NASA Student Launch

2014-2015 CDR for Maxi-MAV

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Section 1. Summary of CDR 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)	41.8
Motor Choice	CTI 3147-L935-IM-P
Recovery System	Dual deployment

Table 1: Launch vehicle overview.

See section 5.3 for milestone timeline.

Section 2. Changes Made Since PDR

1) Vehicle Criteria

The launch vehicle has undergone three design changes since PDR. One of the changes was to address a point of concern regarding our fin retaining system. The remaining changes address a design change in how the cache will be deployed from the launch vehicle during descent. The changes made since the proposal are as follows:

- The rear fin retainer has been modified to allow a 6-32 UNC-2A set screw to be installed upon fin insertion.
- The launch vehicle will now feature a fairing that will deploy the cache payload, rather than utilizing an ejection via black powder method.
- Due to the implementation of the fairing design, the actuation of the door assembly has been modified to be one of linear movement rather than rotational.

After our PDR review, a point of concern was brought to our attention regarding fin flutter and fin retention. To further increase the rigidity of the fin retention system, the design of the rear fin retainer has changed such that a set screw can be installed up against the rear tab of each fin. With the press fitment of the fins into each machined centering ring, and the added retention of the set screw, the fins will be in a static state from the fin tab down to the centering ring.

Throughout the critical design phase of the launch vehicle, it was determined that ejecting the cache payload via black powder would yield unsatisfactory results. There would be an inherent risk of either damaging the electronics, or the recovery, to accomplish the task as originally planned. To alleviate all issues, the cache containment bay has been converted into a fully functional fairing deployment bay. This will allow for a secure fitment of the payload into the launch vehicle, and will ensure a safe and reliable deployment.

Due to the nature of the fairing design, one having a section of airframe split down the middle, a rotating door assembly can no longer be used. Rather, the door will be actuated linearly from the fore section of the cache bay towards the aft section. The door assembly will still be driven by a servo motor, and will be driven on a rack and pinion gear train.

2) AGSE Criteria

The AGSE has seen multiple major design changes since PDR, these changes are explained below:

- The ground station transportation method has changed into 3 distinct sections
- Locations for all electronics and power supplies has been added to the ground station
- The auto platform leveling system has been detailed

- Anti-friction tape has been replaced with a spray on anti-friction coating
- The ignition station has been changed to one motor
- The ignition station has added an extra gear
- The outrigger station has had their motor sized
- The material for all components has been re-selected

The ground station was changed for transportation reasons, with the three sections will be structurally rigid for transportation as each individual section and use pins to attach to each other. The locations for the batteries and control electronics were added and needed to ensure proper fitment and clearance with the vehicle in the AGSE.

The anti-friction tape was changed to a spray on coating because it is more cost effective and simpler application. To prevent the chance of one motor having to overcome another motor in the ignition station, one motor has been removed and an idler gear has been added in its place.

Analysis was performed on the outrigger drive screw to determine the required motor torque and required rpm's of the motor to meet mission performance requirements. The material has been determined to be AISI 1020 for all AGSE steel components except for the four shaft blocks that connect the launch platform to the ground station, which are AISI 4130. All AGSE aluminum components are 6061-T6, the material change and definition are required for material order and fabrication information.

Section 3. Launch Vehicle Criteria

1) Design and Verification of Launch Vehicle

Design Overview

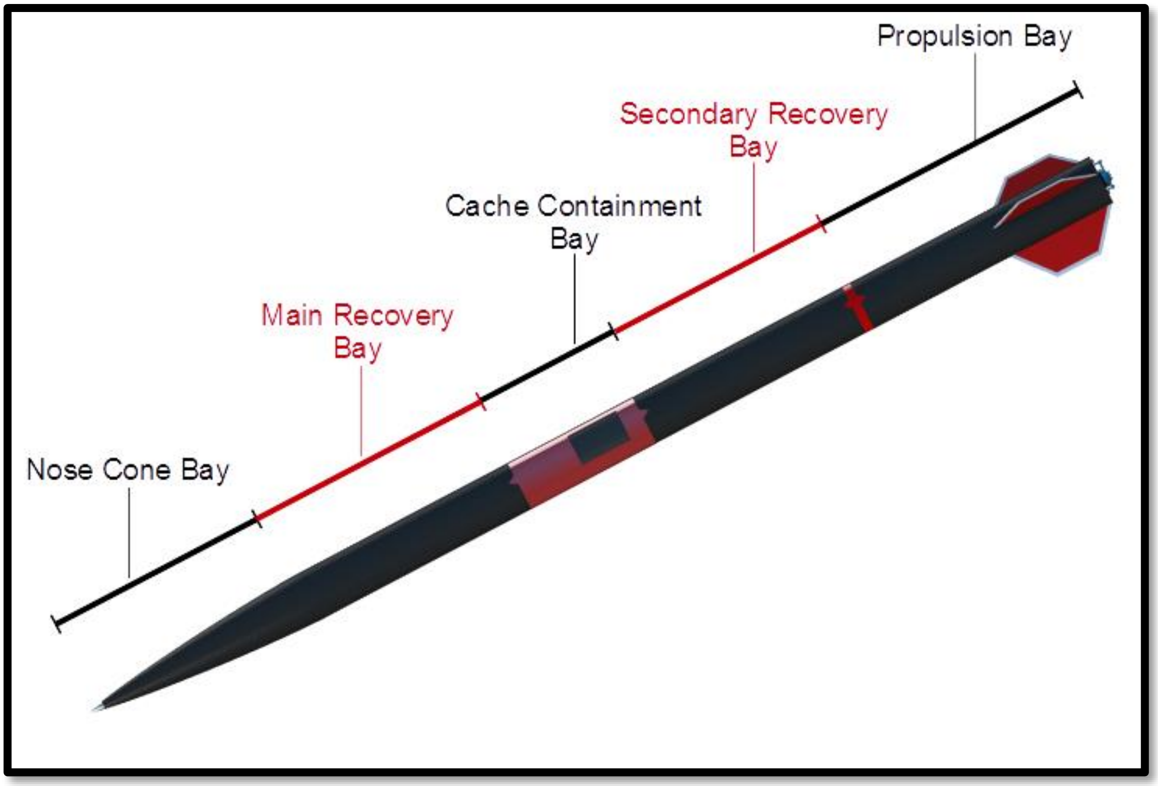

Figure 1: Layout of the primary launch vehicle sections.

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

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

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.

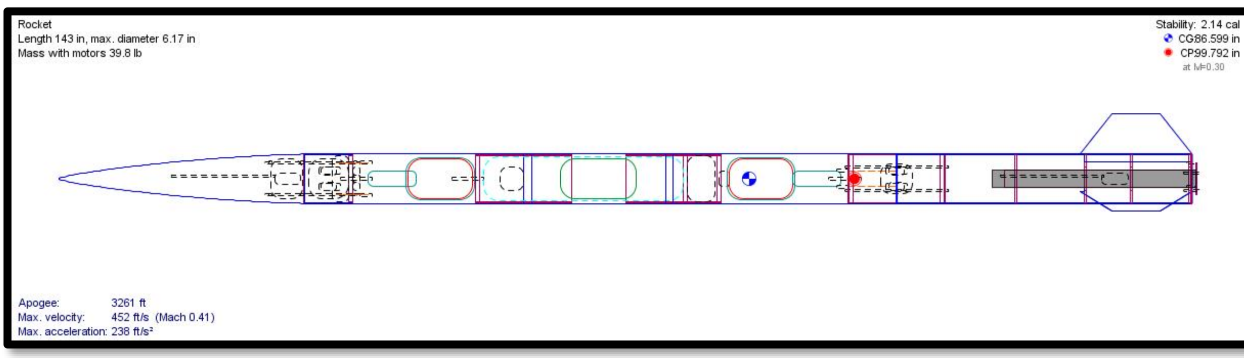

Figure 2: OpenRocket simulation of the launch vehicle.

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. 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. Those section that are to stay intact throughout the course of the entire flight and descent will be joined with the appropriate 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. This epoxy was chosen for its superior strength, as seen in Table 2.

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.

Nose Cone Design

The Von Karman Nosecone, seen in Figure 3, was chosen due to its performance through subsonic and transonic speeds.

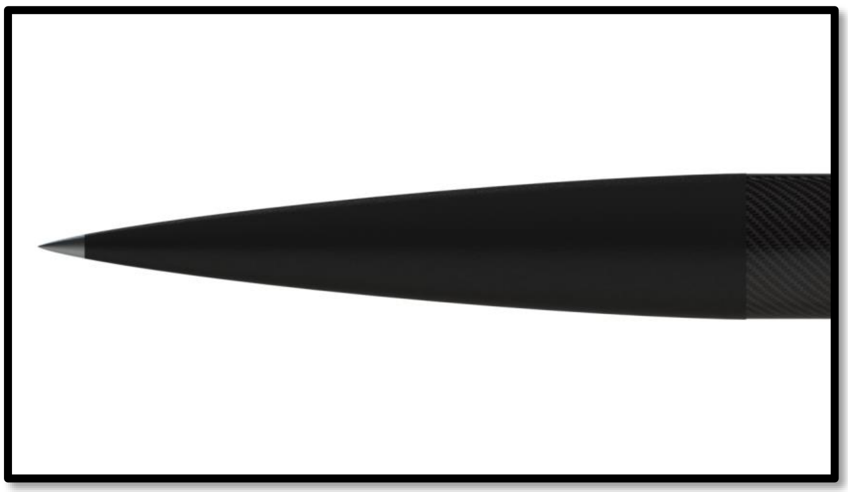

Figure 3: Von Karman nose cone modeled in SolidWorks.

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.

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.

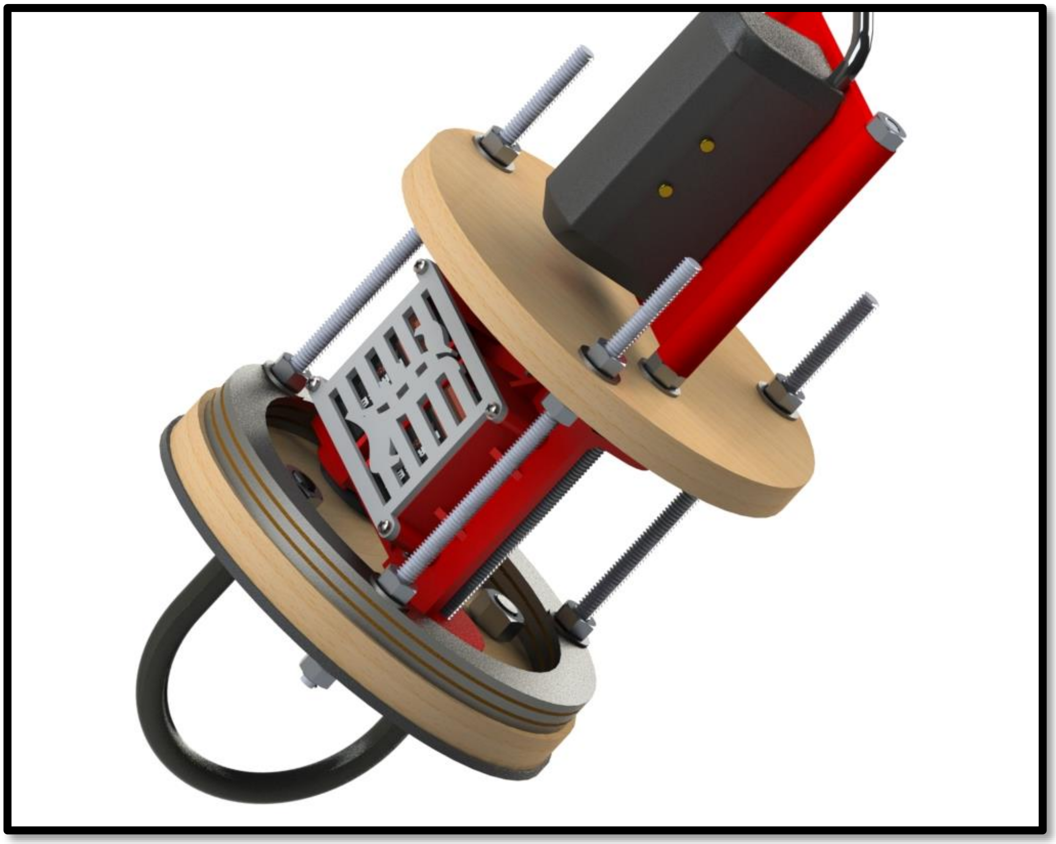

Figure 4: Rendered image of the nose cone's ballast system.

The primary goal in the design of the ballast system is to ensure it did not interfere with any other systems. Figure 4 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 5 shows the detailed drawing for the steel rings used as the weighted ballast.

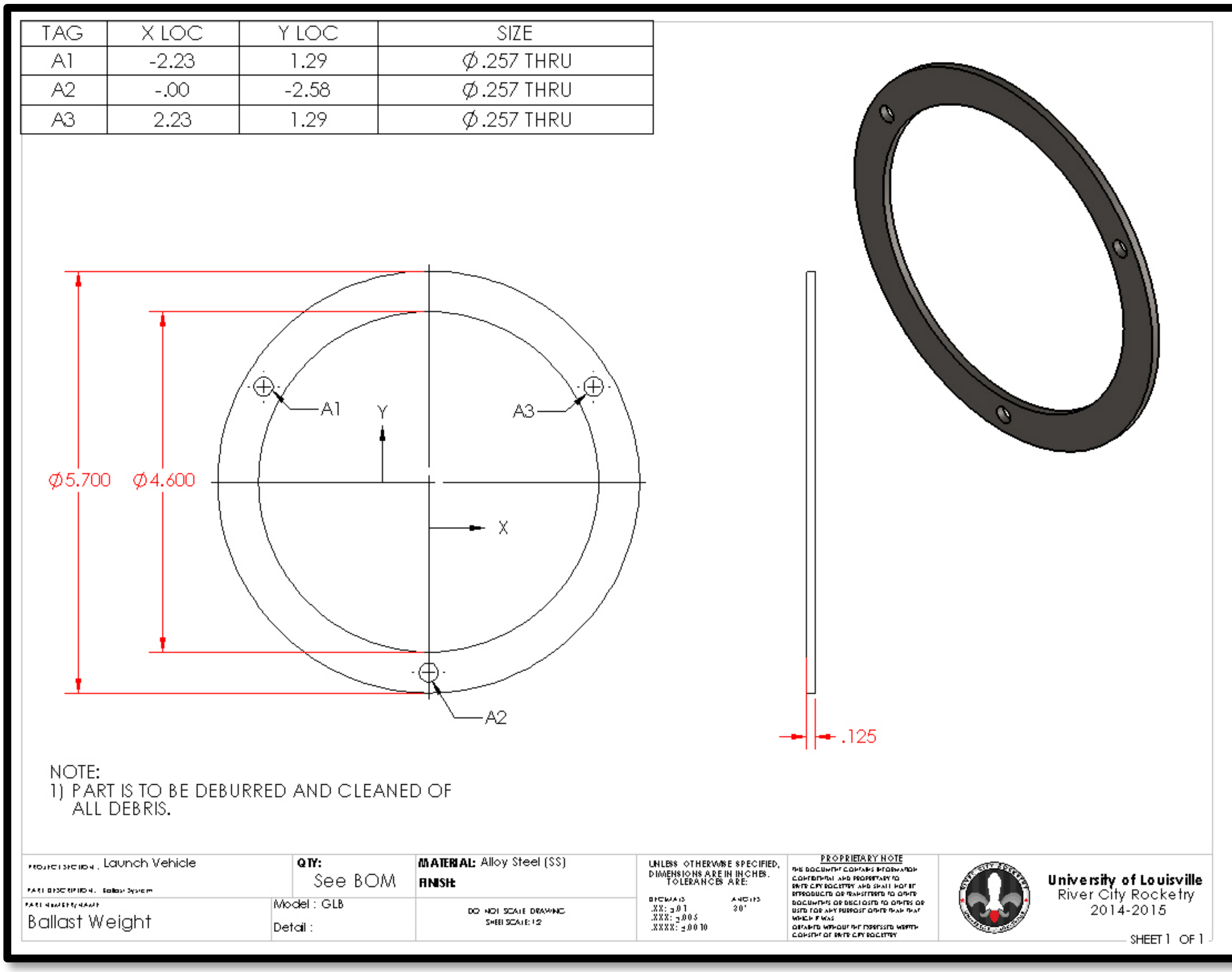

Figure 5: Detailed drawing of the ballast weight.

Figure 6 shows the detailed drawing of the rubber ballast spacer.

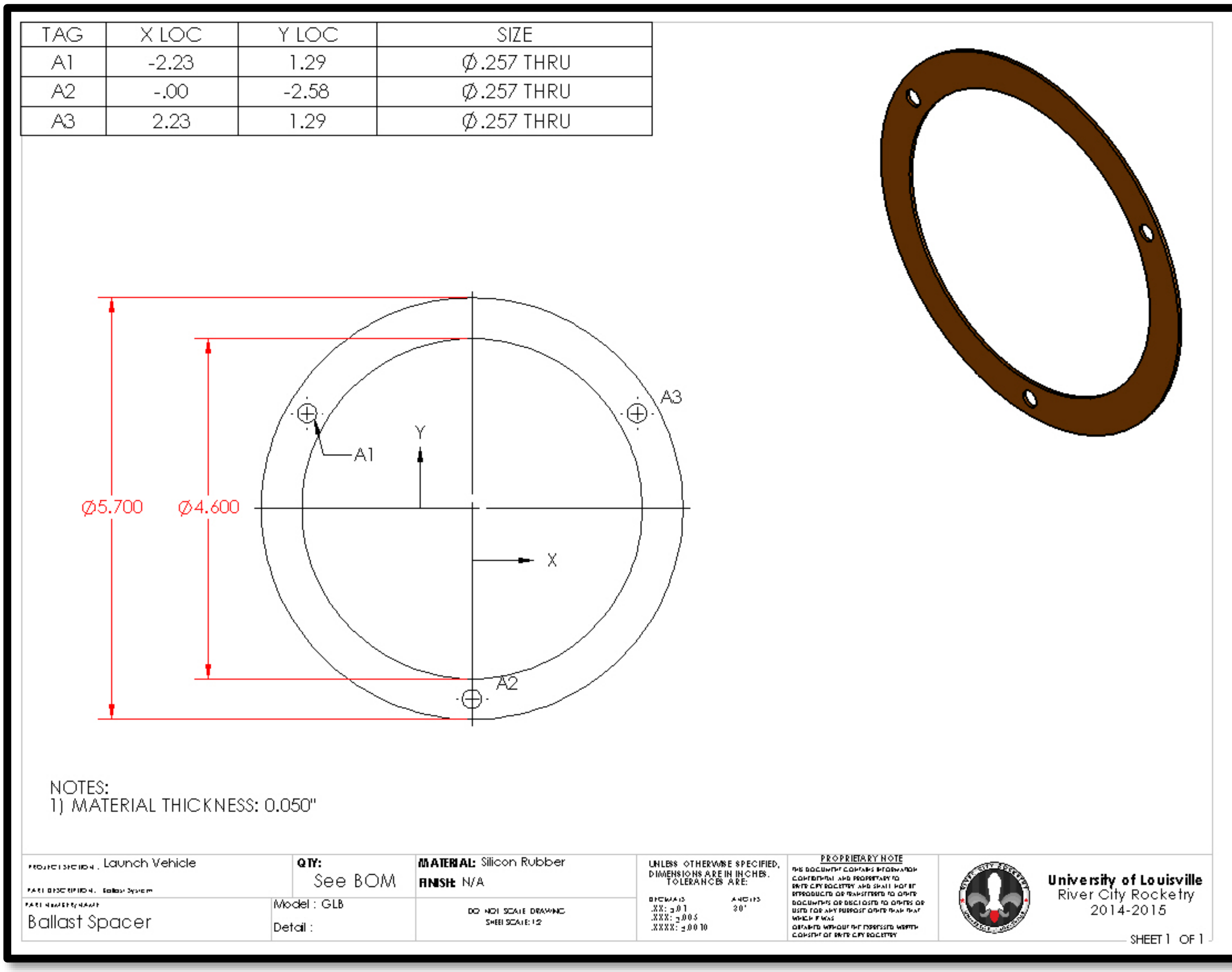

Figure 6: Detailed drawing of the ballast spacer.

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 3 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 3: 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.

Propulsion Bay Design

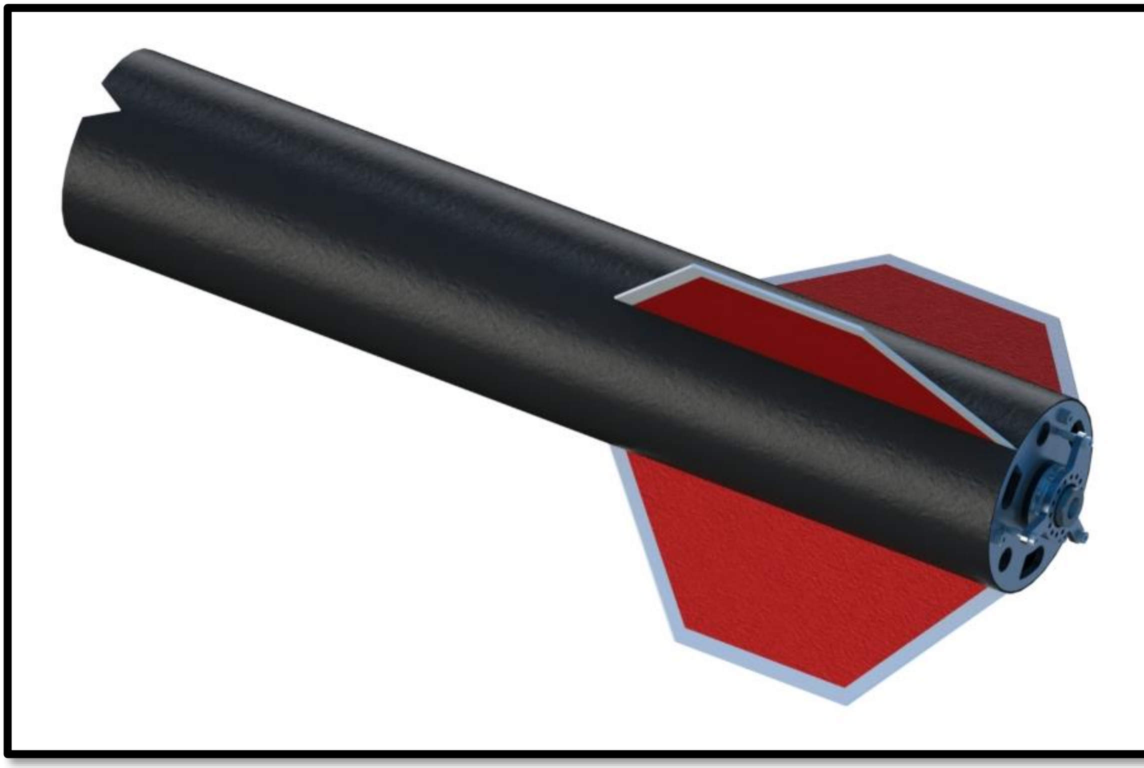

Figure 7: Assembled propulsion bay.

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.

