blow. Ensure that the fins are fully seated.
7. ___ Install fin retainer using three ¼-20 bolts.
8. ___ Slide motor casing fully into the motor mount tube.
9. ___ Attach motor retention ring using three ¼ - 20 bolts. Do not over-torque.
   Note: This step must be completed after fin installation and the fin retainer is secure.
4. ___ Set completely assembled bay on stand; do not rest on fins.
5. ___ Inspect each fin for any signs of cracking or fatigue.
   Note: If any damage is identified, **immediately** inform both of the team captains and the safety officer. The rocket will be deemed safe to fly or a corrective action will be decided upon and implemented.

DANGER The motor is not allowed to be handled by personnel without proper certifications. Individuals handling the motor need to ensure assembly is stored in a safe and secure place void of moisture and open flames.

Safety Checklist: General Preparations

To be checked and initialed by River City Rocketry team member.

River City Rocketry Team Member Signatures:

1. ____________________________ *2.* _______________________________

<u>Prior to leaving for launch site:</u>

Required Equipment:

- *Clear black powder capsules (x4)*
- *E-matches (x4)*
- *Drill*
- *1/8” drill bit*
- *Electrical tape*
- *Scissors*
- *Black powder*
- *Paper towels*

Required PPE:

- *Safety glasses*

Black Powder Charge Preparation

2. ___ Drill a 1/8” hole in the bottom of each of the clear black powder capsules.
   ⚠**CAUTION**: Safety glasses are to be worn while drilling.
2. ___ Unwind one e-match.
3. ___ Feed wire from the e-match through the hole in the base of a capsule. Ensure the pyrotechnic end of the e-match is inside the capsule.
4. ___ Wrap electrical tape to secure the e-match in place and to ensure that black powder will not leak from the capsule.
   ⚠WARNING If the capsules are not completely sealed, black powder will leak when the capsules are filled. Leakage could potentially result in ejection charges being too small or failing altogether, causing a catastrophic failure in recovery.
5. ___ Fill capsules with black powder up to line on container. Fill excess space with a piece of paper towel to ensure black powder remains in contact with the pyrotechnic tip of the e-match no matter the orientation of the capsule.
6. ___ Repeat steps 2 through 4 four times.
7. ___ Store modified capsules and e-matches in explosives box.

DANGER E-matches are explosive. The black powder charges and leads must be kept clear from batteries and any open flames in order to avoid accidental firing.

GPS Preparations

Required Equipment:

- *GPS units (x2)*
- *GPS charger*

3. ___ Check GPS units for full charge. If not fully charged, charge GPS units.

Launch Day Procedures:

Lower Sustainer GPS Installation

Required Equipment:

- *Lower sustainer GPS*
- *M3 screws (x2)*
- *Socket set*
- *Lower sustainer door*
- *GPS tracking device*

7. ___ Check lower sustainer for contact with tracking device.
8. ___ Securely mount GPS to GPS sled in lower sustainer using 2 M3 screws and washers.

Safety Checklist: Recovery

To be checked and initialed by Recovery Safety representatives.

Recovery Representative Signatures:

2. ___________________________ *2.* ______________________________

Prior to leaving for launch site:

Parachute Packing

Required Equipment:

- *Small fabric hair ties*
- *Hook*
- *Clamp*
- *Lower sustainer parachute*
- *Lower sustainer parachute deployment bag*
- *Upper sustainer parachute*
- *Upper sustainer parachute deployment bag*
- *Cache capsule parachute*
- *Cache capsule deployment bag*
- *Pilot parachute*
- *Swivel (3x)*

5. ___ Inspect canopy and lines for any cuts, burns, fraying, loose stitching and any other visible damage.

   Note: If any damage is identified, **immediately** inform both of the team captains and the safety officer. The rocket will be deemed safe to fly or a corrective action will be decided upon and implemented.

6. ___ Lay parachute canopy out flat.
7. ___ Ensure shroud lines are taut and evenly spaced and not tangled.
8. ___ Fold parachute per the folding procedures document in the team owncloud folder. Use clamps as necessary to ensure a tight fold.
9. ___ Place folded parachute into respective deployment bag with shroud lines coming directly out of the bag.

   WARNING Ensure that the shroud lines are not wrapped around the parachute inside the deployment bag. This will result in the parachute getting stuck in the deployment bag. Verify that the parachute fits loosely in the deployment bag.

10. ___ Secure deployment flaps using shroud lines and fabric hair ties.

11. ___ Use hook to assist in securing extra length of shroud lines through loops stitched in deployment bag. Continue this pattern in the same direction around the deployment bag in order to prevent tangling.
12. ___ Attach swivel to recovery system.
13. ___ Attach pilot parachute to upper airframe parachute deployment bag ONLY.
10. ___ Repeat steps 1 through 9 for each parachute.

  ___ Lower airframe parachute packed
  ___ Upper airframe parachute packed
  ___ Cache capsule parachute packed

Upper Airframe Avionics Bay:

- *Precision flathead screwdriver*
- *Standard Phillips head screwdriver*
- *Nosecone altimeter sled*
- *StratoLogger altimeter (x2)*
- *4x40 shear pins (x8)*
- *Battery holster cover*
- *Duracell 9V battery (x2)*
- *Battery clips (x2)*
- *Multimeter*
- *3-36 Phillips head (x4)*
- *Garmin GPS Dog collar*
- *M3 screws (x2)*

13. ___ Verify proper shielding.

  WARNING Ensure that the entire inside of the avionics bay is properly shielded in order to protect from interference. In the incident that interference occurs, pyrotechnic devices may be actuated prematurely, causing potential harm to personnel and mission failure.

14. ___ Verify StratoLogger altimeters are properly programed in accordance with file in team Dropbox folder.
15. ___ Verify 9V battery has a minimum charge of 8V.
16. ___ Mount StratoLoggers onto standoffs on sustainer altimeter sled using 4-40 shear pins.
17. ___ Securely mount GPS to sled in nosecone using 2 M3 screws and washers.
18. ___ Attach batteries to battery clips and install into holster.
19. ___ Attach battery holster cover using four, 4-40 shear pin.
20. ___ Ensure screw switches are turned off and wire screw switches to switch terminal on StratoLogger.

21. ___ Wire battery to +/- terminal on StratoLogger.
22. ___ Wire main and drogue terminals on StratoLogger to terminal blocks on middle sustainer.
23. ___ Install altimeter sled into avionics bay.

Lower Airframe Altimeter Housings:

- *Precision flathead screwdriver*
- *Standard Phillips head screwdriver*
- *Nosecone altimeter sled*
- *StratoLogger altimeter (x2)*
- *4x40 shear pins (x8)*
- *Battery holster cover*
- *Duracell 9V battery (x2)*
- *Battery clips (x2)*
- *Multimeter*
- *3-36 Phillips head (x4)*
- *Garmin GPS dog collar*
- *M3 screws (x2)*

1. ___ Verify proper shielding.

   WARNING Ensure that the entire inside of the avionics bay is properly shielded in order to protect from interference. In the incident that interference occurs, pyrotechnic devices may be actuated prematurely, causing potential harm to personnel and mission failure.
2. ___ Verify StratoLogger altimeters are properly programed in accordance with file in team Dropbox folder.
3. ___ Verify 9V battery has a minimum charge of 8V.
4. ___ Mount StratoLoggers onto standoffs on sustainer altimeter sled using 4-40 shear pins.
5. ___ Securely mount GPS to sled in nosecone using 2 M3 screws and washers.
6. ___ Attach batteries to battery clips and install into holster.
7. ___ Attach battery holster cover using four, 3-36 Phillips head screws.
8. ___ Ensure screw switches are turned off and wire screw switches to switch terminal on StratoLogger.
9. ___ Wire battery to +/- terminal on StratoLogger.
10. ___ Wire main and drogue terminals on StratoLogger to terminal blocks on middle sustainer.
11. ___ Install altimeter sled into avionics bay.

Cache Capsule Avionics

Required Equipment:

- *Precision flathead screwdriver*
- *StratoLogger altimeter*
- *TeleMetrum altimeter*
- *4x40 shear pins (x12)*
- *Duracell 9V battery (x2)*
- *Battery clips (x2)*
- *Multimeter*
- *3-36 Phillips head (x4)*
- *Cache capsule electronics bay cover*

1. ___ Verify StratoLogger altimeter is properly programed in accordance with file in team Dropbox folder for the cache capsule.
2. ___ Verify TeleMetrum altimeter is properly programmed in accordance with file in team Dropbox folder for the cache capsule.
3. ___ Mount each altimeter onto standoffs in each altimeter housing in the fairing using 4, 4x40 shear pins each. Ensure that each altimeter is securely mounted.
4. ___ Verify 9V battery has a minimum charge of 8V.
5. ___ Attach batteries to battery clips and install into housings.
6. ___ Ensure screw switches are turned off and wire screw switches to switch terminal on StratoLogger.
7. ___ Wire battery to +/- terminal on StratoLogger.
8. ___ Wire battery to +/- terminal on TeleMetrum.

<u>*Launch day procedures*</u>

Lower Airframe Parachute Assembly:

Required Equipment:

- *Nomex cloth*
- *Shock chord*

1. ___ Attach quicklink on shock chord to U-bolt on avionics bay.
2. ___ Wrap deployment bag in Nomex.
3. ___ Attach deployment bag to eye bolt on fairing.
4. ___ Insert parachute into airframe.

Cache Capsule Assembly:

1. ___ Attach cache capsule parachute deployment bag to bulk plate.
2. ___ Attach shroud lines to cache capsule on the rover ensuring that the shroud lines do not become tangled.
3. ___ Insert parachute into airframe.

Upper Airframe parachute Assembly:

Required Equipment:

- *Nomex cloth*
- *Shock chord (x2)*
- *Swivel*
- *Pilot parachute*
- *QuickLink*

1. ___ Attach upper airframe shock chord to U-bolt on nosecone via quick link.
2. ___ Attach shock chord to swivel.
3. ___ Attach second length of shock chord to U-bolts on fairing.
4. ___ Attach parachute to swivel
5. ___ Attach pilot parachute to deployment bag.
6. ___ Wrap deployment bag in Nomex.
7. ___ Insert parachutes into airframe.

Lower Airframe Avionics Bay:

Required Equipment:

- *Multimeter*
- *Precision flathead screwdriver*

1. ___ Verify both batteries have a charge greater than 5V.
2. ___ Verify proper shielding.

   WARNING Ensure that the entire inside of the avionics bay is properly shielded in order to protect from interference. In the incident that interference occurs, pyrotechnic devices may be actuated prematurely, causing potential harm to personnel and mission failure.
3. ___ Plug a battery into each altimeter.
4. ___ Verify wiring of altimeters is correct.
5. ___ Install avionics bay into lower airframe.

Nosecone Avionics Bay:

Nosecone Assembly

Required Equipment:

- *Precision flathead screwdriver*
- *¼"-20 nut (x4)*
- *¼"-20 washer (x4)*
- *GPS tracking device*
- *Black powder charges (x4)*

1. ___ Check GPS for connection with tracking device.
2. ___ Verify wiring of altimeters is correct.
3. __ Wire a black powder charge to each terminal block.
4. ___ Install bulk plate onto threaded rods. Ensure that fiberglass plate is fully seated against the coupler tubing.
5. ___ Secure bulk plates in place using ¼-20 nuts and washers.

Safety Checklist: Overall Final Assembly Checklist

Final Assembly Representative Signatures:

2. ____________________________ *2.* ________________________________

Required Equipment:

- *Allen Wrench Set – SAE*
- *Phillips Head Screwdriver (large)*
- *Flat Head Screwdriver (Large)*
- *Small Screwdriver Set (Small)*
- *Socket Wrench Set for ¼-20 Nuts*
- *Masking tape*
- *Socket Cap Screws*
- *4-40 shear pins*
- *Painters tape*

7. ___ Attach propulsion bay to lower avionics bay using six 8-32 metal bolts.
8. ___ Attach lower avionics bay to secondary recovery bay using four 8-32 metal bolts
9. ___ Attach fairing to the secondary recovery bay using 4-40 shear pins. Ensure that all shear pins are tight fitting and will not fall out during ascent.
10. ___ Attach fairing to main recovery bay using 4-40 shear pins. Ensure that all shear pins are tight fitting and will not fall out during ascent.
11. ___ Check that the coupling does not allow for any flexing of the rocket between the fairing and the upper sustainer. Should this occur, add layers of painters tape to the coupler tubing on the fairing until sufficient coupling is achieved.
12. ___ Attach nose cone to upper sustainer using six 8-32 metal bolts.
13. ___ Tape motor igniter to the outside of the lower sustainer in a place easily seen by the field RSO.
14. ___ A final visual inspection will need to be done to ensure all systems are go.

Safety Checklist: Clear to Leave for Launch Pad:

All sections of the safety checklist preceding the "at the launch pad checklist" must be complete prior to leaving for the launch pad. A signature of completion is required for launch.

*General Pre-Launch Day Preparations:*_________________________________

*Stability and Propulsion:*____

Recovery: ____

Overall Final Assembly: ____

Signatures indicating the rocket is a "Go" for launch:

Team Captain: ____

Team Co-Captain: ____

Safety Officer Signature: ____________________________________

Safety Checklist: At Launch Pad Checklist

Required Equipment:

- *Pen or pencil*
- *Level 2 Certification card.*
- *Propulsion Bay Stand*
- *Magnetic Switch Magnet*
- *Switch Rods*
- *GoPro camera*
- *Level*

8. ___ Verify flight card has been properly filled out and permission has been granted by RSO to launch.
9. ___ Place rocket on launch pad.
10. ___ Tilt and rotate the launch pad in desired direction, or in direction ruled necessary by RSO. Use level to ensure desired launch angle. Use turnbuckles for fine adjustments.
11. ___ Ensure proper connection has been made with ground station electronics.
12. ___ Arm all electronics in the following order: payloads, cameras, and altimeters (in order as follows: StratoLoggers in nose cone, StratoLogger and Telemetrum in cache capsule, StratoLogger in lower airframe). Check for correct LED readout, beeping pattern, etc.
13. ___ Before leaving launch pad area, double check for signs that all electronics are still operating correctly.
14. ___ Arm launch pad camera and begin recording.
15. ___ Clear launch pad area and do not return until range has been reopened by the RSO.

Safety Checklist: During and After Flight (DAF):

Flight Events:

First Event: Nosecone separation from rocket – deployment of vortex ring.

Observer Signature: ___________________________ *Time:* ______

Second Event: Ejection of lower airframe from rocket – deployment of cruciform parachute.

Observer Signature: ________________________ *Time:* ______

Third Event: Ejection of cache capsule – deployment of cruciform parachute.

Observer Signature: ________________________ *Time:* ______

Landing Events:

Upper airframe

Observer Signature: ________________________ *Time:* ______

Lower airframe

Observer Signature: ________________________________ *Time:* ______

Cache capsule

Observer Signature: _________________________________ *Time:* ______

Video Recorder Signature: ________________________________

Photographer Signature: _________________________________

Rapid Retrieval Team Member #1: _________________________

Rapid Retrieval Team Member #2: _________________________

Rapid Retrieval Team Member #3: _________________________

Required Equipment:

- *Stopwatch or phone timer.*
- *Magnetic Switch Magnets*
- *Small Phillips head screwdriver*
- *Camera*

8. Rapid Retrieval team members are to be within close vicinity to a vehicle ready to move within a few seconds notice.
9. Start stopwatch upon liftoff and call out time in 5 second intervals until T-10 seconds until first event. Continue to call out times until T-10 seconds to second event.
10. Maintain line of sight with rocket at all times. Indicate any observed anomalies out loud to alert spectators.
11. While retrieving rocket, disarm all rocket recovery systems first.
12. Prior to touching the rocket or parachute, take photo documentation of how the rocket landed.
13. Before disturbing the rocket, note any damages and anomalies with root causes. Document these for later examination.
14. Disassemble the rocket looking for any signs of wear, damage, or fatigue. Note what repairs will have to be made, if any.

After Flight Checklist: To be checked and initialed by Recovery Safety representative.

Recovery Representative Signatures:

2. ____________________________ *2.* _______________________________

5. ___ Inspect all shroud lines for any damage, or burn marks.
6. ___ Inspect all shroud attachment points for damage.
7. ___ Inspect entire canopy for any damage, or stretching.
8. ___ Inspect deployment bag for damage.

Damage found on shroud lines? Y / N

*Notes:*____

Damage found on attachment points? Y / N

*Notes:*____

Damage found on deployment bag? Y / N

*Notes:*____

Tearing or stretching found on canopy? Y/N

If yes, sketch approximate location below:

Damage Notes:

____

____

____

Repair Plan:

____

____

____

Altitude Achieved: ________________

Motor Used: ______________________

Location: ______________________

Temperature: ___________________

Pressure: ______________________

Wind Speed: ___________________

Event #1 Success: Y or N

Event #2 Success: Y or N

Captain Approval: 1. ____

2. ____

Section 8. Appendix III – Risk Assessment

Lab and Machine Shop Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Using power tools and hand tools such as blades, saws, drills, etc.	1. Improper training on power tools and other lab equipment.	1a. Mild to severe cuts or burns to personnel. 1b. Damage to rocket or components of the rocket. 1c. Damage to equipment	2	4	Low	1. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them. 1. Safety glasses must be worn at all times. 1. Sweep or vacuum up shavings to avoid cuts from debris.
Sanding or grinding materials.	1. Improper use of PPE. 2. Improper training on the use of a Dremel tool.	1a. Mild to severe rash. 1b. Irritated eyes, nose or throat with the potential to aggravate asthma. 2. Mild to severe cuts or burns from a Dremel tool and sanding wheel.	3	3	Low	1a. Long sleeves should be worn at all times when sanding or grinding materials. 1b. Proper PPE should be utilized such as safety glasses and dust masks with the appropriate filtration required. 2. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them.
Working with chemical components resulting in mild to severe chemical burns on skin or eyes, lung damage	1. Chemical splash. 2. Chemical fumes.	1. Mild to severe burns on skin or eyes. 2. Lung damage or asthma aggravation due to	2	4	Low	MSDS documents will be readily available at all times and will be thoroughly reviewed prior to working with any chemical. All chemical containers will be marked to identify appropriate precautions that need to be taken.

due to inhalation of toxic fumes, or chemical spills		inhalation of fumes,				1. Nitrile gloves shall be used when handling hazardous materials. 1. Personnel are familiar with locations of safety features such as an eye wash station. 1. Safety goggles are to be worn at all times when handling chemicals. 2. When working with chemicals producing fumes, appropriate precautions should be taken such as working in a well-ventilated area, wearing vapor masks, or working under a fume hood.
Damage to equipment while soldering.	1. Soldering iron is too hot 2. Prolonged contact with heated iron	The equipment could become unusable. If parts of the payload circuit get damaged, they could become inoperable.	3	3	Low	1. The temperature on the soldering iron will be controlled and set to a level that will not damage components. 2. For temperature sensitive components sockets will be used to solder ICs to.
Dangerous fumes while soldering.	1. Use of leaded solder can produce toxic fumes. 2. Leaving soldering iron too long on plastic could cause plastic to melt	Team members become sick due to inhalation of toxic fumes. Irritation could also occur.	3	3	Low	1. The team will use well ventilated areas while soldering. Fans will be used during soldering. 2. Team members will be informed of appropriate soldering techniques, avoiding contact of the soldering iron to plastic materials for extended periods of time.

	producing toxic fumes.					
Potential burns to team members while soldering.	Team members do not pay attention while soldering	The team member could suffer minor to severe burns.	4	3	Low	Team members will be trained how to solder and will follow all safety protocols related to soldering.
Overcurrent from power source while testing.	Failure to correctly regulate power to circuits during testing	Team members could suffer electrical shocks which could cause burns to heart arrhythmia	2	4	Low	The circuits will be analyzed before they are powered to ensure they don't pull too much power. Power supplies will also be set to the correct levels.
Use of cutting fluid.	Use cutting fluid when machining metals.	Contains carcinogens.	1	5	Low	Face shield shall be worn at all times when machining metals.
Use of white lithium grease.	Use in installing motor and on ball screws.	1. Irritation to skin and eyes. 2. Respiratory irritation.	3	4	Low	1. Nitrile gloves and safety glasses are to be worn when applying grease. 2. When applying grease, it should be done in a well ventilated area to avoid inhaling fumes.
High voltage shock.	Improper use of welding equipment.	Death or severe injury.	1	5	Low	All team members are required to be trained on the equipment prior to use. Any time personnel is welding, there must be at least two people present.
Break bit on mill.	Spindle speed too high.	Injury to personnel and damage to equipment and/or part.	2	5	Low	All team members are required to be trained on the mill prior to use. If personnel is uncertain about the proper settings, they are to consult an experienced member prior to operation.

Metal shards.	Using equipment to machine metal parts.	Metal splinters in skin or eyes.	2	5	Low	Team members must wear long sleeves and safety glasses whenever working with metal parts.

Table 88: Lab and machine shop risk assessment.

AGSE -Launch Pad Functionality Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Unstable launch platform.	Un-level ground	If the launch pad is unstable while the rocket is leaving the pad, the rocket's path will be unpredictable.	1	3	Moderate	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR. Ensure that the launch pad is stable and secure prior to launch. Outriggers were added to increase the footprint of the launch platform providing increased stability.
Unleveled launch platform.	Un-level ground or improperly leveled launch tower.	The launch tower could tip over during launch, making the flight of the rocket unpredictable.	1	4	Moderate	The launch pad should always be placed on a level surface. Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR. A self-leveling system has been implemented to ensure the platform is level prior to launch.
Rocket gets caught in launch tower or experiences high friction forces.	1.Misalignment of launch tower joints 2.Deflection of launch platform rails	Rocket may not exit the launch tower with a sufficient exit velocity or may be damaged on exit.	2	5	Low	During setup, the launch tower will be inspected for a good fit to the rocket. A spare piece of airframe will run through the launch pad. If any resistance is noted, the joints of the tower can be moved to improve the alignment of the

	3. Payload door jams 4. Anti-friction tape sticks to vehicle or is damaged					tower, allowing the rocket to freely move through the tower. Also, talcum powder will be applied to each beam in order to reduce any frictional forces on the rocket. Analysis will be performed to properly size the launch rails.
Sharp edges on the launch pad.	Manufacturing processes.	Minor cuts or scrapes to personnel working with, around, and transporting the launch tower.	4	3	Low	Sharp edges of the launch pad should be filed down and de-burred.
Brush fire caused by rocket during launch.	Dry launching conditions.	Small brush fire.	4	3	Low	Wait until the range safety officer has cleared personnel to approach the launch pad and extinguish any fires that have been started.
Vehicle not properly aligned.	Incorrect loading of vehicle.	Payload will not be able to be inserted, vehicle maybe unstable, igniter may not be able to be installed	2	3	Moderate	An alignment device has been added to the base of the launch platform which will ensure the vehicle is in the correct orientation for payload insertion. Also, the motor retainer will seat into a plate at the bottom of the rocket to ensure proper vehicle alignment to igniter installation system and launch platform.
Buckling of anti-torsion rings	Material failure	Launch platform may fall, damaging rocket or injuring personnel	1	4	Moderate	Testing will be performed prior to launch day to ensure the rings can handle the expected loads..

Shearing of critical connections.	1.Rail extension connections 2. Bearing connections 3. Articulating connections	Launch platform collapses, damaging vehicle and/or injuring personnel.	1	5	Low	All components will be analyzed for the loads that each component will be experiencing. All personal will be required to maintain a minimum safe distance away from the AGSE during operation.
Movement of pivot or articulating points.	Improper pre-load on fasteners.	Launch platform falls, damaging vehicle, and injuring personnel.	1	5	Low	All fasteners will be properly tightened during assembly and will be checked prior to launch. Locating features were added to launch rails to ensure proper placement of critical connections. All personal will be required to maintain a minimum safe distance away from the AGSE during operation.
Pivot point bearings seize.	1. Load is larger than specifications. 2. Debris enters bearings.	Launch platform will experience higher resistance to motion requiring potential preventing the vehicle raising.	1	3	Moderate	Bearings will be sized based on expected loads with a minimum factor of safety of 2. The launch platform will be cleaned following each launch and will be cleaned prior to each launch.
Personal injury	Personnel pinned between launch platform and ground station.	Minor to serious injuries to personnel working with, around, and transporting the vehicle erector.	1	3	Moderate	All personnel will be required to maintain a minimum safe distance away from the AGSE when in operation.
Failure of ground station connection joints	Load is larger than anticipated	Minor injuries to personnel working with, around, and transporting	1	4	Low	All personnel will be required to maintain a minimum safe distance away from the AGSE when in operation. During assembly this

		ground station. Ground station will collapse under weight and not function				failure mode will be tested to ensure doesn't happen.

Table 89: Launch pad functionality risk assessment.

AGSE – Vehicle Erector Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Sharp edges on the vehicle erector.	Manufacturing processes.	Minor cuts or scrapes to personnel working with, around, and transporting the vehicle erector.	4	3	Low	Sharp edges of the vehicle erector should be filed down and de-burred.
Carriage jams.	1. Carriage tracks not square. 2. Too much track deflection under load. 3. Uneven loading. 4. Nylon guides dislodge. 5. Buildup of foreign objects and debris (FOD) on tracks and/or carriage.	Vehicle erector is unable to complete the task of raising the rocket.	1	2	High	1. Tolerance on tracks will be checked during manufacturing and assembly of vehicle erector. 2. Deflections in the track have been analyzed and are within the tolerances of our system. 3. The carriage geometry was selected to provide a wide base to better distribute the load. This wide geometry reduces the impact of uneven loading. 4. Appropriate fasteners and pre-load on installed fasteners will be used during the assembly of the carriage. 5. The vehicle erection system will be cleaned following each launch

						and will be inspected for FOD prior to each launch.
Shoulder bolts shear.	Material failure.	Launch platform falls back to horizontal position.	1	3	Moderate	Analysis has been performed to determine the minimum bolt specifications based on the maximum loads the bolts will encounter and a factor of safety has been incorporated into the design.
Shoulder bolt unscrews.	Vibration/cycling.	Launch platform falls back to horizontal position.	1	4	Moderate	Appropriate pre-load will be applied to the bolts. Thread locker will be used as a secondary locking mechanism.
Bearing fixtures fail on power screw.	Fatigue.	Launch platform falls and power screw jams.	1	4	Moderate	An appropriate bearing has been selected to handle the expected loads on the power screw. If the bearing fails, a bushing is also used as a secondary bearing which will hold the screw in place.
Articulating arms buckle under load.	Material failure.	Launch platform falls.	1	3	Moderate	Testing will be performed prior to launch day to ensure the rings can handle the expected loads.
Articulating arm interference.	Articulating arms protrude into vehicle or payload arm path.	Launch platform may not be able to reach desired position. Possible damage to rocket and/or payload arm.	1	4	Moderate	All components will be checked for interference with solid models during the design phase and will be physically checked during assembly. Systems that can be manually actuated on launch day will be manually actuated to check for interferences.
Carriage to power screw nut connection fails.	Material failure.	Power screw spins without advancement of	1	3	Moderate	Proper bolt and mounting plate specifications have been determined.

		nut, causing vehicle erector to be motionless.				
Power screw jams.	1. Cross thread. 2. Buildup of debris on screw. 3. Galling of nut.	Vehicle erector will not reach final position.	1	3	Moderate	The power screw will be cleaned after each launch and will be inspected prior to each launch. The power screw nut will not be removed between launches reducing the potential for cross threading. The power screw and nut materials will be selected to prevent galling.
Power screw shears.	Material failure.	Vehicle erector will not reach final position. Launch platform may fall or be at risk of falling back to horizontal.	1	3	Moderate	Analysis has been performed to adequately size the power screw with a minimum factor of safety of 2. Personnel will remain clear of AGSE until the situation has been assessed and deemed safe by the safety officer.
Launch platform travel obstructed.	1. Miscellaneous objects obstruct travel. 2. Ground station is not high enough for launch platform to clear.	Launch platform may not be able to reach desired position. Possible damage to interfering objects.	1	4	Moderate	1. Prior to launch all debris will be removed from the path of the launch platform. Guards will be installed to prevent objects from entering these areas. 2. Safety interlocks will be added to verify ground station has lifted itself off the ground enough for the launch platform to articulate.
Motor fails to raise vehicle.	Motor does not have sufficient torque to raise vehicle.	Launch platform will not be able to reach desired position.	1	3	Moderate	Analysis has been performed to ensure the proper motor was selected.

Pinch points.	1. Power screw. 2. Carriage ends of travel. 3. Carriage and track interfaces. 4. Articulating arms.	Minor to serious injuries to personnel working with, around, and transporting the vehicle erector. Possible damage to surrounding equipment.	2	2	Moderate	Guards will be installed to protect objects and personnel from entering pinch point areas. Personnel will be required to remain clear of AGSE during operation, and will maintain a minimum safe distance away until the system has been deemed safe by the safety officer. Wires, tubing, and other systems will be routed away from pinch point areas to avoid possible damage.
Vehicle is not lifted at a high enough rate.	The motor was not sized correctly.	Vehicle won't be lifted with-in time requirement.	2	3	Moderate	Analysis has been performed to ensure the proper motor was selected.
Personal injury from AGSE.	Personnel in close proximity while AGSE is in operation.	Personal injury.	2	3	Moderate	Power will be disconnected from AGSE prior to working on the system or surrounding systems. When the AGSE is powered on all personnel will be at a minimum safe distance away.
Non-Functioning and unresponsive system.	Break in wires.	1. Rocket will not erect or lower. 2. Rocket will stall at position.	1	3	Moderate	Wires will be shielded from pinch points and other mechanical hazards.
Motor failure.	Motor short.	1. Rocket will not erect or lower. 2. Rocket will stall at position.	1	3	Moderate	Electrical redundancy measures will be implemented.
Electrical failure.	Power loss.	1. Rocket will not erect or lower. 2. Rocket will stall at position.	1	3	Moderate	Electrical redundancy measures will be implemented.

		3. Possible short to exterior parts.				

Table 90: Vehicle erector risk assessment.

AGSE – Ignition Installation Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Sharp edges on the ground station.	Manufacturing processes.	1. Minor cuts or scrapes to personnel working with, around, and transporting the igniter installer. 2. Igniter installation becomes cut, exposing wire causing false signal to be sent, prematurely igniting the motor.	2	3	Moderate	Sharp edges of the igniter installer should be filed down and de-burred.
Igniter is not fully installed in motor.	1.Igniter slips during installation 2. Igniter gets tangled prior to insertion 3. Igniter is not straight upon insertion	Possible catastrophic failure of rocket motor during ignition; loss of vehicle, damage to AGSE, and personnel Injury.	1	2	High	1. Additional feedback mechanisms will be used to confirm the igniter has been fully installed. 2/3.To avoid tangling and to keep the igniter straight as it enters a dowel rod will be attached to the igniter and will equal the length required for igniter to be inserted.
Motor is dislodged from housing.	Igniter causes blockage within motor.	Motor will choke itself causing pressurizing which	1	5	Moderate	The augmented igniter, as described in ignition station section of the report, will be

		could cause an explosion.				calculated and below the calculated blockage percentage.
Damage to igniter.	Extruder assembly applies an amount of pressure to igniter assembly to shear igniter wire.	Unresponsive igniter.	1	3	Moderate	The igniter will be heavily shielded and protected from sharp edges. The igniter installation system will be inspected for any possible sharp edges.
Igniter prematurely lights.	1. EMF feedback from motors causes ignition. 2. Ignitor circuit is prematurely energized.	Injury to personal working around AGSE, damage to systems onboard AGSE.	1	2	High	The igniter will be heavily shielded from EMF radiation using aluminum tape. A safety switch will be placed in the igniter circuit and will be controlled by the AGSE so the circuit will not be able to be completed prior to the AGSE giving clearance. All personnel will be required to maintain a minimum safe distance away from the AGSE during operation.
Pinch point.	Igniter installation wheels.	Minor to serious injuries to personnel working with, around, and transporting the ignition installation system.	2	2	Moderate	Personnel will be required to remain clear of AGSE during operation, and will maintain a minimum safe distance away.
Non-functioning and unresponsive.	1. Break in line. 2. Error in code.	Igniter installation fails.	1	3	Moderate	Wires will be shielded from pinch points and other mechanical hazards.
Motor failure.	Short in stepper motor.	Igniter installation fails.	1	3	Moderate	Additional motors will be on hand for replacement upon failure. All electronics will be checked for

						functionality during pre-launch procedures.
Driver failure.	1. Short on Adafruit driver board. 2. Incorrect wire placement.	Igniter installation fails.	1	3	Moderate	A secondary driver will on hand for quick replacement upon failure.
Gear mechanical failure.	Material failure.	Igniter installation fails.	1	4	Low	All mechanical components will be inspected for damage or signs of fatigue prior to launch.

Table 91: Igniter installation risk assessment.