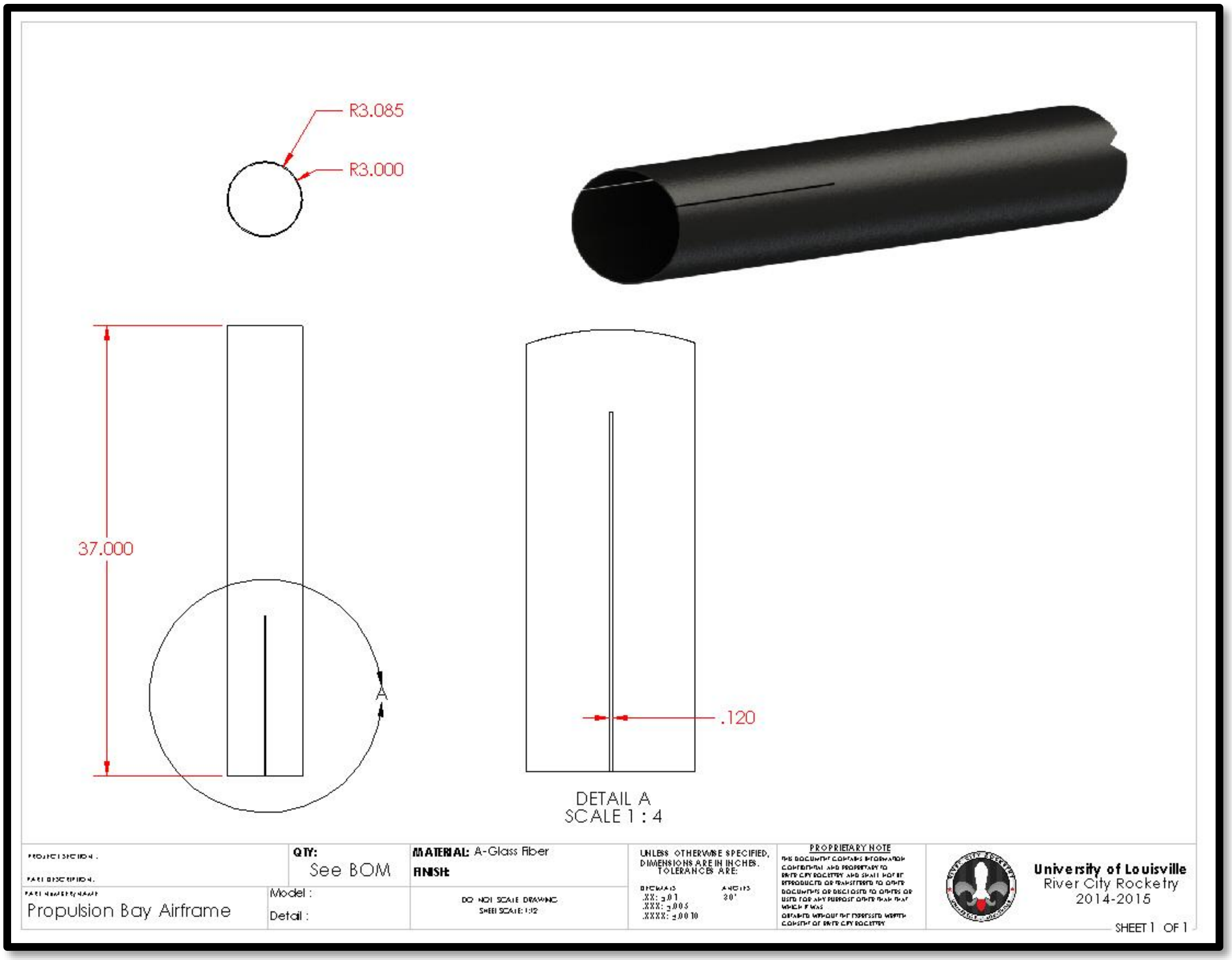

Figure 8: Detailed drawing of propulsion bay airframe.

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.

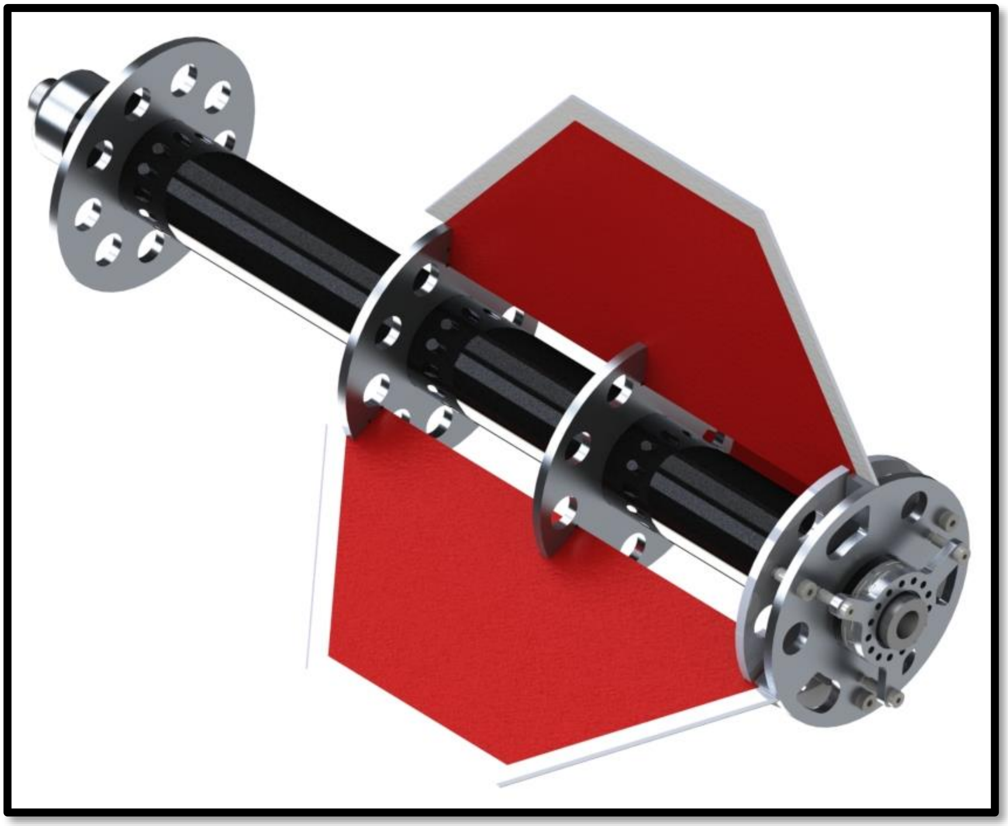

Figure 9: Propulsion bay's removable fin assembly.

Figure 9 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 10.

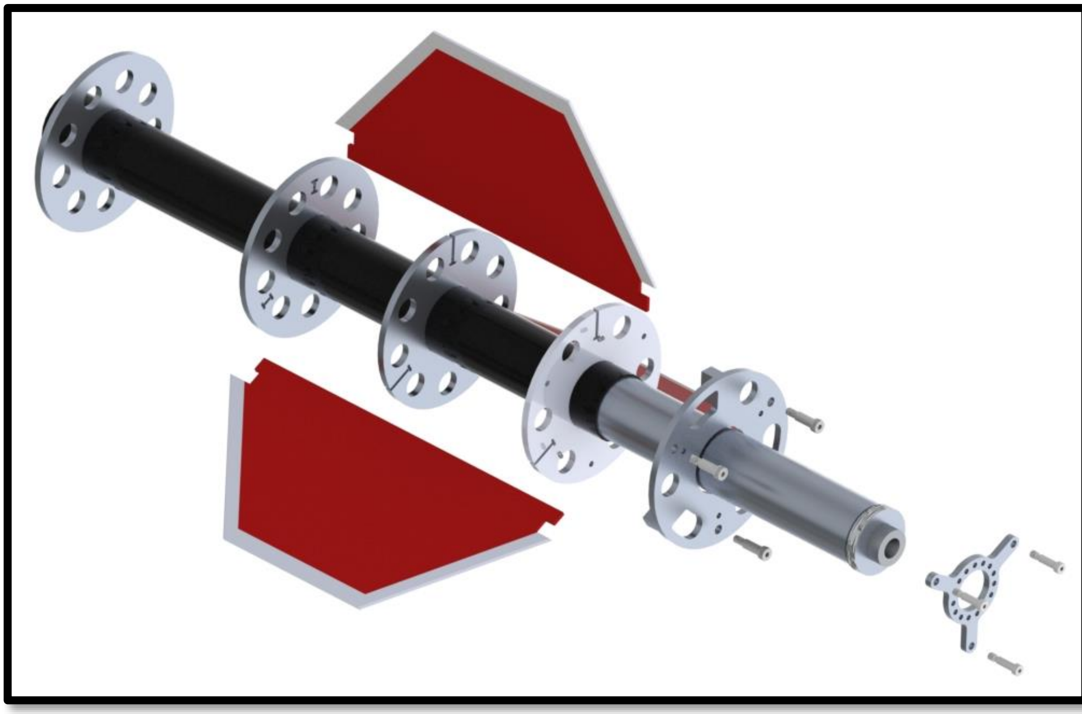

Figure 10: Exploded view of removable fin system.

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.

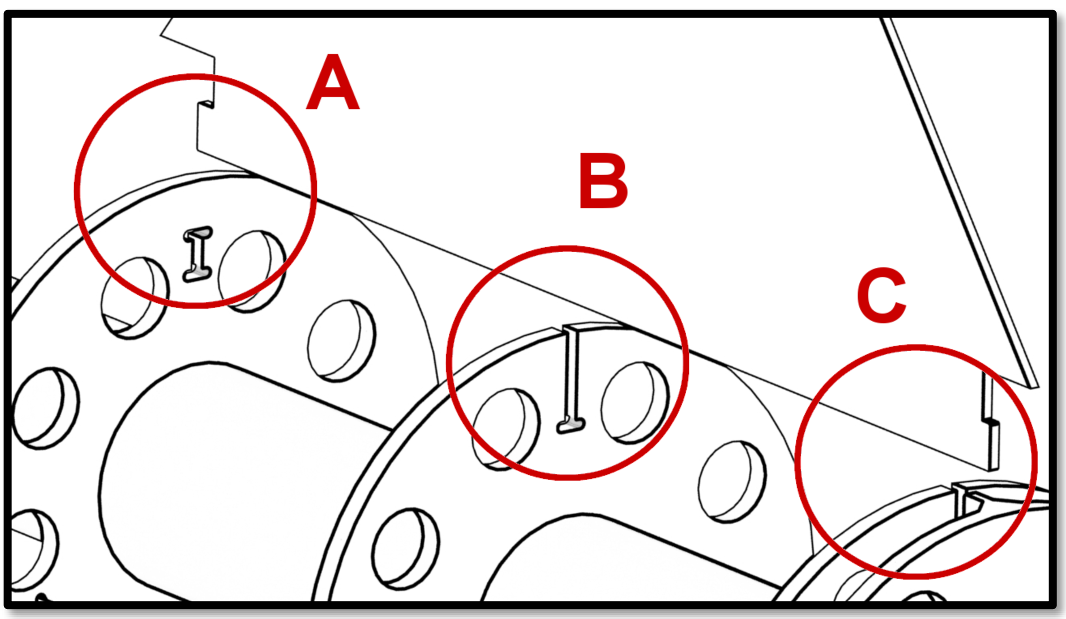

Figure 11: Highlighting the three connections between the fins, centering rings, and fin retainer.

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 12, 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.

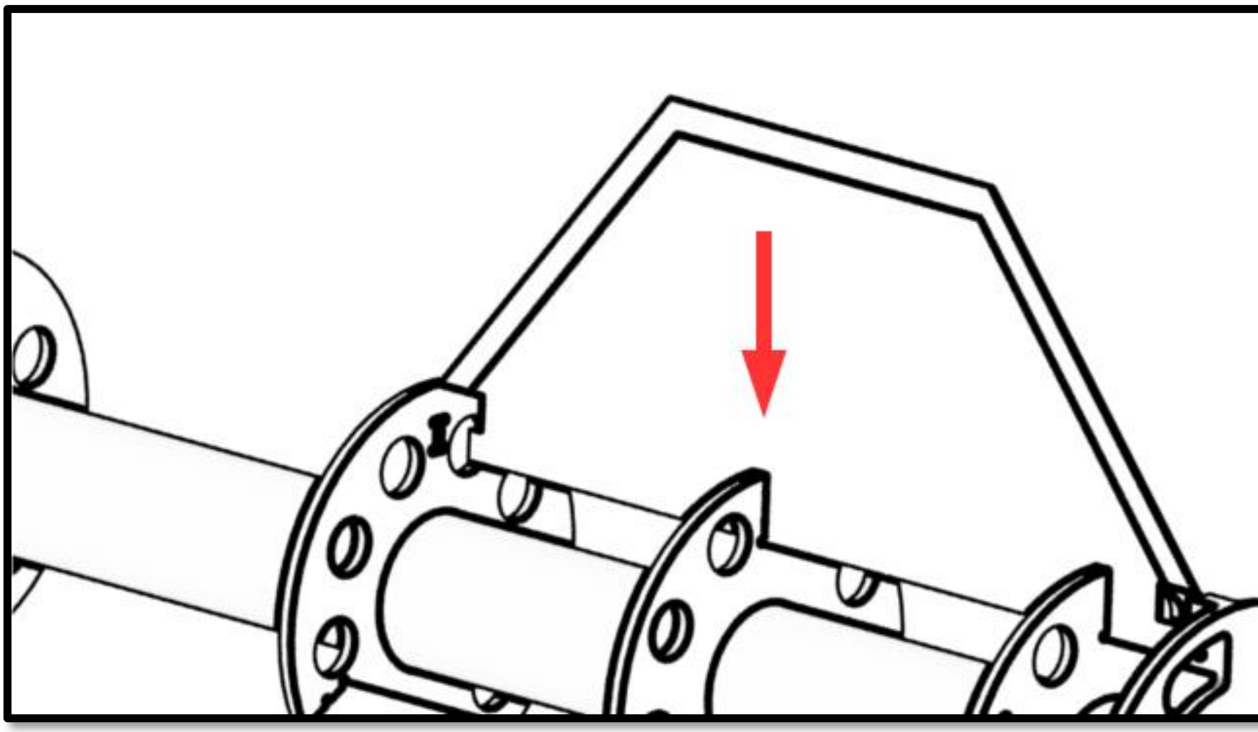

Figure 12: Fin being pushed into centering ring fin slots.

Once the fin is properly seated, the fin is to be pushed forward, as seen below in Figure 13. 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.

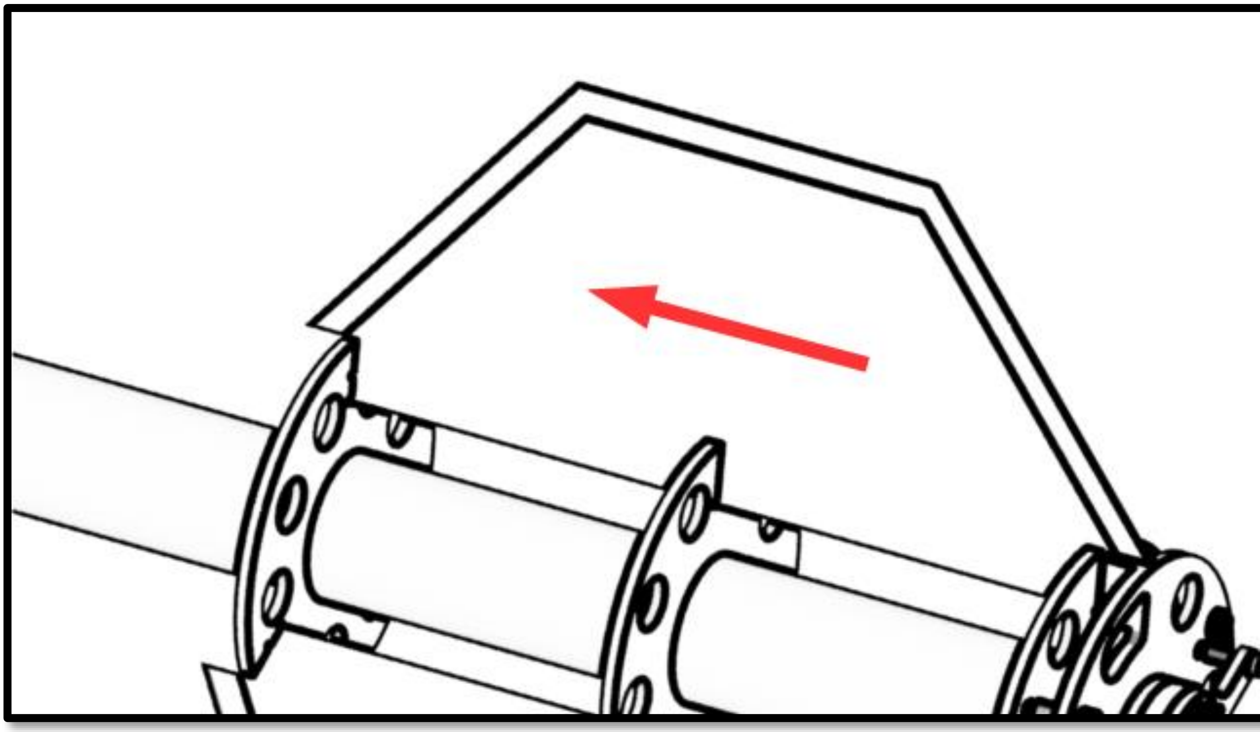

Figure 13: Fin is pushed forward so that the fin tab inserts into aft centering ring.

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 13.

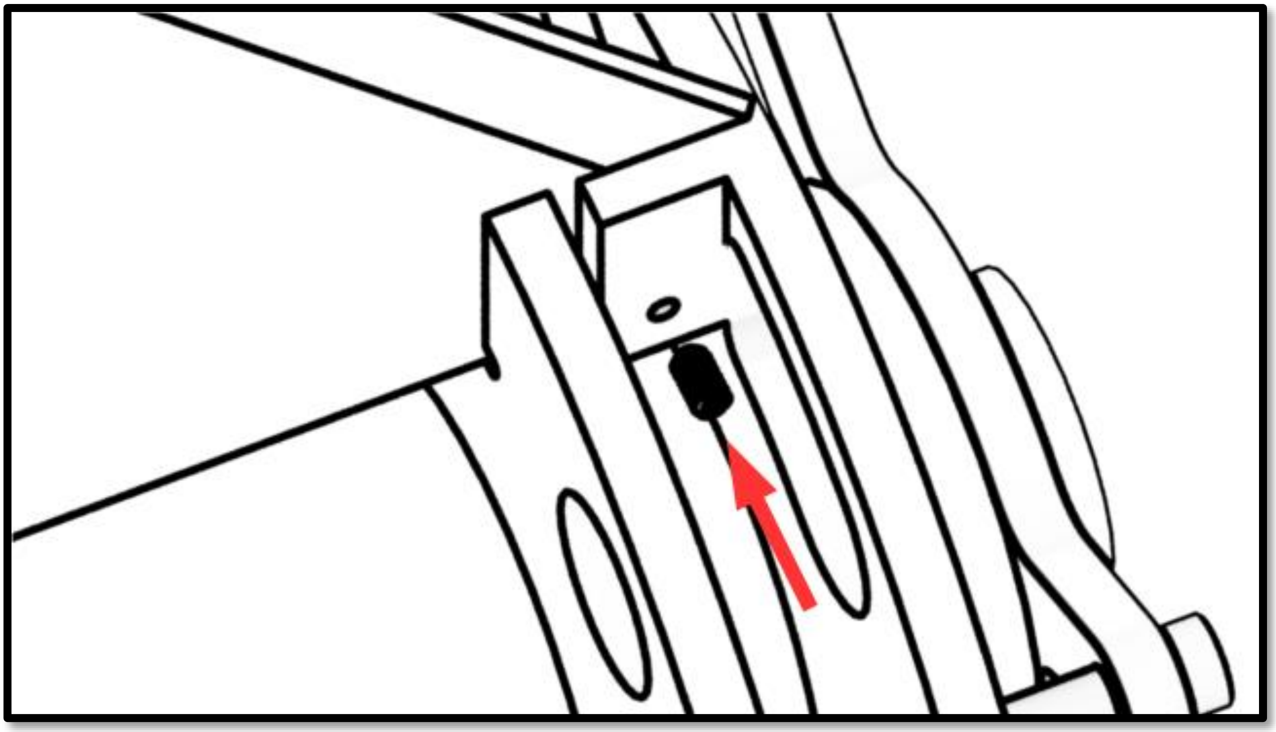

Figure 14: Installing the set screw to secure the fin inside the rear fin retainer.

The set screws used have a thread-locking nylon patch, as seen in Figure 15. 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 15: Thread-locking nonmarring flat point set screws.

The rear fin retainer's technical drawing is shown below in Figure 16.

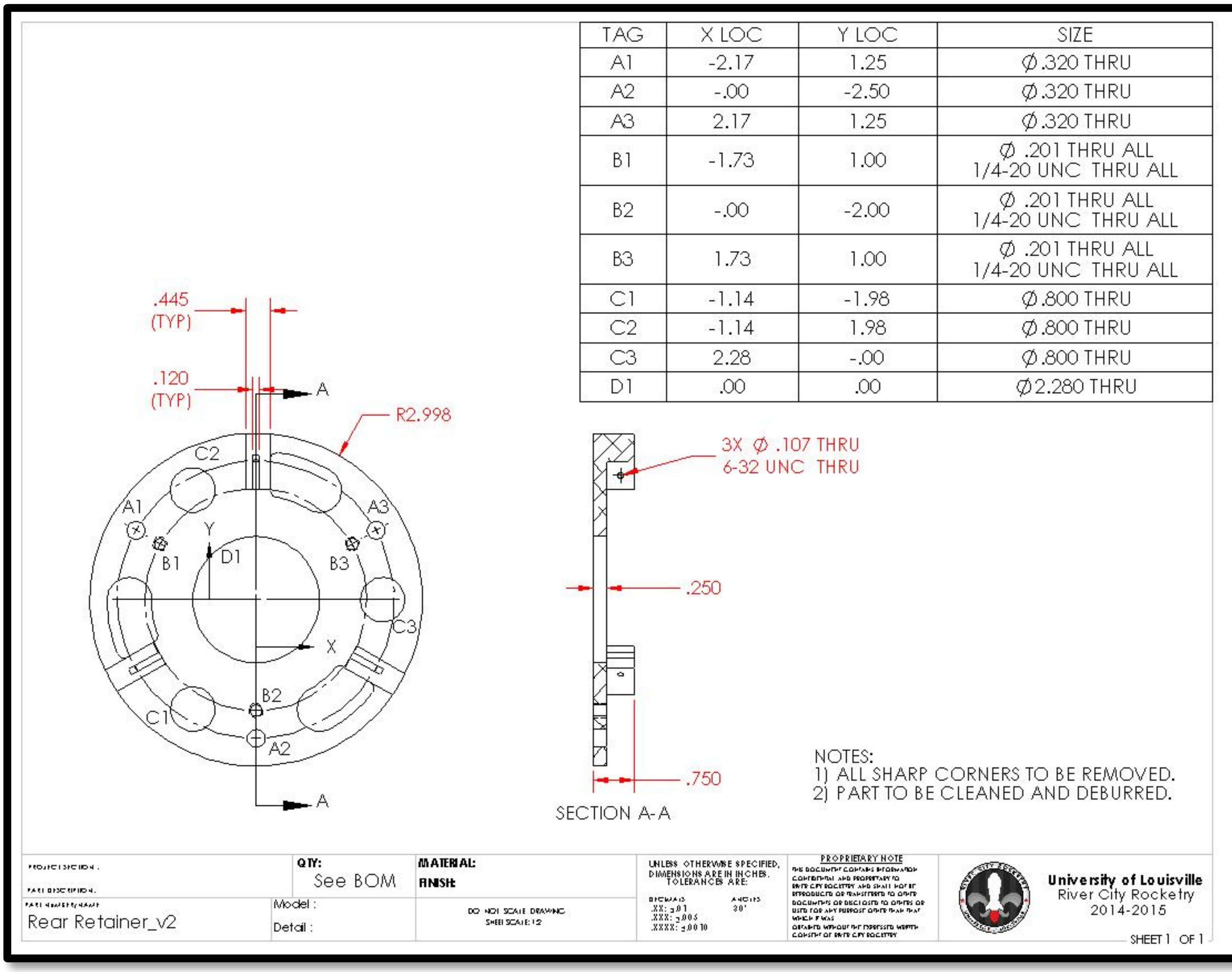

Figure 16: Rear fin retainer technical drawing.

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 17, shown below, shows the modification and the clearance for the Allen key.

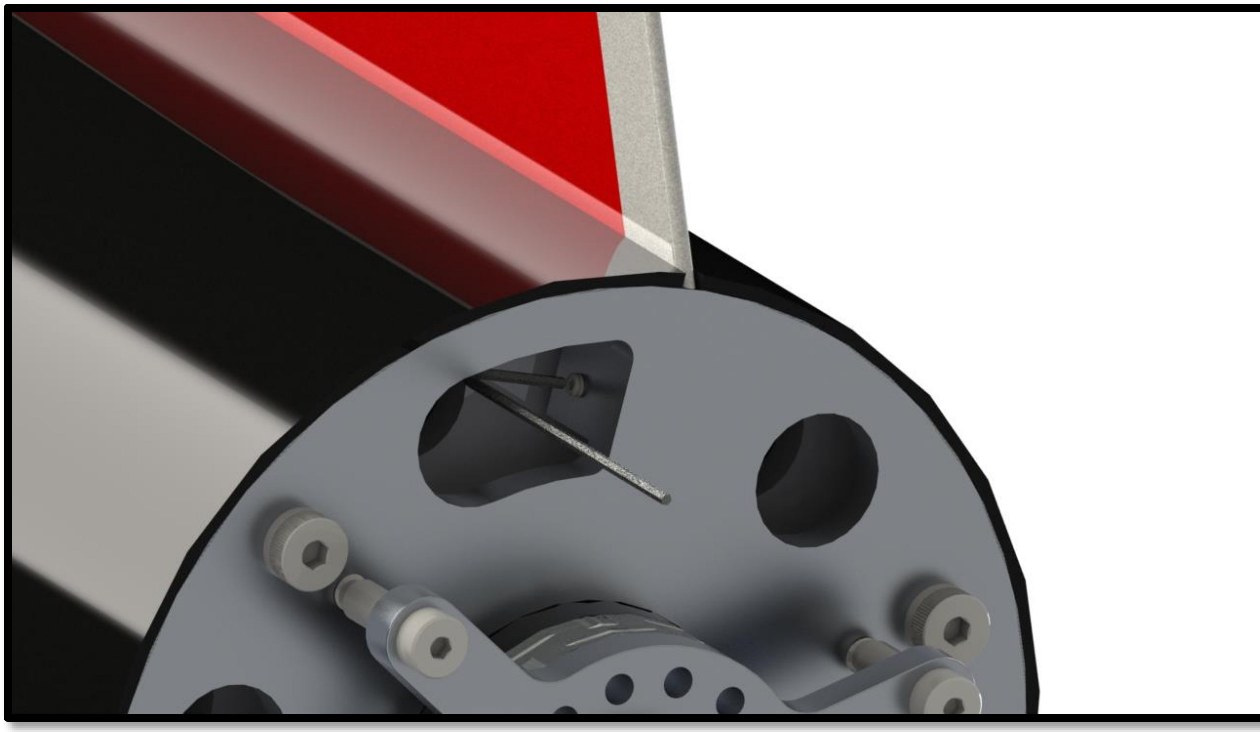

Figure 17: Modified rear fin retainer to allow access for an Allen key.

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 Abrasive waterjet. Figure 18, below, shows the detailed drawing of the launch vehicle’s fin.

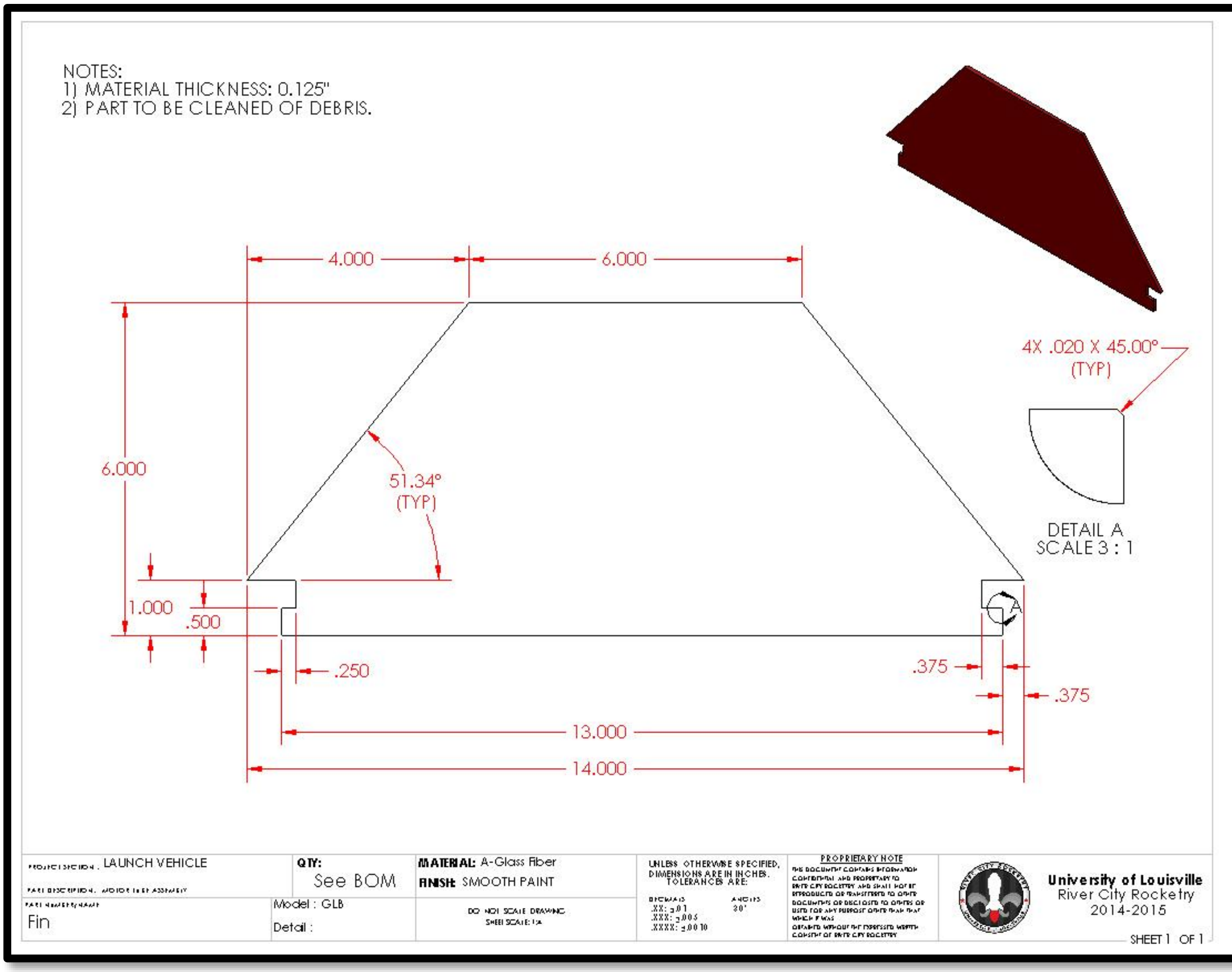

Figure 18: Detailed drawing of the launch vehicle's fin.

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 19. Sets of equally spaced holes of 0.80" diameter will be cut in between each of the machined fin slots.

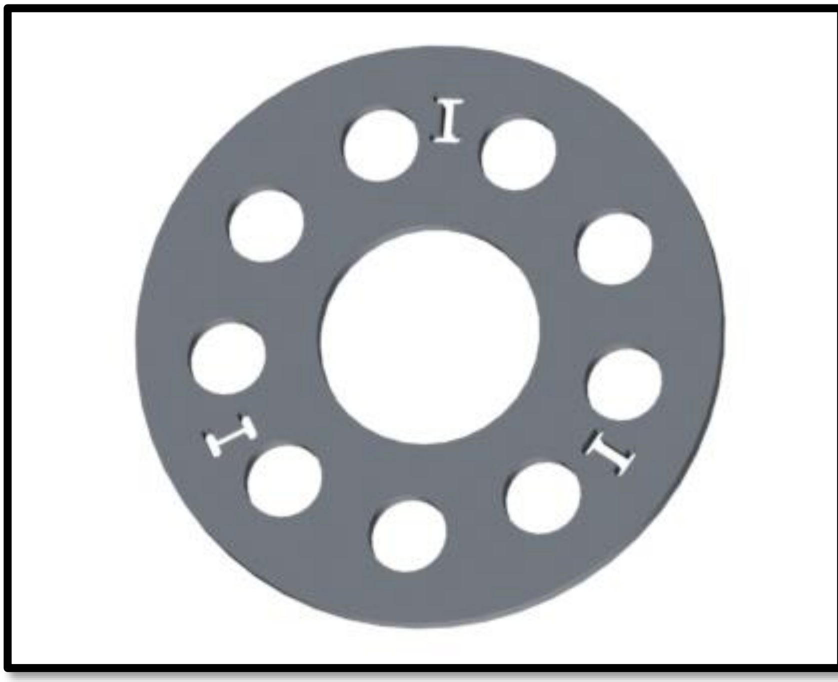

Figure 19: View of the fore centering ring in the removable fin system.

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 20, shows the general geometry of the centering rings.

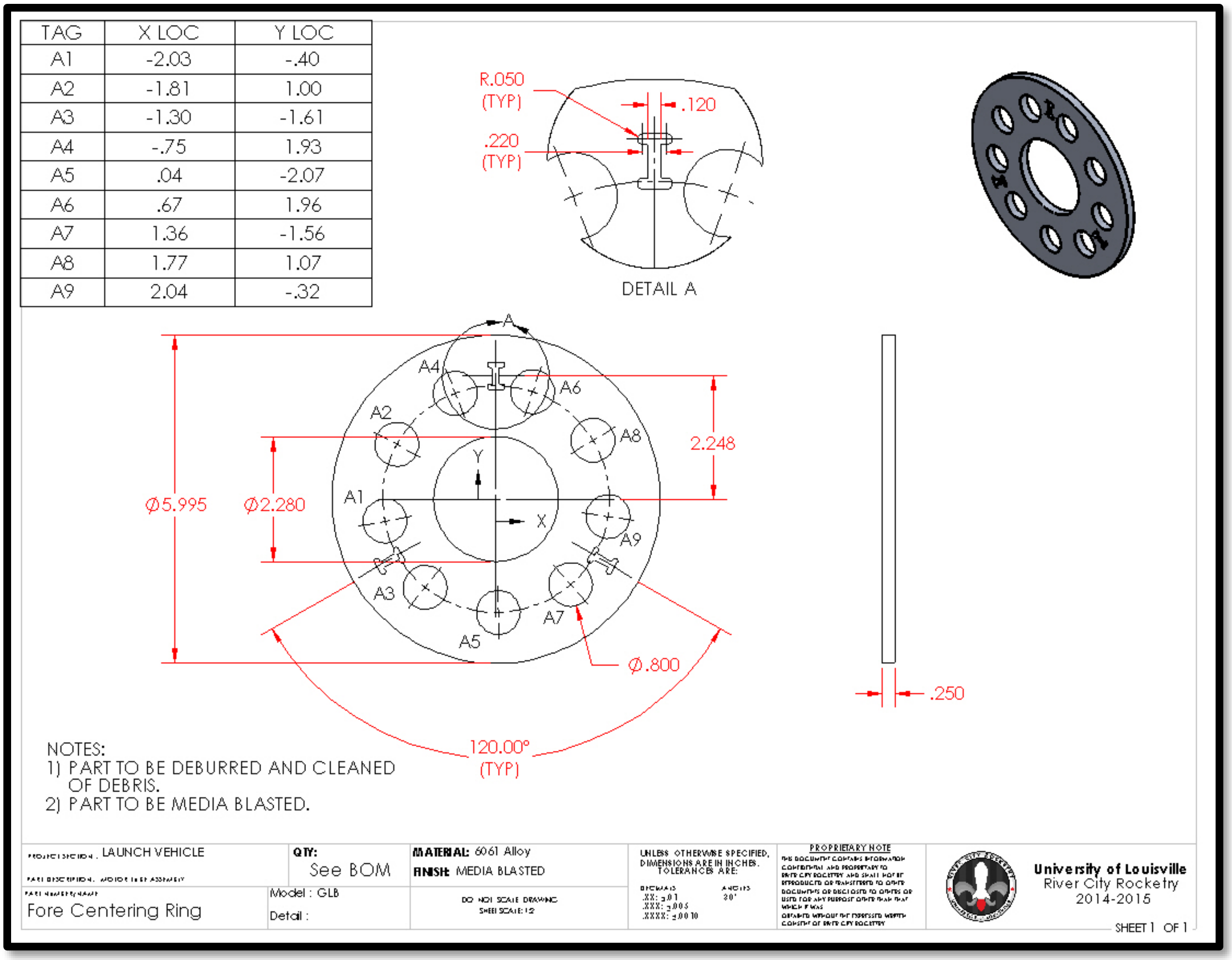

Figure 20: Detailed drawing of the fore centering ring.

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 21, below, shows the detailed geometry of the casing retainer.

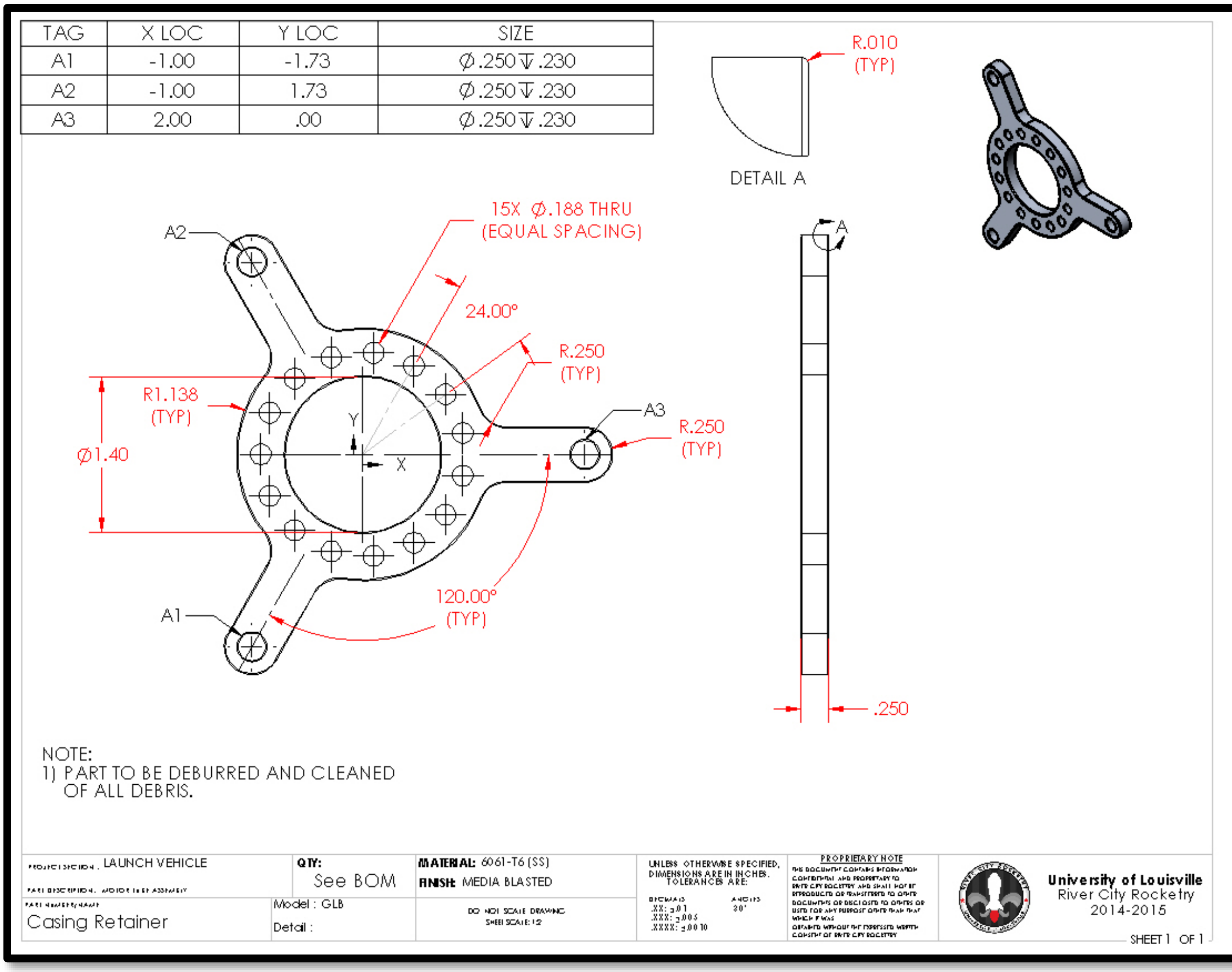

Figure 21: Detailed drawing of the motor casing retainer.

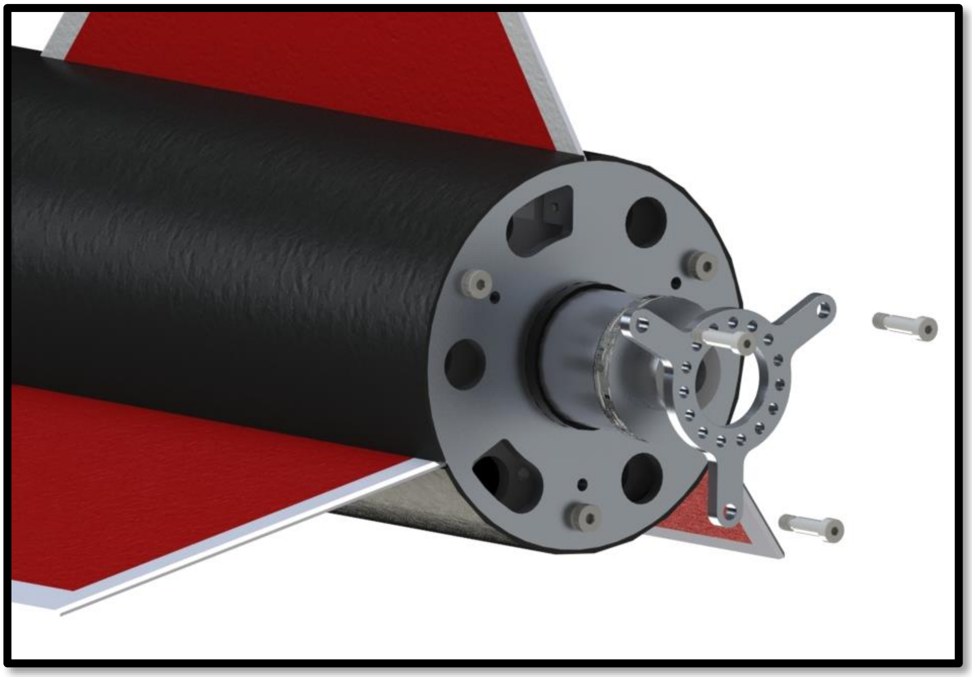

Figure 22: Motor retention components exploded view.

Prior to installation, the fins and rear fin retainer must be installed. As seen above in Figure 22, the motor casing retainer is fastened into place with two 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.

Table 4, 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 4: Material properties of components in the propulsion bay.

Lower Avionics Bay

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.

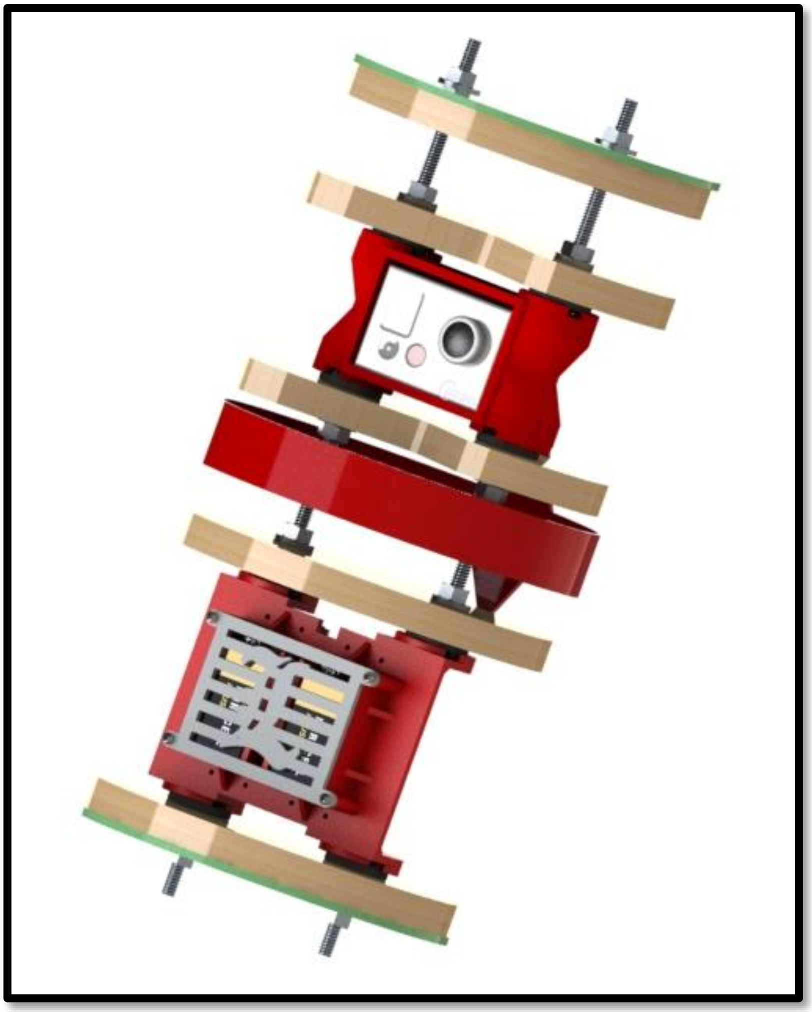

Figure 23: Lower avionics bay with the coupler tubing removed.

Cache Containment Bay and Fairing Payload Integration

A redesign of the vehicle's payload integration occurred post-PDR. A design of a reusable fairing will be implemented to safely secure and deploy the cache capsule. The use of this system will allow 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, you do not notice the compression, 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 24. Representation of fiberglass deformation.

To counteract this issue, the team came up with 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. It was determined that all of the bulkplates and coupler tubing would be installed prior to the cutting of the airframe. After the epoxy had dried, a jig was built so that a band saw could be used to precisely cut the fairing in half. Having the bulkheads already epoxied in place did not allow the fairing airframe and coupler tubing to deform at all. 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 are designed to power and control a single StratoLogger. This called for no separate altimeter bay. The team designed an altimeter housing, shown in Figure 25, that will be

3D printed from ABS plastic. 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 25: 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.

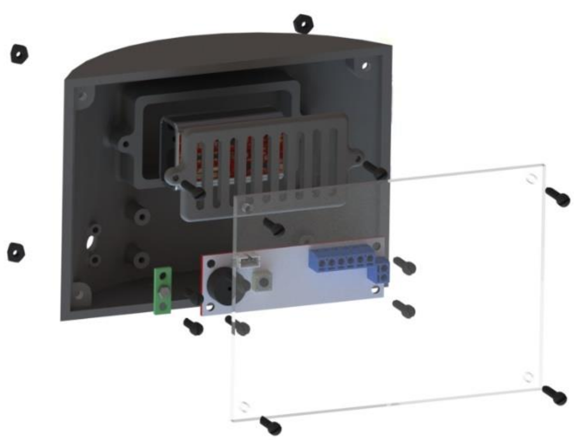

Figure 26: Exploded view of the altimeter housing.

Furthermore, there is a hole in the back of the altimeter housing which can be seen in more detail below in Figure 27. 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.

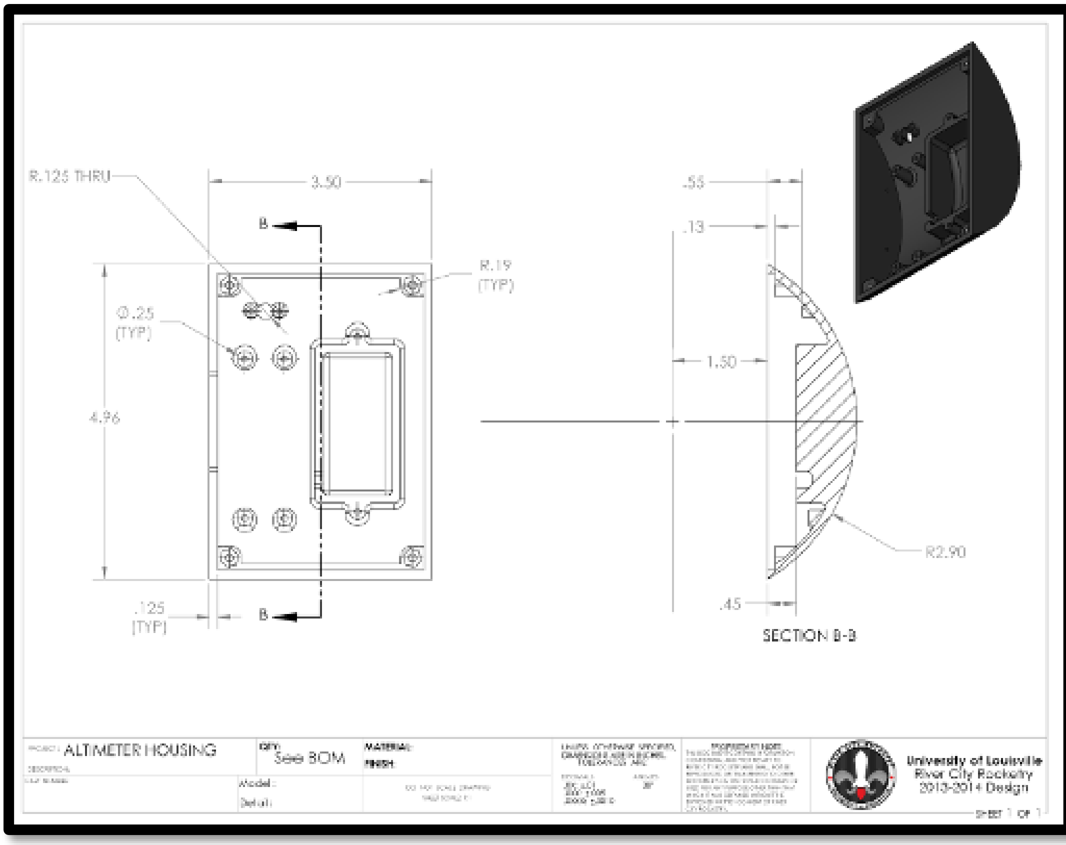

Figure 27: Altimeter housing basic dimensional drawing.

Utilizing information from StratoLogger's website, the port hole size for the altimeter housing was determined. Table 5 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 5: 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 5 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 6: Altimeter housing port hole analysis.

Table 6 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 is designed 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 7 shows the maximum and minimum clearances for the fitment of Shell B into Shell A.