AGSE – Ground Station Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Sharp edges on the igniter installation system.	Manufacturing processes.	Minor cuts or scrapes to personnel working with, around, and transporting the ground station.	4	3	Low	Sharp edges of the ground station will be filed down and de-burred.
Motor fails to raise vehicle.	Motor does not have sufficient torque.	Vehicle does not reach desired location.	1	3	Moderate	Analysis has been performed to ensure the proper motor was selected.
Power screw jams.	1. Cross thread. 2. Buildup of debris on screw. 3. Galling of nut.	Vehicle erector will not reach final position.	1	3	Moderate	The power screw will be cleaned after each launch and will be inspected prior to each launch. The power screw nut will not be removed between launches reducing the potential for cross threading. The power screw and nut materials will be lubricated

					Moderate	with proper lubrication to prevent galling
Improper outrigger pad orientation.	1. Uneven terrain. 2. Object obstructs pad from contacting ground. 3. Pad jams in outrigger.	Unbalanced ground station, possible damage to surroundings/ terrain.	3	2	Moderate	Terrain will be inspected prior to placing ground station and the landing locations of the outrigger pads will be cleared of debris. Design of outrigger pads will avoid possibilities of jamming and orient pad so gravity assists in orientation.
Outrigger pad does not slide on terrain.	1. Obstruction in path of outrigger. 2. Ground too soft. 3. Coefficient of friction between pad and terrain too high.	Ground station will not raise or will raise unevenly.	1	2	High	Terrain will be inspected prior to placing ground station and obstructions will be cleared. Testing will be done to ensure pads will glide easily. Weather conditions will be monitored prior to and on launch day to anticipate ground conditions.
Ground station can't reach leveled position with adequate height.	1. Outrigger travel is not sufficient. 2. Placed on highly unleveled terrain.	Ground station can't raise vehicle.	1	3	Moderate	Outriggers will be designed to have additional travel for terrains that not level. Launch locations will be inspected for level terrain prior to placing ground station.
Outriggers sink into ground.	1. Insufficient surface contact between outrigger pad and ground. 2. Ground is too soft.	Ground station can't raise itself high enough for vehicle erection. Launch platform unstable.	1	2	High	Outriggers will be sized to provide adequate surface contact. Weather conditions will be monitored prior to and on launch day to anticipate ground conditions.
Unstable ground station.	1. Outriggers raise out of sync. 2. High winds.	Ground station falls possibly injury to personnel	1	3	Moderate	System interlocks will track progress of ground station leveling and determine if outriggers are out of sync. If the

	3. Unstable ground. 4. Ground station footprint.	surround ground station.				stability of the ground station reaches a critical point the system will halt progress. Personnel will be required to be a minimum safe distance away from the AGSE at all times while it is in operation. The design of the ground station footprint has been revised to include three wide contact points to increase stability.
Pinch Points/Destructive Components.	1. Power screw pinch point. 2. Outriggers crushing potential. 3. Outrigger geometry pinch points. 4. Pinch points at ground station section connections.	Personal injury to personnel working around AGSE, or damage to surrounding equipment.	2	2	Moderate	Personnel will be required to maintain a minimum safe distance away from the AGSE during operation. All wires, tubing, or other components that could be damaged by pinch points will be routed such that this hazard is avoid. Guards will be installed to protect components and personnel from injury.
Ground station is not lifted and leveled at a high enough rate.	The motor was not sized correctly.	Ground station won't be lifted with-in time requirement.	2	3	Moderate	Analysis has been performed to ensure the proper motor was selected to raise and level the ground station within the time requirement.
Inconsistencies in leveling process time.	Inconsistent terrains between launches.	Ground station won't be lifted with-in time requirement.	2	4	Moderate	Launch fields will be inspected to check for level terrain or terrain that is within the constraints for the leveling system.

Ground station bows/sags.	Material failure.	Carriage may jam, launch platform will be unstable.	1	3	Moderate	Testing will be performed prior to launch day to ensure ground station performs as expected.
Ground station collapses.	Material failure.	Vehicle may be damaged, personal injury to personnel, damage to sub systems.	1	3	Moderate	Testing will be performed prior to launch day to ensure ground station performs as expected.
Ground station interference.	Sub systems collide with ground station structure.	Sub-systems won't be able to complete their tasks.	2	4	Moderate	All components will be checked for interference with solid models during the design phase and will be physically checked during assembly. Systems that can be manually actuated on launch day will be manually actuated to check for interferences.

Table 92: ASGE – Ground station risk assessment.

Payload Retrieval Arm Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Control failure.	1. Code has incorrect set points. 2. Feedback devices malfunction. 3. Code does not execute properly. 4. Actuators unresponsive.	Arm fails to retrieve and load payload.	1	3	Moderate	Tests will be performed to verify operation of arm system.

Payload arm unable to grip payload.	1. Coefficient of friction between grips and payload is insufficient. 2. Grips do not close to specific position. 3. Gripping motor does not have enough torque.	Arm fails to retrieve and load payload.	1	3	Moderate	Testing will be completed to verify grips close consistently on payload.
Failure to insert payload.	1. Payload is dropped. 2. Payload is not aligned properly to enter rocket and/or retaining clips.	Payload is not loaded into rocket.	1	2	High	Testing will be completed to verify payload is gripped adequately and properly oriented when entering rocket.

Table 93: Payload retrieval arm risk assessment.

Main Controller Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Power failure.	Non-functioning power supply.	AGSE fails to operate.	1	4	Moderate	Analysis and testing will be completed to ensure that the power supply is dependable and adequately sized for the AGSE.
Communication failure.	Break in line. Short on board.	AGSE fails to operate.	1	4	Moderate	All wires will be guarded from mechanical hazards to protect wires from damage. Testing will be completed on all electrical systems to ensure wiring was completed properly.

Program execution failure.	Non-functioning code.	AGSE fails to operate.	1	3	Moderate	Testing will be completed to confirm code is running properly prior to launch.
System crash while running program.	1. Loss of power. 2. Break in communication line.	AGSE fails to operate.	1	3	Moderate	Testing will be completed to ensure all components maintain communication and systems do not crash.
Improper sequencing of code.	Improper code sequencing.	AGSE fails to operate.	1	4	Moderate	Testing will be completed to verify all systems are sequenced properly.

Table 94: Main controller assessment.

Leveling System Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Power failure.	Non-functioning power supply.	Launch platform fails to level.	1	4	Moderate	Analysis and testing will be completed to ensure that the power supply is dependable and adequately sized for the AGSE.
Gyroscopic sensor failure.	1. Incorrectly zeroed. 2. Communication failure.	Launch platform fails to level.	1	2	High	Testing will be completed to ensure that the gyroscopic sensor performs as expected. Pre-launch checkpoints will be implemented to ensure all sensors are properly calibrated.

Table 95: Leveling system risk assessment.

Master Controls Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Pause function fails to activate.	1. Mechanical failure in switch.	Damage to AGSE. Personal	1	3	Moderate	All personnel will be required to maintain a minimum safe distance

	2. Communication failure between switch and controller. 3. Code error.	injury to personnel working near or around AGSE.				from the AGSE during operation. Redundancies will be implemented to ensure the pause system performs as expected.
Pause function fails to deactivate.	1. Mechanical failure in switch. 2. Communication failure between switch and controller. 3. Code error.	AGSE mission failure.	1	3	Moderate	Redundancies will be implemented to ensure the pause system performs as expected.
Boot function fails to activate.	1. Mechanical failure in switch. 2. Communication failure between switch and controller. 3. Code error.	AGSE mission failure.	1	3	Moderate	Redundancies will be implemented to ensure the boot system performs as expected.
Boot function enabled at power up.	1. Switch stuck/left in enabled position. 2. Communication failure between switch and controller. 3. Code error.	Improper/ Unpredictable boot sequence.	1	3	Moderate	Redundancies will be implemented to ensure the pause system performs as expected. Pre-launch check sheets will included a check that the boot function is disabled before power is applied to AGSE.
Igniter safety switch fails to activate.	1. Mechanical failure in switch. 2. Communication failure between switch and controller. 3. Code error.	Vehicle fails to launch.	1	3	Moderate	Redundancies will be implemented to ensure the igniter safety system performs as expected.

Igniter safety switch active at power up.	1. Switch stuck/left in enabled position. 2. Communication failure between switch and controller. 3. Code error.	Undesired launch sequence/ personal injury/ disqualification.	1	3	Moderate	Redundancies will be implemented to ensure the igniter safety system performs as expected.
I2C communication error.	1. Short on chip. 2. Heat damage. 3. Water damage.	AGSE systems fail to actuate, mission failure.	1	3	Moderate	Testing will be completed to ensure that the main controller performs as expected.
Power distribution failure.	1. System short. 2. Break in line wires.	AGSE systems fail to actuate, AGSE mission failure.	1	3	Moderate	Testing will be completed to ensure that the main controller performs as expected.
Failure to start/boot.	1. Non responsive programming. 2. Loss of power.	AGSE systems fail to actuate, AGSE mission failure.	1	3	Moderate	Testing will be completed to ensure that the main controller performs as expected.
System sequencing error.	1. Non responsive programming. 2. Incorrect timing.	Damage to sub-systems.	1	3	Moderate	AGSE systems fail to actuate, AGSE mission failure.

Table 96: Master controls risk assessment.

Stability and Propulsion Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Motor fails to ignite.	1. Faulty motor. 2. Delayed ignition. 3. Faulty e-match. 4. Disconnected e-match.	1. Rocket will not launch. 2. Rocket fires at an unexpected time.	3	4	Low	Follow NAR safety code and wait a minimum of 60 before approaching the rocket to ensure that the motor is not simply delayed in launching. If there is no activity after 60 seconds, have

						the safety officer check the ignition system for a lost connection or a bad igniter. If this does not fix the failure mode, be prepared to remove the ignition system from the rocket motor, retrieve the motor from the launch pad and replace the motor with a spare. Igniters have been securely installed throughout the season, having a 100% success rate.
Motor explodes on the launch pad.	Faulty motor.	Rocket and interior components significantly damaged.	1	5	Low	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR in order to ensure that no one is hurt by flying debris. Extinguish any fires that may have been started when it is safe to approach. Collect all debris to eliminate any hazards created due to explosion. The motors the team have selected are from a reliable supplier. The team has had a 100% success rate.
Rocket doesn't reach high enough velocity before leaving the launch pad.	1. Rocket is too heavy. 2. Motor impulse is too low. 3. High friction coefficient between rocket and launch tower.	Unstable launch.	1	5	Low	Too low of a velocity will result in an unstable launch. Simulations are run to verify the motor selection provides the necessary exit velocity. The launch pad will be coated in talcum powder prior to each launch in order to minimize friction. Full scale test

						launches have verified that the launch rocket will exit the launch pad at a safe velocity. Should the failure mode still occur, the issue should be further examined to determine if the cause was due to a faulty motor or in the booster needs to be redesigned.
Fins shear during flight.	Insufficient fin retention during installation resulting in a failure in the epoxy.	Unstable rocket, causing the flight path to become unpredictable.	1	5	Low	Confirm all personnel are alert and at a distance allowed by the Minimum Distance Table as established by NAR. The removable fin system was designed for a press fit tolerance and has been flight tested, resulting in fins remaining rigidly in place.
Airframe buckles during flight.	Airframe encounters stresses higher than the material can support.	Rocket will become unstable and unsafe during flight.	1	5	Low	Through prediction models, appropriate material selection, and a secure factor of safety, this failure mode can be nearly eliminated.
Internal bulkheads fail during flight.	Forces encountered are greater than the bulkheads can support.	1. Internal components supported by the bulkheads will no longer be secure. 2. Parachutes attached to bulkheads will be left ineffective.	1	5	Low	The bulkheads have been designed to withstand the force from takeoff with an acceptable factor of safety. 1. Electrical components are mounted using fasteners that will not shear under the forces seen during the course of the flight. 2. A catastrophic failure is likely. A portion of the rocket or the cache capsule would become

						ballistic. Calculations have been made to ensure that the bulkheads can withstand all forces that will be seen during flight. Flight tests have verified such calculations.
Fins are not properly aligned.	Fins are not mounted straight or do not have equal radial spacing.	Rocket becomes unstable or spins excessively during flight.	1	5	Low	The removable fin design has been incorporated, ensuring that the fins are properly aligned. Due to the capability of machining the centering rings, all slots have been aligned within a tolerance that will not negatively affect the flight of the rocket. Through flight tests with this system, the removable fin design has proven to maintain proper fin alignment.
Retaining bulk plate fails.	Retaining bulk plate tabs are too small.	Fins fall out during flight.	1	5	Low	This system has been integrated before and no signs of stresses were seen in the tabs after multiple flights.
Motor retainer falls off.	Joint was did not have proper preload or thread engagements.	Motor casing and spent motor fall out of rocket during when the main parachute opens.	1	5	Low	This system has been tested during full scale flights without any signs of failure. Analysis has been completed to validate that the current design is strong enough to withstand forces seen during flight.

Table 97: Stability and propulsion risk assessment.

Recovery Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Rocket does not split to allow for recovery system deployment.	1. Not enough pressurization to break shear pins. 2. Coupling has too tight of fit.	Rocket follows ballistic path, becoming unsafe.	1	5	Low	1. The separation section of the rocket was designed to ensure that the black powder charge provides sufficient pressurization, allowing the rocket to separate and deploy its recovery system. Each separation section was both ground tested prior to a full scale flight test to ensure that the black powder charges appropriately sized. 2. The coupling between the sections will be sanded down to have a loose fit, preventing the two sections from getting stuck together during flight. Ground tests will be performed prior to flight to ensure that the black powder charges are properly sized and that the coupling has a low enough coefficient of friction. If separation does not occur, the rocket will follow a ballistic path, becoming unsafe. All personnel at the launch field will be notified immediately.
Altimeter or e-match failure.	Parachutes will not deploy.	Rocket follows ballistic path,	1	5	Low	Multiple altimeters and e-matches are included into systems for redundancy to eliminate this

		becoming unsafe.				failure mode. Should all altimeters or e-matches fail, the recovery system will not deploy and the rocket will become ballistic, becoming unsafe. All personnel at the launch field will be notified immediately.
Parachute does not open.	1. Parachute gets stuck in the deployment bag. 2. Parachute lines become tangled.	1, 2. Rocket follows ballistic path, becoming unsafe.	1	5	Low	Deployment bags have been specially made for the parachutes. This will allow for an organized packing that can reduce the chance of the parachute becoming stuck or the lines becoming tangled. Parachute deployment has been both ground tested and flight tested verifying that the setup results in repeatable successful results. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.
Rocket descends too quickly.	Parachute is improperly sized.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Simulations have been performed to validate the design. All custom made parachutes were extensively ground tested to validate the design. Subscale versions were built and tested to verify the coefficient of drag.

Rocket descends too slowly.	Parachute is improperly sized.	The rocket will drift farther than intended, potentially facing damaging environmental obstacles.	3	3	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Extensive ground testing was performed to verify the coefficient of drag is approximately that which was used during analysis.
Parachute has a tear or ripped seam.	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	Through careful inspection prior to packing each parachute, this failure mode will be eliminated. Rip stop nylon was selected for the parachute material. This material prevents tears from propagating easily. In the incident that a small tear occurs during flight, the parachute will not completely fail.
Parachute or chords become burnt.	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	Parachutes will all be packed in their own, custom deployment bag that is made out of Nomex, a fire retardant material. With proper packing of the parachute and use of Nomex, this failure mode is unlikely.
Recovery system separates from the rocket.	1. Bulkhead becomes dislodged. 2. Parachute disconnects from the U-bolt.	1,2. Parachute completely separates from the component, causing the rocket to	1	5	Low	The cables and bulkhead connecting the recovery system to each segment of the rocket are designed to withstand expected loads with an acceptable factor of safety. Should the rocket become ballistic, all personnel at the

		become ballistic.				launch field will be notified immediately.
Lines in parachutes parachute become tangled during deployment.	Parachute becomes unstable or does not open.	The rocket has a potential to become ballistic, resulting in damage to the rocket upon impact.	2	5	Low	A custom deployment bag has been designed and tested for the vortex ring parachute to ensure that the lines do not tangle during deployment. Ground testing has been performed to ensure that the packing method will prevent tangling during deployment prior to test flights.
Lines in parachutes become twisted during operation.	Parachute becomes unstable and ineffective.	The rocket may land with a kinetic energy higher than allowed, resulting in mission failure and potential damage to the rocket.	2	5	Low	Since the vortex ring parachute is a rotational parachute and the cruciform parachute is prone to rotation, swivels are used to allow the parachute to rotate without translating the rotation to the rocket, reducing the risk of the parachute twisting during operation.
Parachute does not inflate.	Improperly sized lines.	Parachute does not generate enough drag.	1	5	Low	A subscale parachute was constructed and tested to verify the design of the vortex ring. All full scale parachutes have been ground tested to ensure that the parachute will properly inflate during flight.
Vortex ring parachute does not rotate.	Lines are improperly sized.	Parachute does not generate enough drag.	1	5	Low	Ground testing was done to ensure that the vortex ring rotates as it should.

Vortex ring parachute oscillates.	Improper length of centerline.	Unclean deployment of cache capsule and lower airframe.	2	5	Low	The vortex ring was ground tested to ensure that does not oscillate prior to utilizing during a flight.
Swivel does not rotate at the same rate as the parachute.	1. Too much pressure is applied to the swivels to allow for rotation. 2. Swivels do not have a low enough coefficient of friction.	The lines become twisted, leaving the parachute ineffective.	2	5		The vortex ring has been ground tested with the swivel to ensure proper rotation is allowed. Additionally, the swivel will be inspected prior to every launch to verify that the swivel has not become gummed up since the last launch.

Table 98: Recovery risk assessment.

Cache Capsule Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Lower airframe does not eject from the rocket.	1. Nylon shear pins do not fully shear. 2. Friction coefficient between upper and lower airframe is too high.	Cache capsule will be unable to be jettisoned from the rocket. Rocket will still completely recover.	1	5	Low	1. Black powder charges were designed to overcome the shear strength of the shear pins, allowing the rocket to separate easily. The lower airframe separations has been tested with black powder charges to ensure that the sections separate. 2. The coupling between the two sections have been sanded down to have a loose fit, preventing the two sections from getting stuck together during flight.

Battery in altimeter housing dies.	1. Use past the normal life of the battery. 2. Extremely cold weather.	1,2. Ejection charges will not fire, preventing the rocket from splitting and the rover being deployed.	2	5	Low	Batteries will be checked for sufficient charge during launch day preparations. If the launch is delayed and the batteries have been left on, batteries should be rechecked for a sufficient charge to power the systems.
E-match fails.	1. E-match become dislodged. 2. Faulty e-match.	1,2. Ejection charges will not fire, preventing the rocket from splitting and the rover being deployed.	1	5	Low	Redundant altimeters and e-matches are used during flight. This decreases the probability of having a complete e-match failure.

Table 99: Cache capsule risk assessment.

Vehicle Assembly Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Rocket drop (INERT)	Mishandling of the rocket during transportation.	Minimal damage and scratches to components of the rocket.	4	5	Low	The rocket has been designed to be durable in order to survive loads encountered during flight and upon landing. Careful handling should be practiced while transporting the rocket.
Rocket drop (LIVE)	Mishandling of the rocket during transportation.	1. Minimal damage and scratches to components of the rocket if no charges go off. 2. Charges prematurely go off, resulting in a	1	5	Low	The rocket has been designed to be durable in order to survive loads encountered during flight and upon landing. Careful handling should be practiced while transporting the rocket.

		serious safety threat to personnel in the area and significant damage to the rocket.				
Black powder charges go off prematurely.	1. Altimeters send a false reading. 2. Open flame sets off charge.	1,2. Charges prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket.	1	5	Low	All electronics will be kept in their OFF state for as long as possible during preparation. Altimeters are not to be armed until the rocket is in the launch pad and all autonomous systems have been completed. Open flames and other heat sources will be prohibited in the area.
Seized nut or bolt due to galling or cross threading.	Repetitive uninstalling and reinstalling of parts made of materials prone to galling.	Component becomes unusable, potentially ruining expensive, custom machined parts. Amount of rework depends on the location and component that seized.	2	4	Low	Through proper choice in materials, appropriate pre-load, and proper installation, the risk of galling can be eliminated.

Table 100: Vehicle assembly risk assessment.

Environmental Hazards to Rocket Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Low cloud cover.	N/A	Unable to test entire system.	1	4	Moderate	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system.
Rain.	N/A	1. Unable to launch. 2. Damage electrical components and systems in the rocket.	1	4	Moderate	1. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. 2. Have a plan to place electrical components in water tight bags. Have a location prepared to store the entire rocket to prevent water damage. Electronics on the ground station are all stored in water tight control boxes to seal out any moisture.
Thunderstorms.	N/A	Damage due to electrical shock on system.	1	5	Low	When planning test launches, the forecast should be monitored in order to launch on a day where the weather does not prohibit launching or testing the entire system. Should a storm roll in, the entire system should be promptly packed and removed from the premise to avoid having a large metal object exposed

						during a thunderstorm. In the event that the system cannot be removed, personnel are not to approach the launch pad during a thunderstorm.
High winds.	N/A	1. Have to launch at high angle, reducing altitude achieved. 2. Increased drifting. 3. Unable to launch.	1	4	Moderate	1,2,3. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. If high winds are present but allowable for launch, the time of launch should be planned for the time of day with the lowest winds.
Trees.	N/A	1. Damage to rocket or parachutes. 2. Irretrievable rocket components.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. Drift calculations have been computed, so we can estimate how far each component of the rocket will drift with a particular wind velocity. The rocket should not be launched if trees are within the estimated drift radius.
Swampy ground.	N/A	Irretrievable rocket components.	1	4	Moderate	With the potential of the ground being extremely soft at local launch sites and in Huntsville, the rocket should not be launched if there is swampy ground within the predicted drift radius that would prevent the team from retrieving a component of the rocket.

Ponds, creeks, and other bodies of water.	N/A	1. Loss of rocket components. 2. Damaged electronics.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. The rocket should not be launched if a body of water is within the estimated drift radius. Should the rocket be submerged in water, it should be retrieved immediately and any electrical components salvaged. Electrical components are to be tested for complete functionality prior to reuse.
Extremely cold temperatures.	1. Batteries discharge quicker than normal. 2. Shrinking of fiberglass.	1. Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events. 2. Rocket will not separate as easily.	1	5	Low	1. Batteries will be checked for charge prior to launch to ensure there is enough charge to power the flight. Should the flight be delayed, batteries will should be rechecked and replaced as necessary. 2. If the temperatures are below normal launch temperature, black powder charges should be tested to ensure that the pressurization is enough to separate the rocket. If this test is successful, the rocket should be safe to launch.
Humidity.	N/A	Motors or black powder charges become saturated and don't ignite.	1	5	Low	Motors and black powder should be stored in a location free from moisture.
UV exposure.	Rocket left exposed to sun	Possibly weakening	4	4	Low	Rocket should not be exposed to sun for long periods of time. If the

	for long periods of time.	materials or adhesives.				rocket must be worked on for long periods of time, shelter should be sought.

Table 101: Environmental Hazards to Rocket Risk Assessment

Hazards to Environment Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Harmful substances permeating into the ground or water.	Improper disposal of batteries or chemicals.	Impure soil and water can have negative effects on the environment that in turn, work their way into humans, causing illness.	4	3	Low	Batteries and other chemicals should be disposed of properly in accordance with the MSDS sheets. Should a spill occur, proper measure are to be followed in accordance with the MSDS sheets and any EHS standards.
Release of hydrogen chloride into the atmosphere.	Burning of composite motors.	Hydrogen chloride dissociates in water forming hydrochloric acid.	4	1	Moderate	While the probability of hydrochloric acid forming is high, the amount that would be produced over the course of a season is negligible. Fewer than six motors are predicted to be fired during the year, all of which are relatively small in size.
Release of reactive chemicals.	Burning of composite motors.	Reactive chemicals work to deplete ozone layer.	4	1	Moderate	While the probability of releasing reactive chemicals into the environment is high, the quantity released will result in negligible effects. Fewer than six motors are predicted to be fired during the year, all of which are relatively small in size.

Release of toxic fumes in the air.	Burning of ammonium perchlorate motors.	Biodegradation.	4	1	Moderate	Ammonium perchlorate will be burned in small quantities and infrequently. The amount of toxins released will cause minimal degradation.
Production of styrene gas.	Through the use of fiberglass in the overall design, fiberglass is manufactured by a second party.	Toxic air emissions.	4	1	Moderate	Productions methods for fiberglass produces toxic air pollutants, particularly styrene, which evaporate during the curing process. Due to the quantity of fiberglass utilized on the rocket, the amount of pollutants produced throughout manufacturing process will have a negligible effect on the environment.
Spray painting.	The rocket will be spray painted.	1. Water contamination. 2. Emissions to environment.	2	5	Low	All spray painting operations will be performed in a paint booth. This prevents any overspray from entering into the water system or air.
Soldering wires.	All wires will be soldered together to retain strength and proper connection.	1. Air contamination 2. Ground contamination	4	1	Low	The amount of vapor from the soldering process is at such a low quantities that no action will be needed.
Use of lead acid battery leakage.	Old or damaged housing to battery	1. Acid will leak onto the ground and get into the water system. 2. Chemical reaction with organic material that could	3	4	Low	1. We are using new batteries that have been factory inspected and tested. 2. Proper lifting and storing procedures according to manufacturer's specifications will be adhered to.

		potentially cause a fire.				
Plastic waste material.	Plastic using in the production of electrical components and wiring.	1. Sharp plastic material produced when shaving down plastic components could harm animals if ingested by an animal. 2. Plastic could find its way down a drain and into the water system.	3	5	Low	1. All plastic material will be disposed of in proper waste receptacles.
Wire waste material.	Wire material used in the production of electrical components.	1. Sharp bits of wire being ingested by an animal if improperly disposed of.	3	5	Low	1. All wire material will be disposed of in proper waste receptacles.
CO_2 emissions.	Travel to launch sites and competition.	Destroying the ozone layer.	4	1	Moderate	While the effects of CO_2 emissions cannot be reversed, the amount produced is negligible.

Table 102: Hazards to Environment Risk Assessment

Section 9. Appendix IV – Technical Drawings

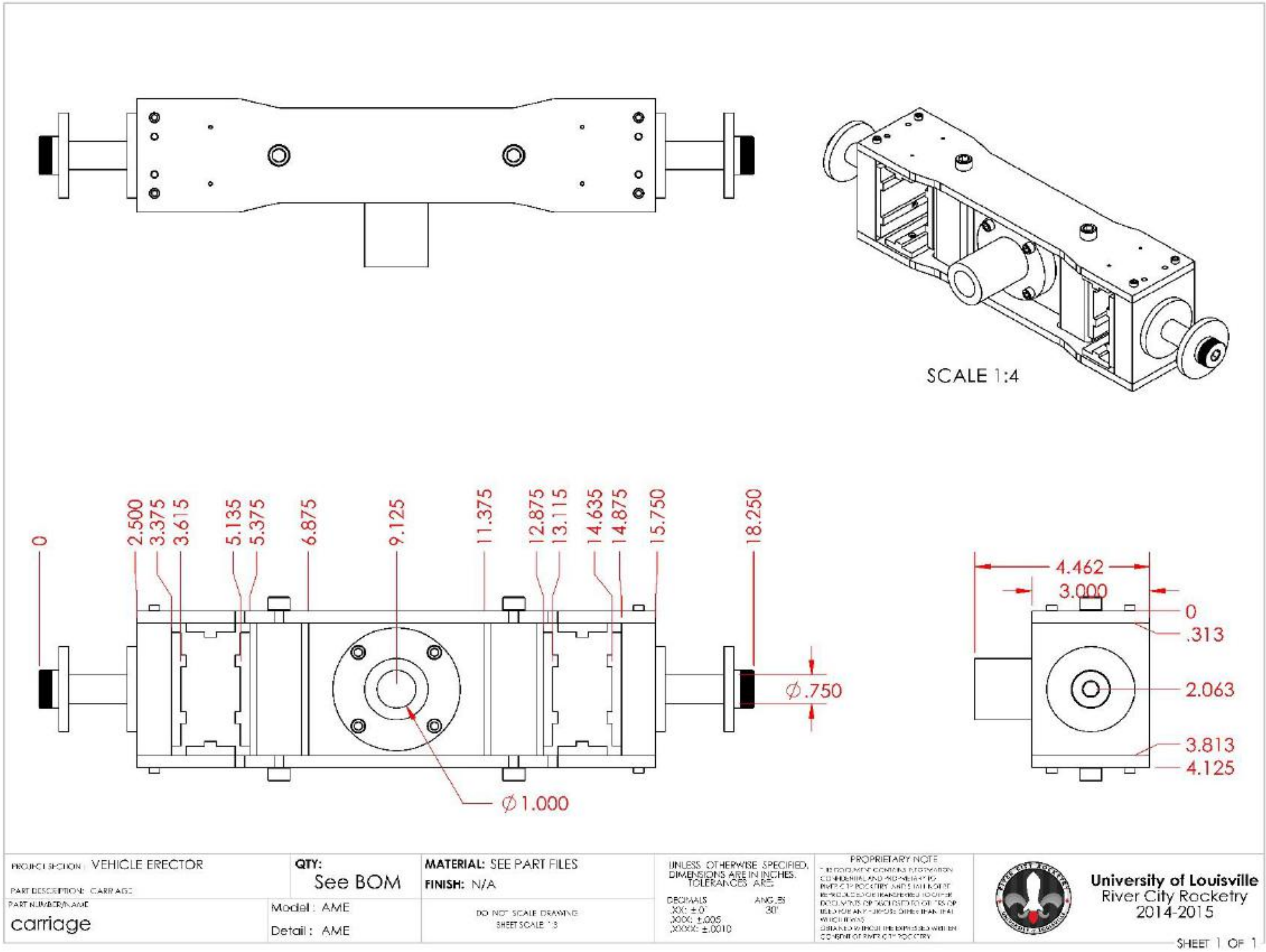


Figure 334: Carriage assembly.

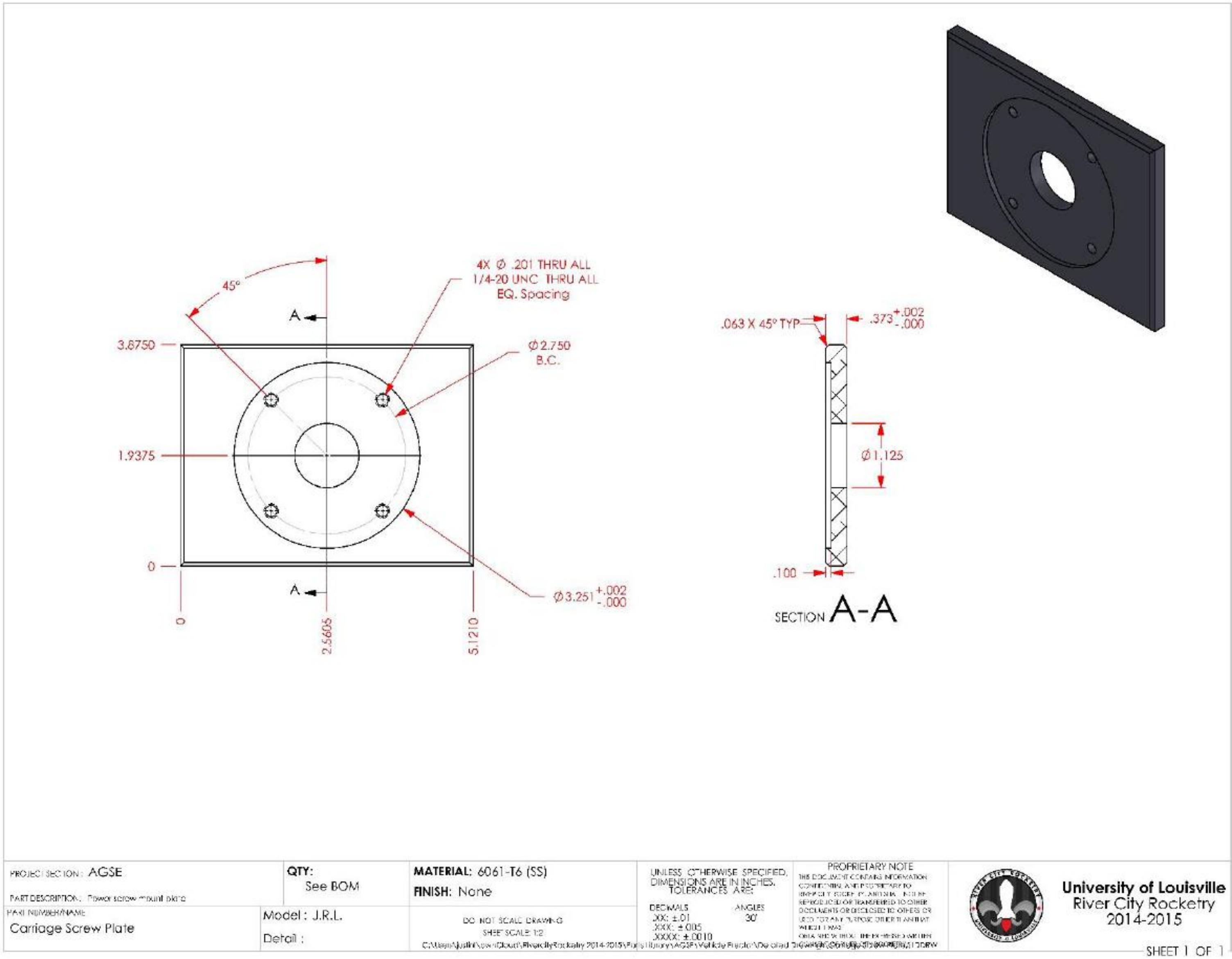


Figure 335: Carriage screw plate.

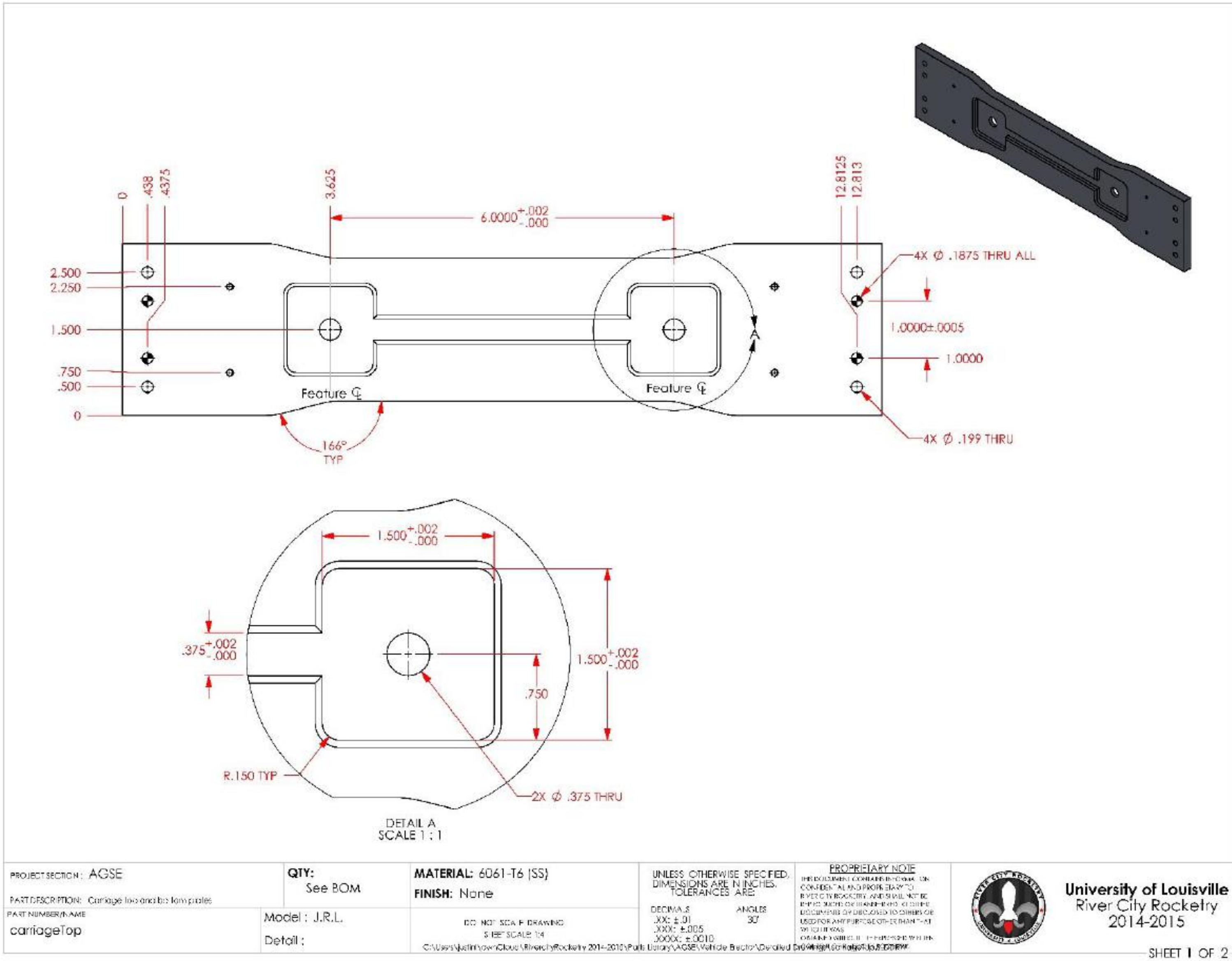


Figure 336: Carriage top plate, view A.

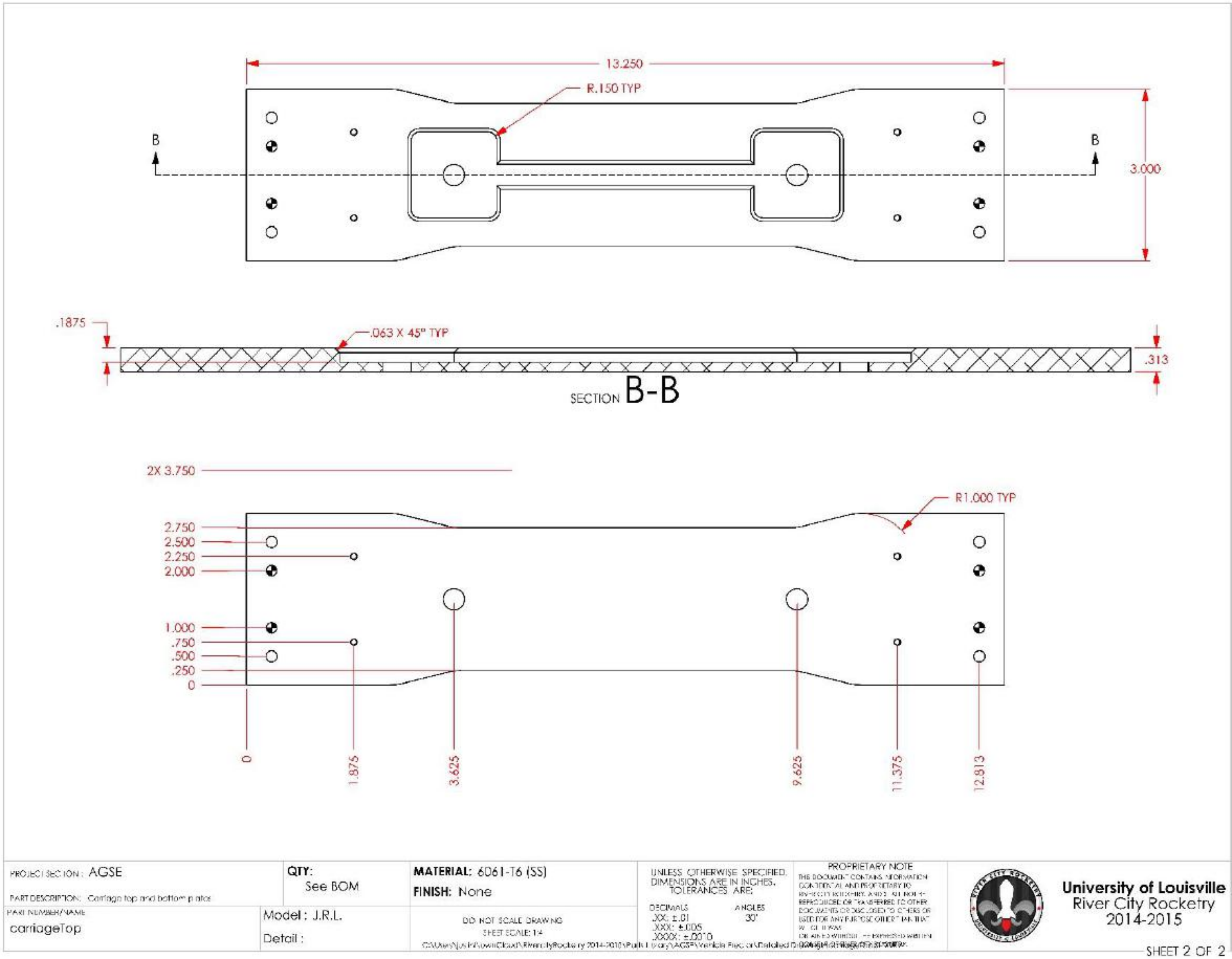


Figure 337: Carriage top plate, view B.

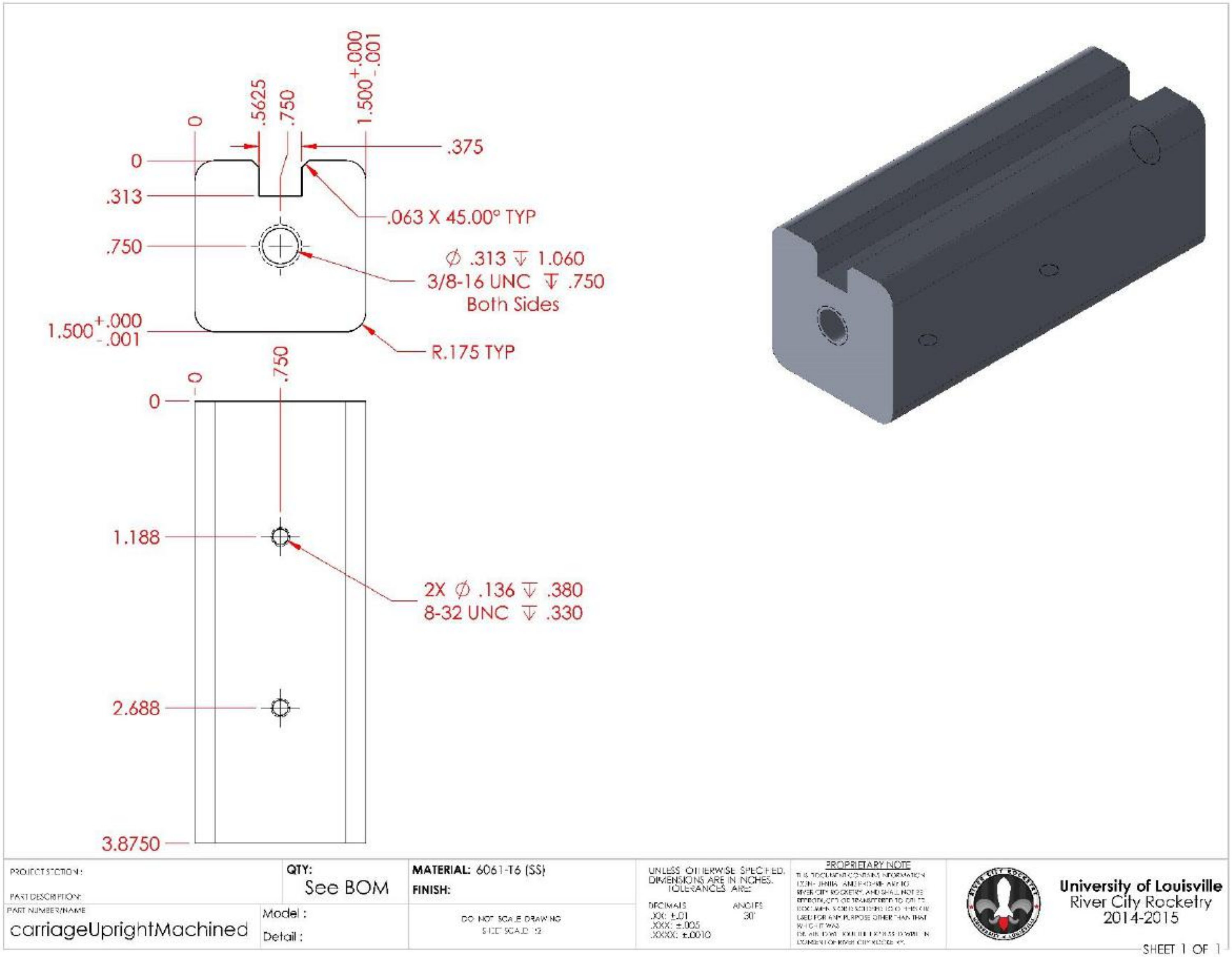


Figure 338: Carriage upright.

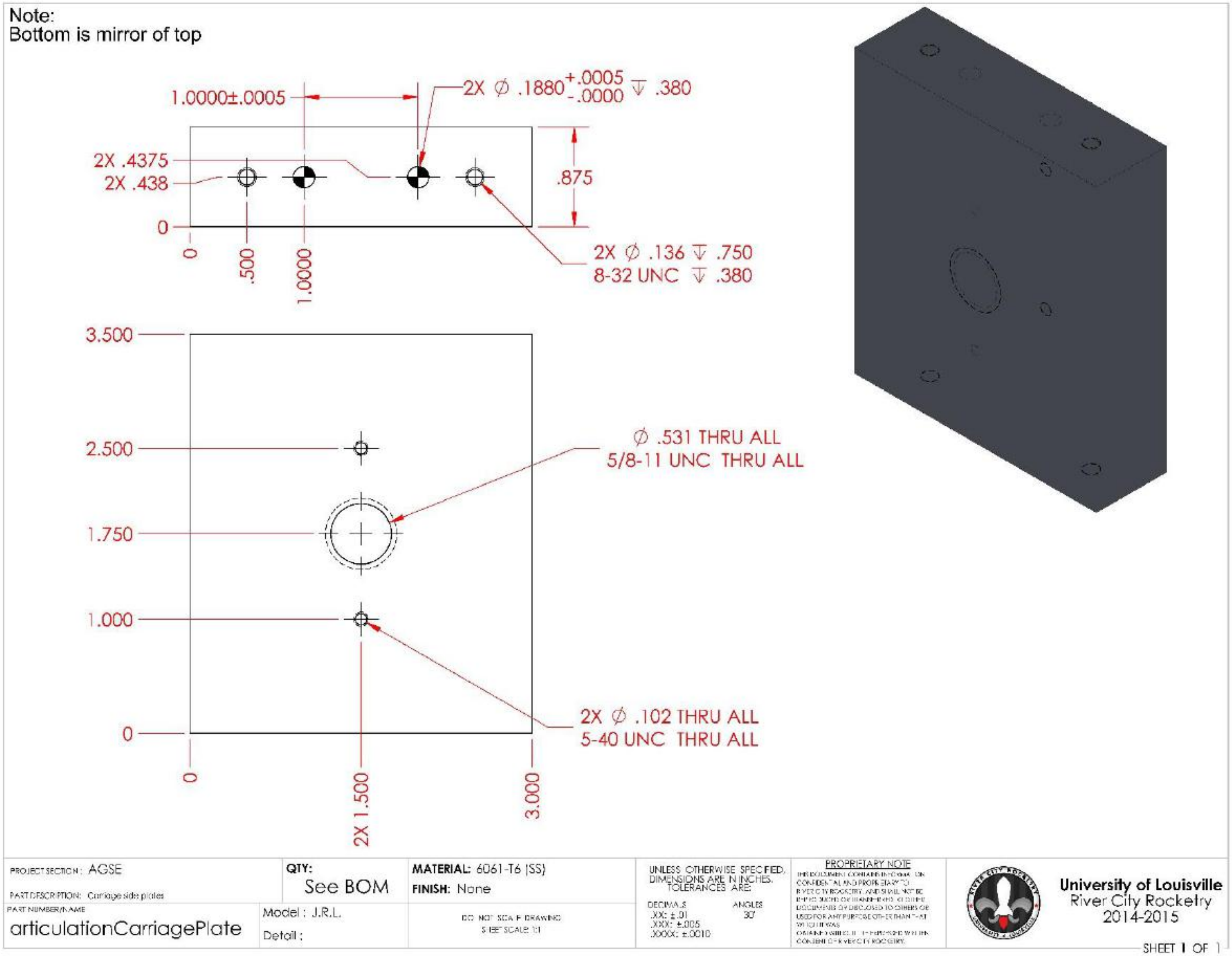


Figure 339: Carriage articulation interface plate.

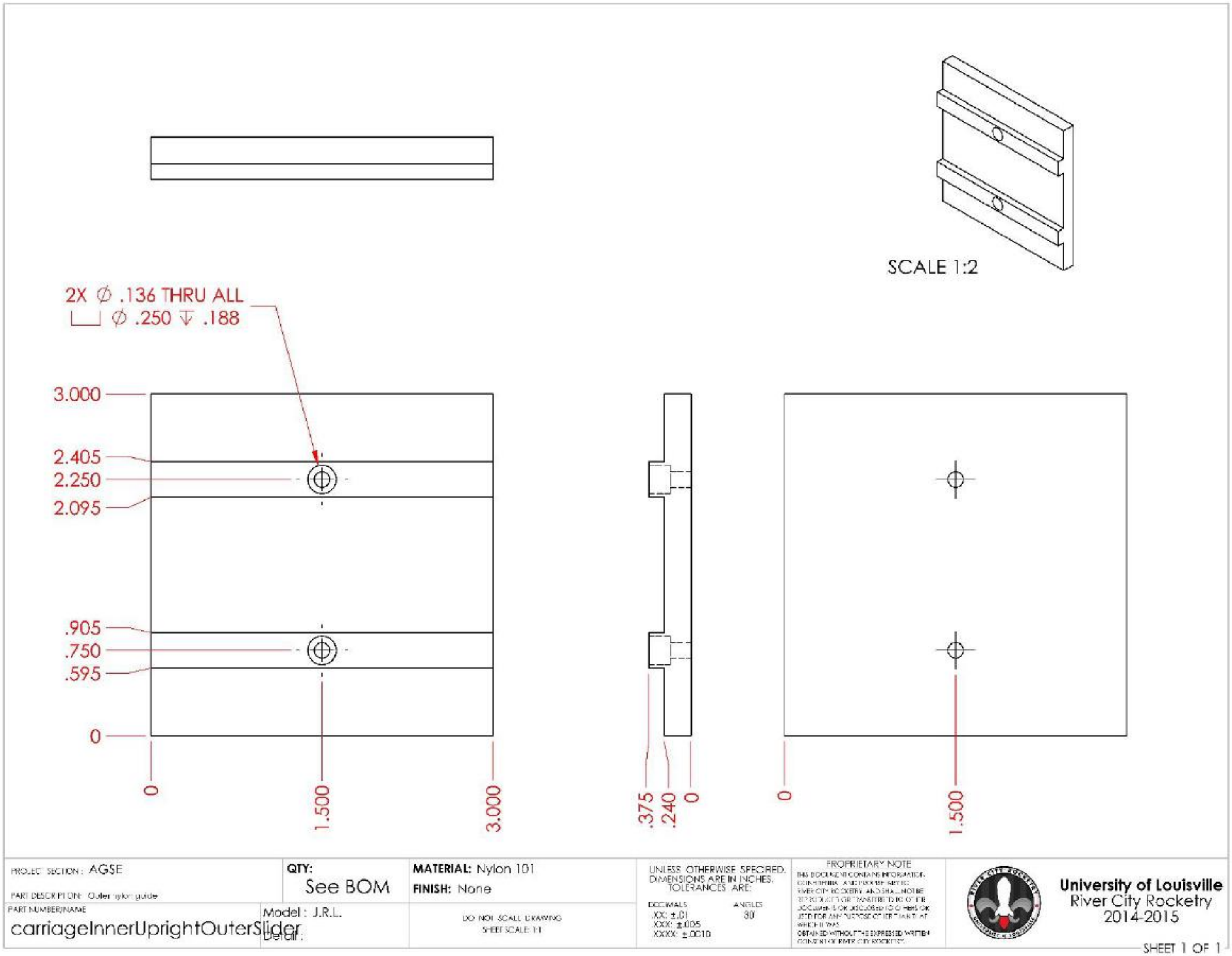


Figure 340: Carriage outer nylon slide.

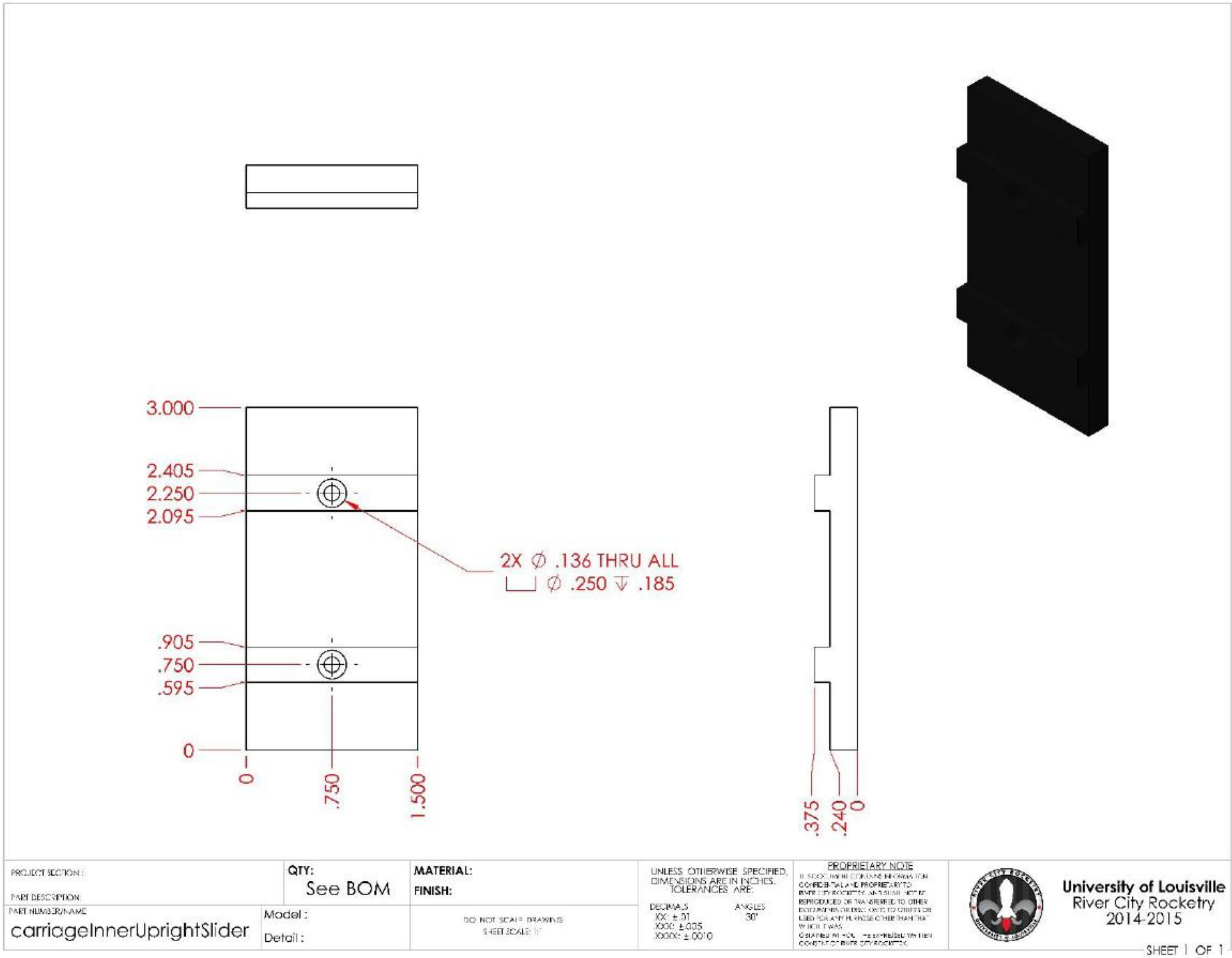


Figure 341: Carriage inner nylon slide.

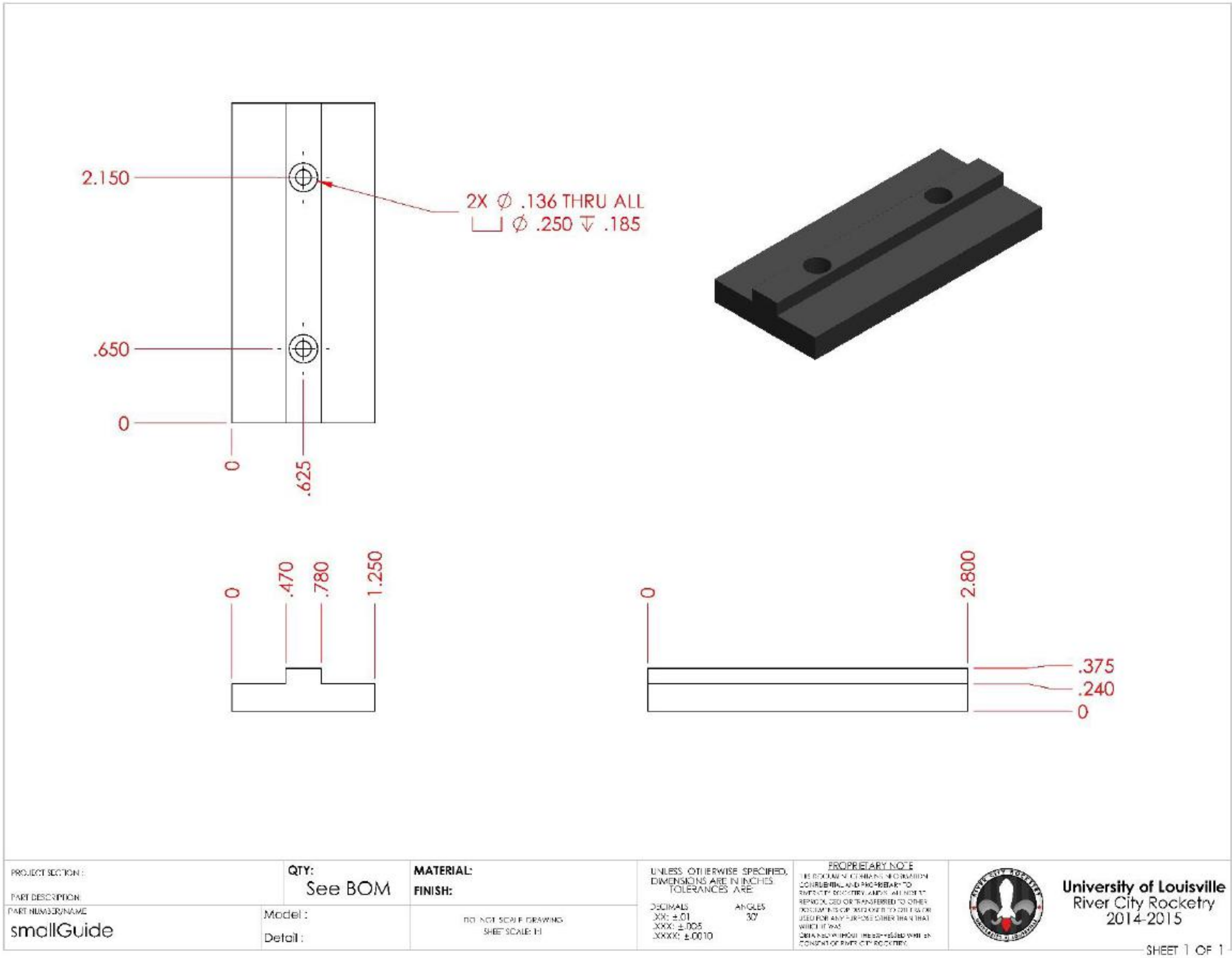
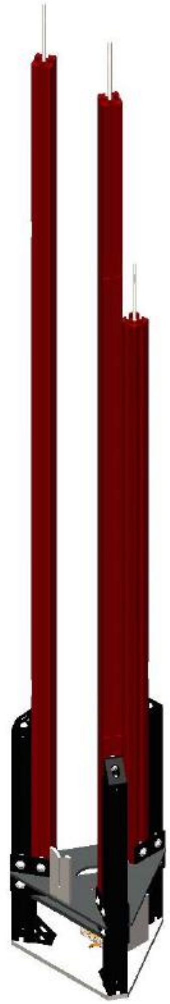


Figure 342: Carriage vertical nylon slide.



ITEM NO.	PART NUMBER	QTY.
1	LP-002	1
2	Ignition Station	1
3	LP-001-01	3
4	LP-001-06	2
5	LP-001-05	1
6	4332	9
7	LP-003	1
8	LP-004	1
9	4307	12
10	LP-012	1
11	92210A862	3
12	92620A599	6
13	47065T97	33
14	92949A578	6
15	92949A582	3
16	91253A110	1
17	92949A819	4

PROJECT SECTION: Launch Platform
PART DESCRIPTION: Launch platform base
PART NUMBER/NAME: Base
QTY: See BOM
MATERIAL: None
FINISH: None
Model: JRL
Detail: JRL
DO NOT SCALE DRAWING
SHEET SCALE: 1:24
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010
ANGLES 30'
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Figure 343: Launch platform base.

ITEM NO.	SW-File Name(File Name)	QTY.
1	Tower Ring	1
2	LP-001-XX	1
3	LP-001-XX	2
4	Guide Fasteners	3

Figure 344: Launch platform upper section.

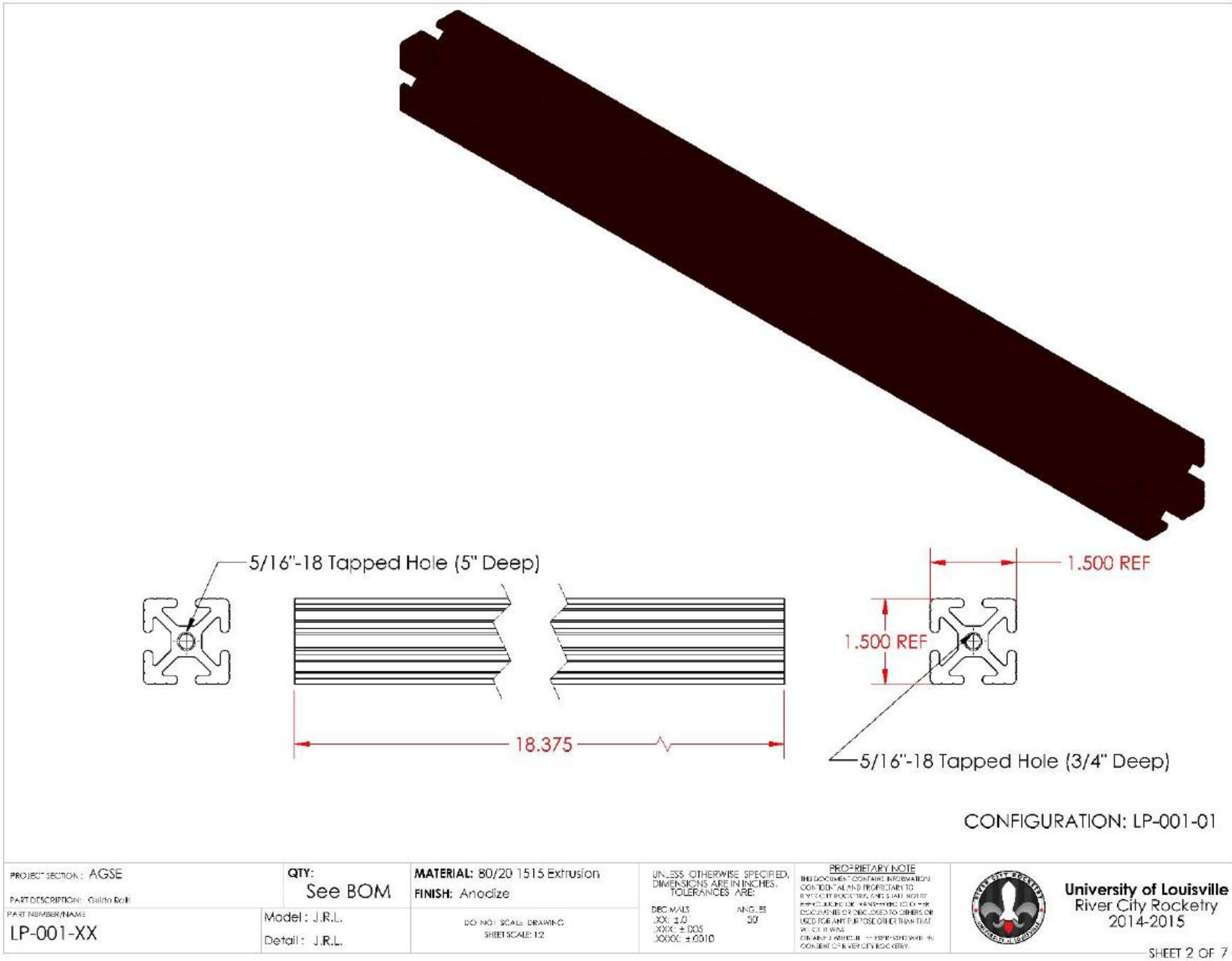


Figure 345: Launch platform brace rail.