Maximum (in)	0.013
Minimum (in)	0.003

Table 7: Fitment clearances for Shell B into Shell A.

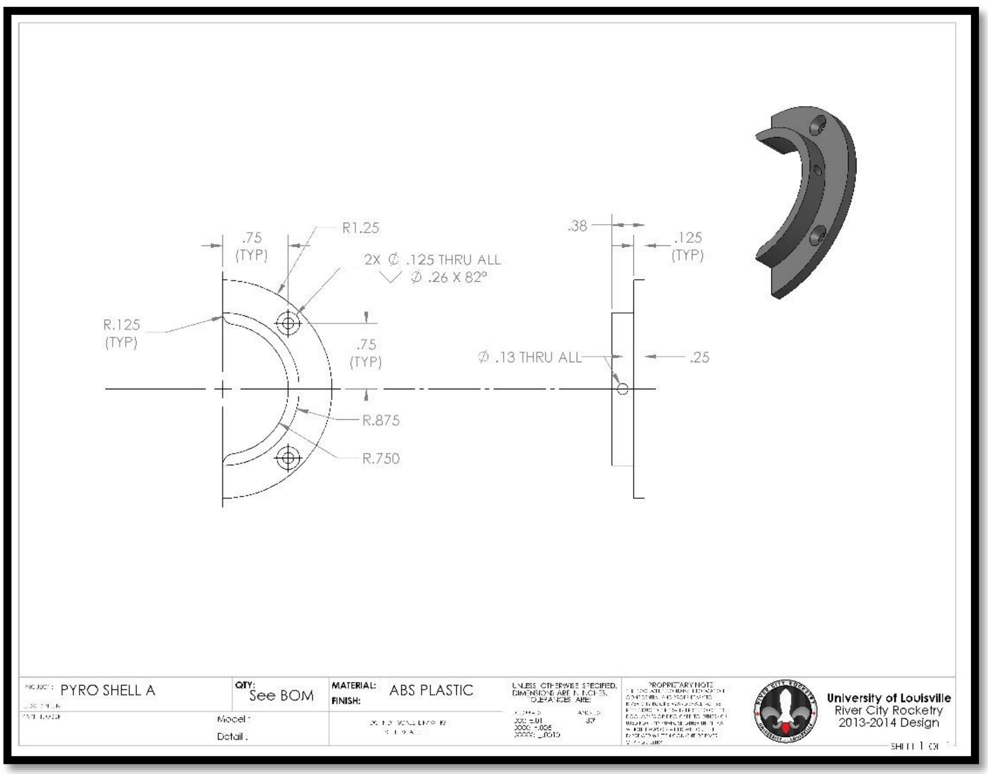

Figure 28: Detailed drawing of Shell A.

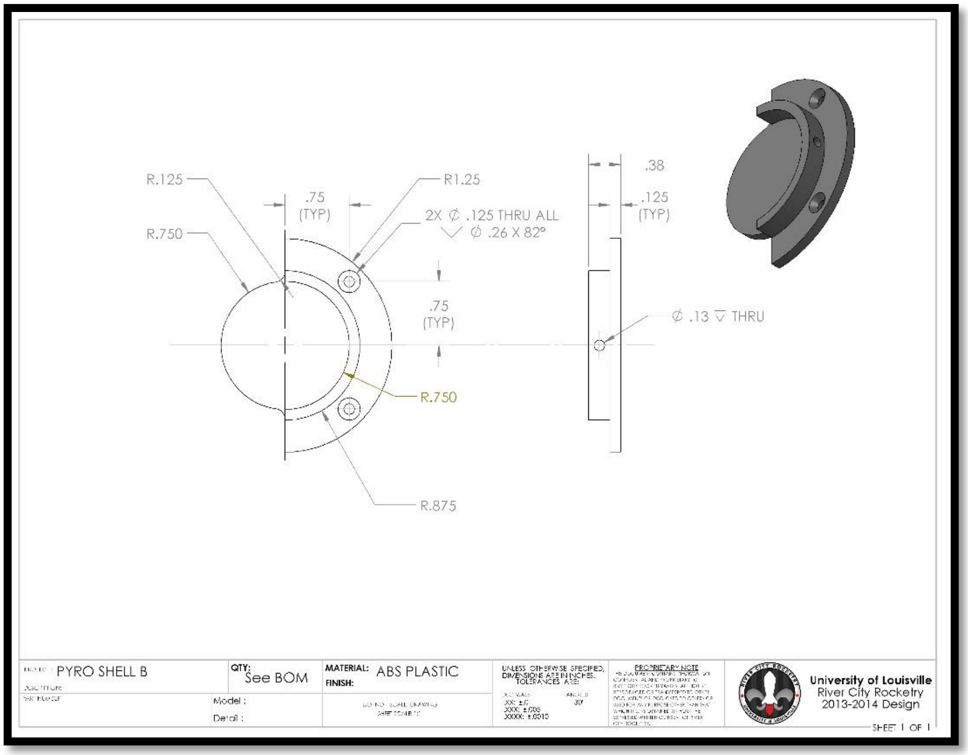

Figure 29: Detailed drawing of Shell B.

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 30 shows the clearance fitment for the pyro cap into the assembly.

Maximum (in)	0.026
Minimum (in)	0.006

Table 8: 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.

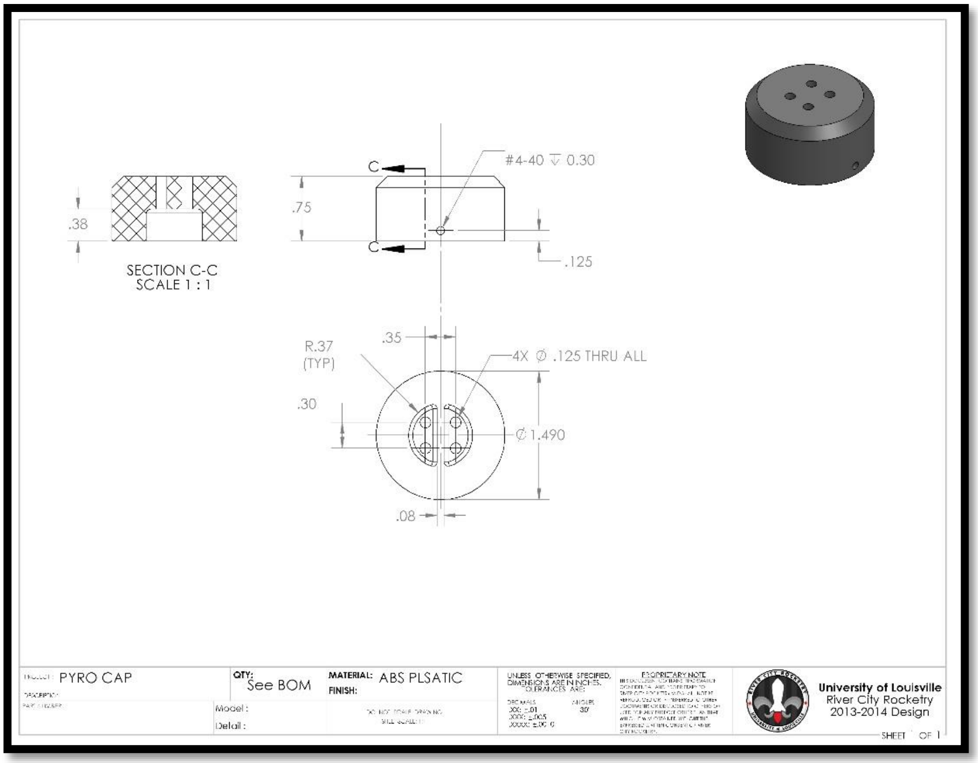

Figure 30: Detailed drawing of the pyro cap.

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 9: Pyro cap black powder well dimensions.

Table 9 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.

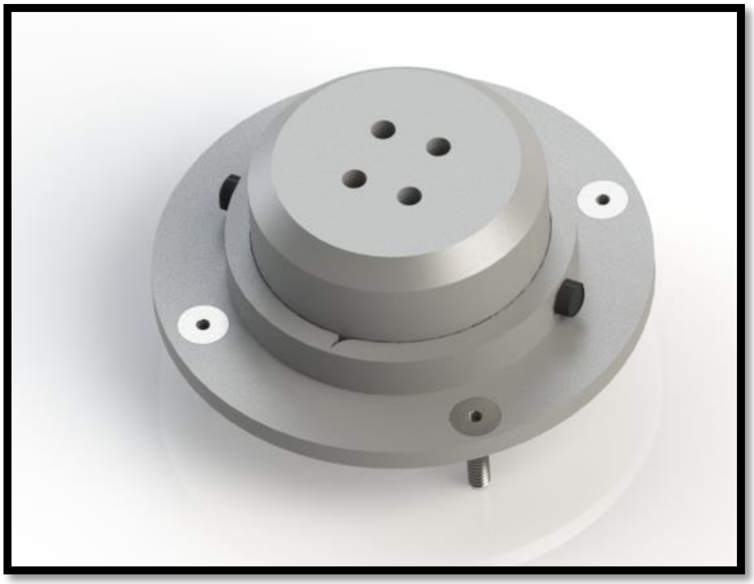

Figure 31: Pyro cap assembly.

The pyro cap is secured into place by two 4-40 nylon screws, as shown in Figure 31. 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 round where it could cause damage people 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 will be to have 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 will prove useful in shaping it to conform to the body of the cache capsule.

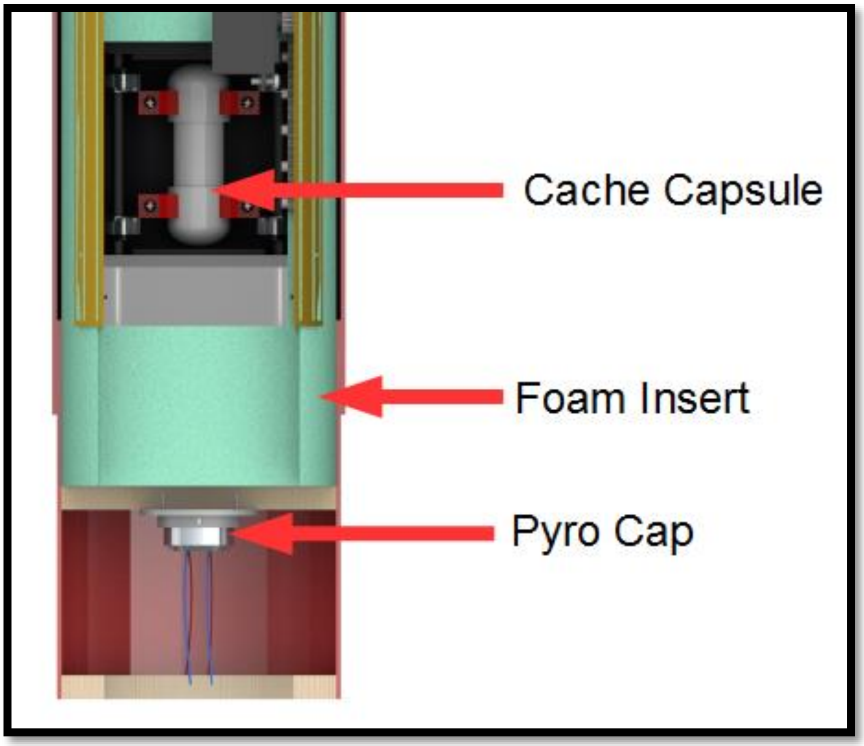

Figure 32: Integration of the cache capsule into the fairing.

Figure 32 lays out 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. Two steel spring joining the two U-bolts. This set up, shown below in Figure 33 causes the fairings static state, without the pyro cap installed, to be open.

Figure 33: View of spring actuated payload ejection system.

2) Recovery Subsytem

Design 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 34.

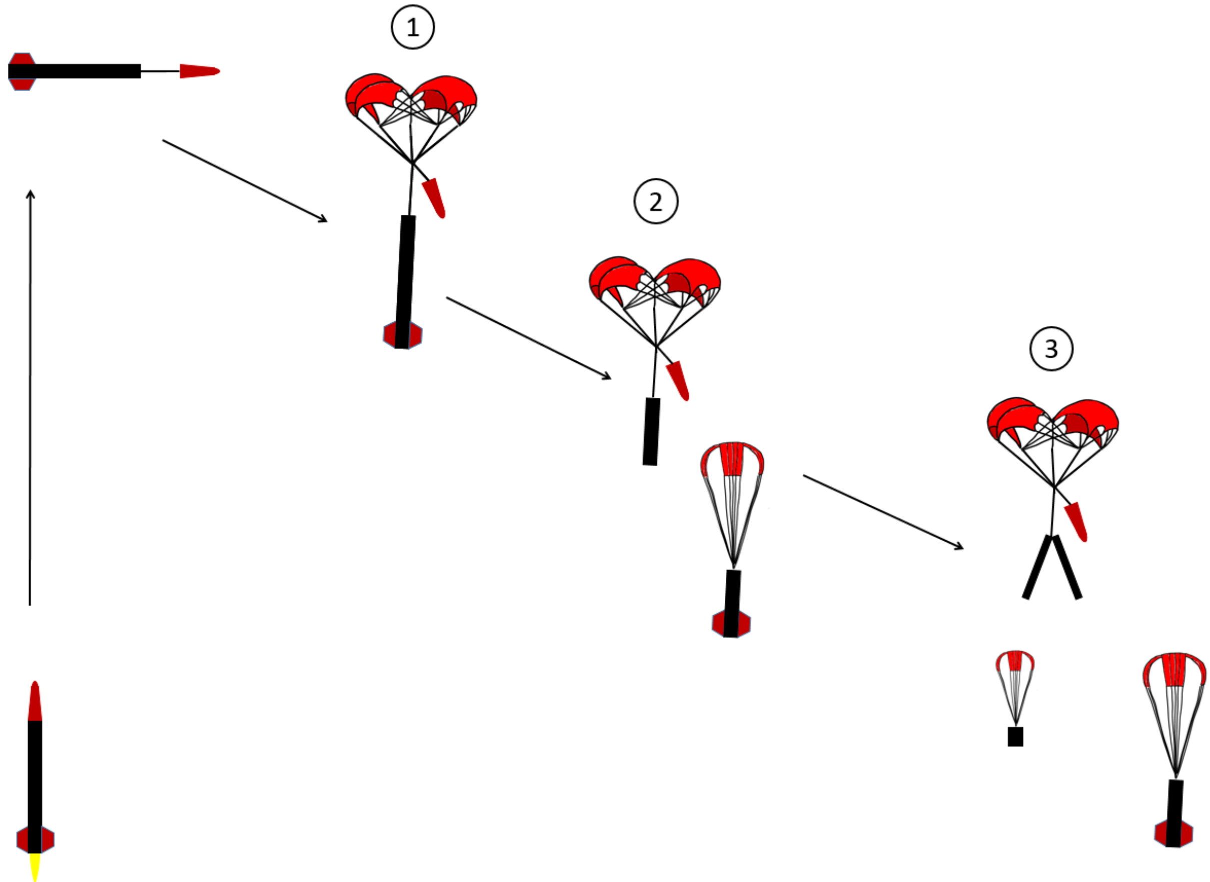

Figure 34: Recovery sequence of events.

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

Table 10.

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 10: Recovery events and descriptions.

Drift calculations have been performed under worst case scenario for the upper airframe at various wind speeds, yielding the results shown in Table 11.

Wind speed (mph)	Distance drift from launch pad (ft)
0	0
5	324.5
10	649.0
15	973.5
20	1297.9

Table 11: Drift calculations.

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 35.

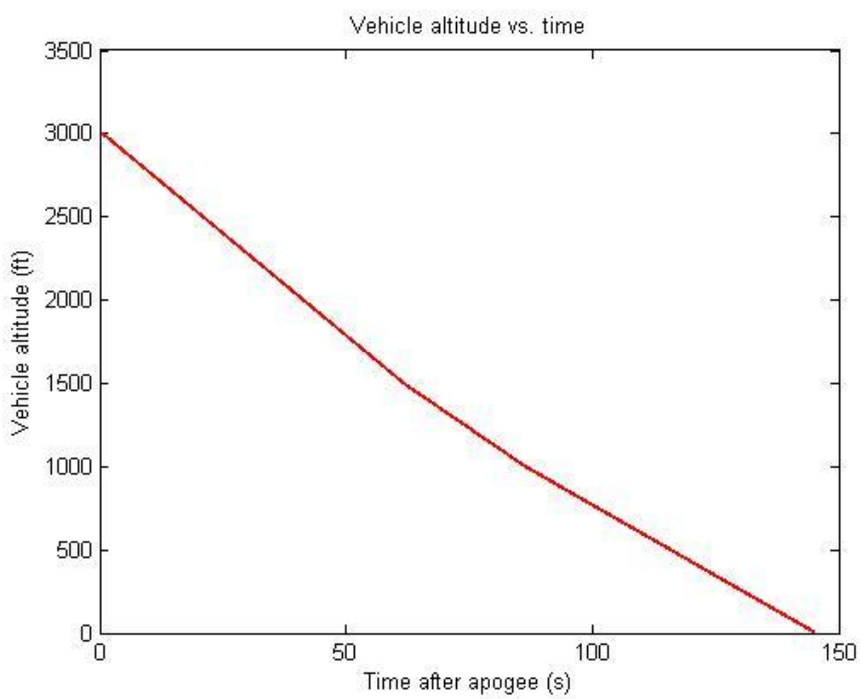

Figure 35: Upper airframe altitude versus time plot for worst case scenario.

The decent velocity versus time is shown in Figure 36 for the vortex ring.

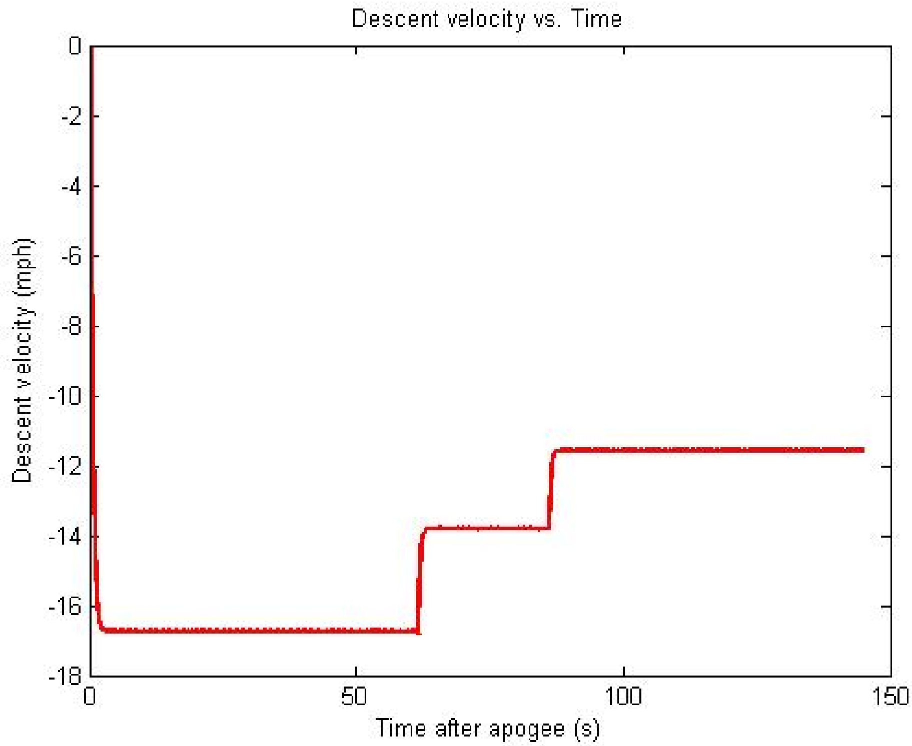

Figure 36: Upper airframe decent velocity versus time for worst case scenario.

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.

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 12.

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 12: 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 13.

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 13: 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.

Sizing

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

$$V=\sqrt{\frac{2Eg_c}{m}} \tag{18}$$

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

$$V=\sqrt{\frac{2mg}{\rho C_d A}} \tag{19}$$

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.

$$A=\frac{m^2 g}{\rho C_d E g_c} \tag{20}$$

The nominal diameter of the parachute was calculated using

$$D_o=\sqrt{\frac{4A}{\pi}} \tag{21}$$

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 14.

Section of rocket	Mass (lb_m)	Area (ft^2)	Diameter (ft)	Velocity (ft/s)	E (lb_f-ft)
Upper airframe	16.7	42.8	7.4	15.20	60
Lower airframe	11.2	38.5	7.0	18.57	60
Cache capsule	7.02	30.2	6.2	16.58	30

Table 14: 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.

Layout

The vortex ring will be manufactured in accordance with the schematic shown in

Figure 37.

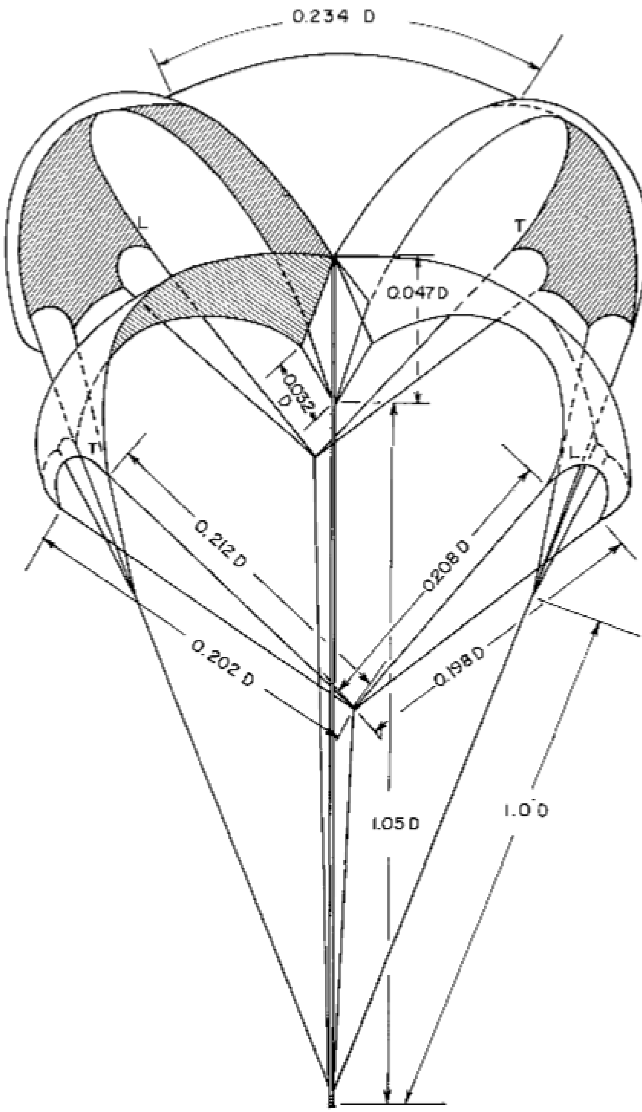

Figure 37: Vortex ring schematic for lines that tether the panels together.

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 38. Every line on the parachute was given a unique number and is indicated by a circle. Each of the lines are connected with lines from other panels at uniquely numbered connection points which are indicated by a triangle.