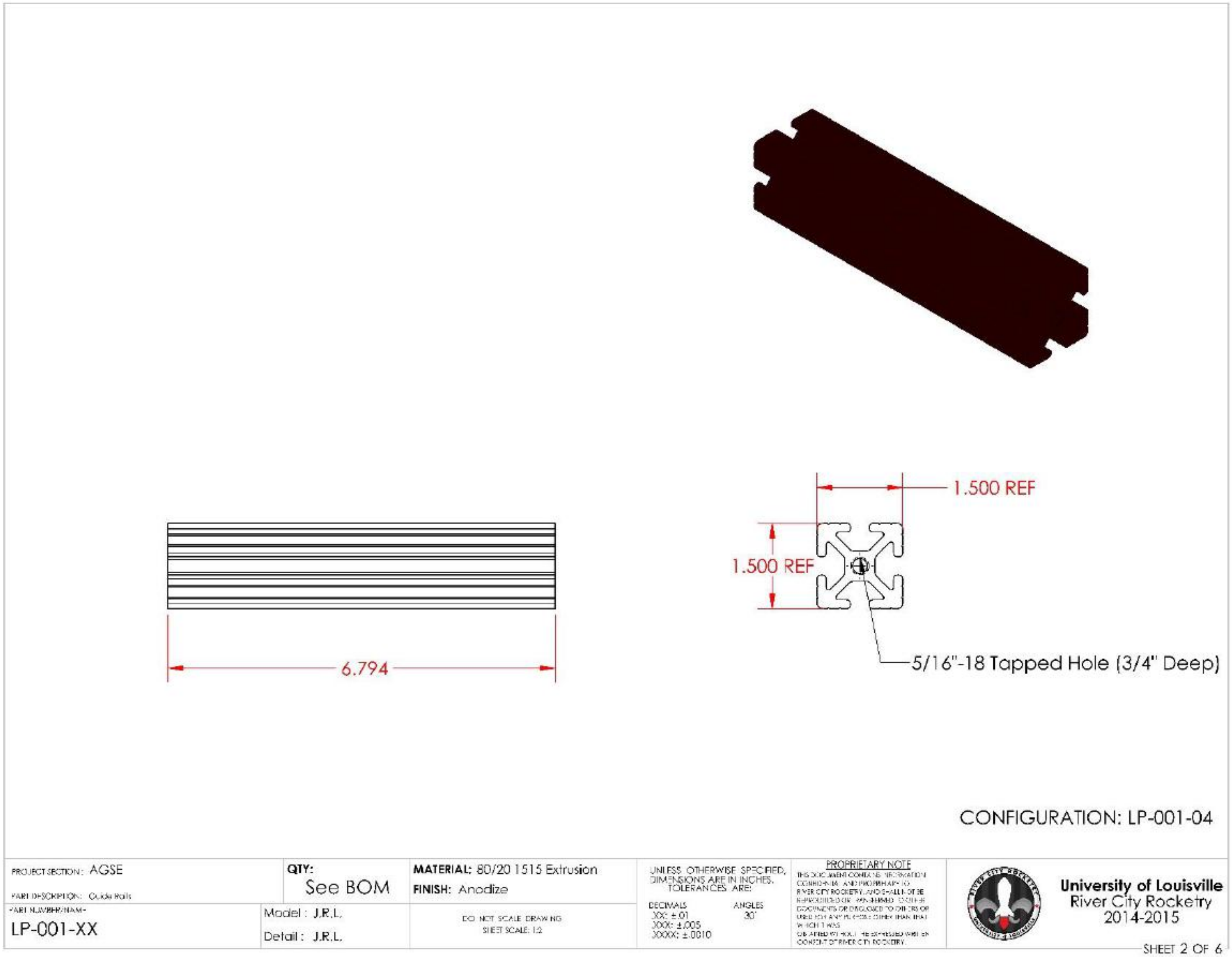


Figure 346: Launch platform ring standoff.

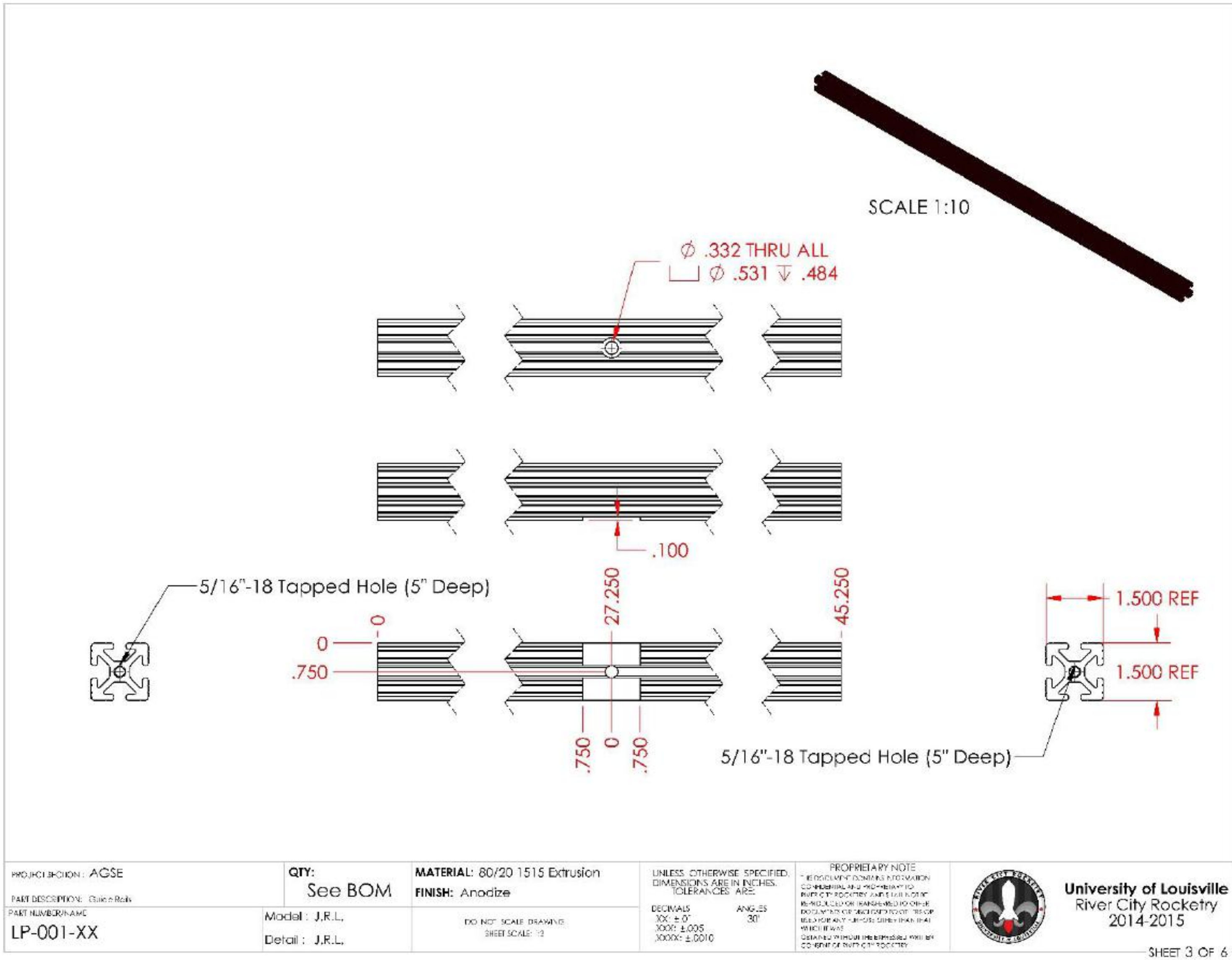


Figure 347: Launch platform rail section A.

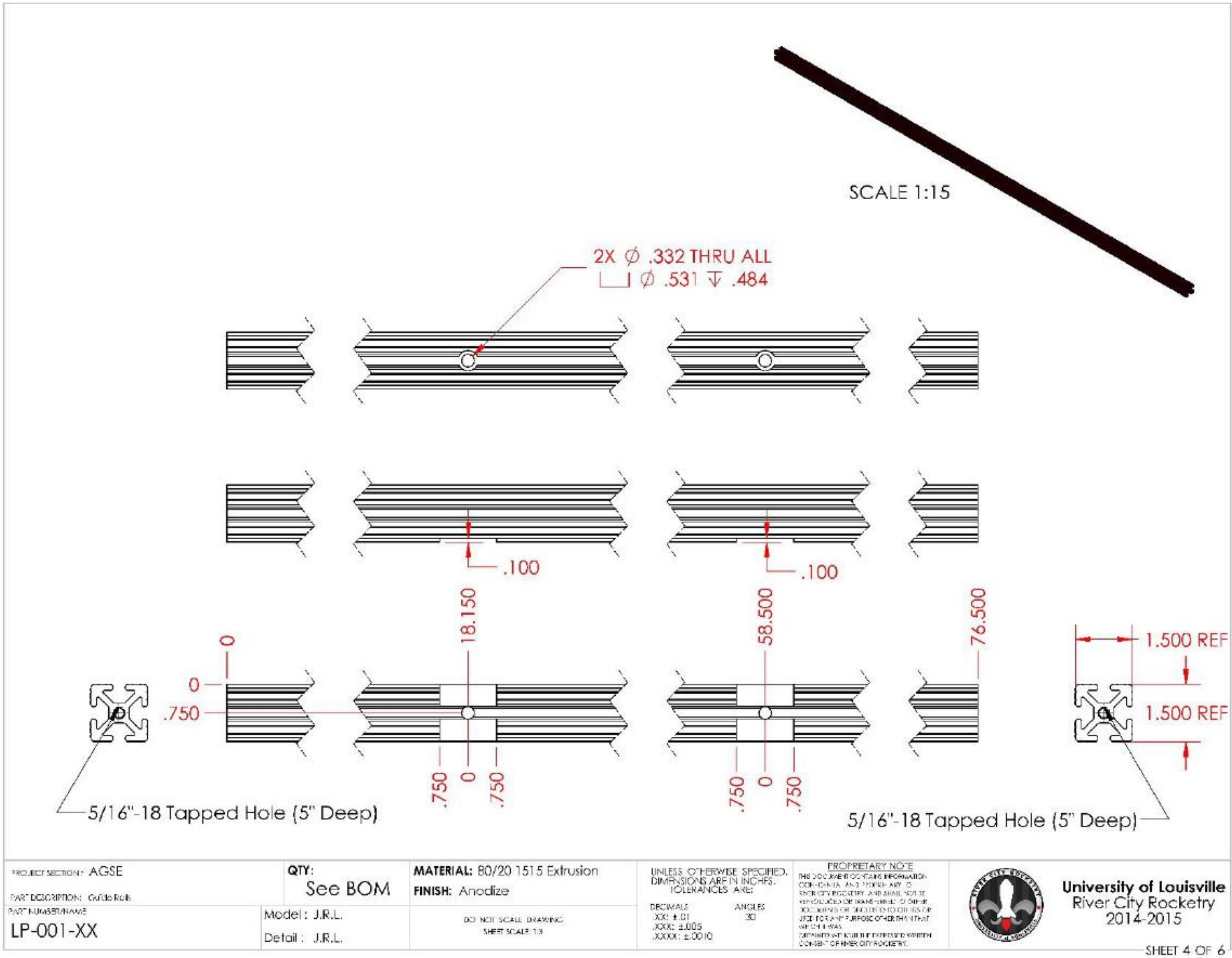


Figure 348: Launch platform rail section B.

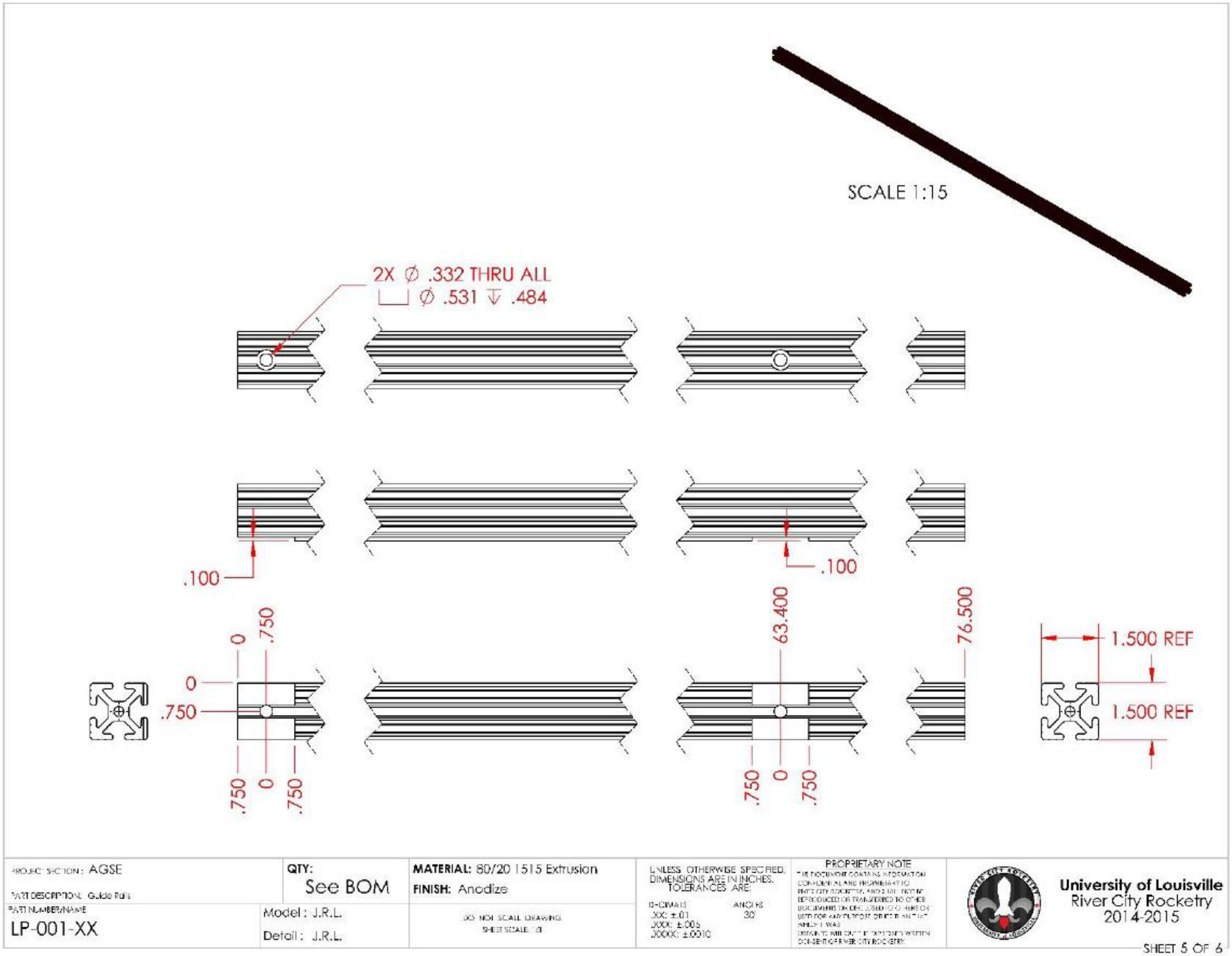


Figure 349: Launch platform rail section C.

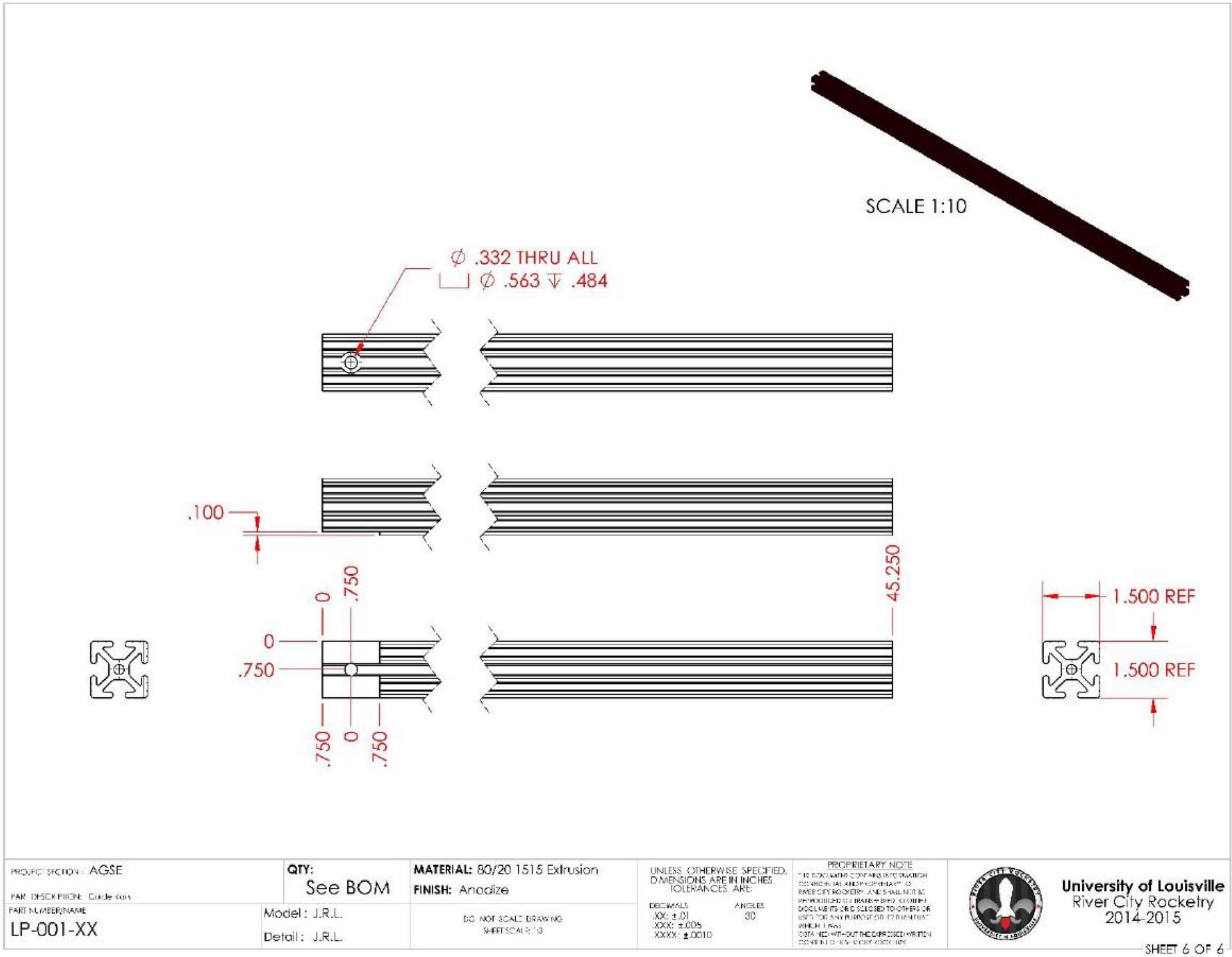


Figure 350: Launch platform rail section D.

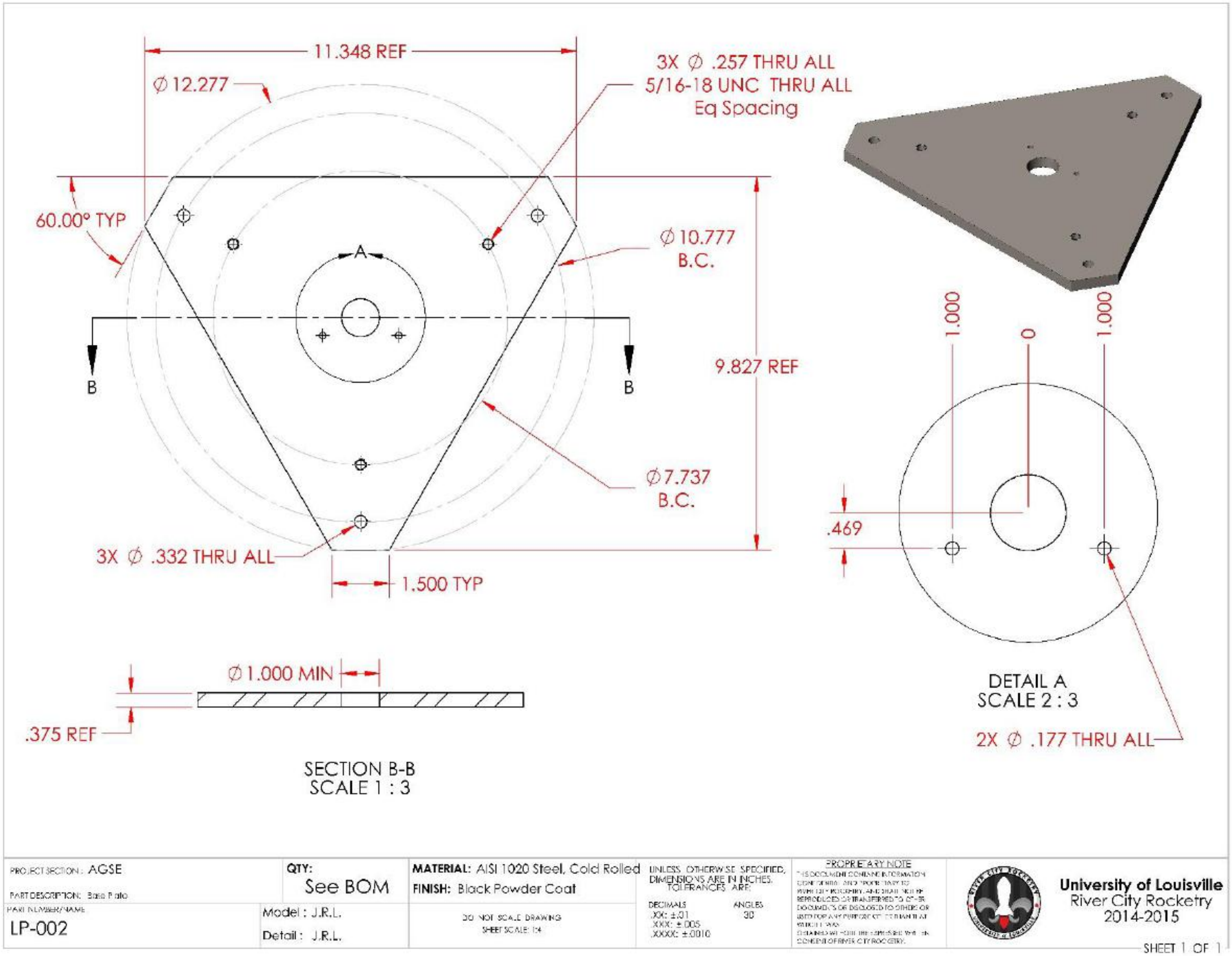


Figure 351: Launch platform base plate.

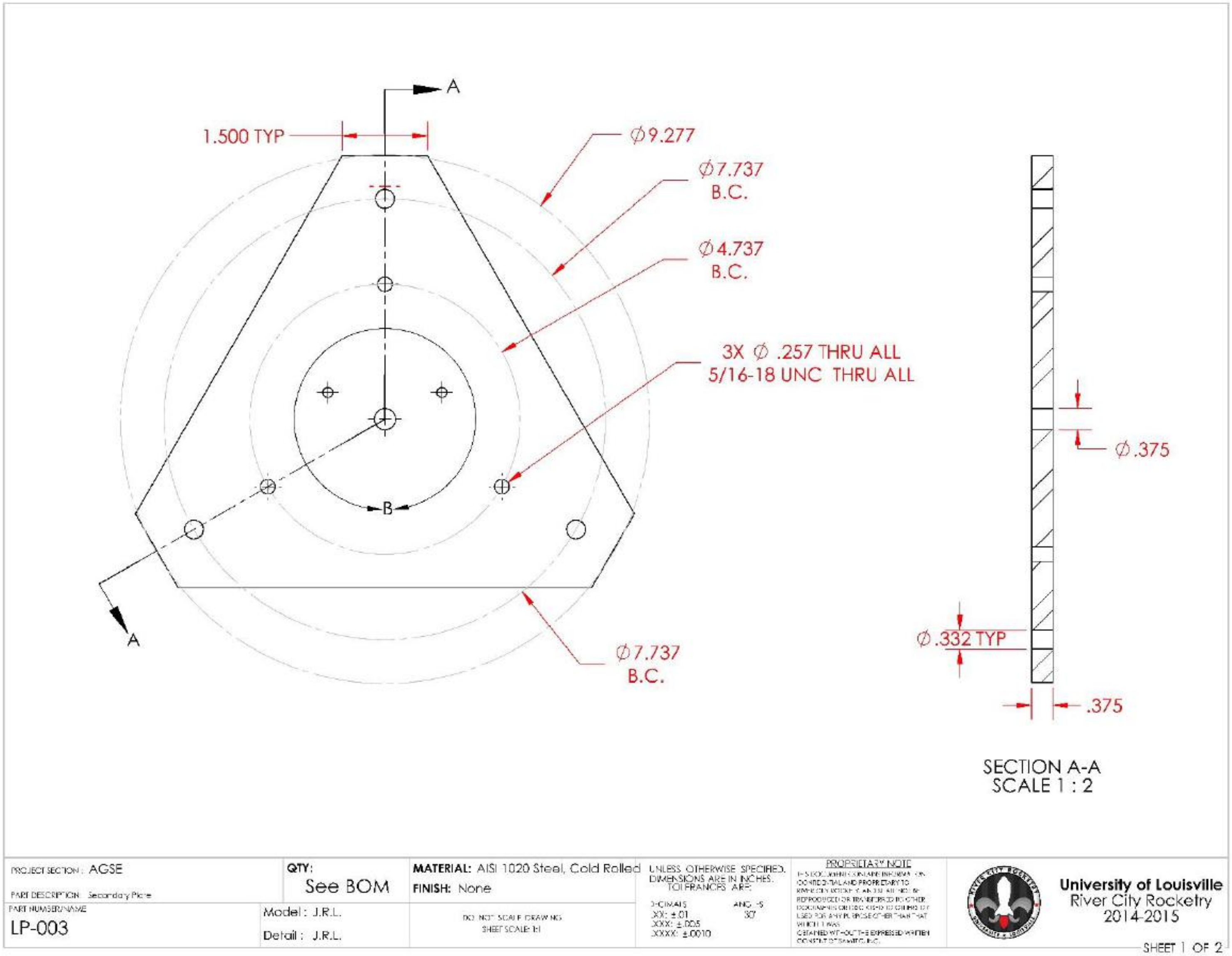


Figure 352: Launch platform middle plate, view A.

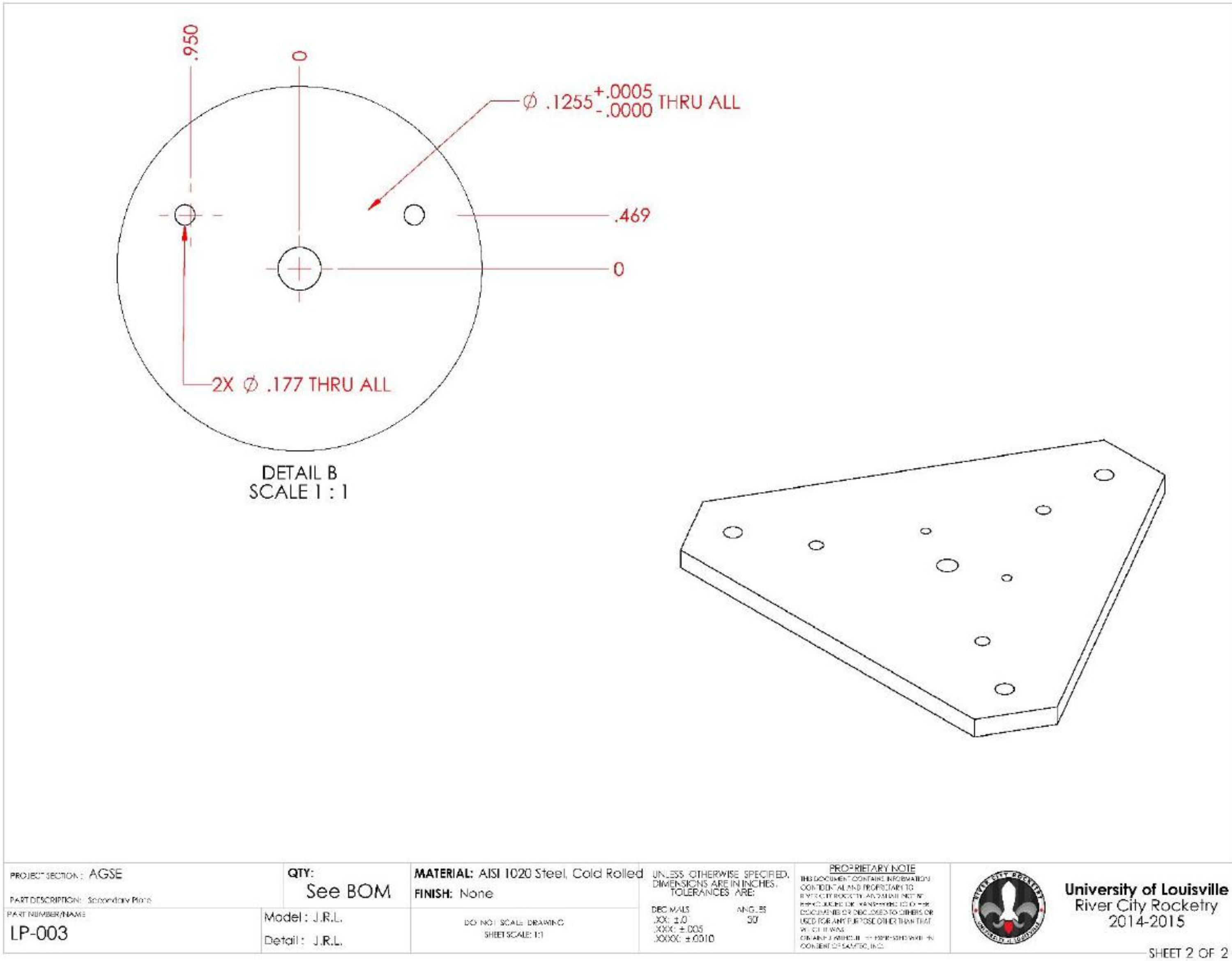


Figure 353: Launch platform middle plate, view B.

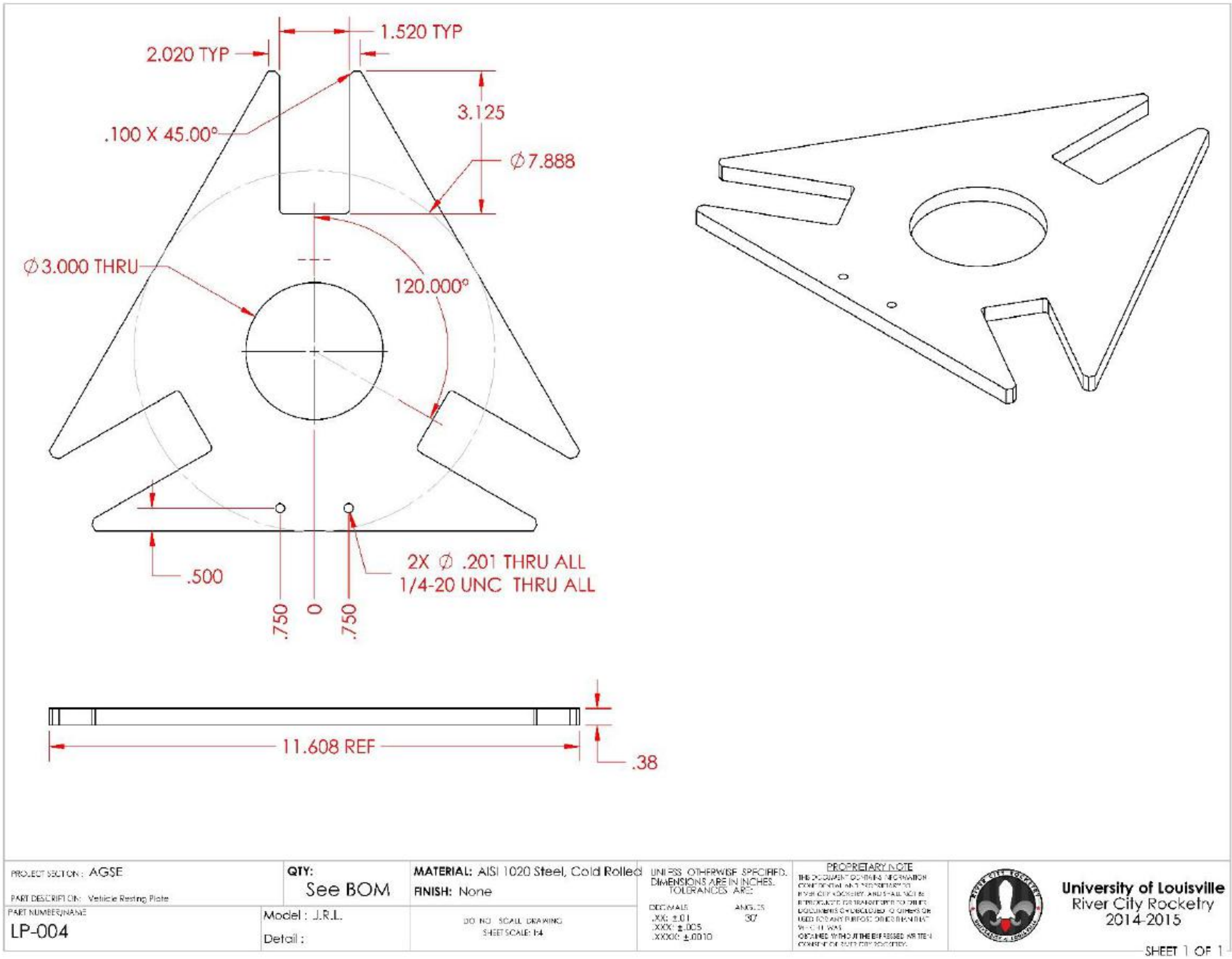


Figure 354: Launch platform top plate.

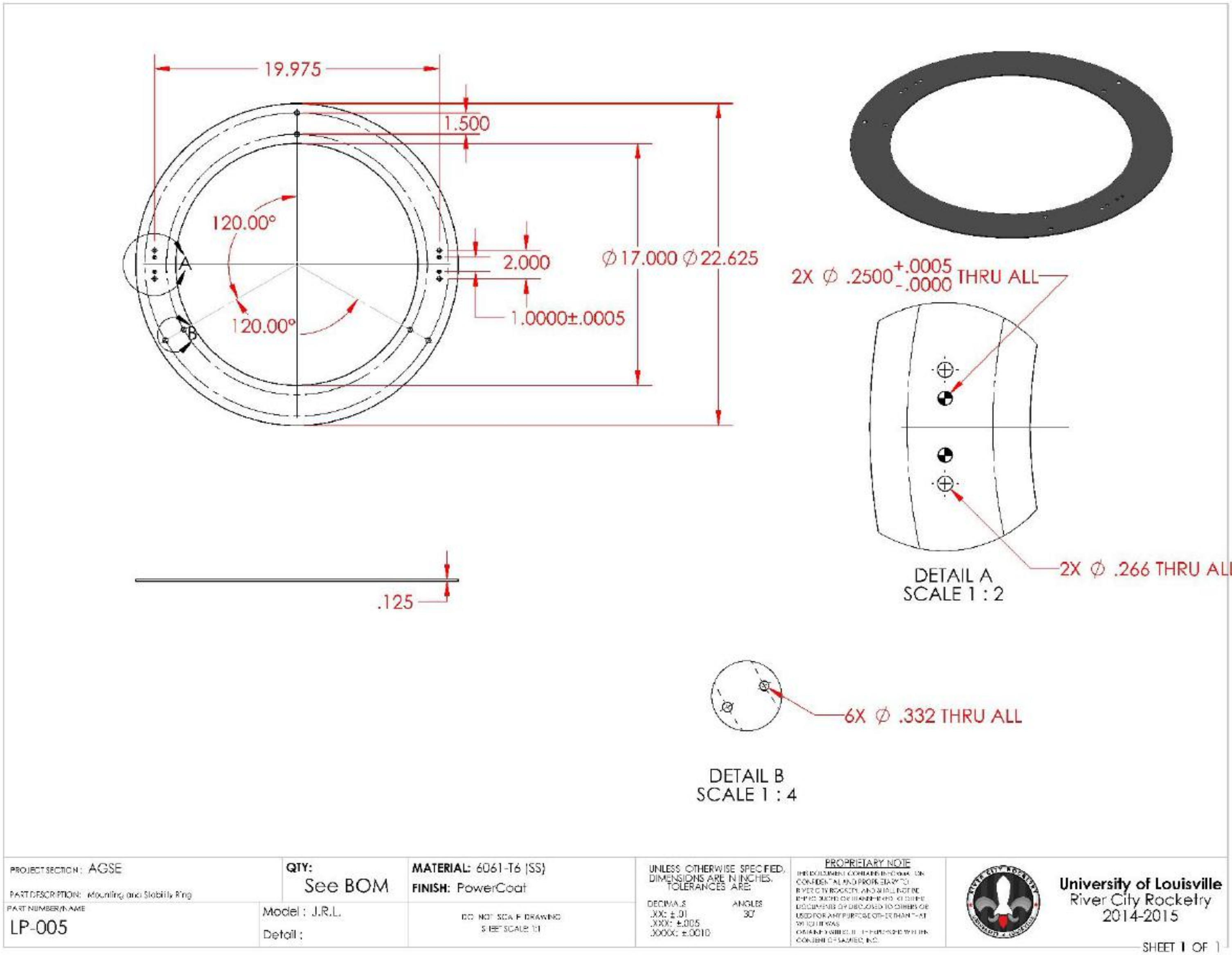


Figure 355: Launch platform tower ring.

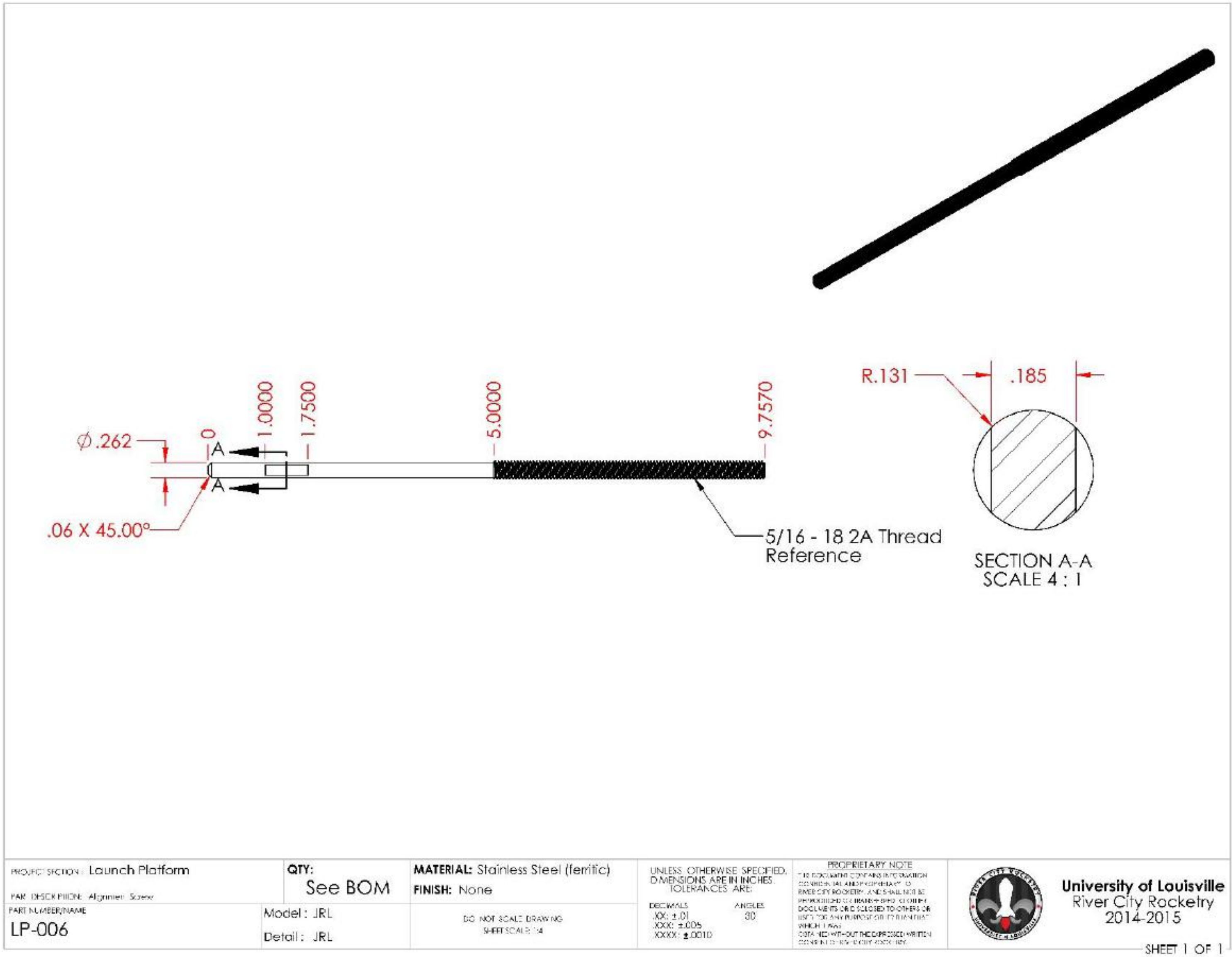


Figure 356: Launch platform rail stability rod.

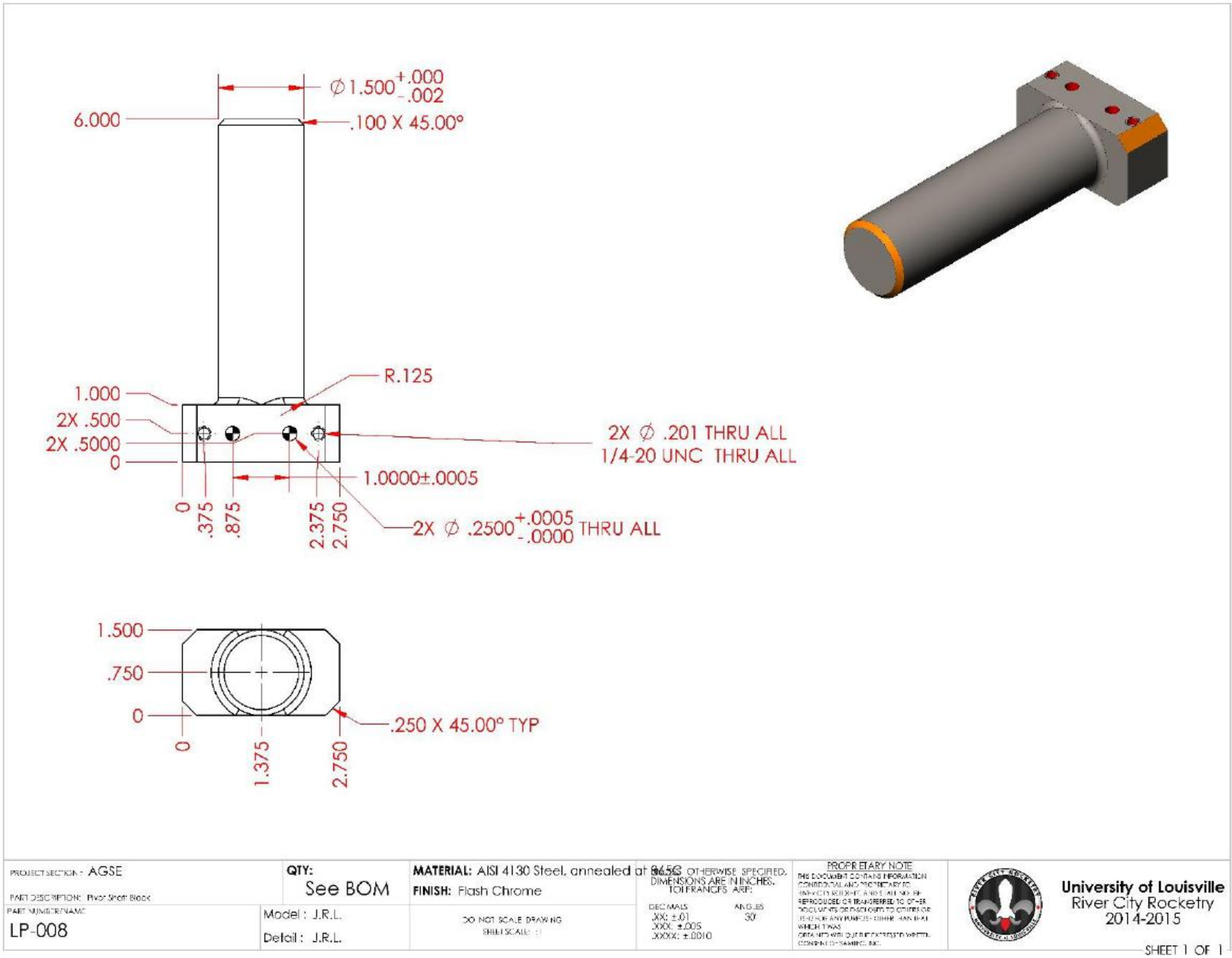


Figure 357: Launch platform pivot point connection.

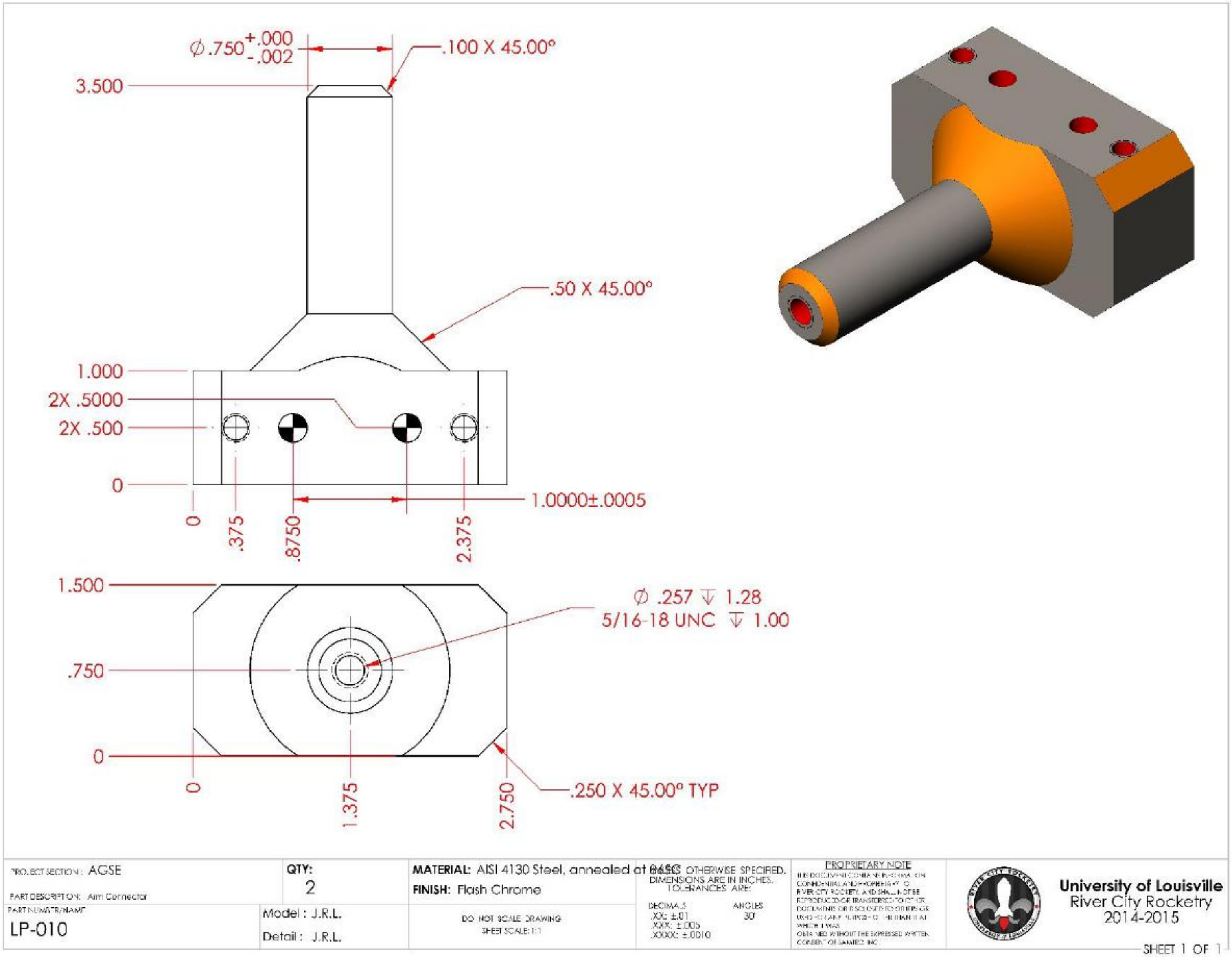
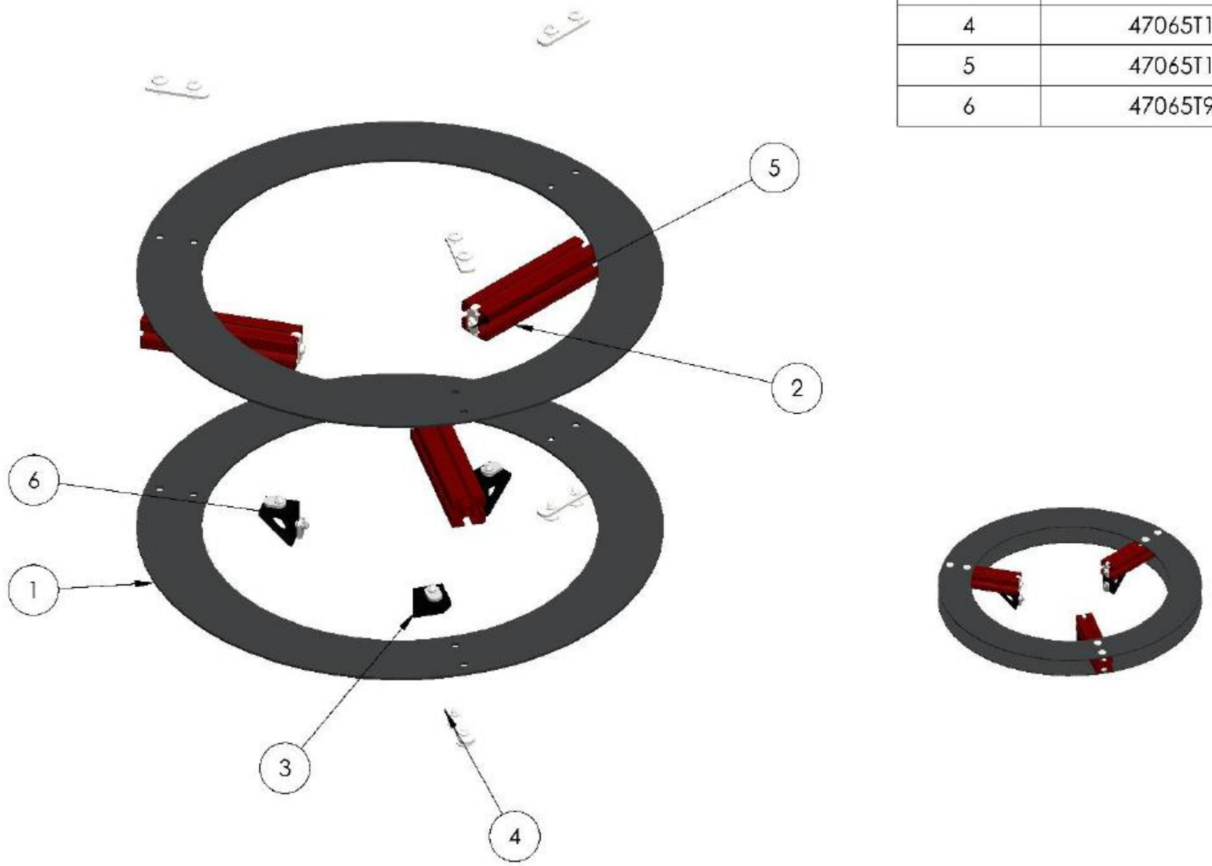


Figure 358: Launch platform articulating point connection.



ITEM NO.	SW-File Name(File Name)	QTY.
1	LP-009	2
2	LP-001-XX	3
3	4332	3
4	47065T149	6
5	47065T156	3
6	47065T970	6

PROJECT SECTION: Launch Platform
PART DESCRIPTION: Upper tower ring
PART NUMBER/NAME
Tower Ring

QTY: See BOM
Model : JRL
Detail :

MATERIAL: None
FINISH: None
DO NOT SCALE DRAWING
SHEET SCALE: 1:12

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010
ANGLES 30'

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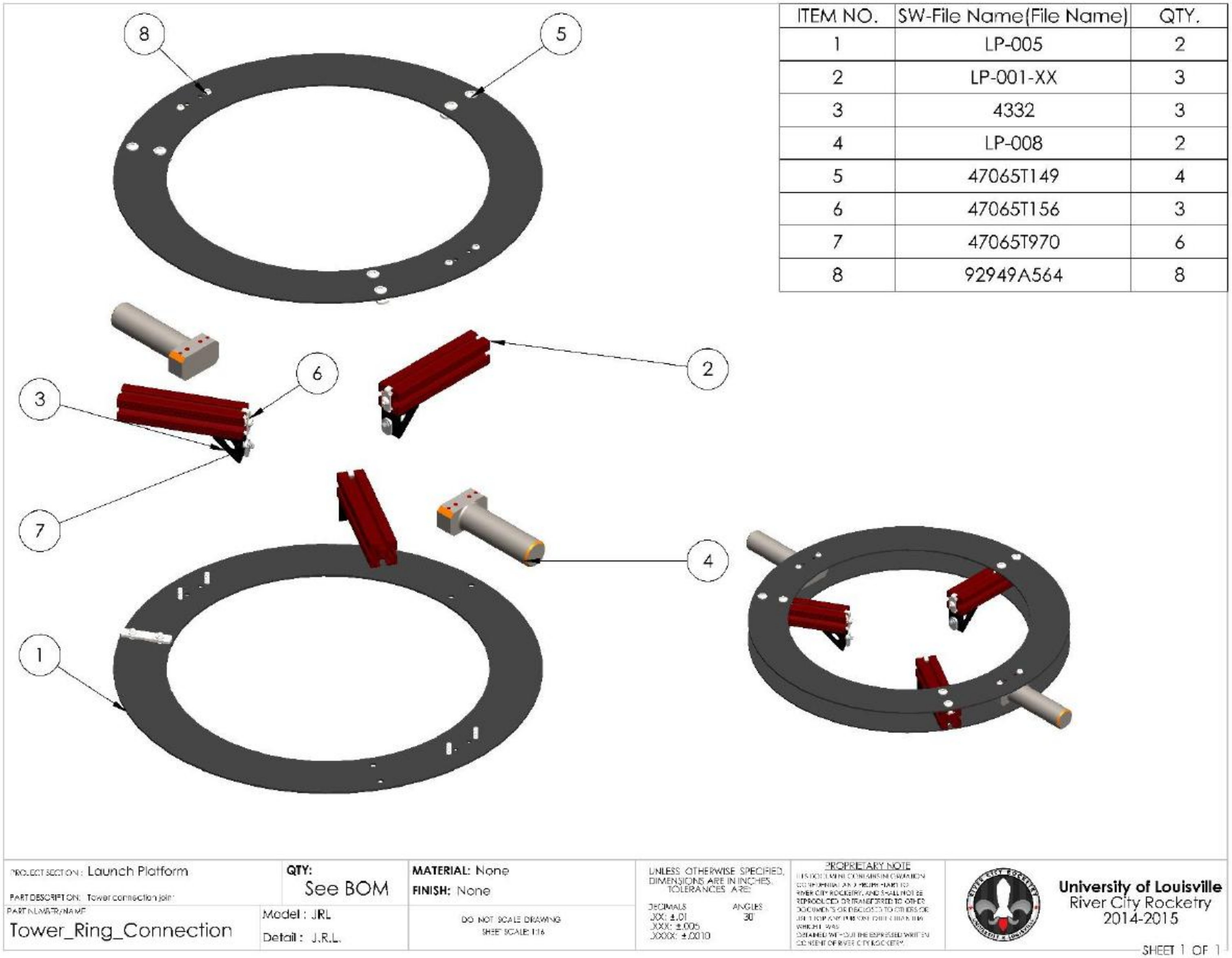
Figure 359: Launch platform tower ring.



ITEM NO.	SW-File Name(File Name)	QTY.
1	LP-005	2
2	LP-001-XX	3
3	4332	3
4	LP-008	2
5	47065T149	4
6	47065T156	3
7	47065T970	6
8	92949A564	8

Figure 360: Launch platform tower connection ring.

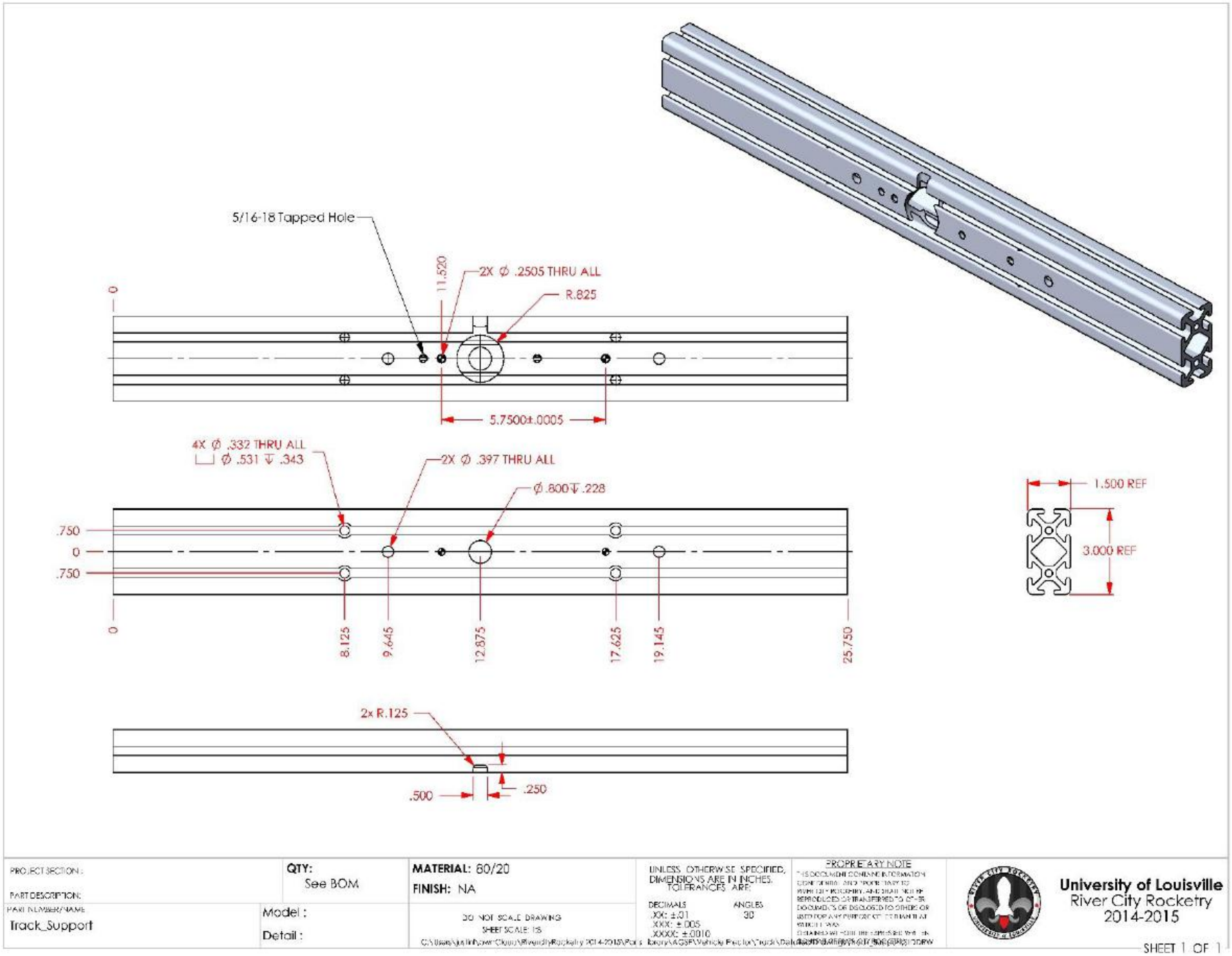


Figure 361: Vehicle erection track motor crossbar.

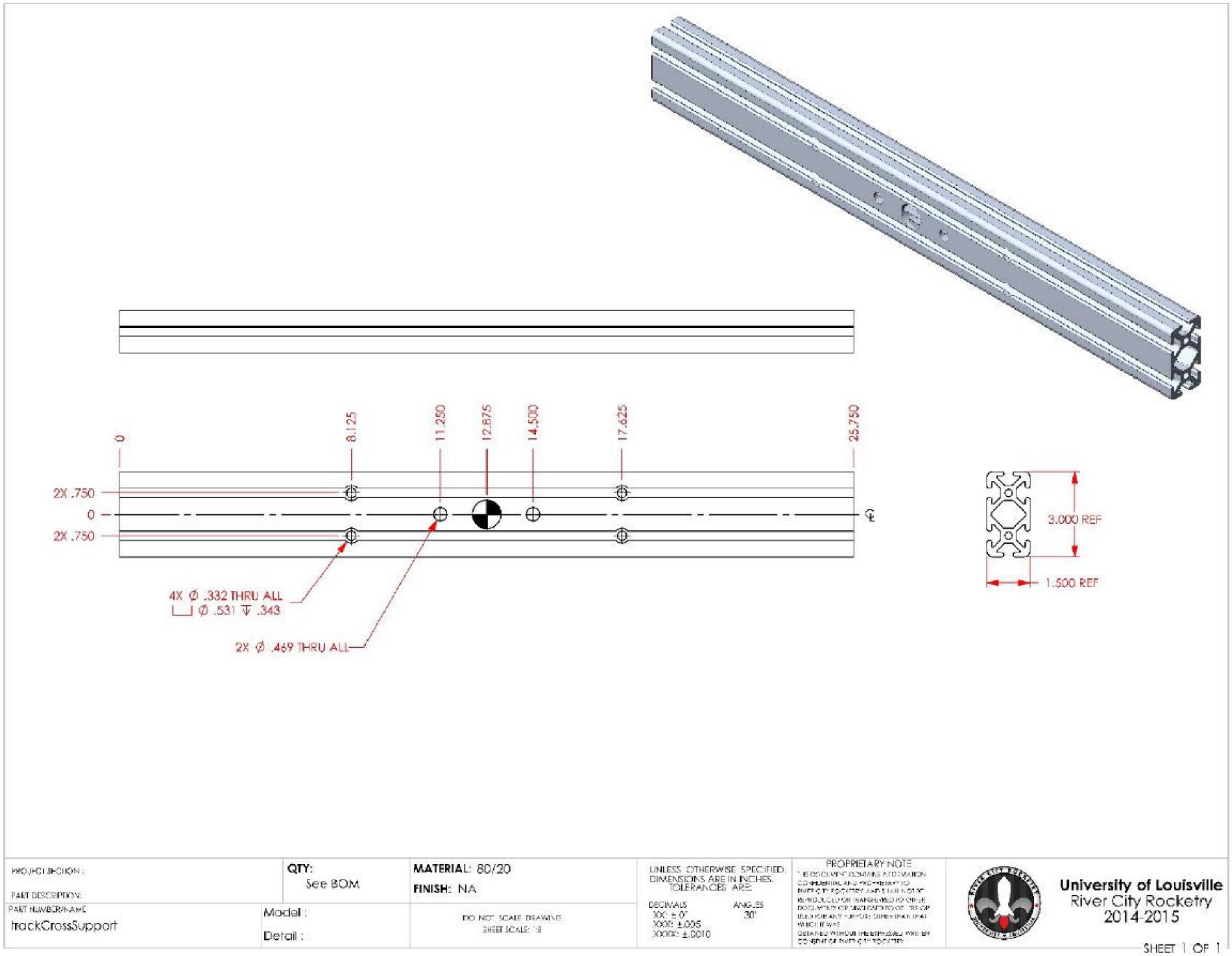


Figure 362: Vehicle erection track bearing cro1.5ss bar.