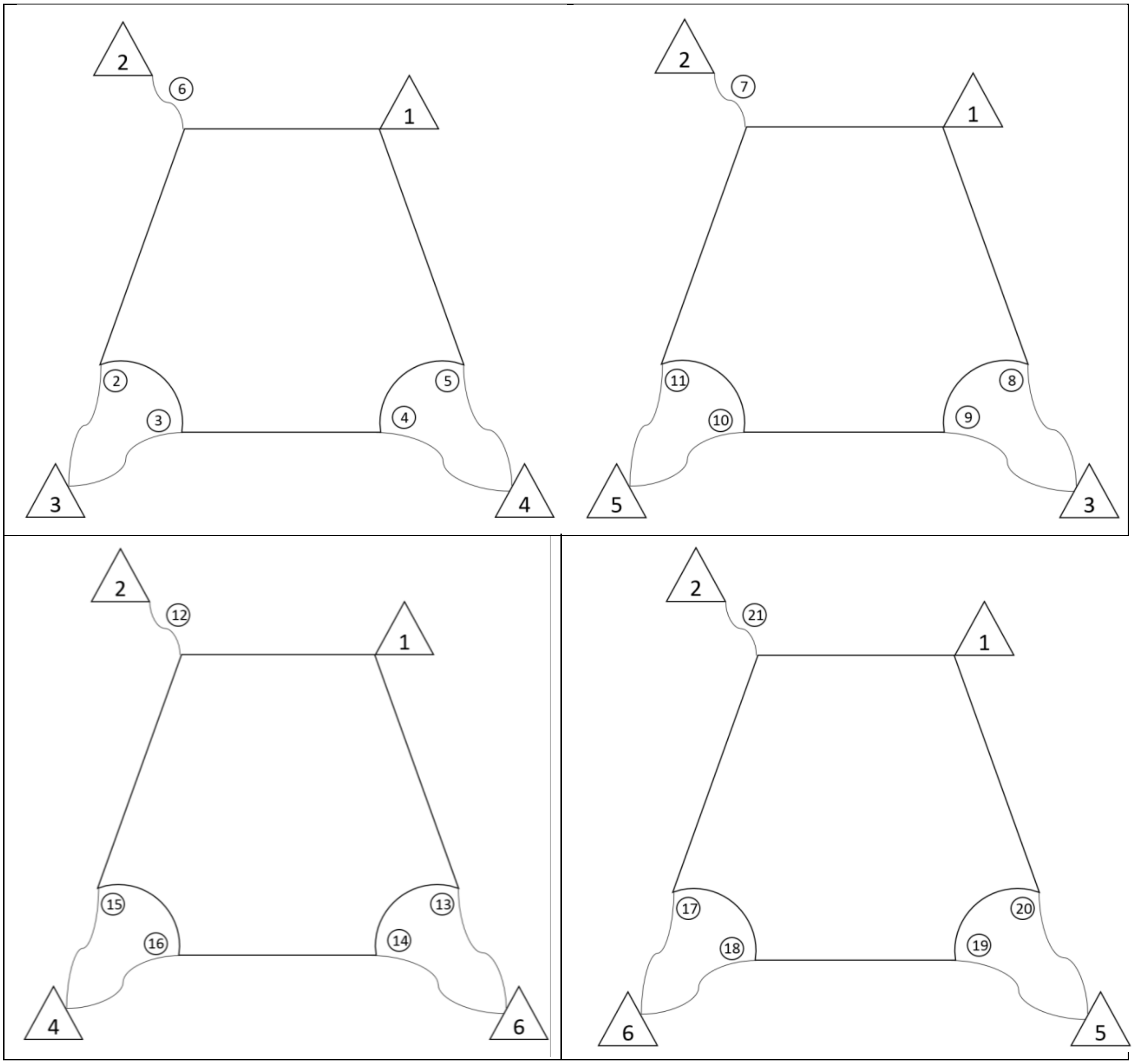

Figure 38: Vortex ring parachute divided into four sections with corresponding lines and connection point labels.

The lengths of each of the lines were calculated using a relationship to the parachute diameter in feet, which are listed in

Table 15. 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 37. 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 15: 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 15.

The original parachute that was manufactured presented several problems. First, it did not rotate. 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. As a result of this, the initial pitch of the panels increased. In order to force the parachute to spin and generate lift, it was apparent that these lines needed to be changed. 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 ideal 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 39.

Figure 39: Subscale parachute test rig.

This 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

$$C_d = \frac{2F_d}{\rho v^2 A} \qquad (22)$$

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 16.

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 16: 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. 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 17: 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 much 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 40 with all modifications made from the testing.

Figure 40: Completed subscale vortex ring parachute.

The dimensions calculated for the full scale vortex ring parachute using the same equations that were verified through the subscale testing are shown in

Table 18.

Lines	Equation	Full scale length [in]
5, 8, 13, 20	2.544D+12	30.83
4, 9, 14, 19	2.424D+12	29.93
3, 10, 16, 18	2.376D+12	29.58
2, 11, 15, 17	2.05D+12	27.17
Centerline	12.16D+6	95.98
Head	0.564D+12	16.17
6, 7, 12, 21	0.384D+6	8.84
Suspension Line	12D+6	94.8

Table 18: Calculated dimensions for full scale vortex ring parachute.

The shroud lines and the lines used to tether together the panels are designed based off the schematic shown in

Figure 37. All lengths are functions of the nominal diameter of the parachute.

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

Figure 41.

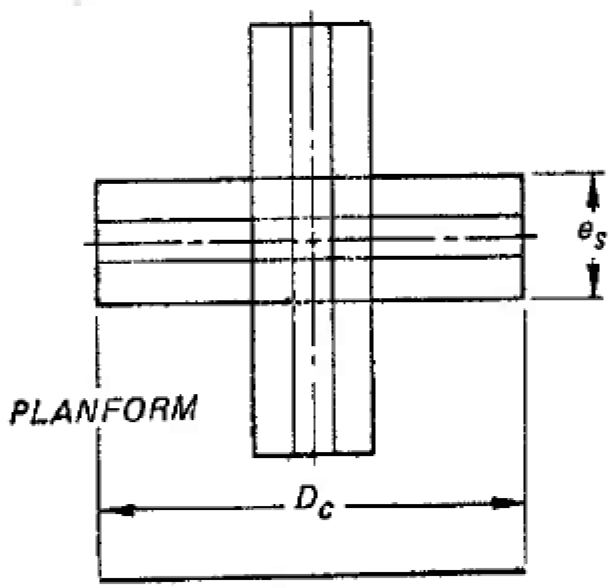

Figure 41: Cruciform construction schematic.

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

$$\frac{e_s}{D_c} = 0.263 \; to \; 0.333 \tag{23}$$

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

$$D_o = 2D_c e_s - e_s^2 \tag{24}$$

The inflated profile of the cruciform parachute is shown in Figure 42.

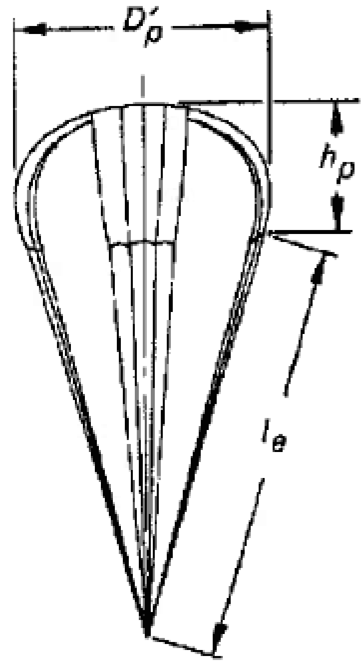

Figure 42: Inflated cruciform parachute schematic.

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

$$\frac{I_e}{D_o} = 1\ to\ 2 \tag{25}$$

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 19.

Section of rocket	e_S (ft)	D_C (ft)	I_e (ft)
Lower airframe	1.23	4.11	14.00
Cache capsule	1.09	3.65	11.10

Table 19: 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.

Each hem will be constructed by folding over the material two times. This will help prevent the material from fraying. The hem fold and stitch pattern are shown in Figure 43.

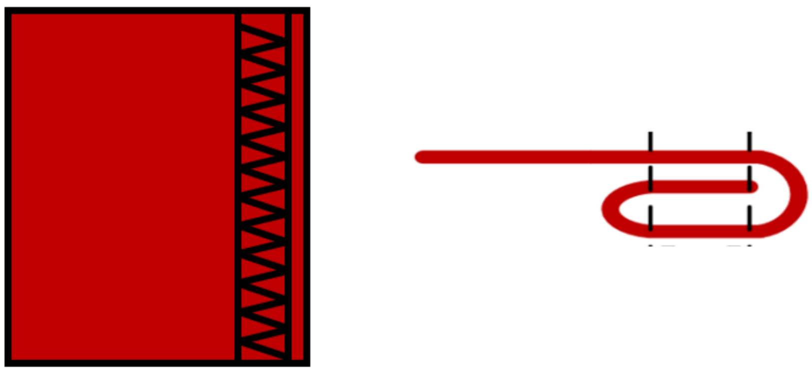

Figure 43: Hem fold and stitch pattern for parachutes.

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. This connection is then covered in heat-shrink tubing to help prevent lines from coming unstitched and to prevent the lines from snagging on anything. The line connection pattern is shown in Figure 44.

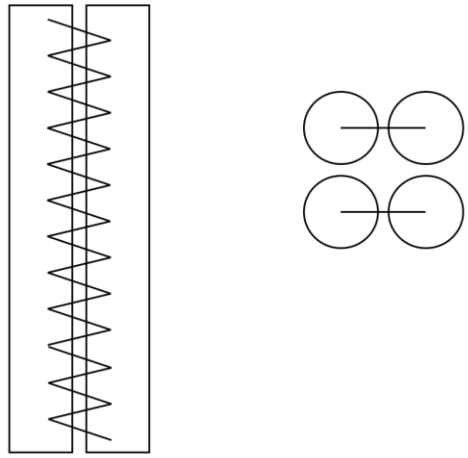

Figure 44: Suspension line connection pattern.

The harness that connects the suspension lines to the launch vehicle will be 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.

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

Bulkheads

Each bulkhead used in the rocket will be custom made and will consist of two parts. The first half of the bulkhead will be a plate cut from half inch plywood using a ShopBot. 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 45.

Figure 45: Custom fabricated bulkhead configuration.

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 will be tested in flight with the subscale rocket. Due to launch cancellations due to weather, this test has been postponed until after CDR.

The main disadvantage of the vortex ring is that is it difficult to pack and deploy properly without tangling the shroud lines. A custom deployment bag will be constructed to and tested prevent tangling during deployment. Ground testing will be performed to ensure that the parachute properly deploys from the bag without any of the lines tangling.

Another advantage of the vortex ring is that there are no scale effects upon the drag coefficient. Therefore, the information gathered from any sub-scale tests will be accurately translated to the full scale parachute, giving the team confidence in the design. The full scale parachute will undergo the same ground testing procedures as the subscale prior to integration into the full scale rocket.

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. Custom sleds have been designed for each of these components. All of the sleds will be 3D printed out of ABS and will be treated with acetone for strengthening. 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, Perfect Flite StratoLoggers, pictured in

Figure 46, will be used. These will be used to trigger black powder ejection charges.

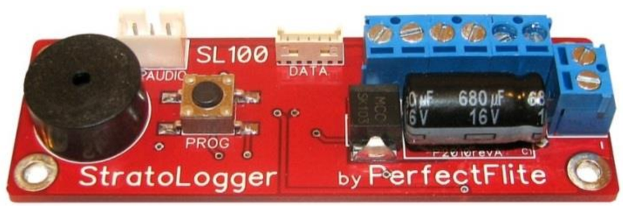

Figure 46: PerfectFlite StratoLogger

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.

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 47.

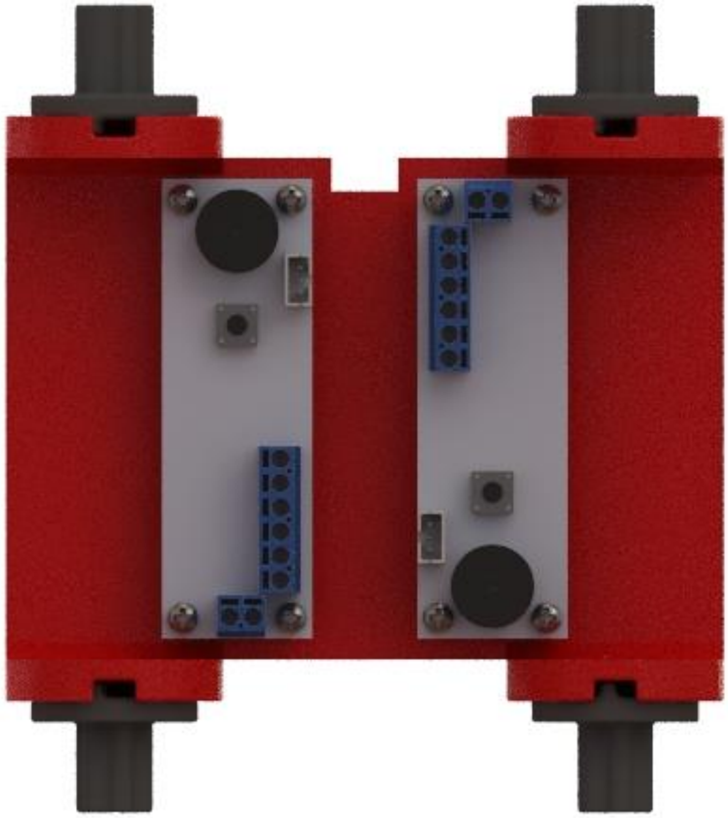

Figure 47: Altimeter sled.

Each StratoLogger will be mounted using four 4-40 screw onto four 18-8 stainless steel hex standoffs. Each StratoLogger will be 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 will be mounted on the opposite side of the altimeter sled, as shown in Figure 48.

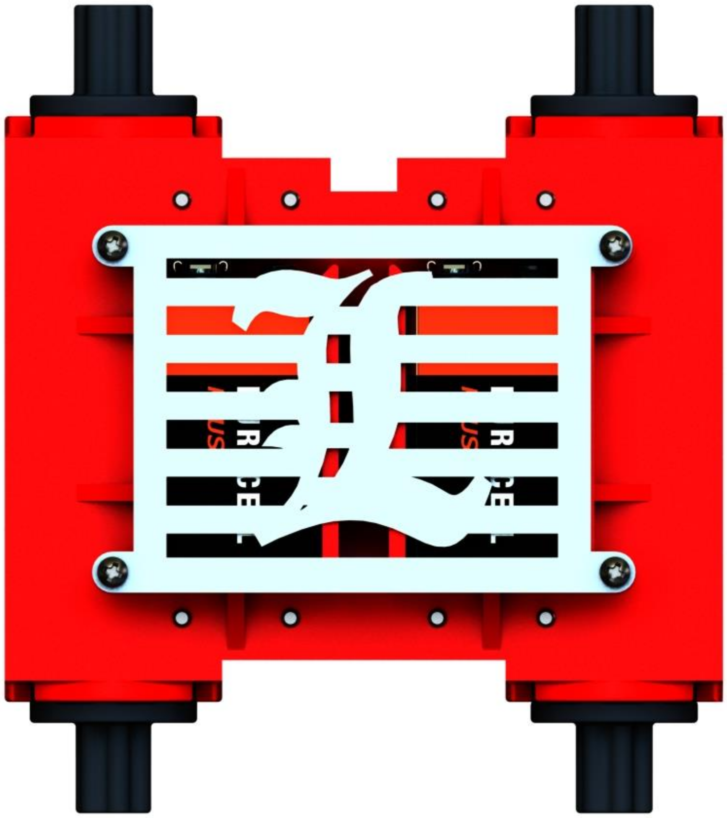

Figure 48: Battery clips view of altimeter sled.

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 49, 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 49: Rubber dampener.

The altimeter sleds will be mounted on ¼ inch threaded rods between two sets of bulk plates as shown in Figure 50.

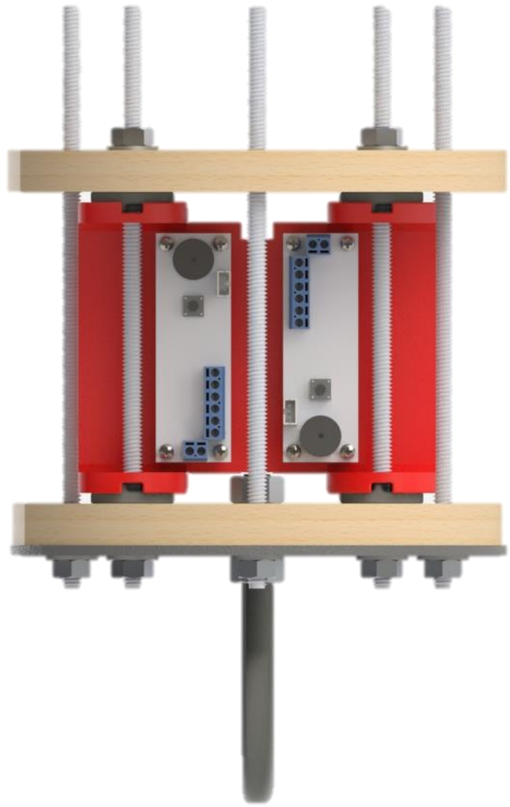

Figure 50: Altimeter sled full assembly.

Each altimeter will be locked into the on position through use of a Featherweight screw switch, shown in Figure 51. 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.

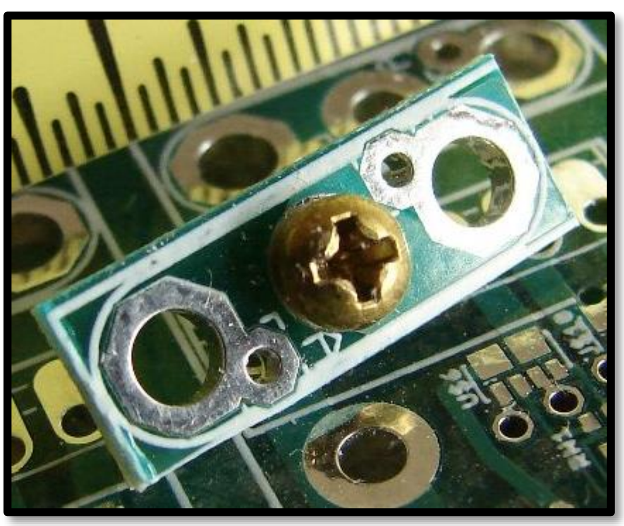

Figure 51: Featherweight screw switch.

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 52. 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.

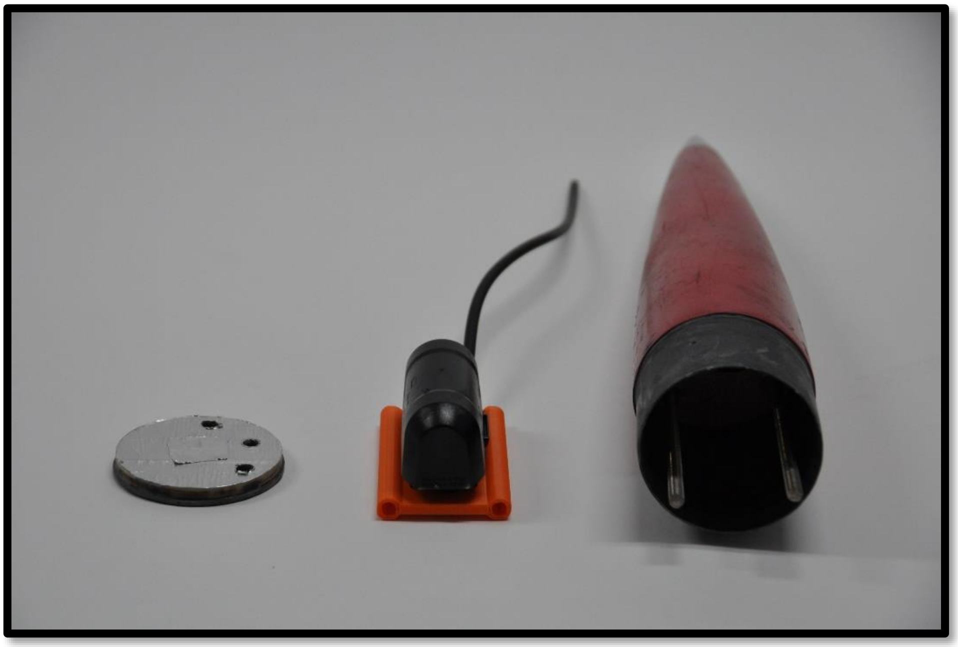

Figure 52: Garmin tracker mounted on custom 3D printed sled.

To satisfy the GPS requirement for the cache capsule, the capsule will house an Eggfinder GPS tracking system, shown in Figure 53. 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.

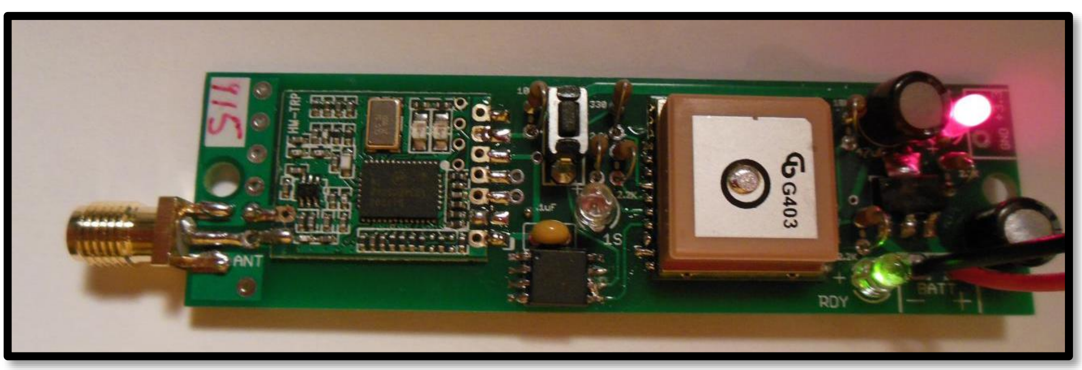

Figure 53: Eggfinder GPS tracking device.

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.

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.

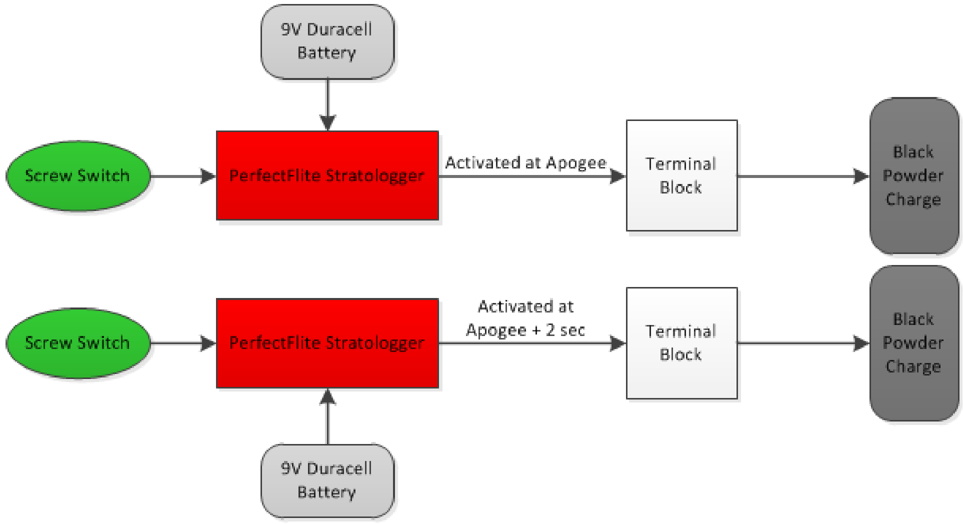

Figure 54: Main recovery electrical schematic.

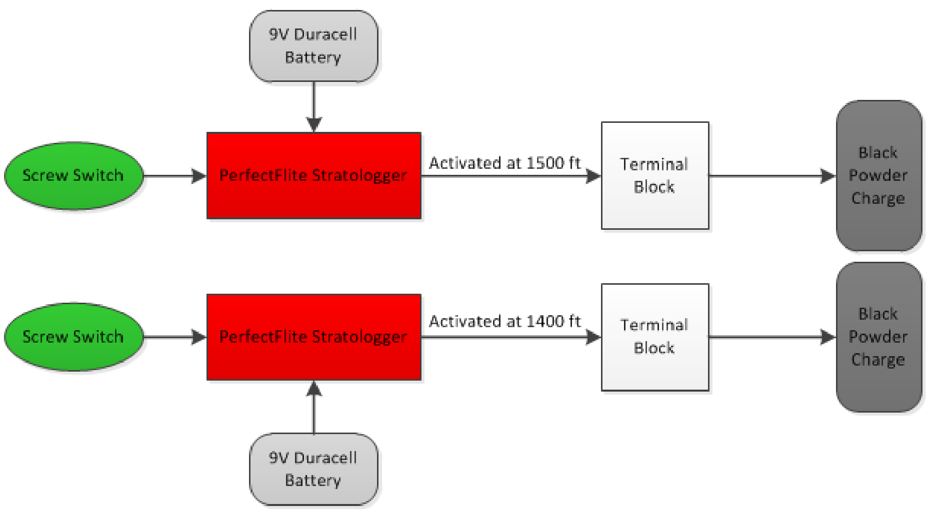

Figure 55: Lower airframe recovery electrical schematic.

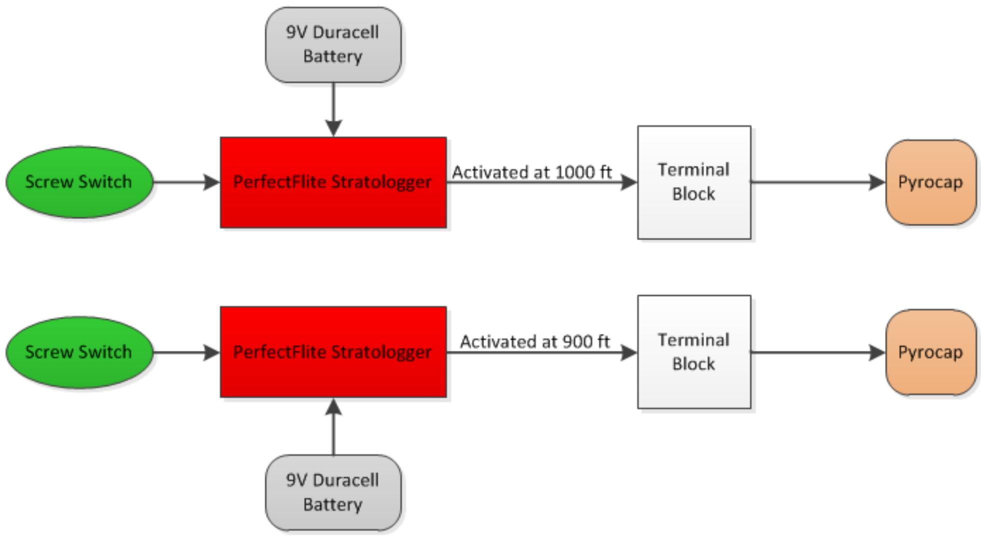

Figure 56: Fairing recovery electrical schematic.