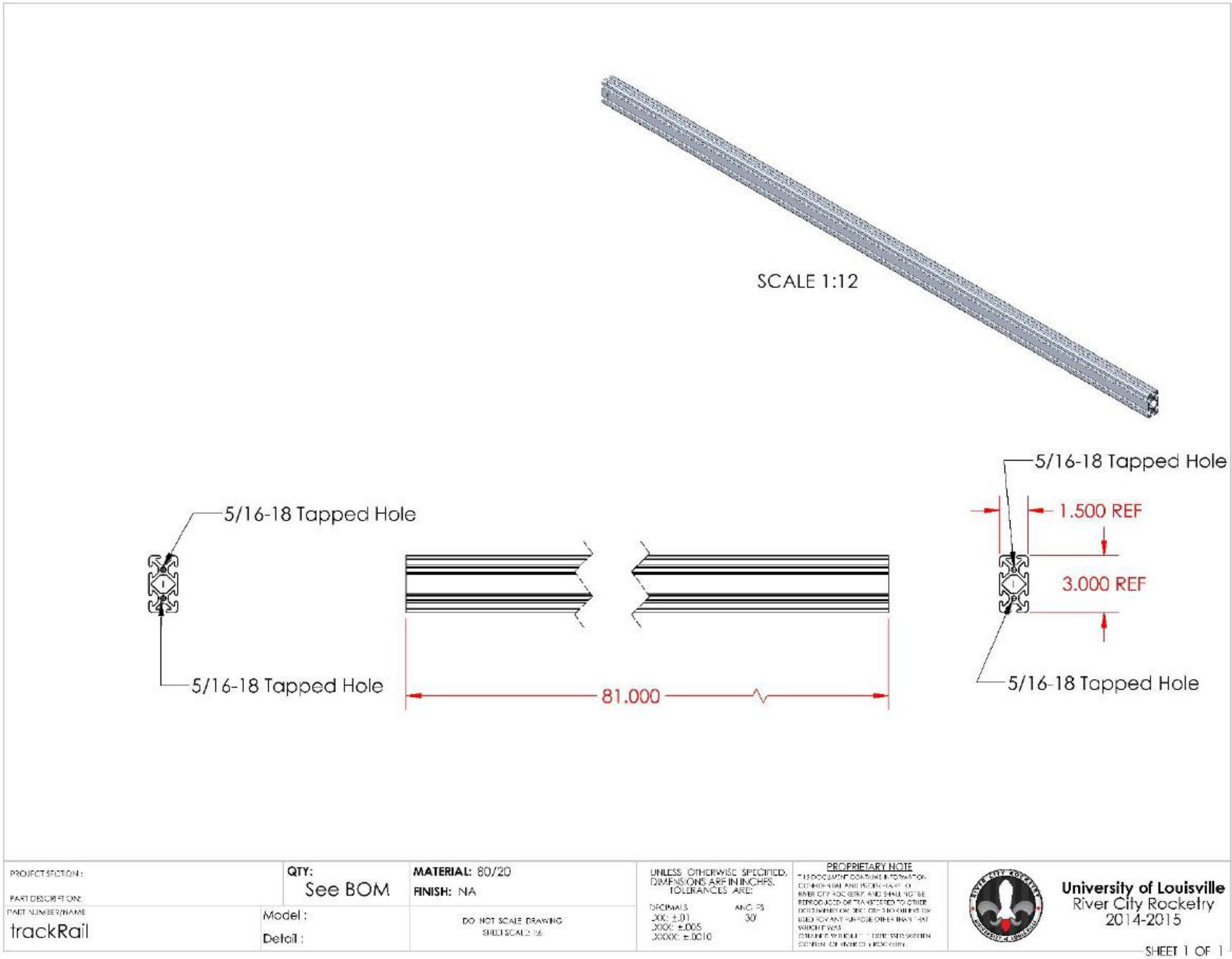


Figure 363: Vehicle erection track rail.

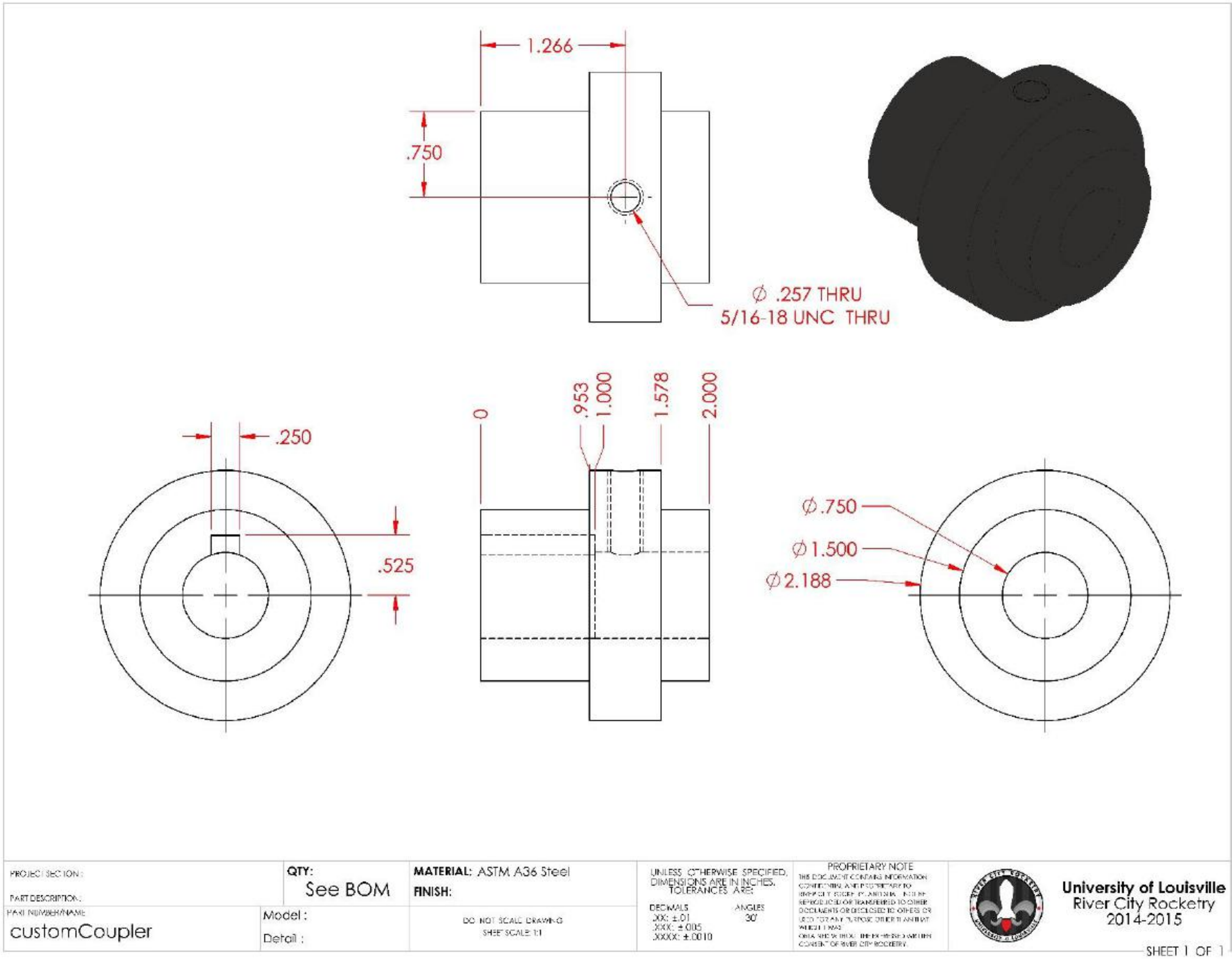


Figure 364: Vehicle erection ball screw coupler.

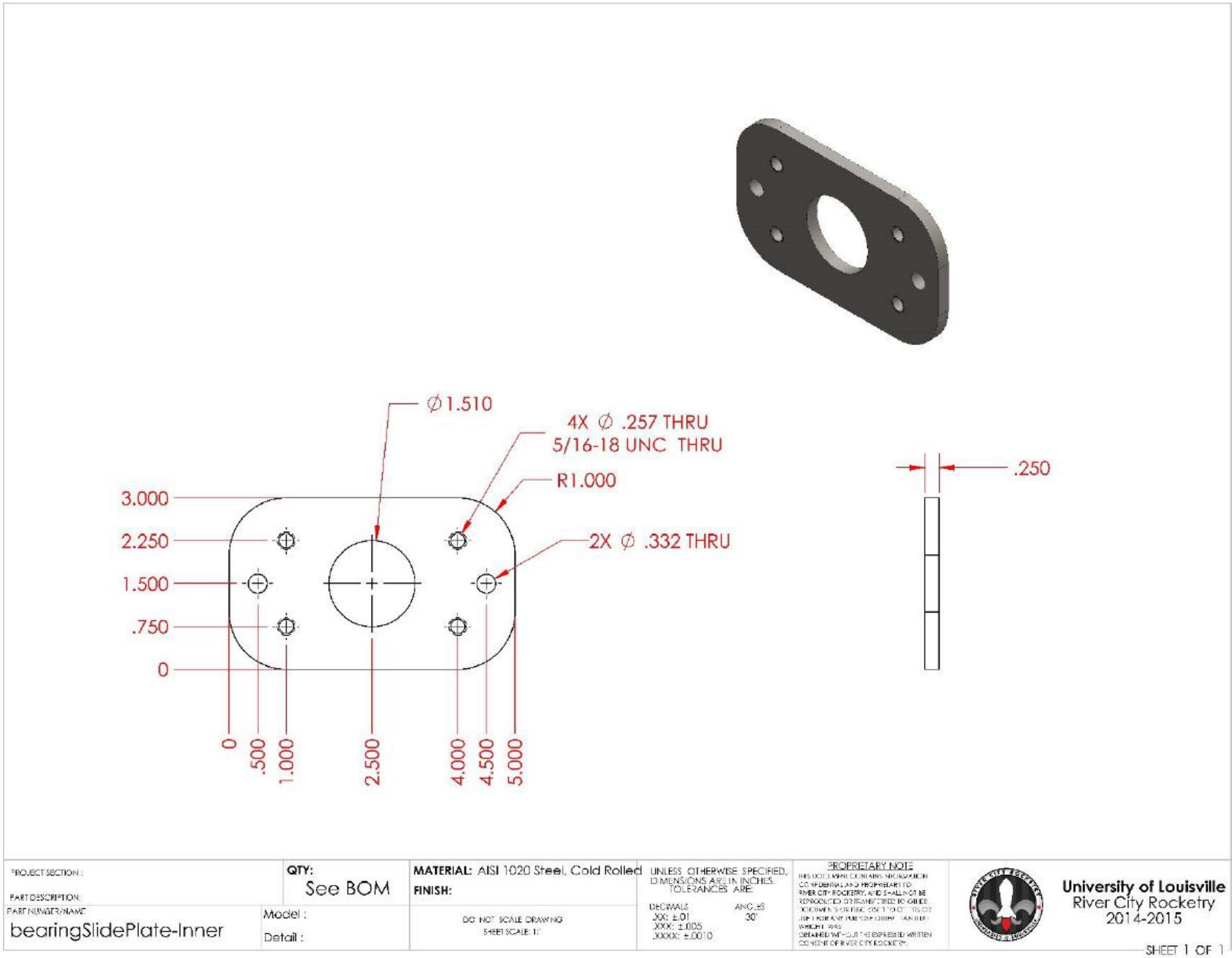


Figure 365: V.E.S. inner thrust bearing plate.

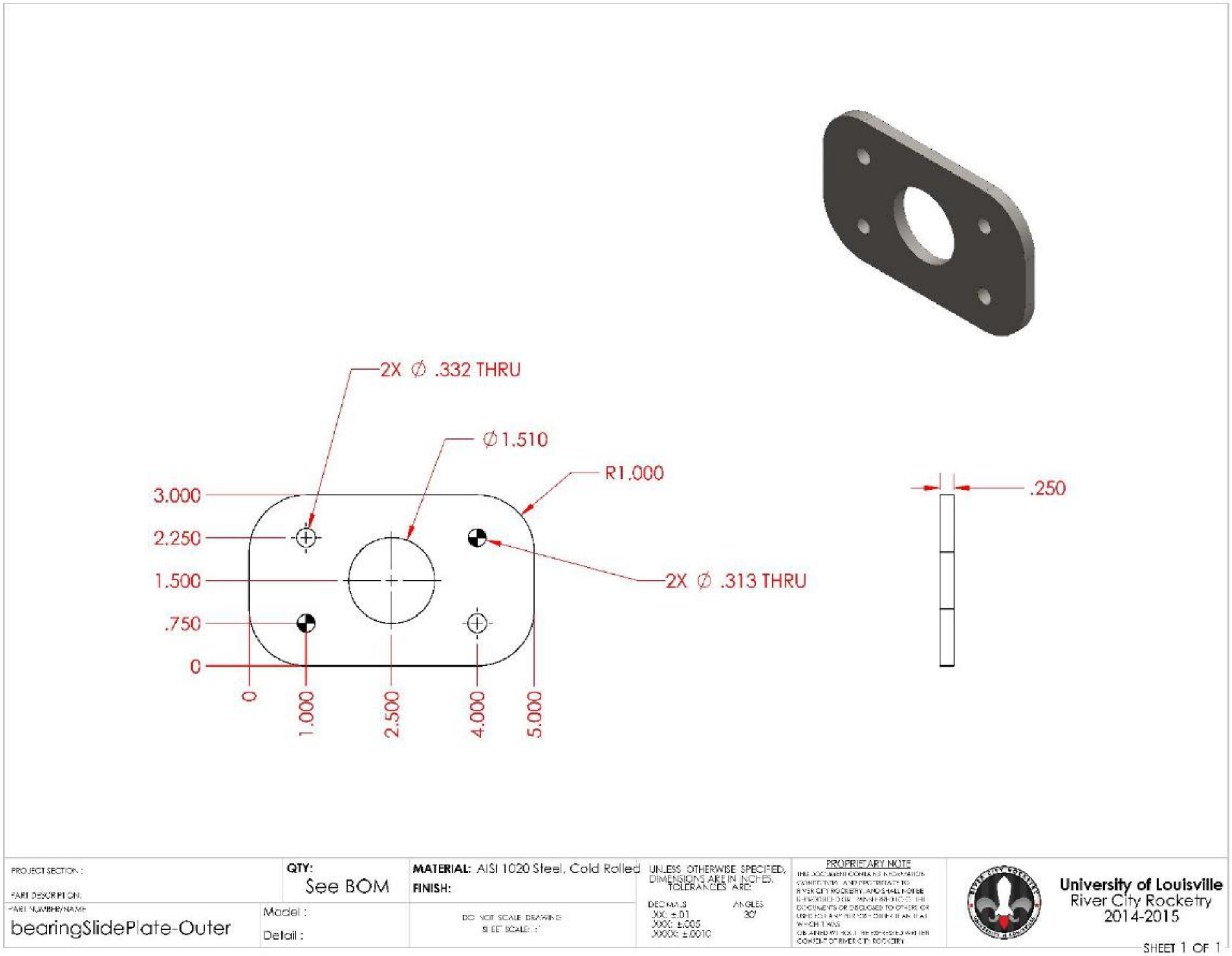


Figure 366: V.E.S. outer thrust bearing plate.

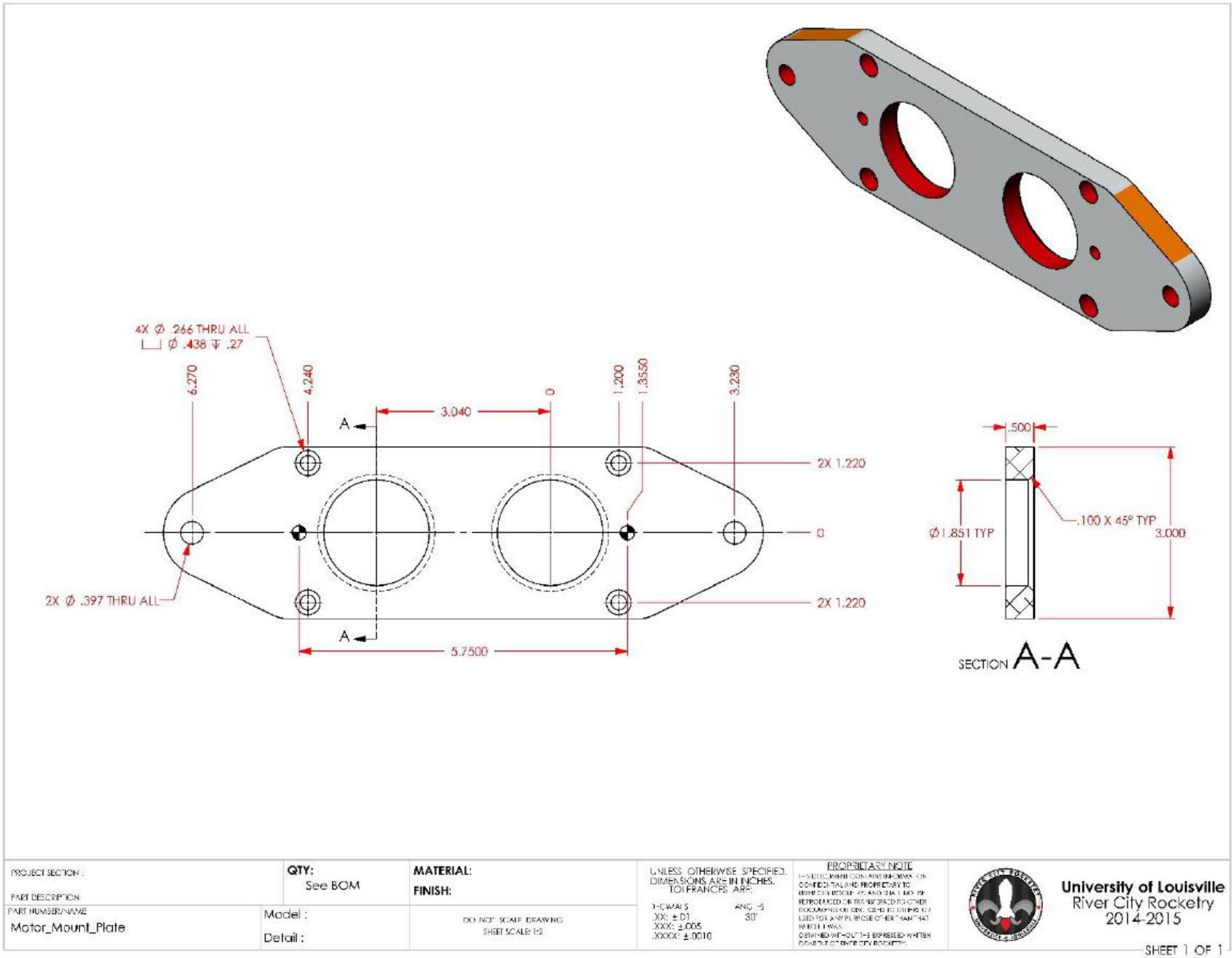


Figure 367: V.E.S. motor mount.

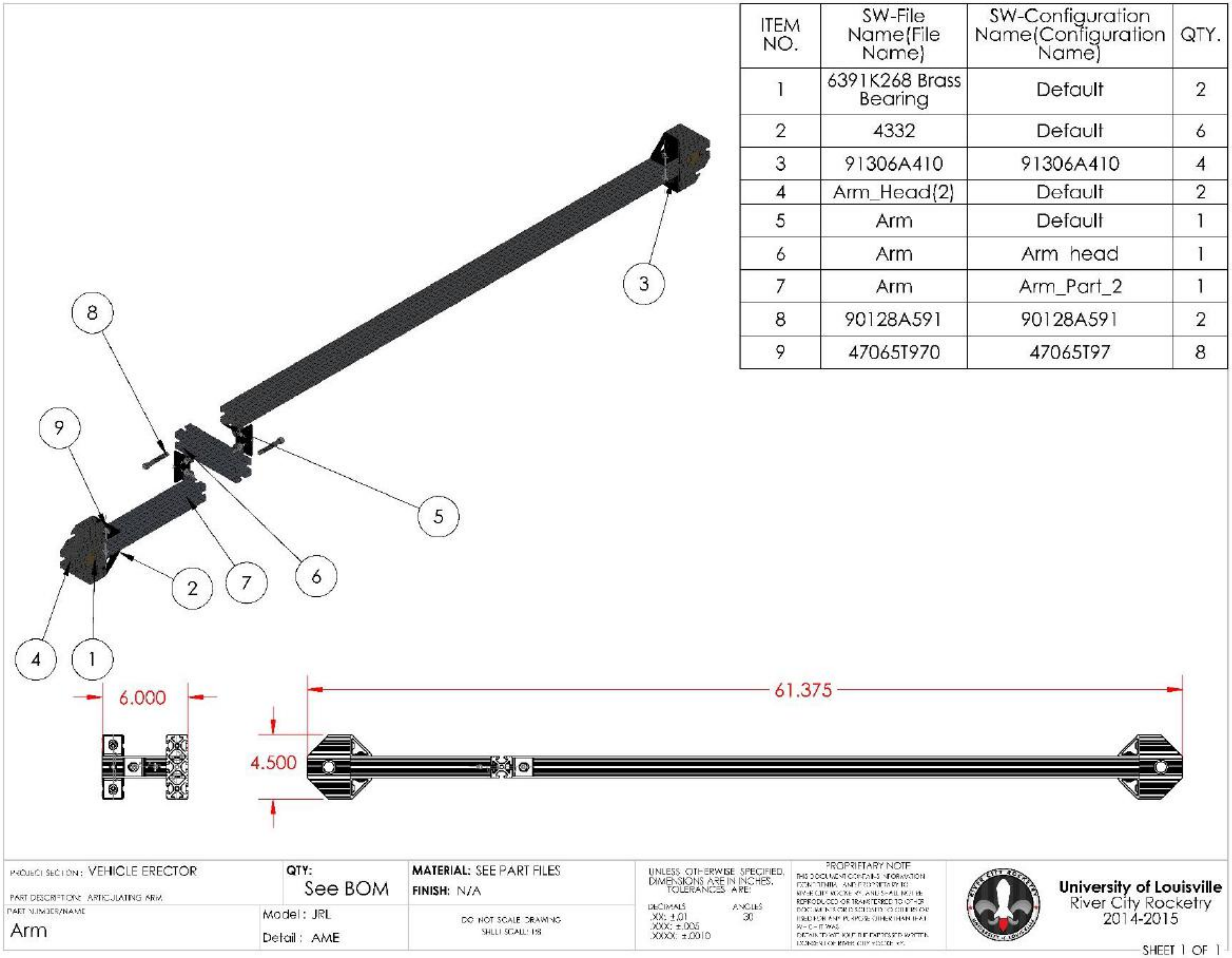


Figure 368: Articulating arm assembly.

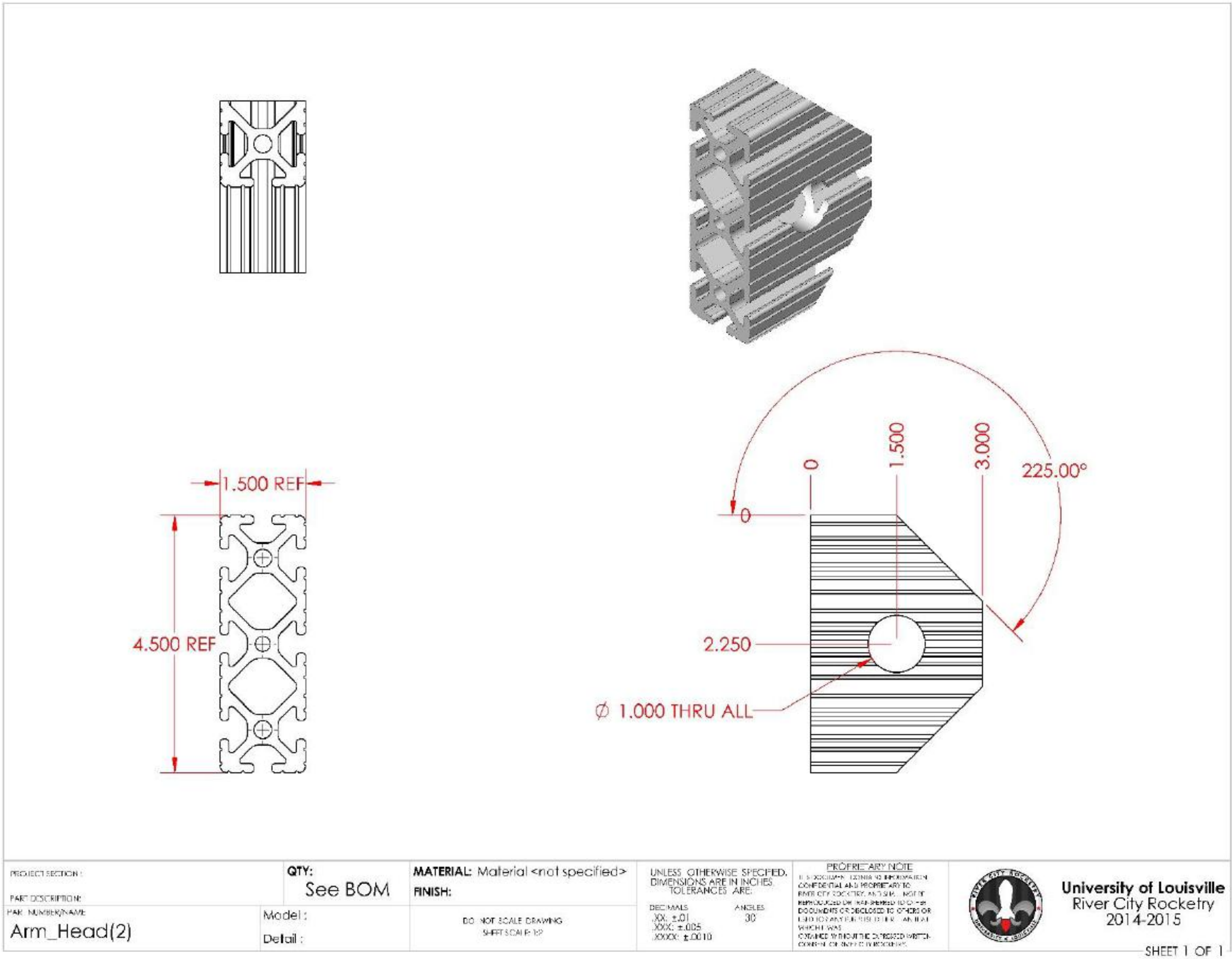


Figure 369: Articulating arm head cap.

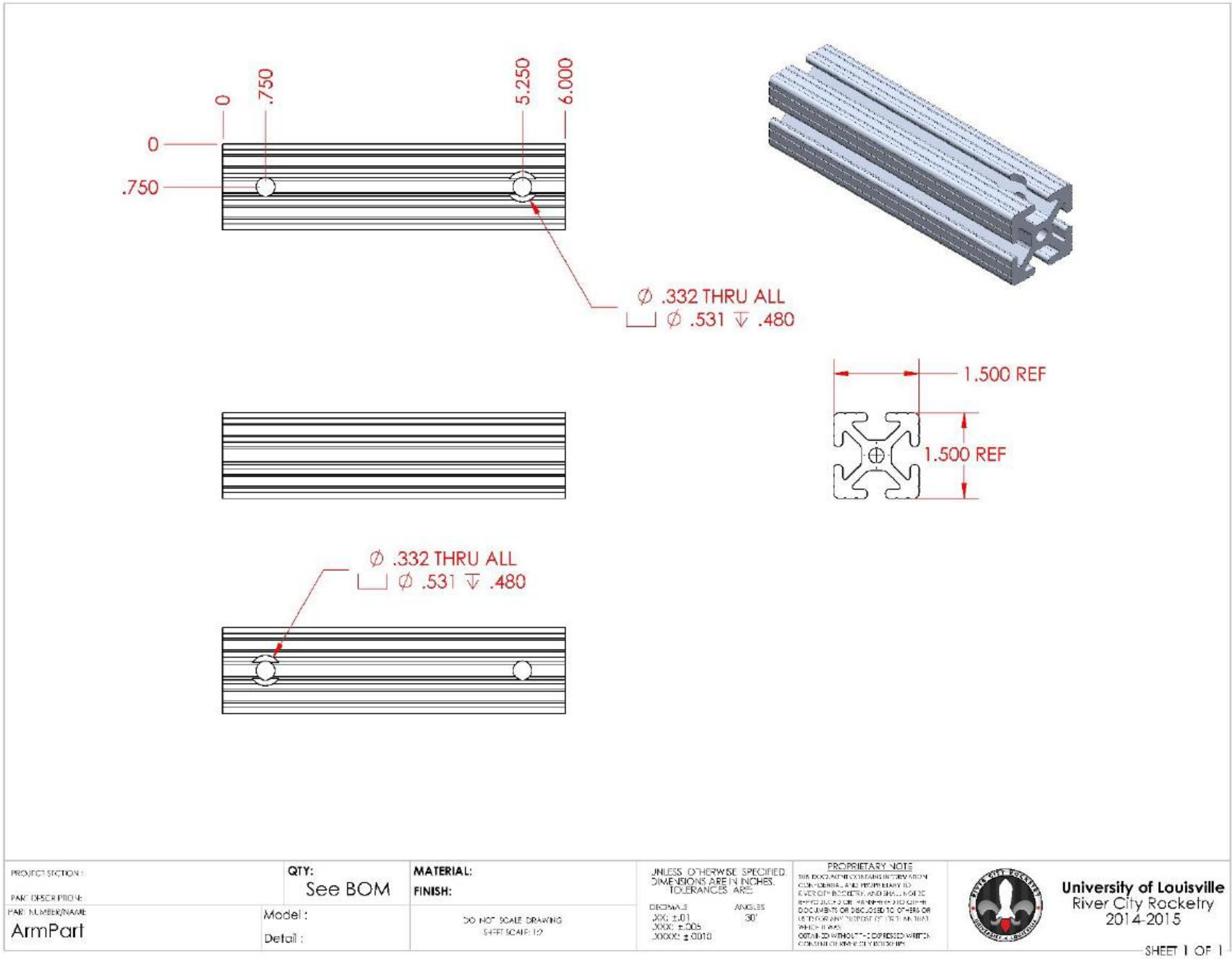


Figure 370: Articulating arm crossbar.

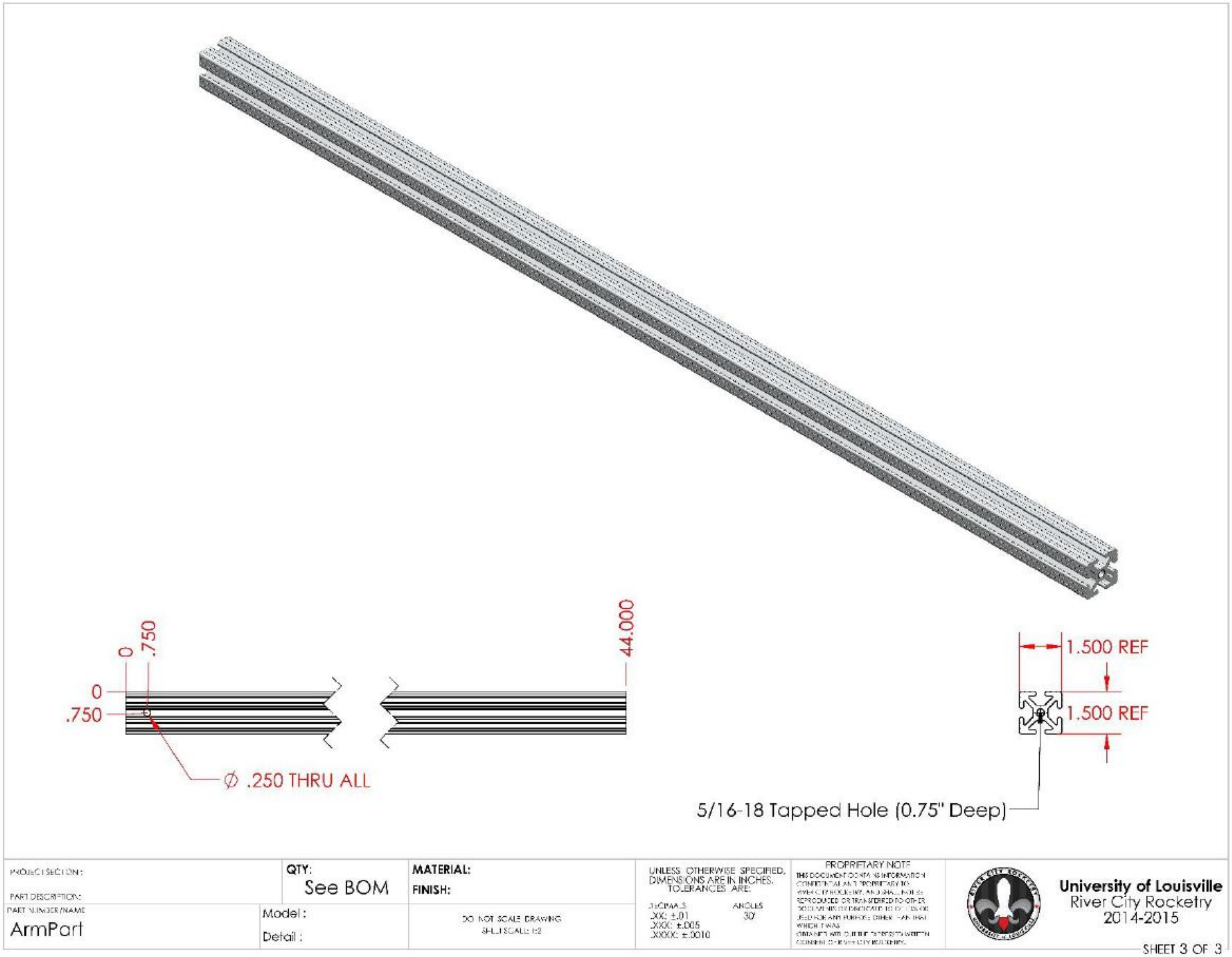


Figure 371: Articulating arm long bar.

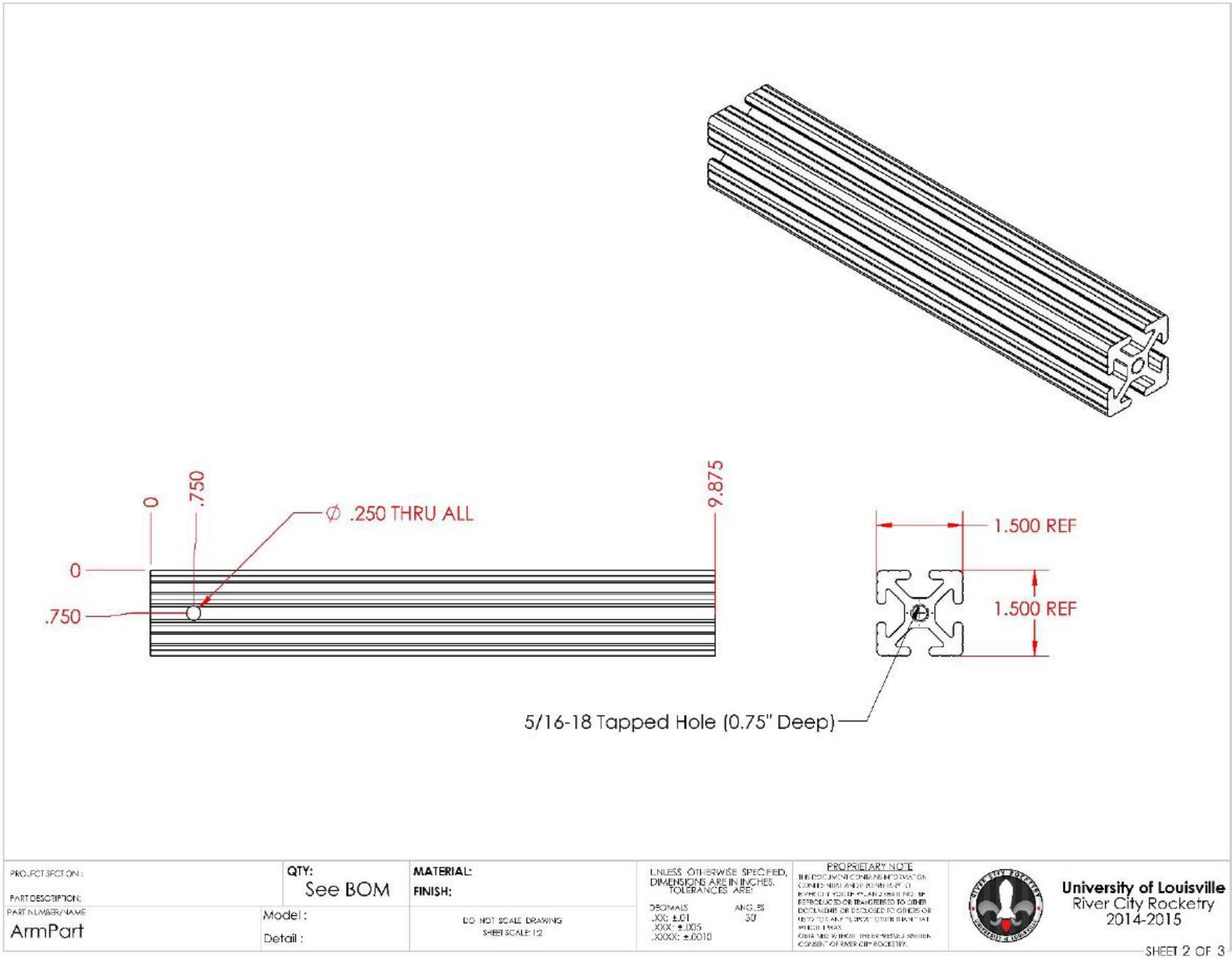
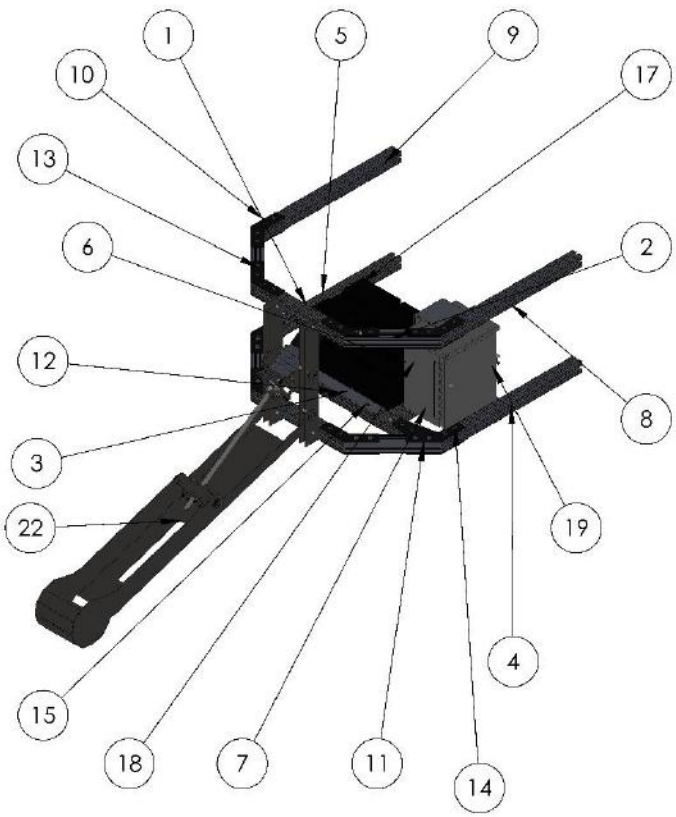


Figure 372: Articulating arm short bar.



ITEM NO.	SW-File Name(File Name)	SW-Configuration Name(Configuration Name)	Launch Ready/QTY.
1	GS-001-XX	GS-001-04	2
2	GS-001-XX	GS-001-17	4
3	GS-001-XX	GS-001-11	1
4	GS-001-XX	GS-001-15	1
5	GS-001-XX	GS-001-01	1
6	GS-001-XX	GS-001-09	1
7	GS-001-XX	GS-001-10	2
8	GS-001-XX	GS-001-16	1
9	GS-001-XX	GS-001-13	1
10	Fastening Plates	Default	12
11	Fastening Plates-batteryConnection	Default	4
12	batteryWell	Default	1
13	90128A253	90128A253	36
14	90670A029	90670A029	36
15	91306A280	91306A280	10
16	47065T156	47065T156	6
17	batteryBox	Default	2
18	electronicsEnclosureMount	Default	1
19	7649K450	Default	1
20	92949A853	92949A853	4
21	90490A030	90490A030	4
22	outriggerNew	Launch Ready	1
23	90128A138	90128A138	4

PROJECT SECTION:
PART DESCRIPTION:
PART NUMBER/NAME: Front End

QTY: See BOM
Model:
Detail:

MATERIAL: SEE PART FILES
FINISH:
DO NOT SCALE DRAWING
SHEET SCALE: 1:15

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010
ANGLES 30'

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2014-2015

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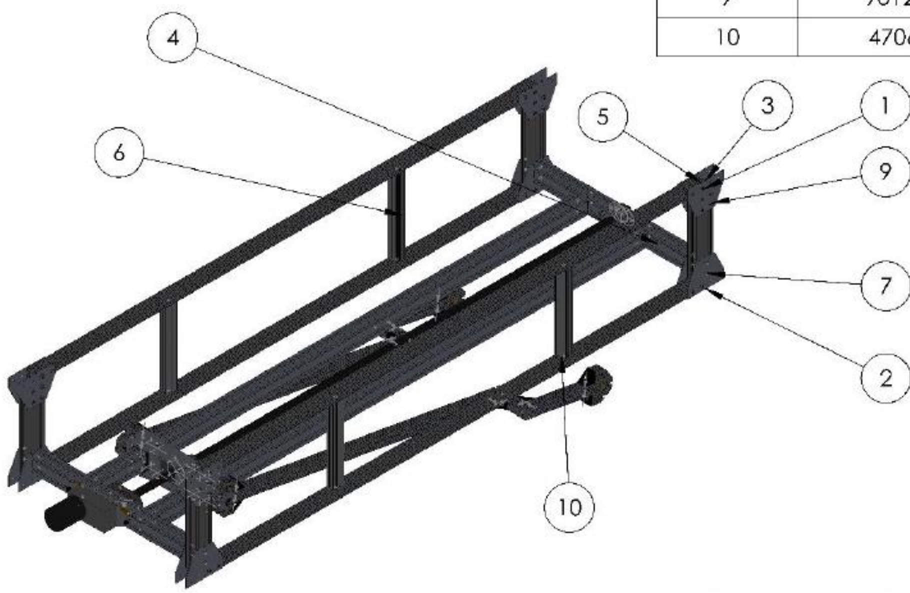
Figure 373: Ground station front end assembly.

ITEM NO.	SW-File Name(File Name)	SW-Configuration Name(Configuration Name)	QTY.
1	GS-002	Default	4
2	joiningGusset-trackOuter	Default	8
3	joiningGusset	Default	8
4	vehicleErector	Default	1
5	GS-001-XX	GS-001-02	4
6	GS-001-XX	GS-001-05	4
7	90128A592	90128A592	8
8	90670A029	90670A029	32
9	90128A253	90128A253	32
10	47065T156	47065T156	8



PART NUMBER/NAME
MiddleFrame

QTY: See BOM

Model :
Detail :

MATERIAL: SEE PART FILES
FINISH:

DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010
ANGLES 30'

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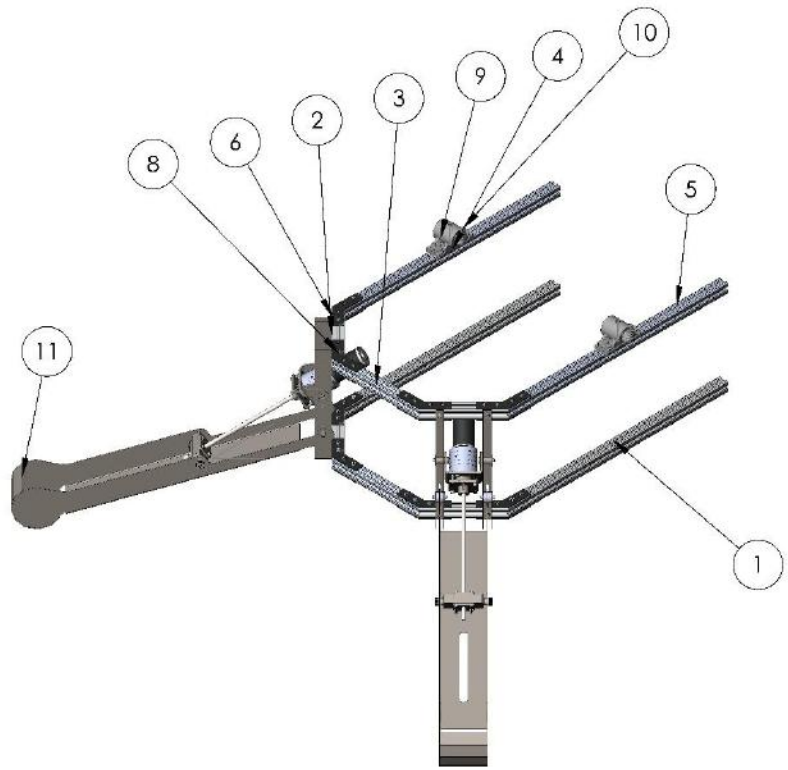
Figure 374: Ground station middle assembly.



ITEM NO.	SW-File Name(File Name)	SW-Configuration Name(Configuration Name)	Launch Ready/QTY.
1	GS-001-XX	GS-001-06	2
2	GS-001-XX	GS-001-03	4
3	GS-001-XX	GS001-18	2
4	GS-001-XX	GS-001-14	1
5	GS-001-XX	GS-001-12	1
6	Fastening Plates	Default	16
7	90670A029	90670A029	32
8	90128A253	90128A253	32
9	6359K220	6359K22	2
10	91251A018	91251A018	4
11	outriggerNew	Launch Ready	2
12	90128A138	90128A138	8

PROJECT SECTION:
PART DESCRIPTION:
PART NUMBER/NAME
Rear End

QTY: See BOM
Model:
Detail:

MATERIAL:
FINISH:
DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010
ANGLES 30'

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Figure 375: Ground station rear assembly.

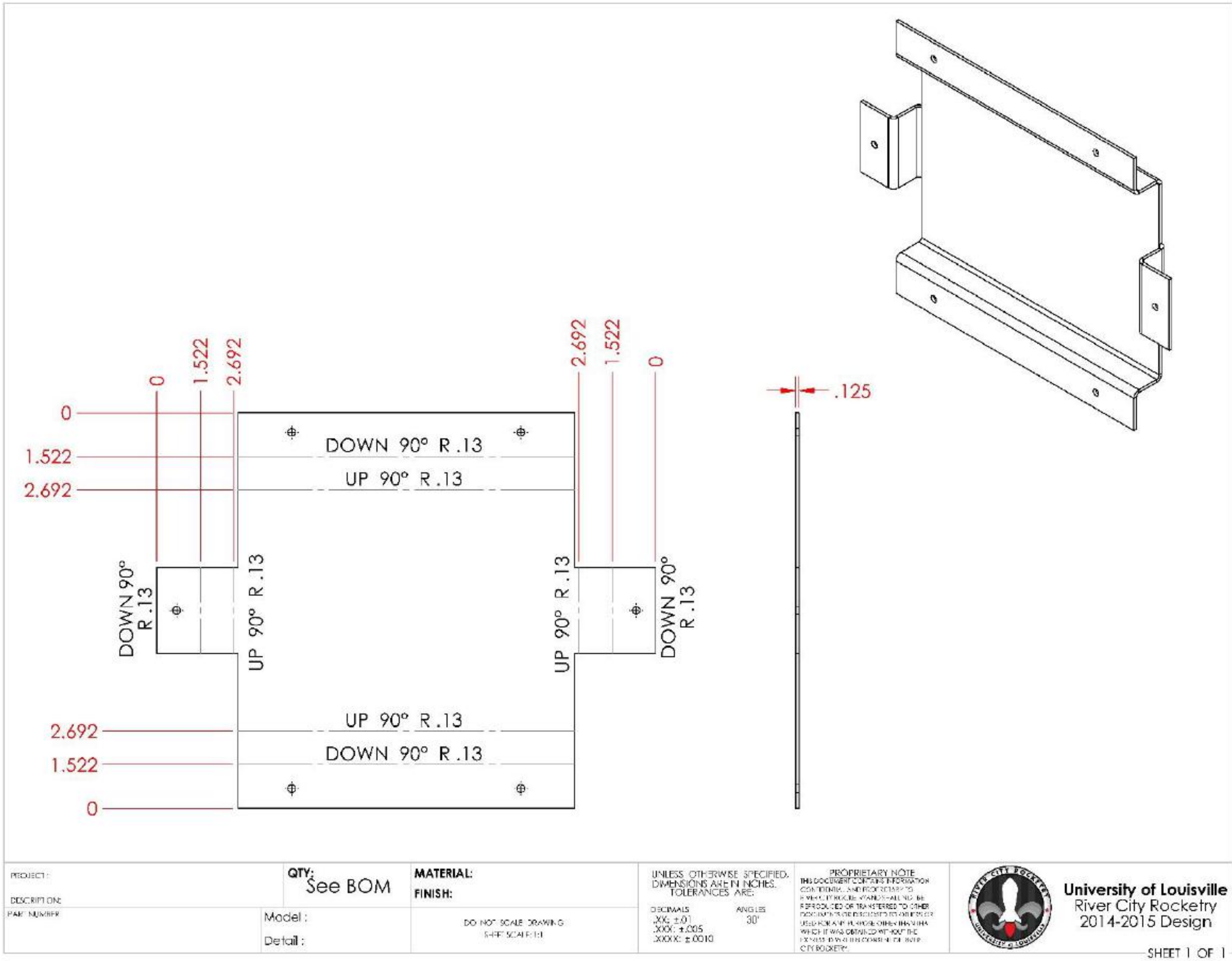

Figure 376: Ground station battery well.

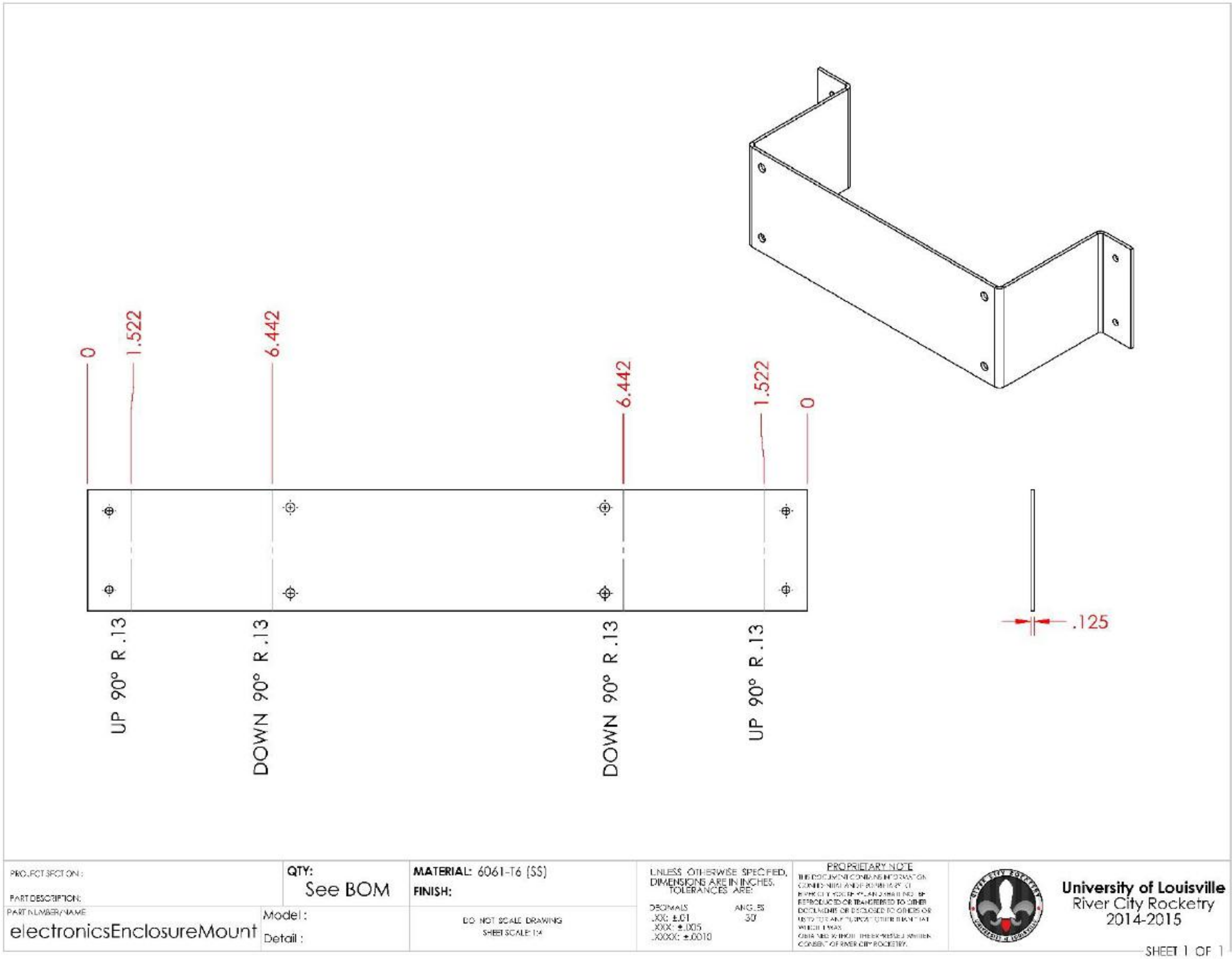

Figure 377: Ground station electronics enclosure mount.

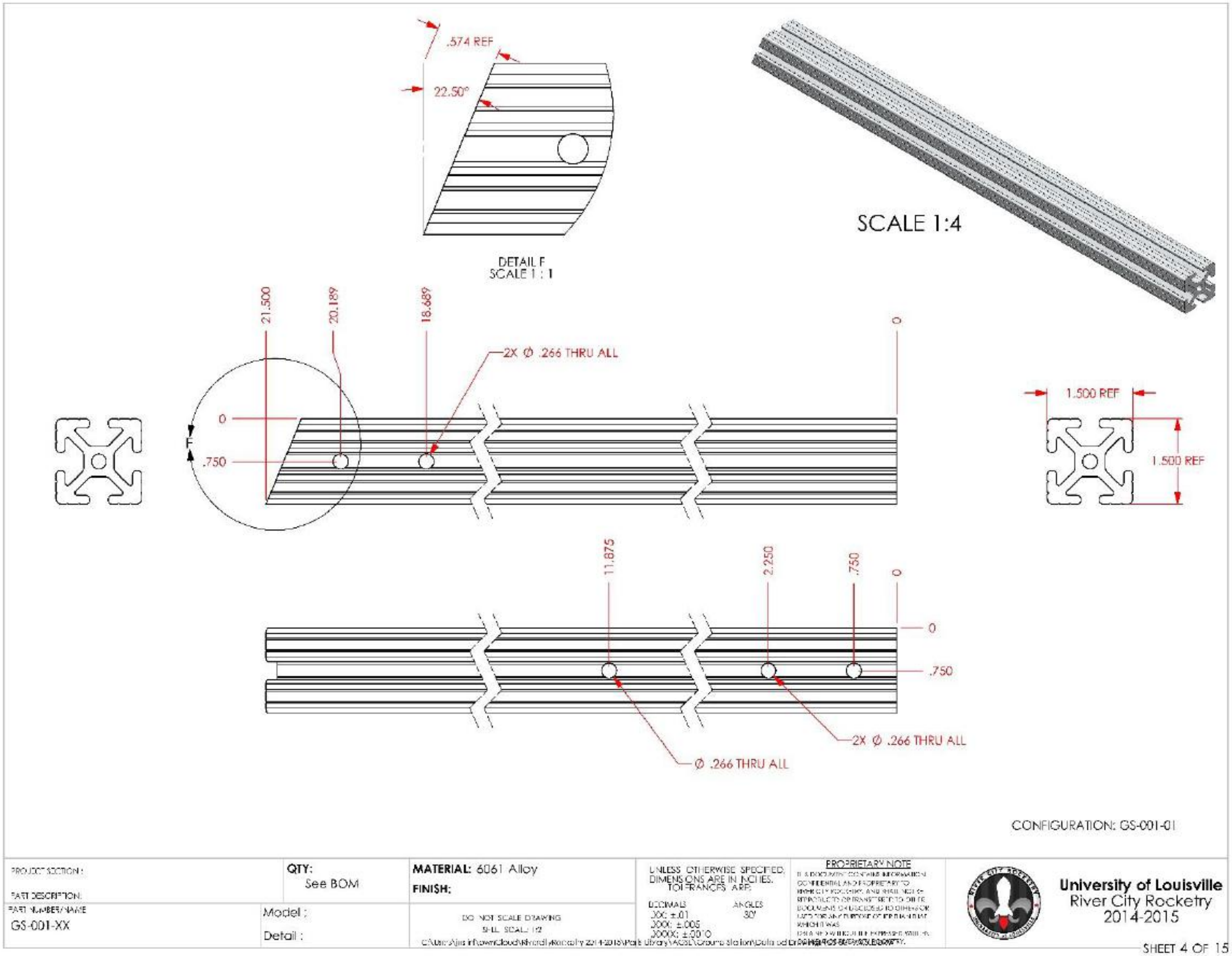

Figure 378: Ground station front bottom right rail.

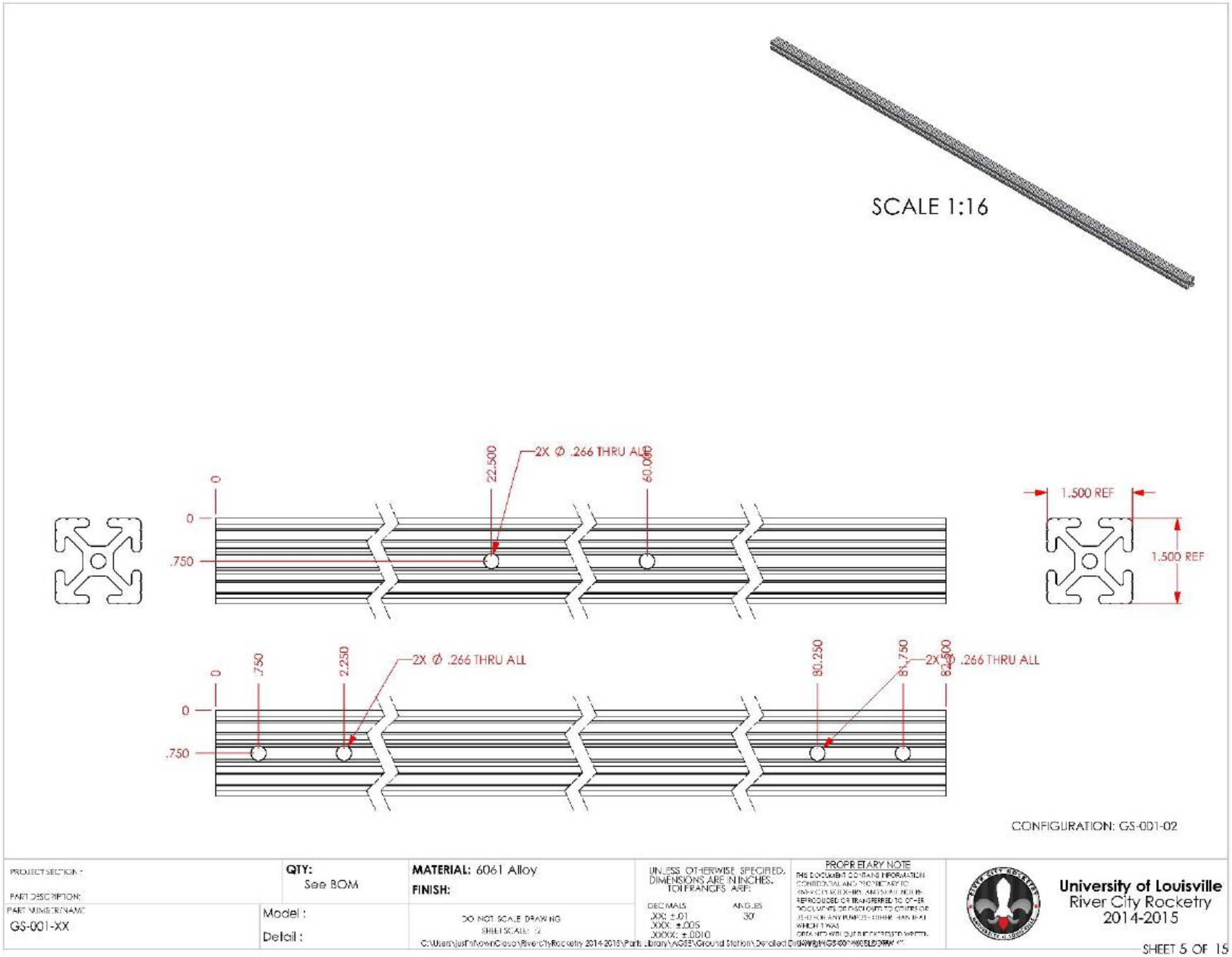

Figure 379: Ground station middle long rail.

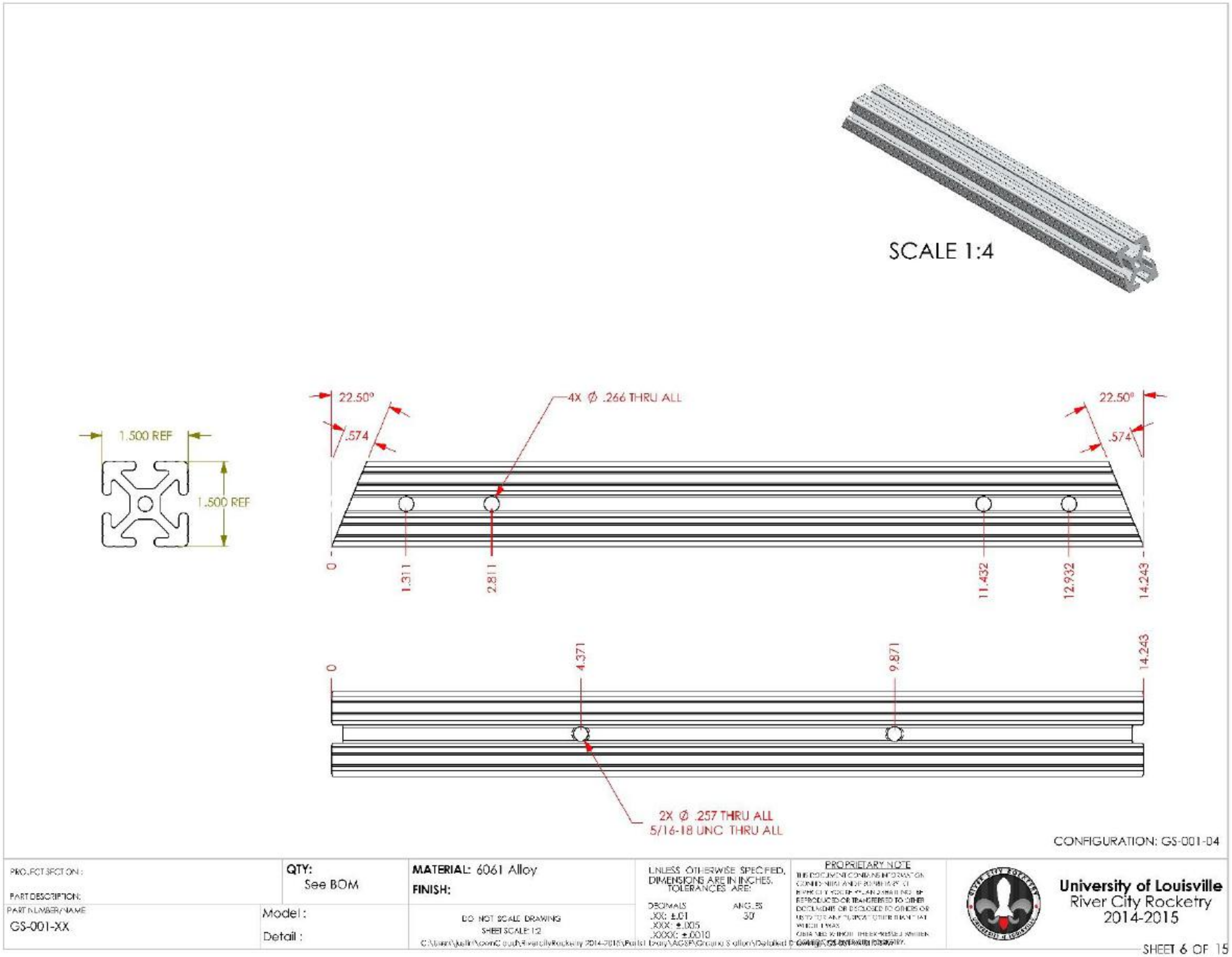

Figure 380: Ground station front cross member.