__Bay Layout__

For each recovery event, there is a uniquely designed recovery bay. The main recovery bay schematic is shown in Figure 57. .

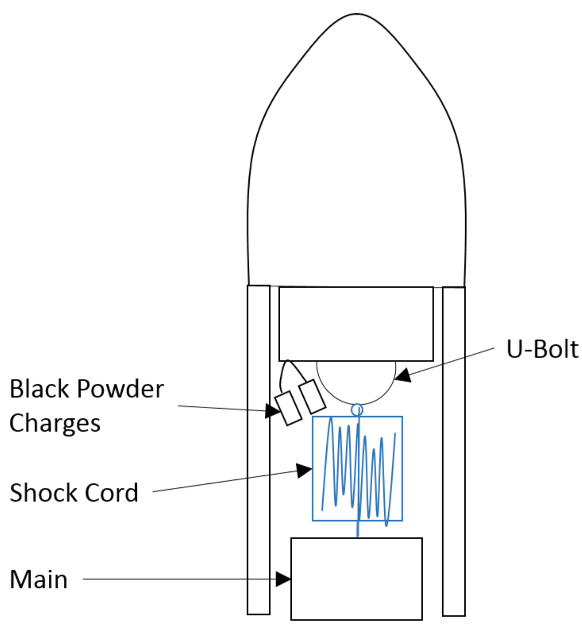

Figure 57: Main recovery bay schematic.

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 58.

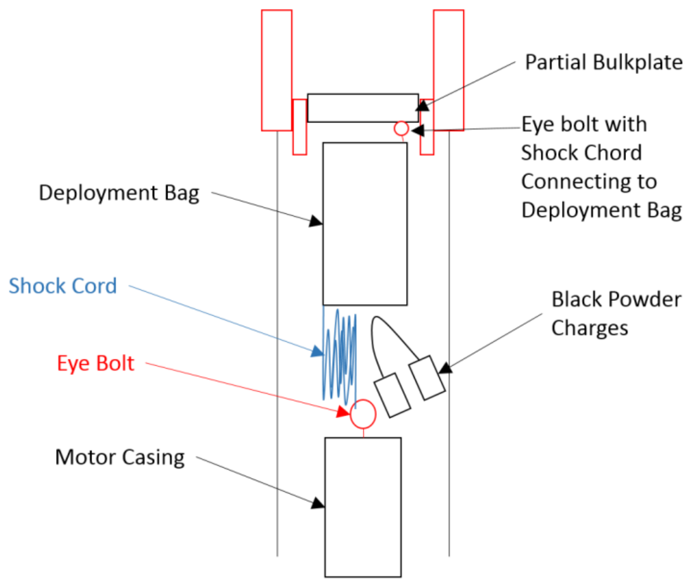

Figure 58: Lower airframe deployment recovery schematic.

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 59.

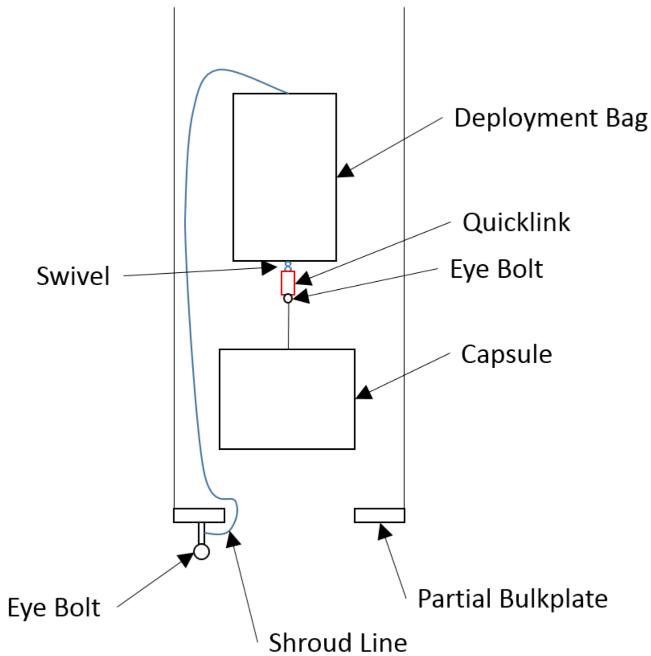

Figure 59: Cache capsule deployment schematic.

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.

Challenges

The primary recovery challenges are shown in Table **20**.

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 20: 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 60, 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: 39.8 lbs
- Stability Margin: 2.14 caliber (From tip: CG – 86.60 in, CP – 99.79 in)

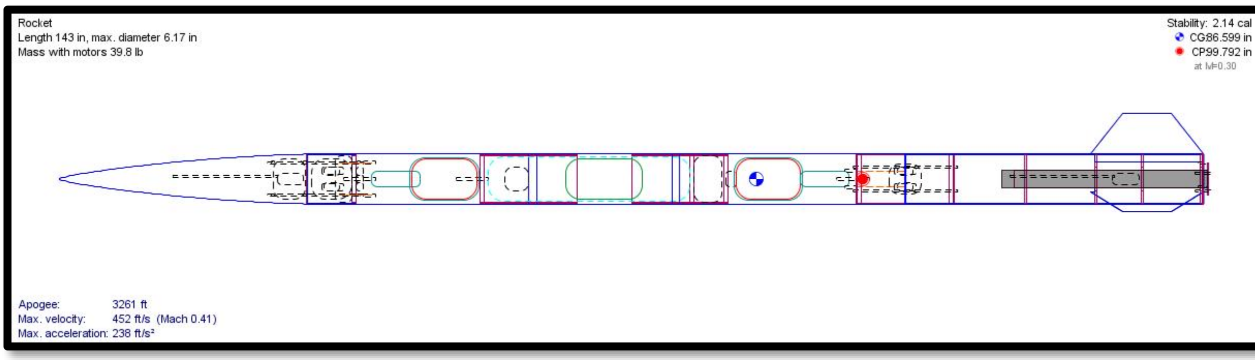

Figure 60: OpenRocket schematic of the full scale launch vehicle.

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 21 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	5.335
Main Recovery Bay	27.5	5.905
Cache Containment Bay	16.75	7.83
Secondary Recovery Bay	28	4.977
Propulsion Bay	37	9.948
Witness Rings	2	0.201
Motor	N/A	5.604
	Total Mass	**39.8**

Table 21: 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 61.

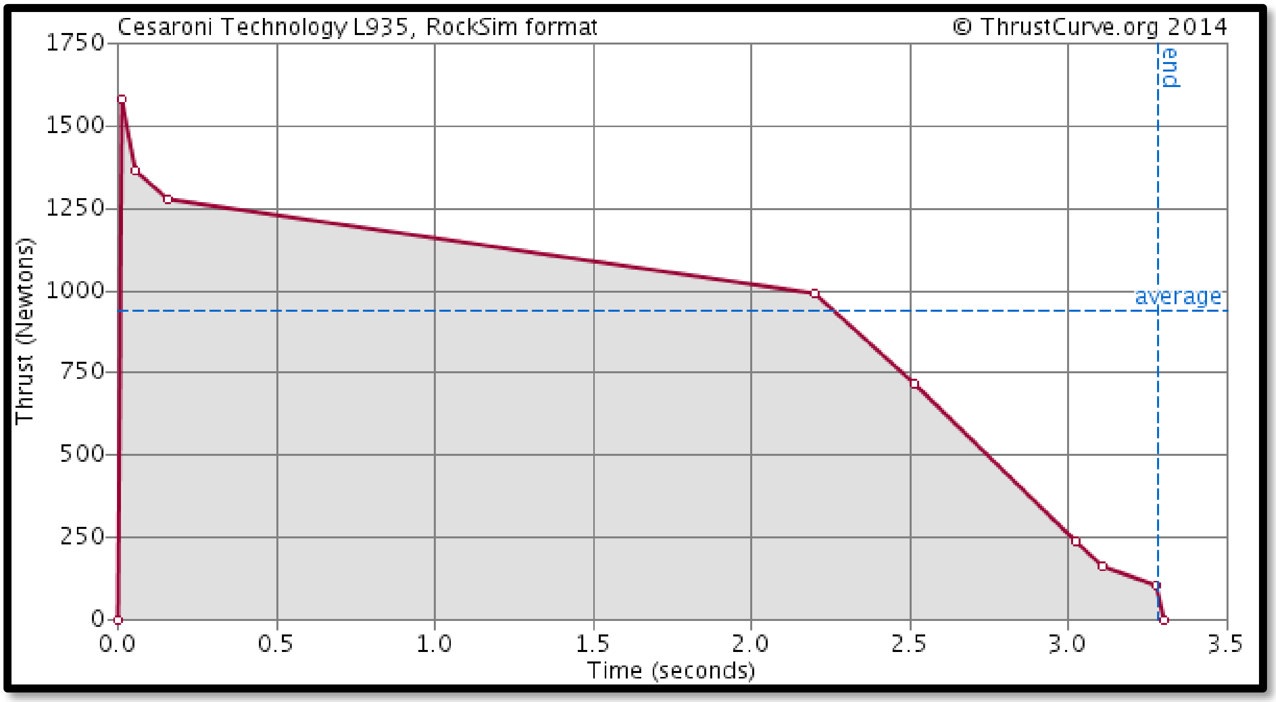

Figure 61: Thrust curve of the CTI 3147-L935-IM-P motor.

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 22 lists simulated vehicle information and motor details as justification for the motor selection.

Thrust-to-Weight Ratio	5.27
Rail Exit Velocity	65.4 ft/s
Projected Altitude (w/o Ballast)	3,261 ft
Projected Altitude (w/ Ballast)	3,033 ft
Maximum Acceleration	225 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 22: Justification for motor selection.

The following plots shown in Figure 62 through Figure 65 display various simulation results indicating the proper motor selection, CG and CP locations.

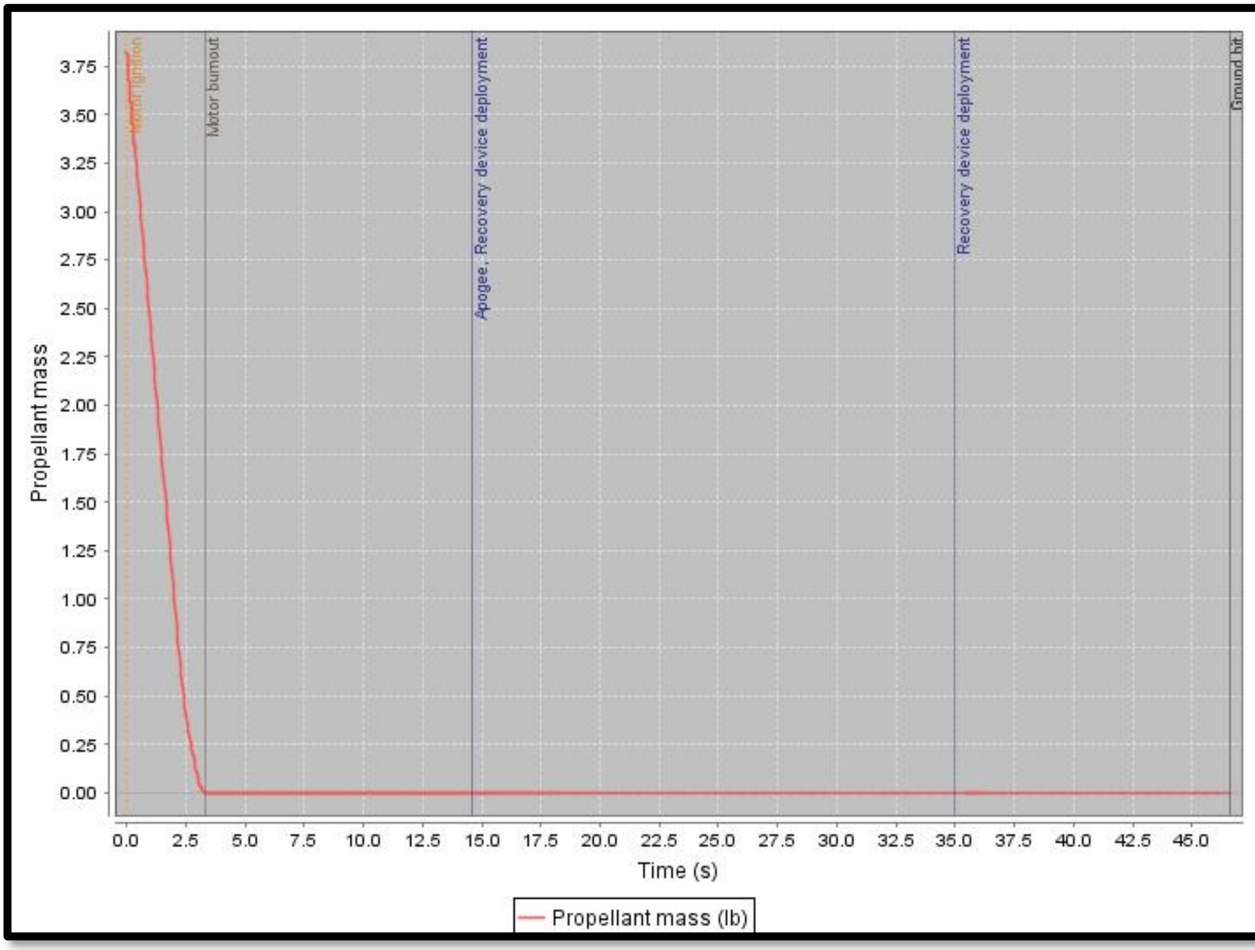

Figure 62: A plot of mass propellant versus time.

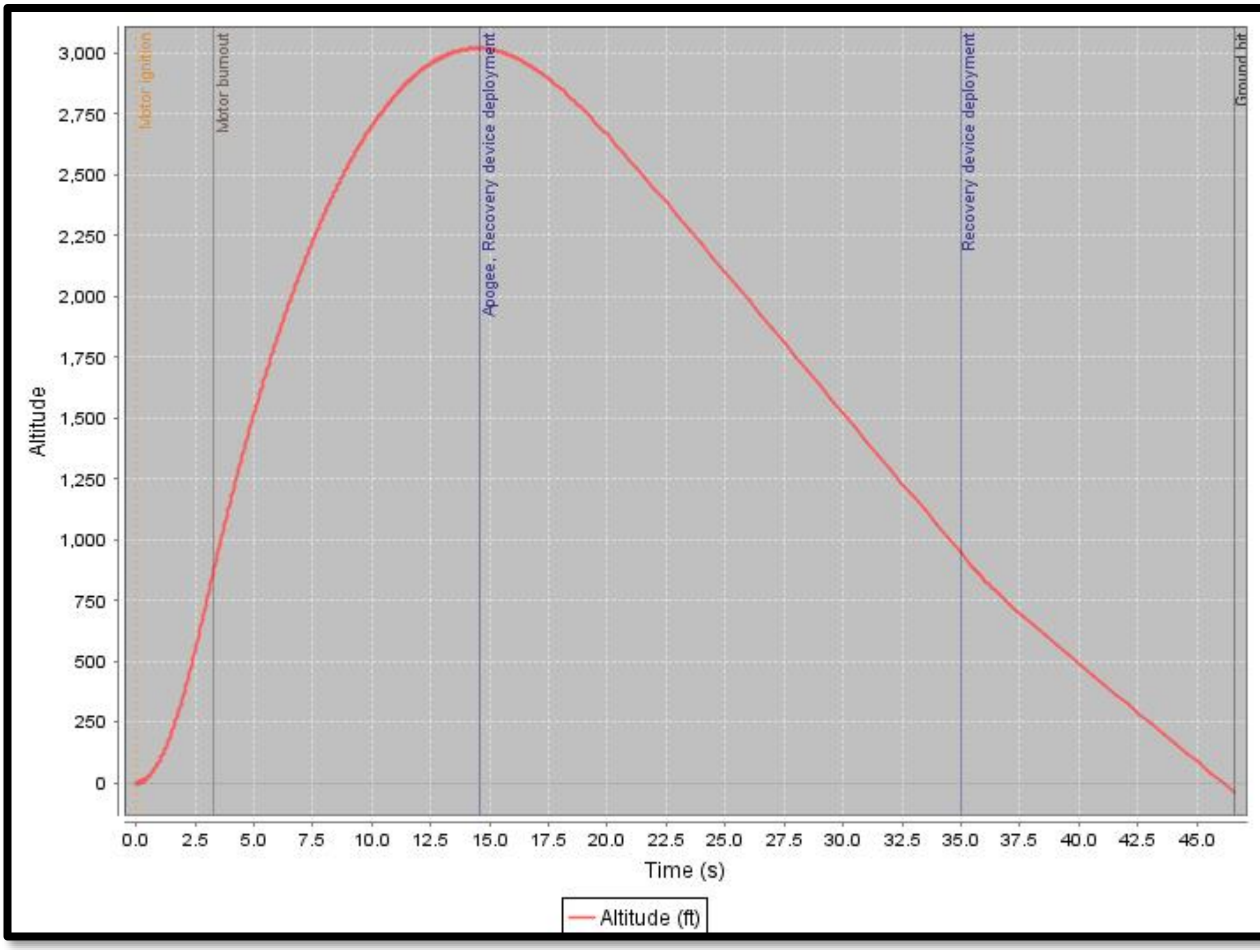

Figure 63: A plot of altitude versus time.

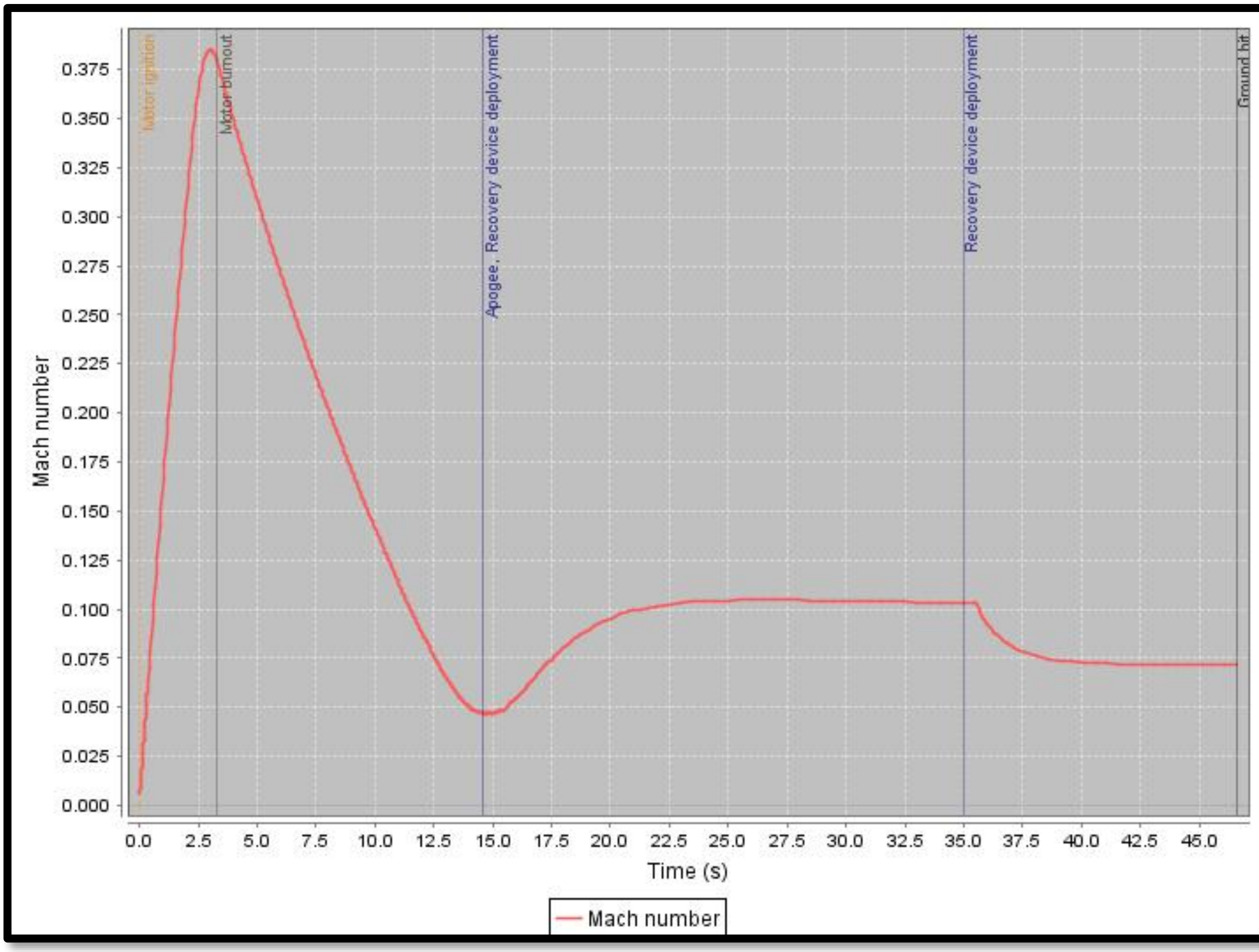

Figure 64: A plot of Mach number versus time.

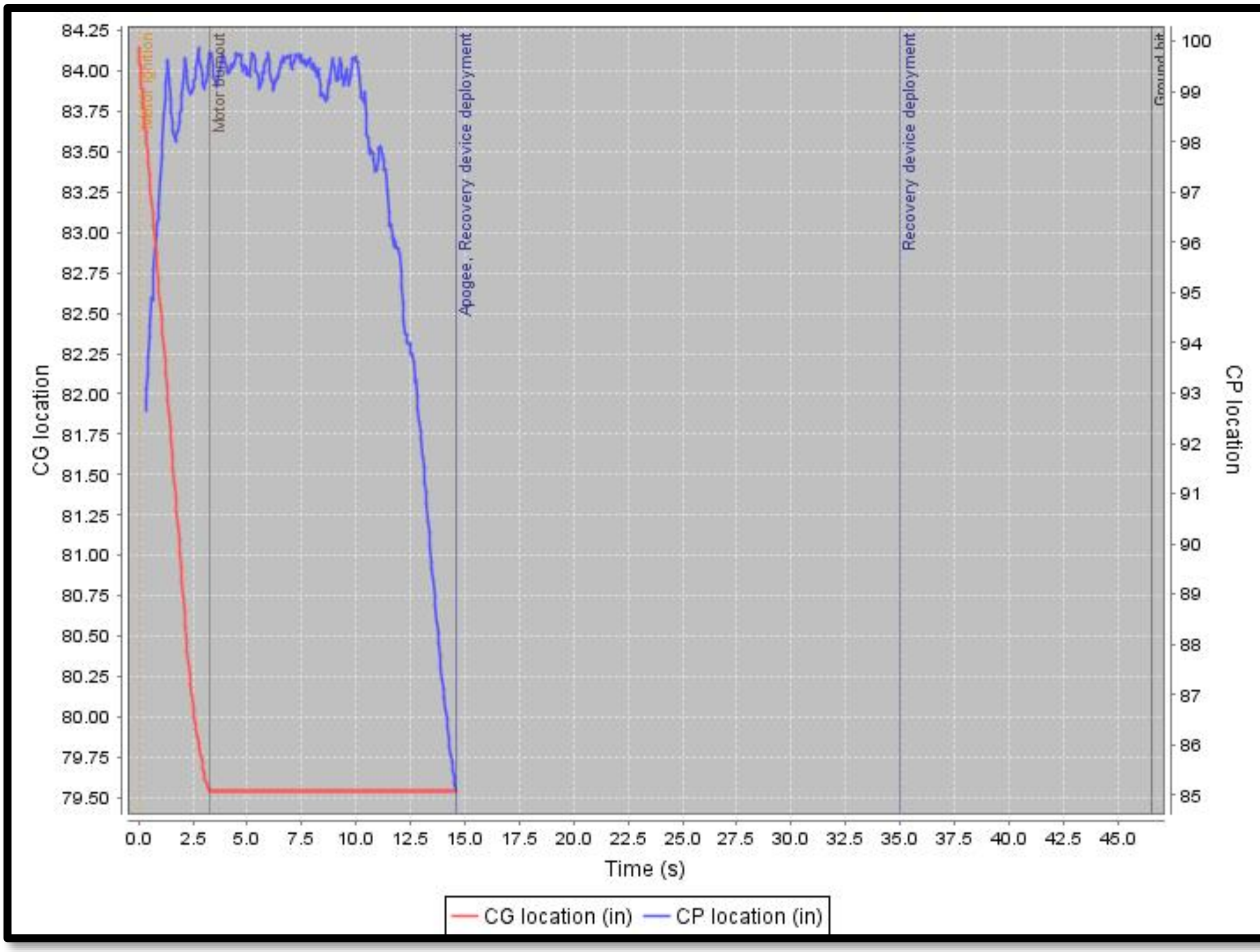

Figure 65: A plot of CG and CP locations versus time.

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 23, below details the various challenges and their related solutions.

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 23: 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 66 and Figure 67. The overall size of the capsule with the doors closed is 8.375" x 5.25" x 2.7".

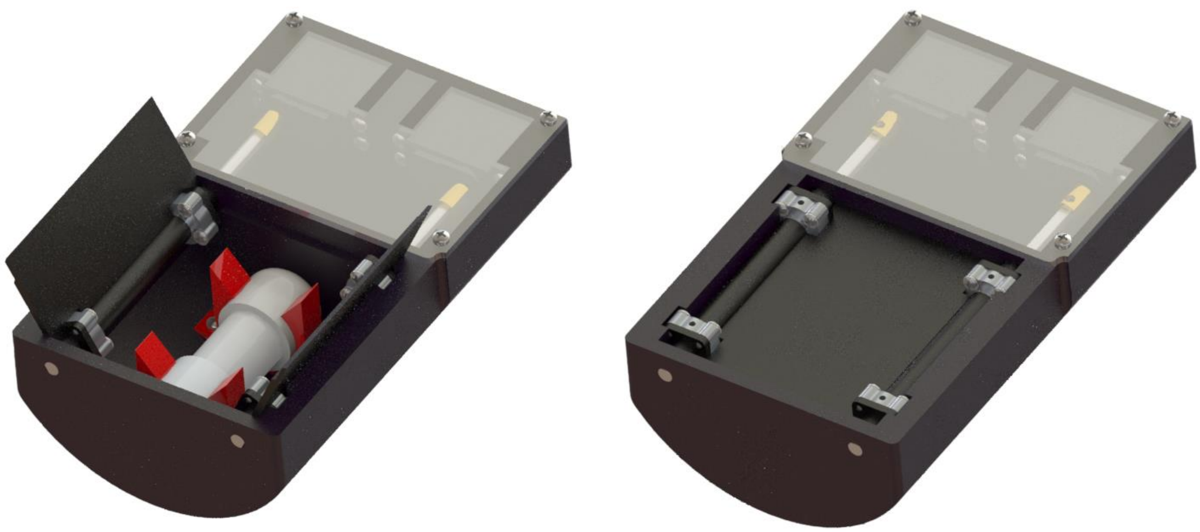

Figure 66: Payload capsule with open (left) and closed (right) doors.

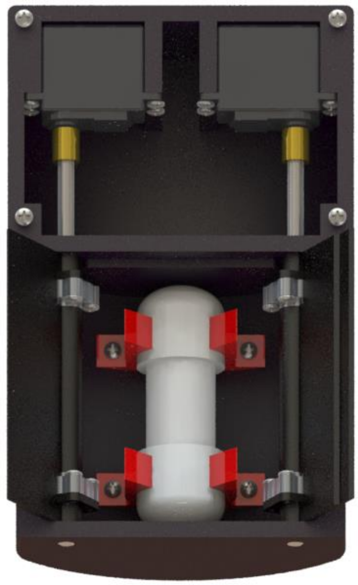

Figure 67: Top view of payload capsule.

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 will be two separate compartments, one will contain the payload and the other will contain any necessary electronics. The electronics compartment will have a clear acrylic cover on it that will screw into the capsule body using four #6-32 UNC screws.

The lower section contains two retaining clips, shown in Figure 68. 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 68: 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 will protect the cache from moving around 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. Each door will be operated via a Hitec HS-5485HB servo which outputs 89 oz-in of torque. If it is determined that more torque is needed to keep the doors closed, another servo can easily be swapped in. The servos will be located at the back of the electronics section. There will be a small pocket for the servos to slide in screw into using four #6-32 UNC screws. A brass coupler will be used to connect the servos to an aluminum D-shaft that will run almost the entire length of the capsule. The shaft will slide through a slot in the doors. Two aluminum set screw hubs will connect the doors to the D-shafts. The doors will have a flange on each end where the hubs will be able to screw into using four #6-32 UNC screws. A better view of the doors is shown in Figure 69.

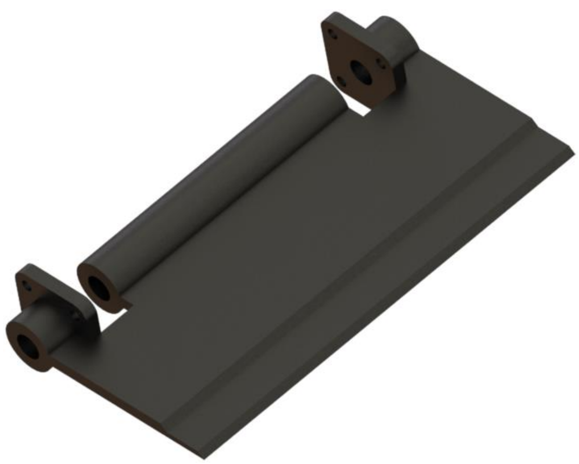

Figure 69: Capsule door.

The doors have a cut-out on the end that will allow them to overlap each other. Due to their overlap, one door will have to close before the other. Since the servos can be independently controlled, the doors will be timed to close such that they don't hit each other by having one close first and then the other.

On the sides of the payload compartment, a flange will be located where the doors rest on once they're closed. A magnet will also be located on the flange to help keep the doors closed. The doors will therefore have a corresponding magnet. 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 will be 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.	Servos to close doors are activated by a switch on a time delay. Testing will be performed to ensure the necessary timing of events.

Table 24: Cache Capsule Challenges

Door System

Design

To keep the ground station and launch vehicle systematically autonomous, a retractable door will be incorporated into the launch vehicle. The door will be located in the cache containment bay on the launch vehicle, as seen in Figure 70 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 70: 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 big 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 Objet Connex2 printer. The printer allows for various different durometers of materials to be tested. While the design of the door is complete, the team will set up a test to determine which material property best suits the needs of the system.

Track System

Figure 71 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 ULTEM 9085 guides. By having the door linearly open instead of rotationally, we are able to save space inside the launch vehicle.

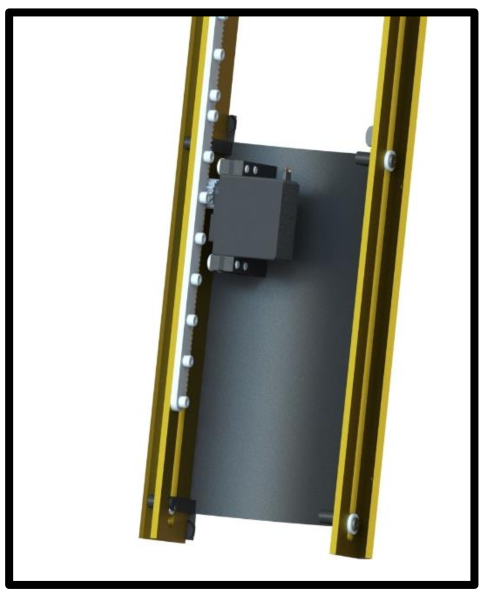

Figure 71: Complete door and track assembly.

Polyethylene track wheels will be installed into the door and track system using 4-40 UNC-2A threaded shoulder pins, as seen in Figure 72. Polyethylene was the material of choice for the track wheels for having a static coefficient of friction of 0.195 between itself and the ULTEM 9085 track guides.

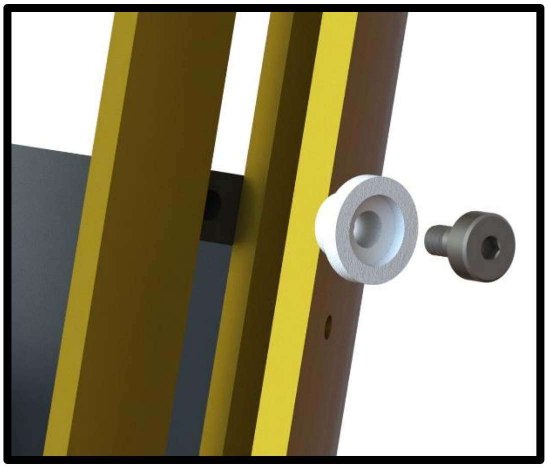

Figure 72: Exploded view of the track guide system.

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 73 below.

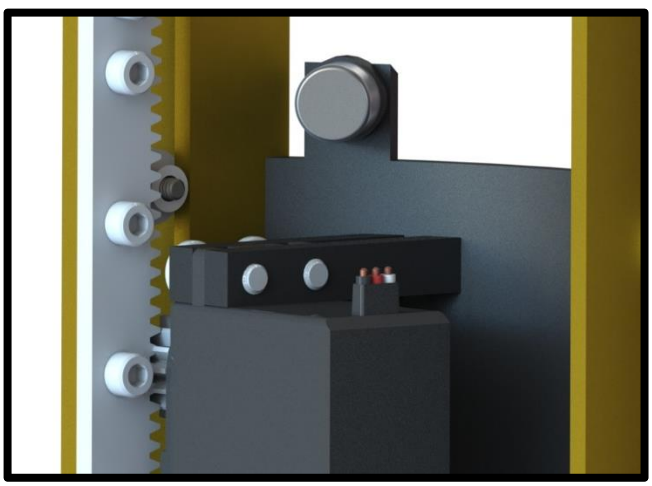

Figure 73: View of N52 magnet location

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 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 70.

With a gap of 0.125 inches, as seen in Figure 74, the team used online calculators found on the magnet supplier's, K&J Magnetics, Inc., website to get generalized pull force values between the two neodymium magnets.

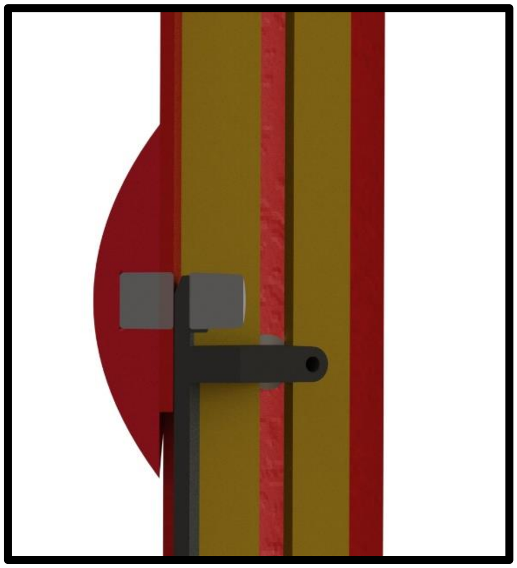

Figure 74: View of the gap between the neodymium magnet and ferrous target.

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 designed to be as large as the door's geometry allowed. The geometry of the magnet can be seen below in Figure 75.

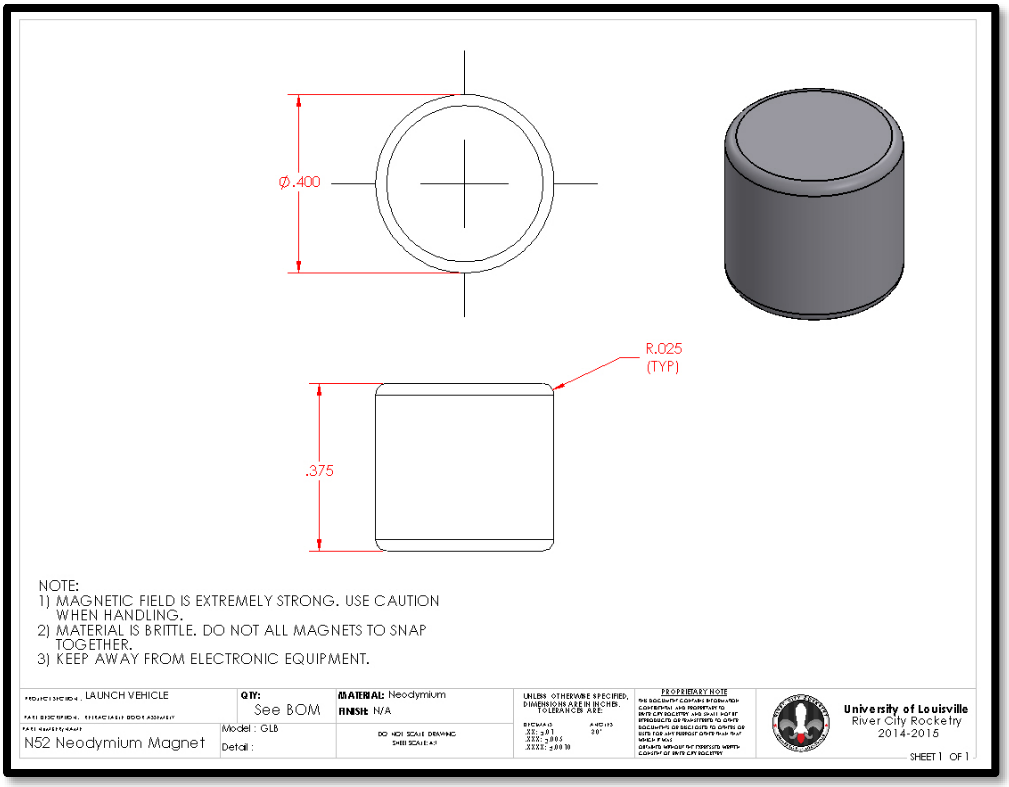

Figure 75: Detailed drawing of the N52 neodymium magnet.

With the geometry defined, the team extrapolated a pull force value of 3.01 lbs between the two N52 neodymium magnets. Figure 76, below, shows a plot of distance between magnets versus pull force.

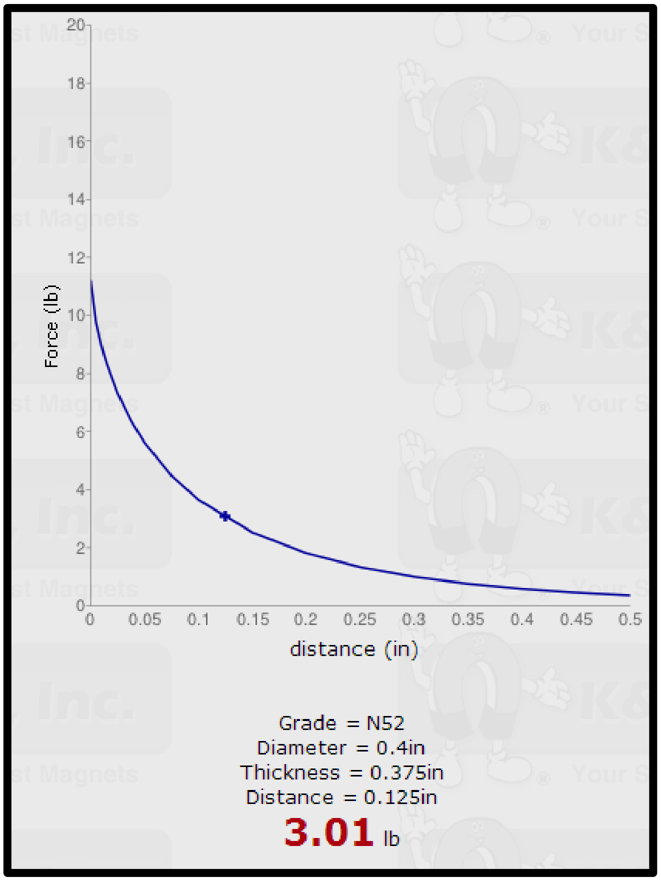

Figure 76: Graph of distance between magnet and ferrous target versus pull force.

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 25: 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 will be controlled by a Hitec continuous rotation servo. The servo, which is mounted to the door as seen in Figure 73.

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 below in Figure 77, has the rack for the gear system attached to threaded slots in the rail guide using #8-32 UNC 2A bolts.

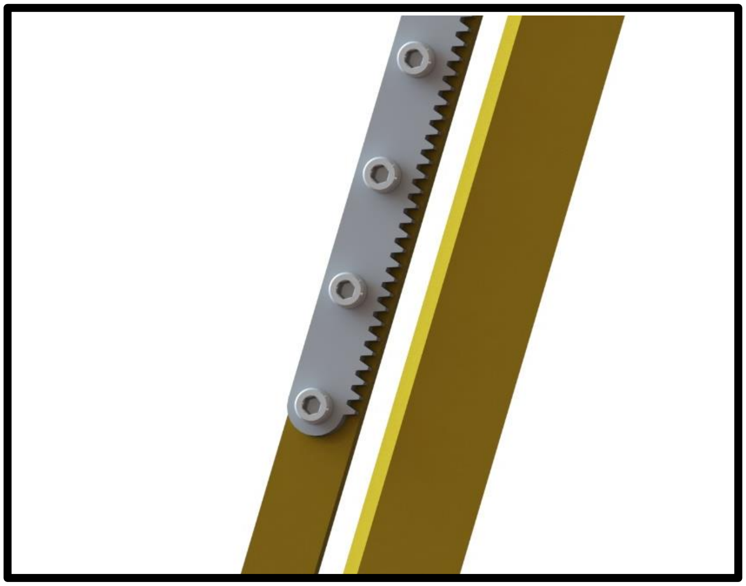

Figure 77: Bottom view of the lower guide with gear system rack.

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 26 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
Polyethylene UHMW	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 26: 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 27.

Challenges	Solutions
Design the door such that the cache payload and arm device will 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 will 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 proper servo motor, the door system can be "locked" shut to be certain the door will not back itself through the guides during flight.

Table 27: 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 78 below.

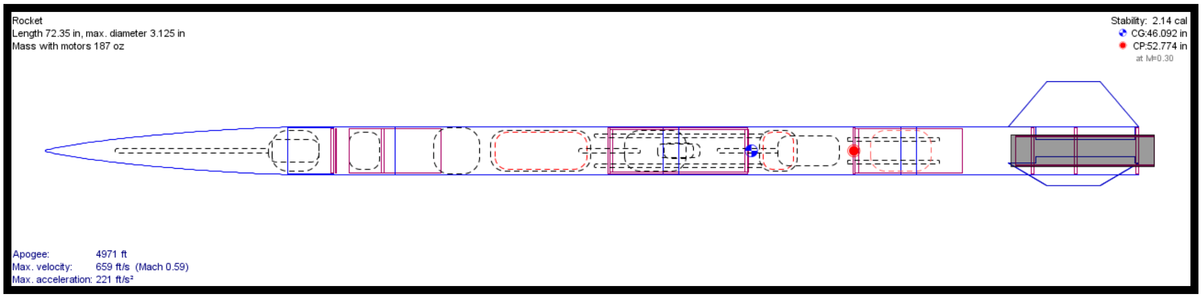

Figure 78: Subscale launch vehicle configuration.

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 28 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 28: Comparison of vehicle launch characteristics.

The similarity of launch vehicle characteristics shown in

Table 28 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 79 Below. The Bluetooth test results are completely covered in the Testing subsection of the Electronics Systems section.

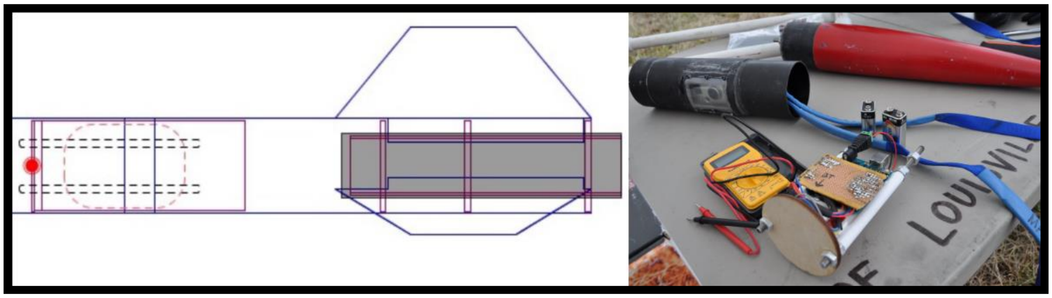

Figure 79: Bluetooth bay configuration.

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 80 below. The redundant altimeter data has not been included due to data recording and transfer error.

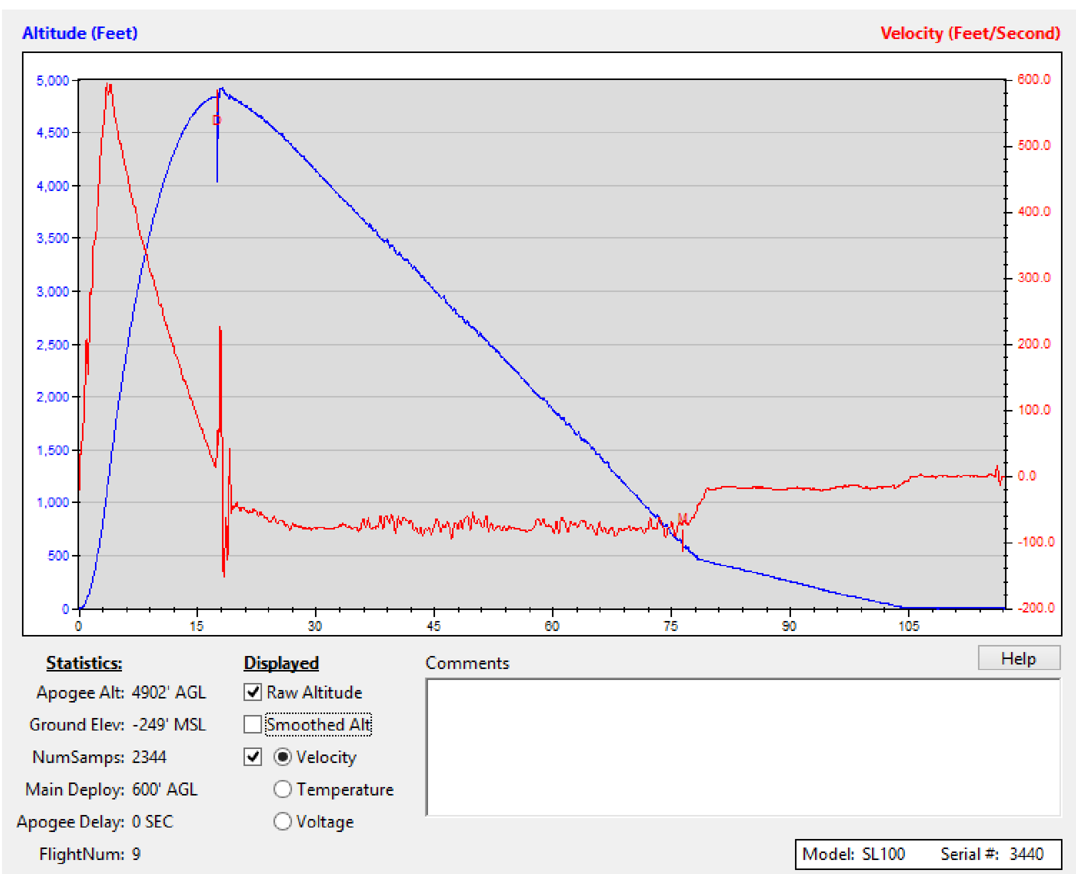

Figure 80: Primary altimeter flight results.

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) Safety

Safety Plan

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 red 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 31, 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 29.

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 29: 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 30.

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 30: 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 31. 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 31: Risk assessment matrix.

Preliminary risk assessments have been completed for possible hazards that have been identified at this stage in the design. Acknowledging the hazards now brings attention to these particular failure mechanisms. As the design continues to move forward, the team can design with these possible failures in mind. The team will work to mitigate the hazards during the design phase. The identified hazards can be found below.

Some risks are currently unacceptably high. This is because all risk mitigation has been implemented in through concept design work and some hand calculations. No testing has been done on any of the systems to support the risk mitigation. Risk levels will only be lowered once physical testing has been performed to support the design.

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 65 are risks present from working with machinery, tools, and chemicals in the lab.

Launch Pad Functionality Risk Assessment

The hazards outlined in Table 66 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 67 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 68 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 69 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 70 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 71 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 72 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 73 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 74 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 75 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 76 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 77 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 78 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 79 are risks that construction, testing or launching of the rocket or AGSE.

NAR/TRA Procedures

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	All launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any safety issues.

be inhibited except when my rocket is in the launching position.	
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 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.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.
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 32: 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/States/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.

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 33.

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 electronic match after vehicle has been safely erected.

Table 33: AGSE sub-stations.

Figure 81: Fully deployed system.

The overall system dimensions are shown in Table 34.