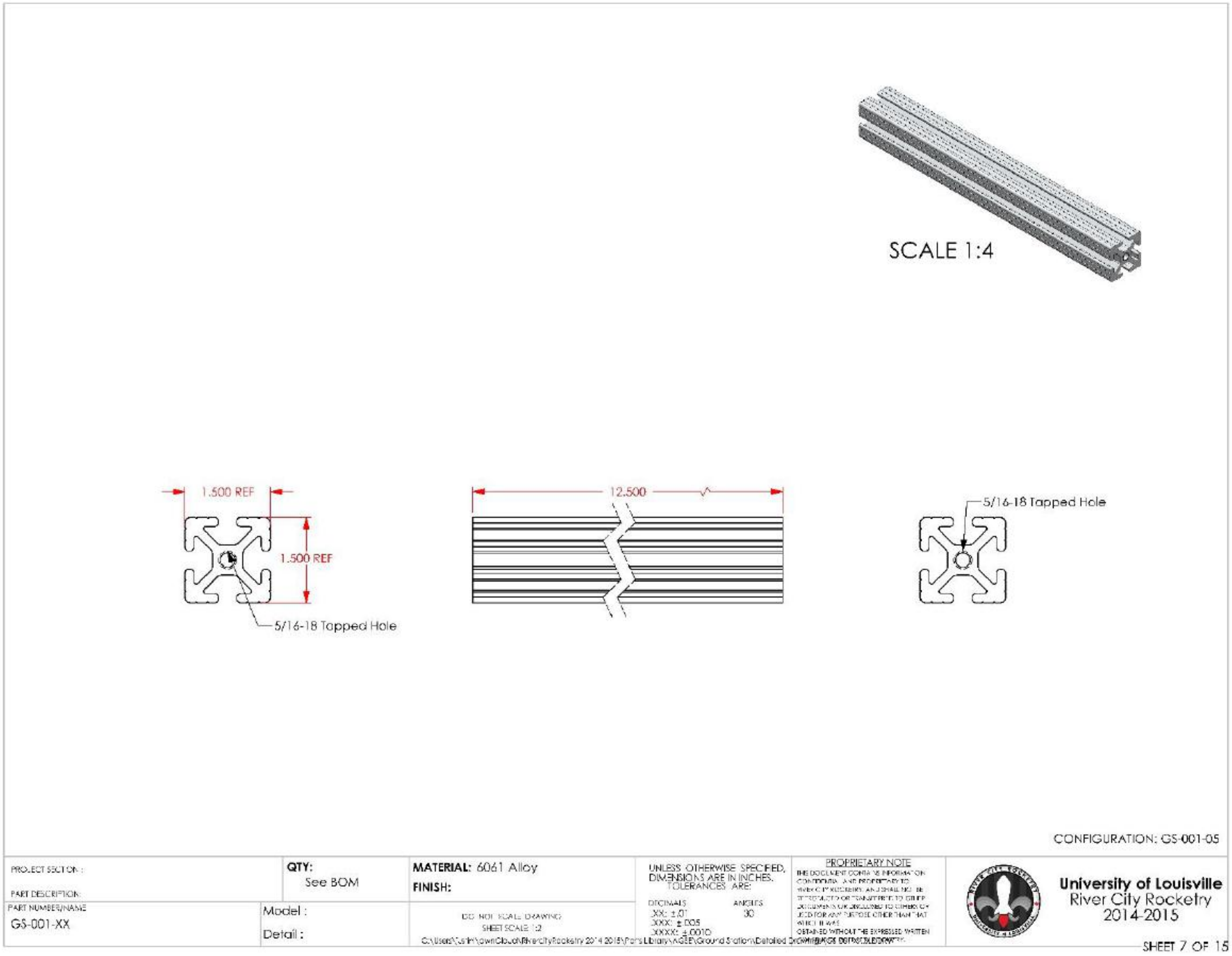

Figure 381: Ground station struts.

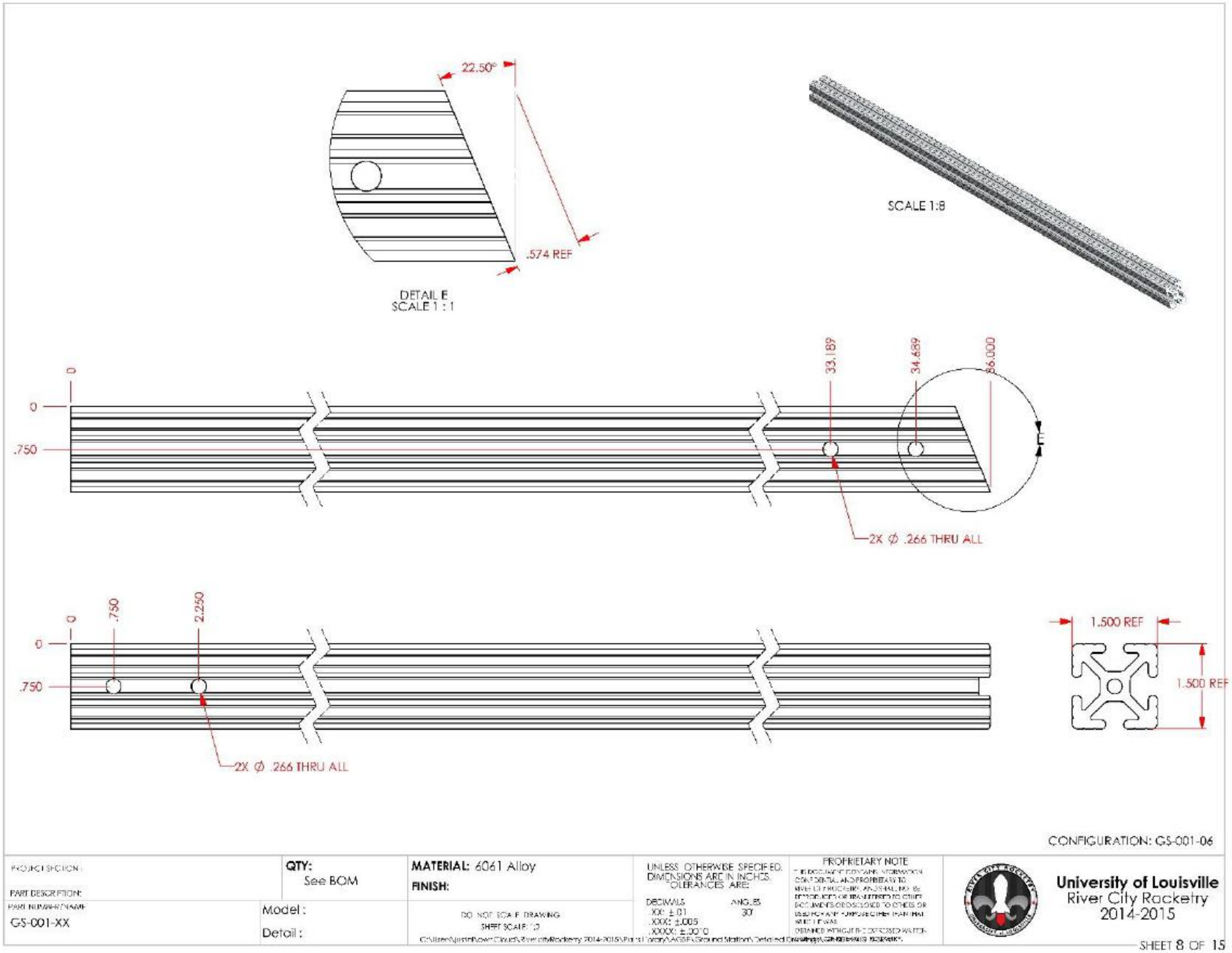

Figure 382: Ground station rear bottom rail.

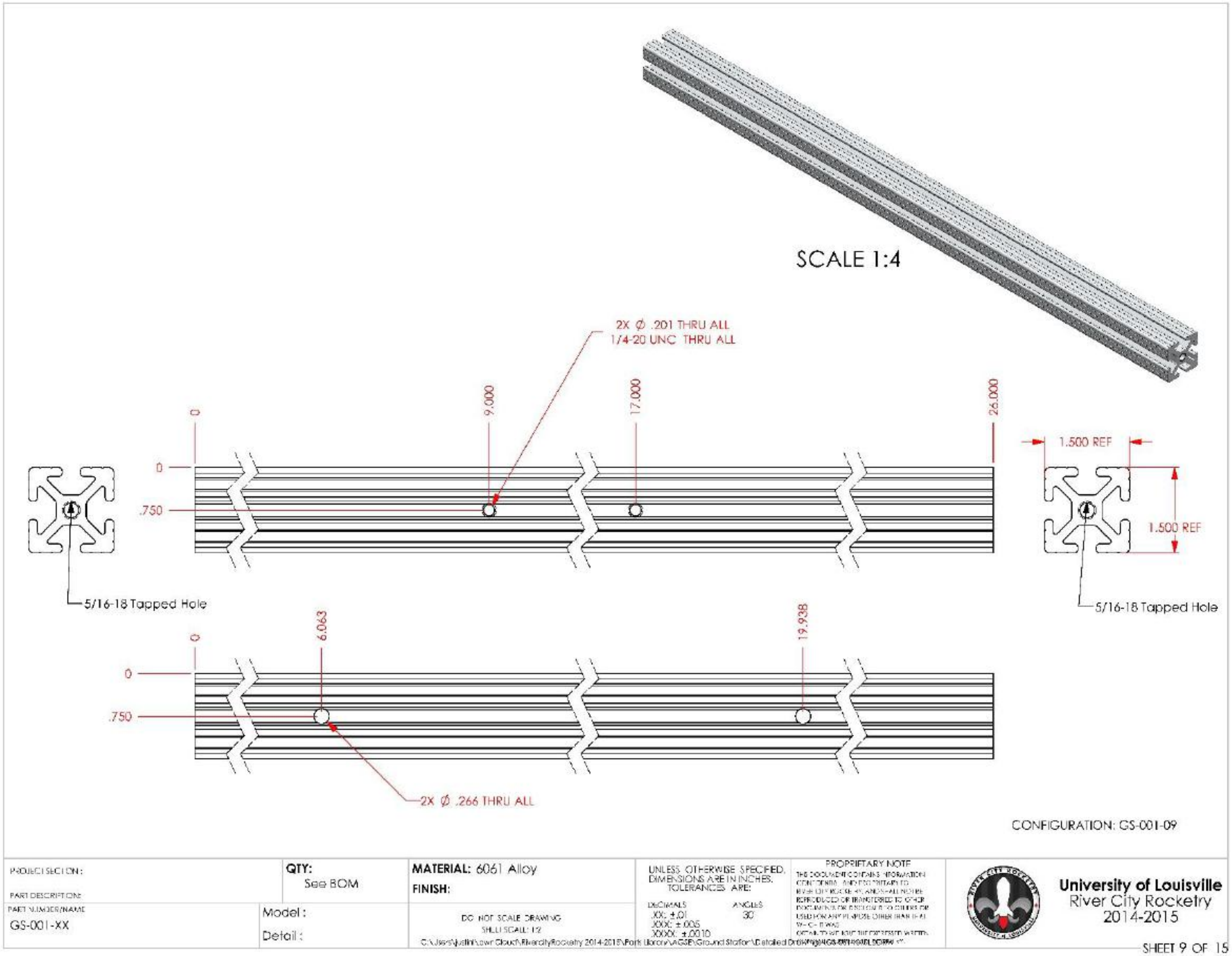

Figure 383: Battery well rear support.

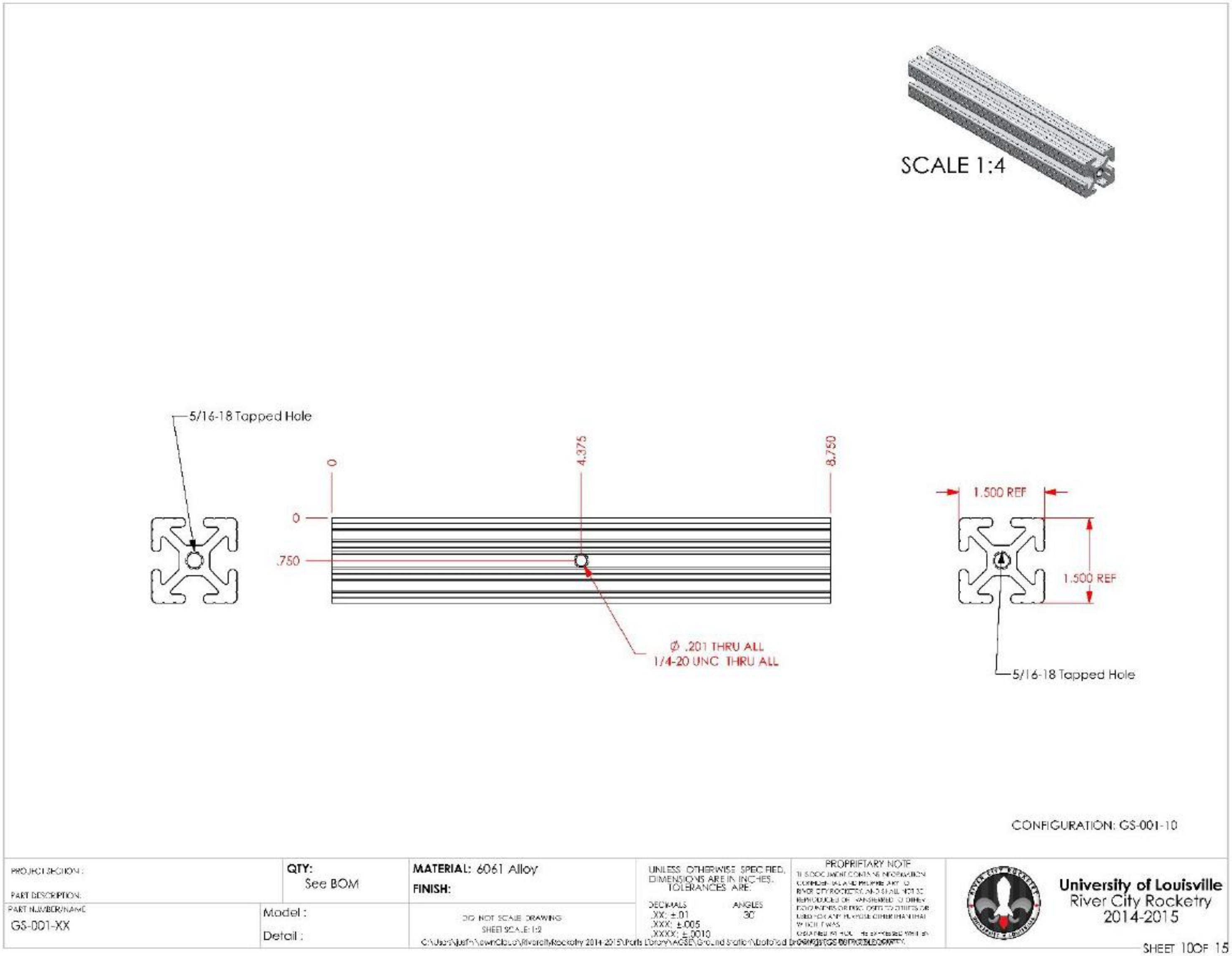

Figure 384: Battery well support.

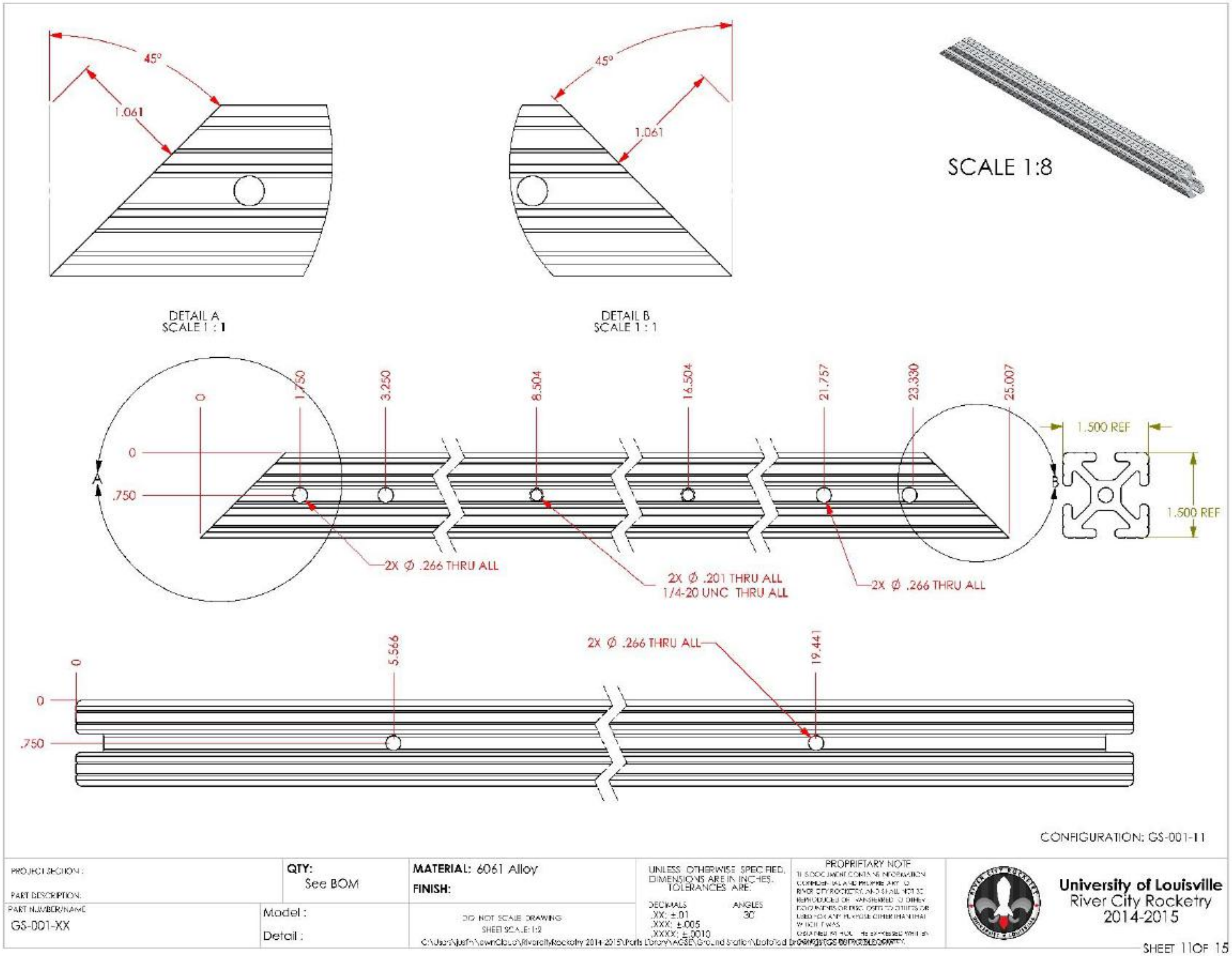

Figure 385: Battery well forward support.

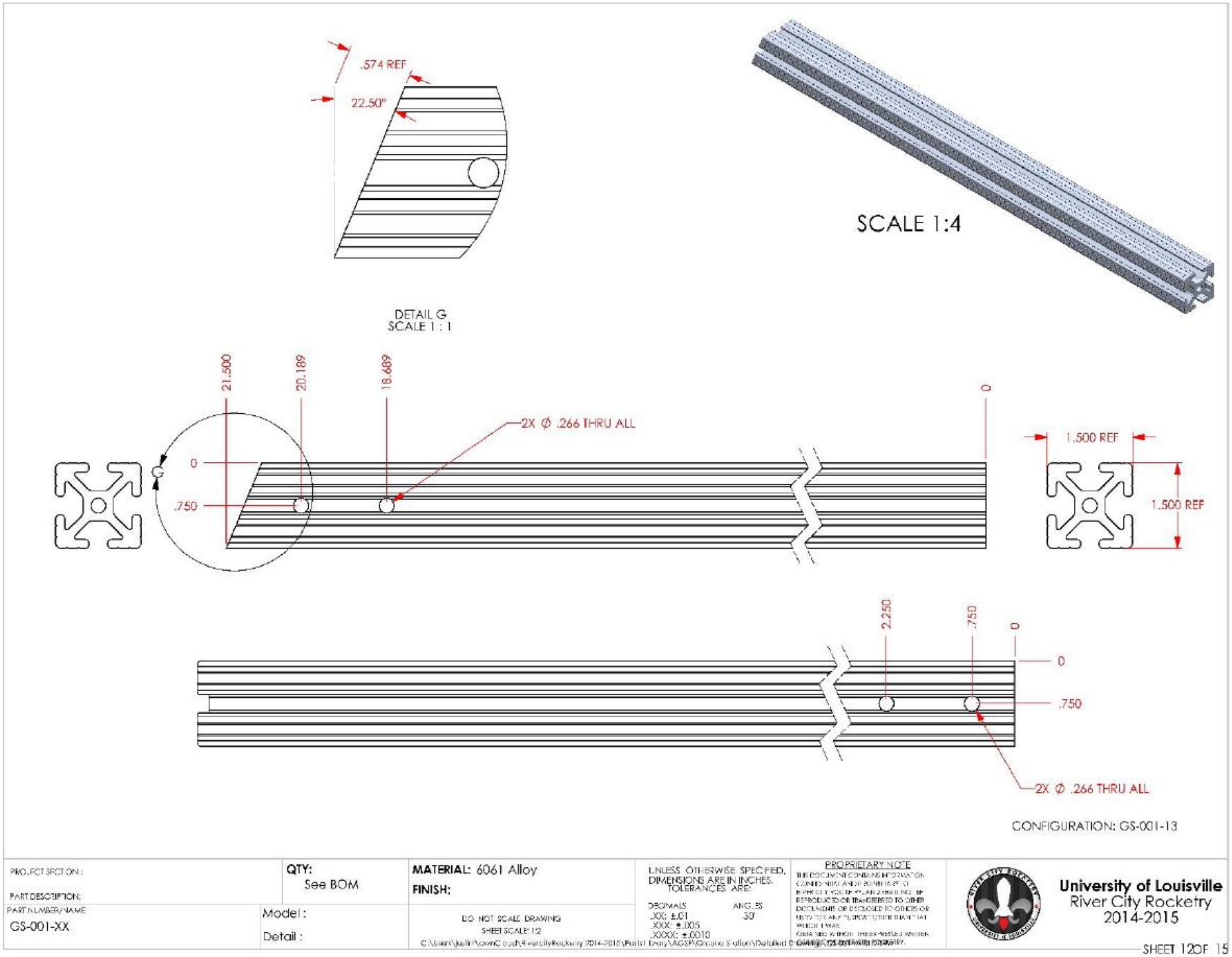

Figure 386: Ground station front right top rail.

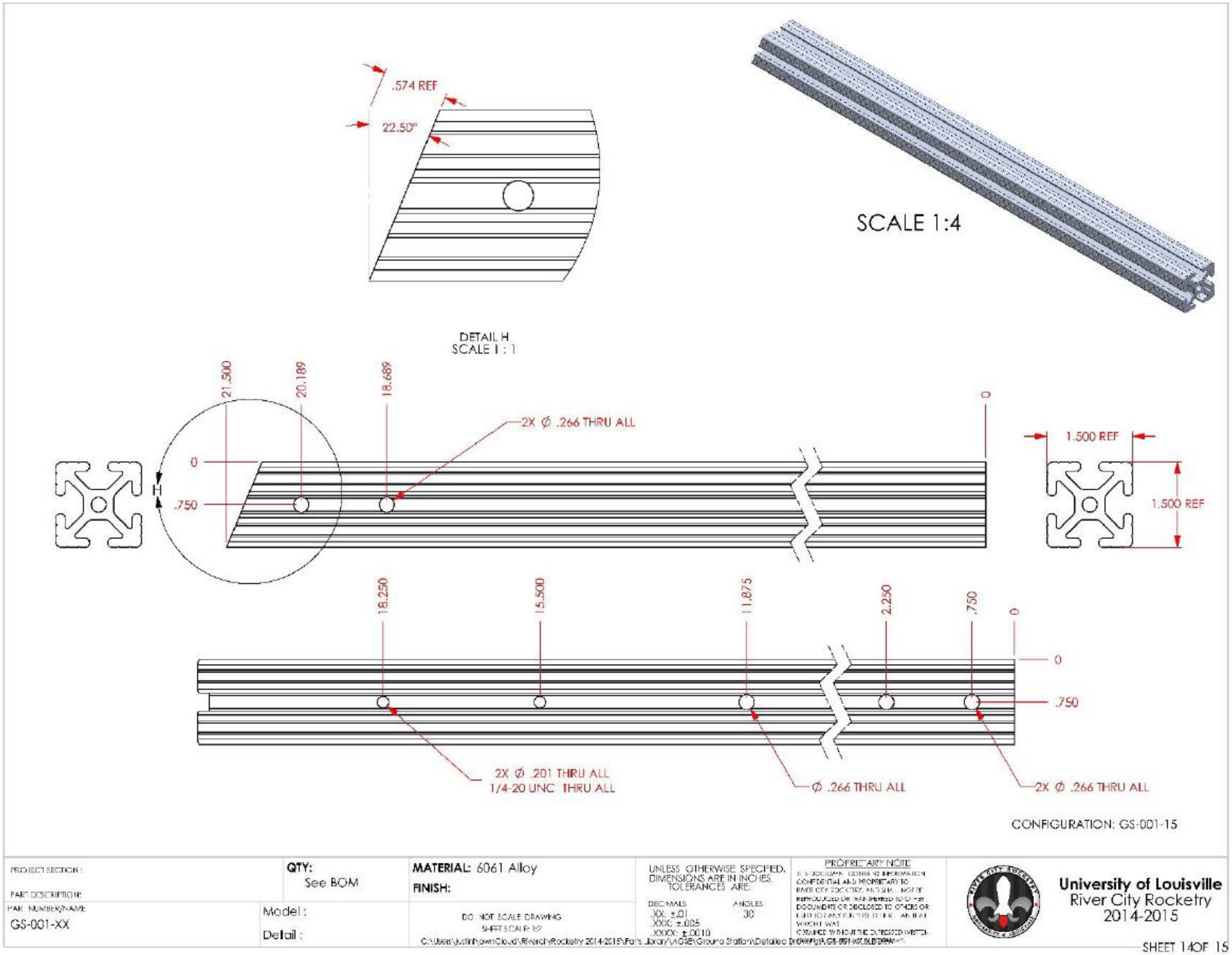

Figure 387: Ground station front left top rail.

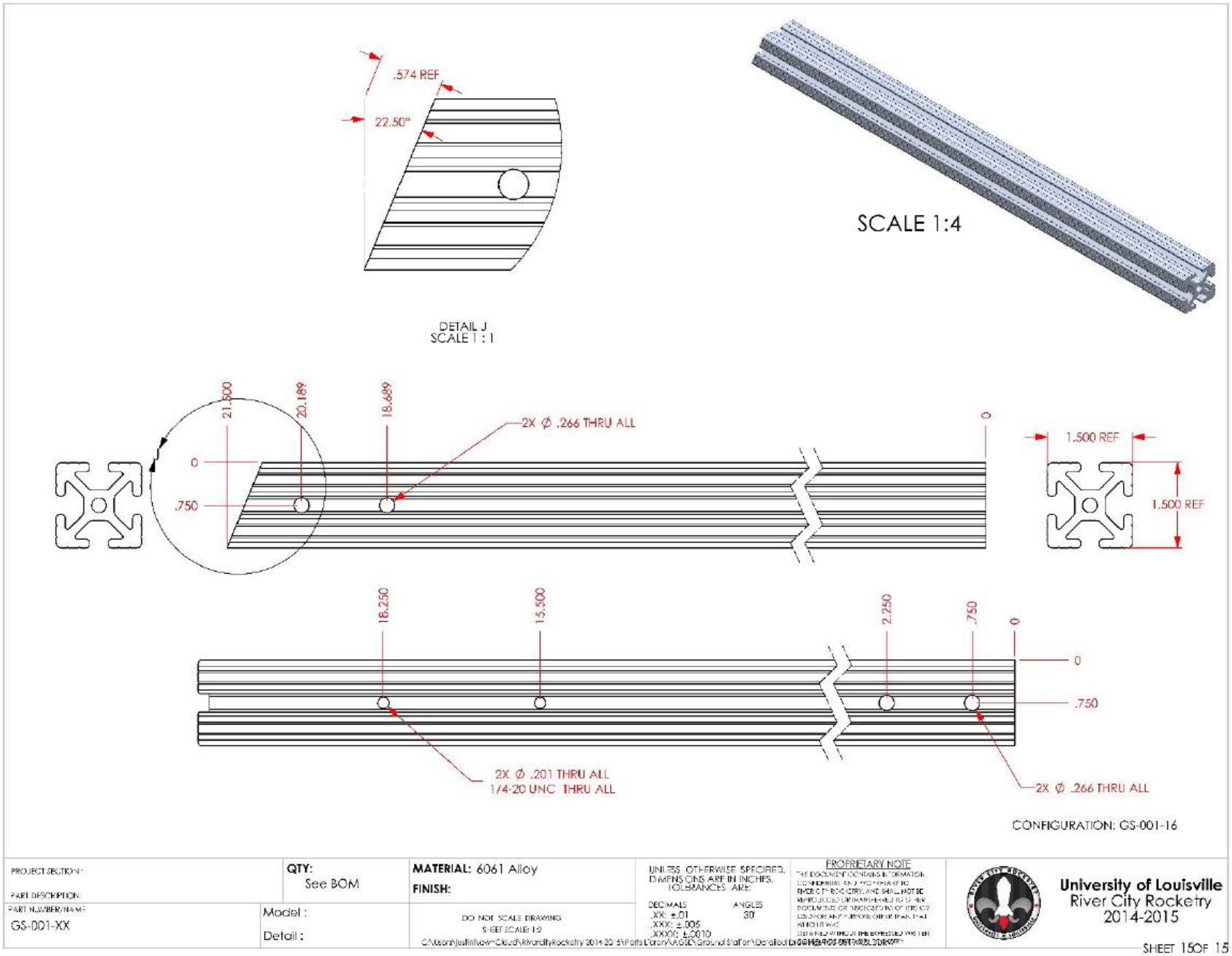

Figure 388: Ground station front bottom left rail.

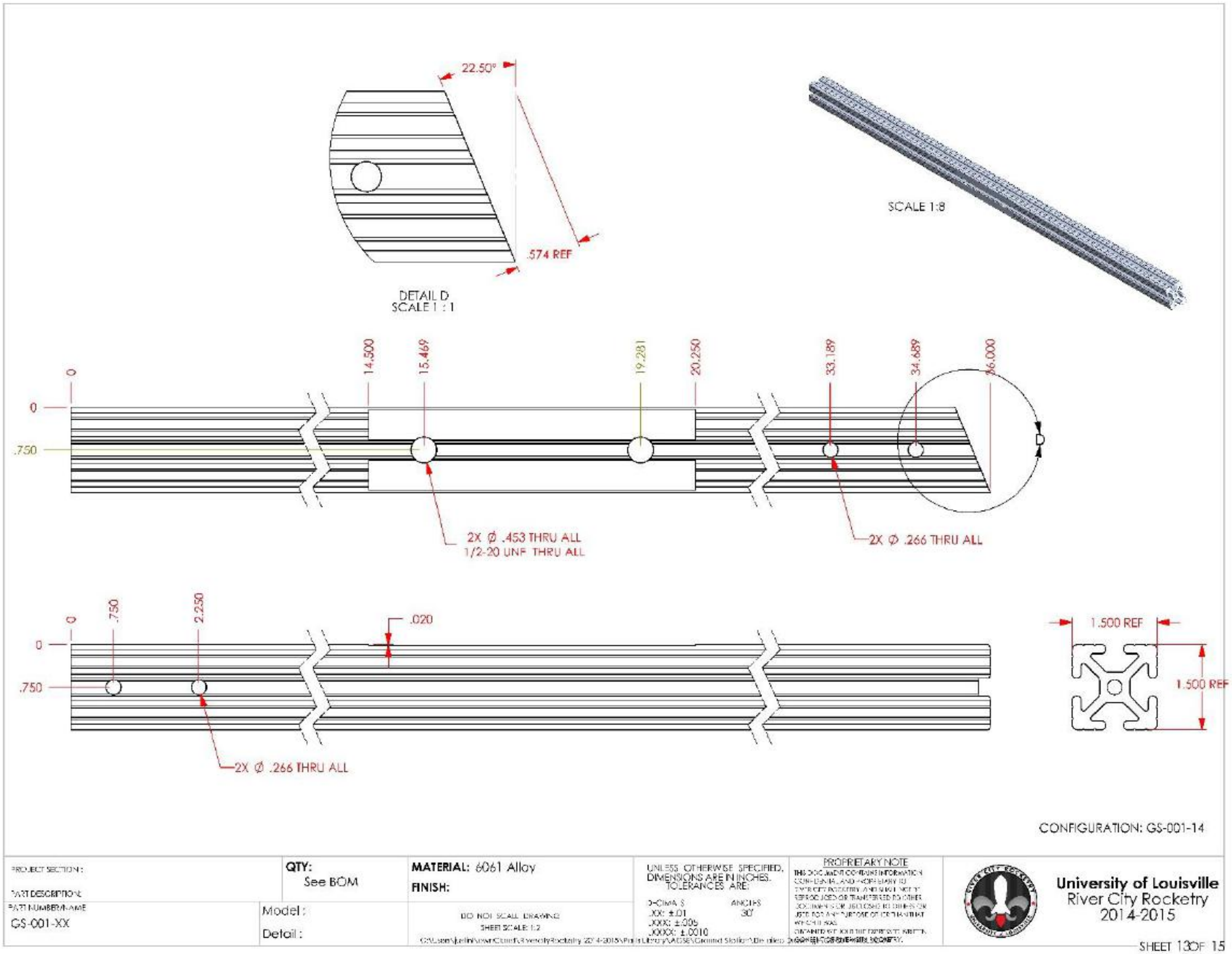

Figure 389: Ground station rear right top rail.