Overall Mass (lb_m)	Overall Width (in)	Overall Height (fully erected) (in)	Overall Height (closed) (in)	Overall Length (in)
352.59	29.25	144.83	30.84	203.02

Table 34: Overall system dimensions.

Changes since PDR

Table 35 shows the changes since proposal for the overall system. Each sub-system changes will be shown in their system description.

Change	Justification of Change
Weather station has been defined in more detail.	Increase science value of system.
Construction has begun of various portions of the ground station and the vehicle erection system	Testing of those systems cannot be completed until the system has been fabricated.

Table 35: Changes since proposal.

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 82.

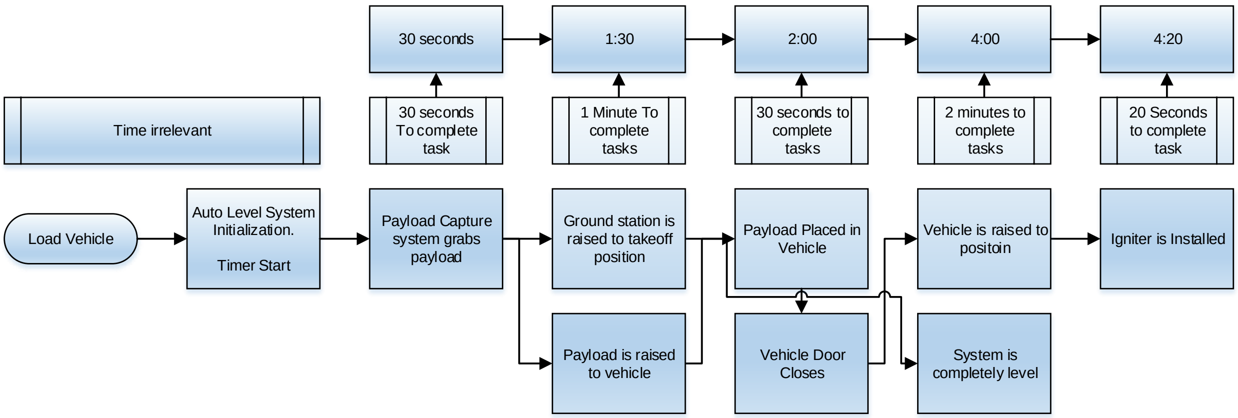

Figure 82: System timeline.

2) 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 will mount onto a side rail of the AGSE. The payload will be placed underneath the AGSE so the arm will be able to start facing the rocket. The payload arm is shown in its vertical and horizontal position in Figure 83 and Figure 84 respectively. The general dimensions of the payload arm are shown in Table 36.

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

Table 36: General dimensions of payload arm not Including length of shafts

Figure 83: Payload arm in vertical position.

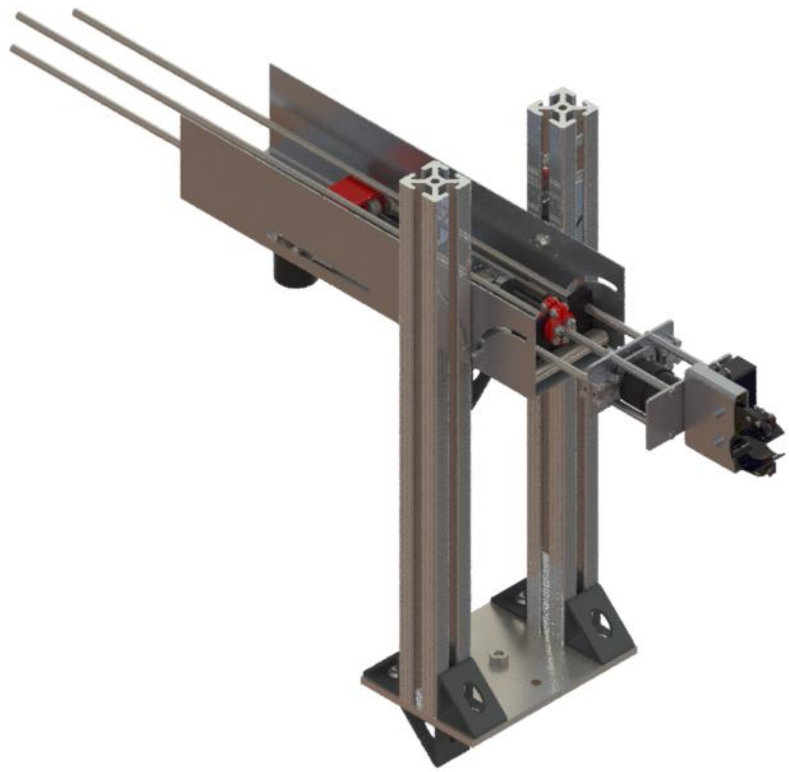

Figure 84: Payload arm in horizontal position.

Design

Gripper Assembly

The gripper assembly will be responsible for holding the payload and for driving the payload vertically and horizontally with the help of a motor. Figure 85 shows the gripper assembly.

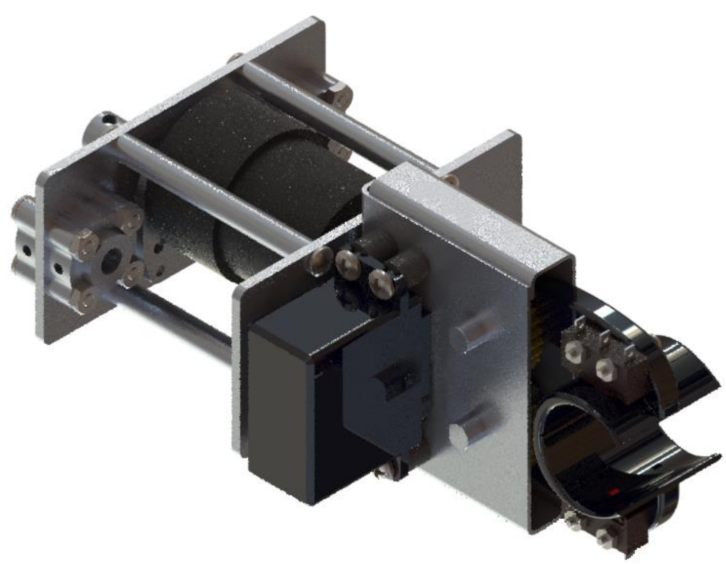

Figure 85: Gripper assembly.

Currently, a 10RPM 12VDC motor with a maximum torque of 368 oz-in is going to be used. The motor specifications might change later once more analysis is done on the speed required to complete the task within the allotted time and the torque required to move the gripper assembly. The motor has holes for screws that will be used to attach to a 0.125in 6061 aluminum plate shown in Figure 86.

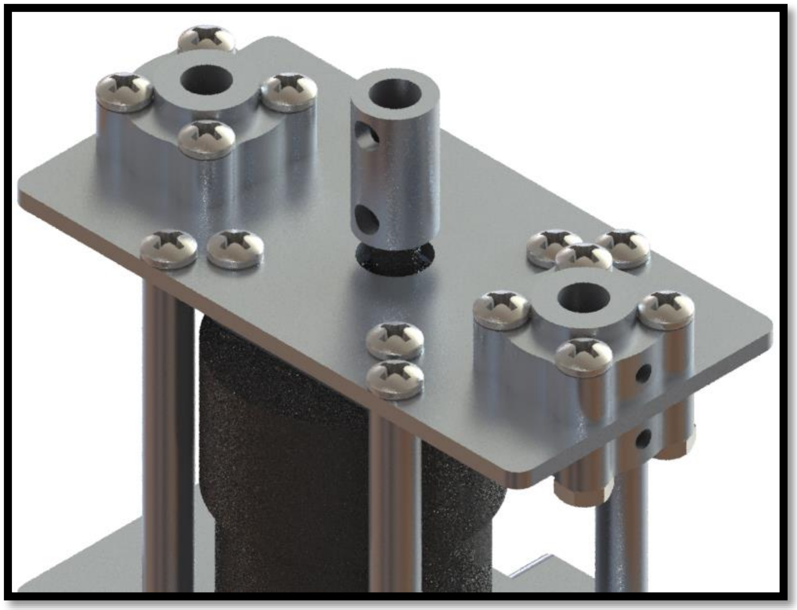

Figure 86. View of motor attachment plate

The motor's shaft will have a coupler that will connect to a 0.25in steel shaft that will move the gripper assembly upwards. To add support to the assembly, another 0.25in steel shaft will mount on each side of the motor. Set screw hubs will hold these shafts in place. The hubs will mount onto each side of the plate using #6-32 UNC screws. To connect the motor plate to the actual gripper, four 2.25in x6-32 UNC threaded standoffs will be used to connect to another plate, which is better shown in Figure 87.

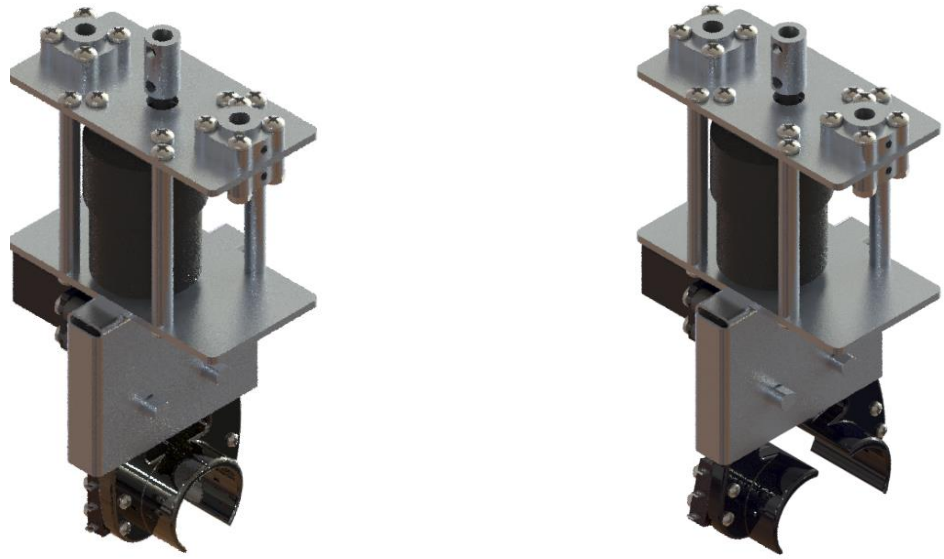

Figure 87. Gripper assembly with closed (left) and open (right) payload arms.

This plate will be spot welded to a 32 gauge aluminum sheet metal cover. In case the welds were to fail, the cover will still have a screw that attaches it to the plate underneath the motor. This cover will house the gears used to open and close the arms holding the payload. The cover will be cut out using a water jet. The gripper assembly without the cover is shown in Figure 88.

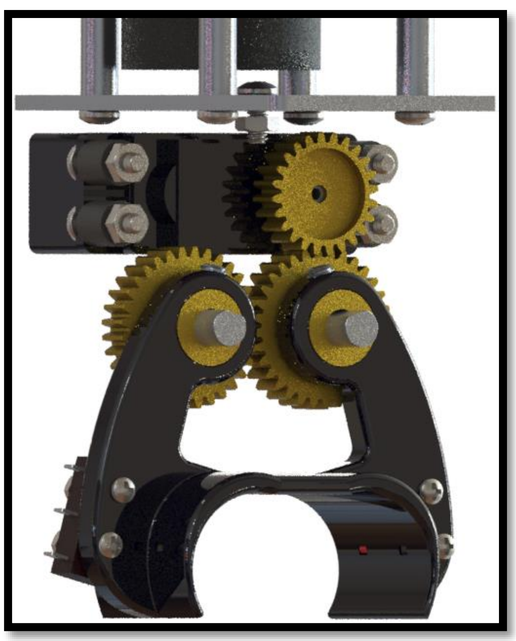

Figure 88. View of gears used to move payload arms.

To open and close the payload arms, a Hitec HS-5485HB servo will be used which will be mounted on the outside of the cover using four #6-32 UNC screws and nuts. The servo has maximum torque of 89 oz-in. If more torque is needed to hold the payload, the servo can easily be swapped for another with more torque. A brass gear will be attached to the servo which will in turn drive two other brass gears. The gears will be store bought and their specifications are shown in Table 37.

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 37: Gripper 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 have an extrusion which allows them to attach to a 0.25in diameter D-shaft using a #10-32 UNC set screw. The payload arms will slide over the extrusion and will be held in place using the same set screw used for the gears. The part of the arms that will hold the payload are dimensioned to be the same as the outer diameter of the inner tube of the payload. The payload arms will be 3D printed out of Vero Black plastic. Vero Black plastic was chosen over ABS due to having better material properties as shown in Table 38.

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 38: Vero Black compared to ABS Plastic.

To verify that the payload is held within the arms, a touch sensor will be placed on one side of each arm. The arms will have a slot for the pin of the touch sensor to go through which is can be seen as a small red dot in the middle of the arm in Figure 88. Two #2-56 UNC screws and nuts will attach the sensors to the arms. When the system gets activated, the arms will 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 will be connected to a 0.25in diameter shaft. The length of it will be adjusted later on depending on the required height from the ground to the rocket. Since the height can vary from at least 18in to 48in, the system has to be easily adjustable. A threaded rod and ball screw is a common solution, but unfortunately, the price of the threaded rod and ball nut increases as the height from the ground increases which made the idea unappealing if the height from rocket to ground was large. Instead, a threadless ball screw idea was chosen which will help decrease the cost of the system if larger heights are required.

Figure 89: Threadless ball screw assembly.

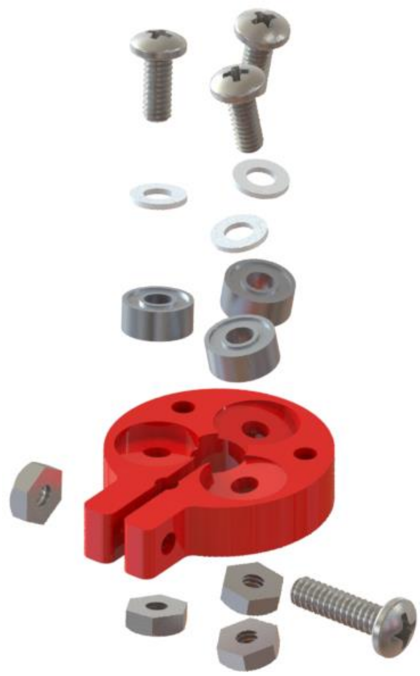

Figure 90. Exploded view of threadless ball nut.

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

$$P = \pi D \tan(\theta) \quad (27)$$

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 the current bearing angle of 10degrees where the bearings will be mounted on. A #6-32 UNC screw and nut will hold the bearing in place. A nut will go between the inner race of the bearing and screw.

The threadless ball bearing system is used commonly in 3D printing machines due to their low cost since a regular threadless shaft is cheaper. Two of these assemblies will be placed on opposing sides of an L-shaped bracket to provide more support. All of these parts will be 3D printed out of Vero Black plastic. To insure that the gripper assembly can be held securely, force tests will conducted to determine what force is require to make the shaft slip.

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 91.

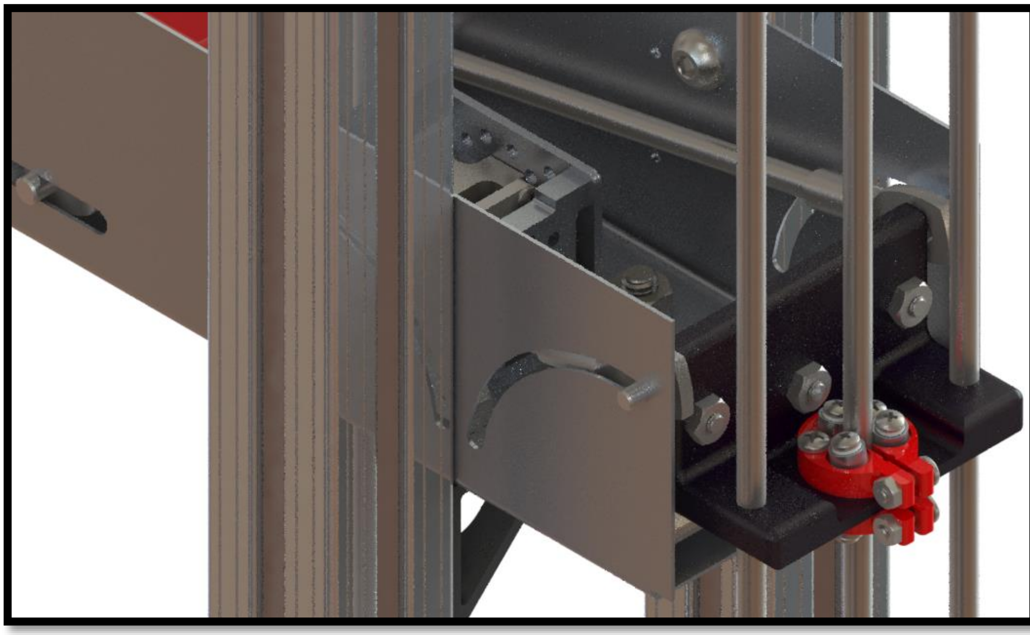

Figure 91. Threadless ball screw assembly mounted on U-shaped channel.

The L-bracket that the threadless nuts mount on will be attached to the U-shaped channel in between the two towers using a mortise style hinge which is rated for a 40lb load. Three #10-32 UNC flat head screws and nuts will attach the hinge to the bracket as well as to the U-shaped channel. The U-shaped channel will be made out of 32 gauge aluminum sheet metal that will be cut out using a water jet. To limit the angle of rotation to 90 degrees, a slot will be cut into the channel. The L-bracket will have a though-hole near the top for a 0.25in shaft. The shaft will then go through the slot in the channel.

Once the gripper assembly reaches a vertical distance, yet to be determined, the system will begin to rotate back until it is horizontal. To accomplish this task, a belt system will be turned used, shown in Figure 92. 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.

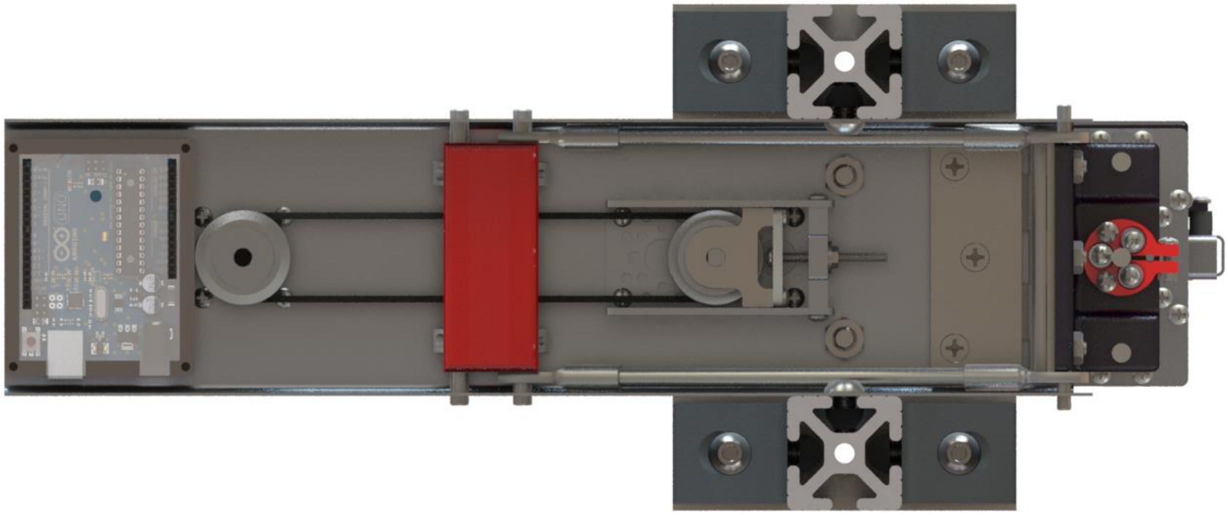

Figure 92. Top view of payload arm assembly.

The timing belt will be connected to two pulleys, one of which will be driven by another 12VDC motor that is mounted underneath the U-channel and another which will act as the belt tensioner. To add tension to the belt, the second pulley will be free to slide within a smaller U-channel, shown in Figure 93.

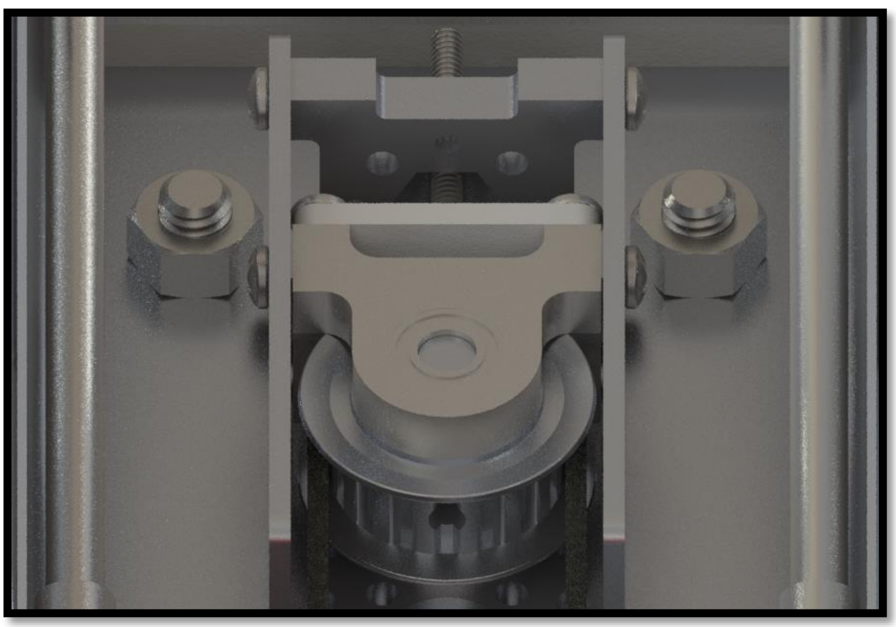

Figure 93. Belt tensioning pulley.

Two bearing mounts will go on each side of the pulley. A 0.25in diameter D-shaft will go through the bearings and the pulley. The bearing mounts will be screwed into a plate using #6-32 UNC screws. At the end of the smaller U-channel, a 0.25in thick 6061 aluminum end plate will be attached using four #6-32 UNC screws. Another #6-32 UNC screw will then connect the plate mounted on the bearing mounts and the plate at the end of the U-channel. This screw will be responsible for increasing or decreasing the tension on the timing belt. The smaller U-channel, end plate, timing belt, pulleys, and bearings will be bought off the shelf from ServoCity.com.

The timing belt will clamped in between 316 stainless steel belt mount plates which will screw into a slider, printed out of Vero Black material, using four #6-32 UNC screws as shown in Figure 94 and Figure 95.

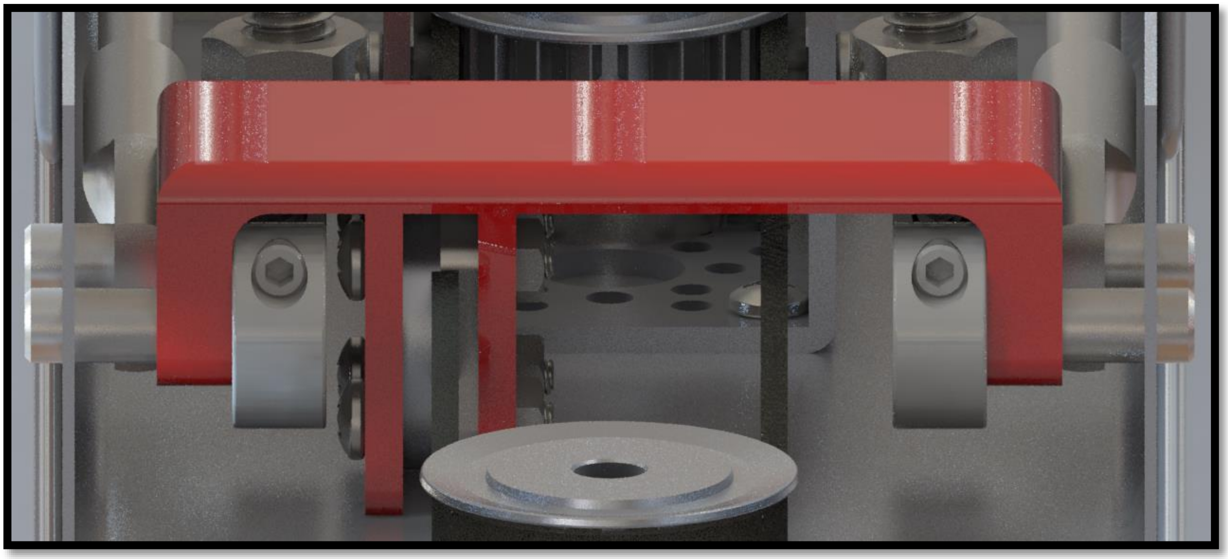

Figure 94. Slider mounted on timing belt.

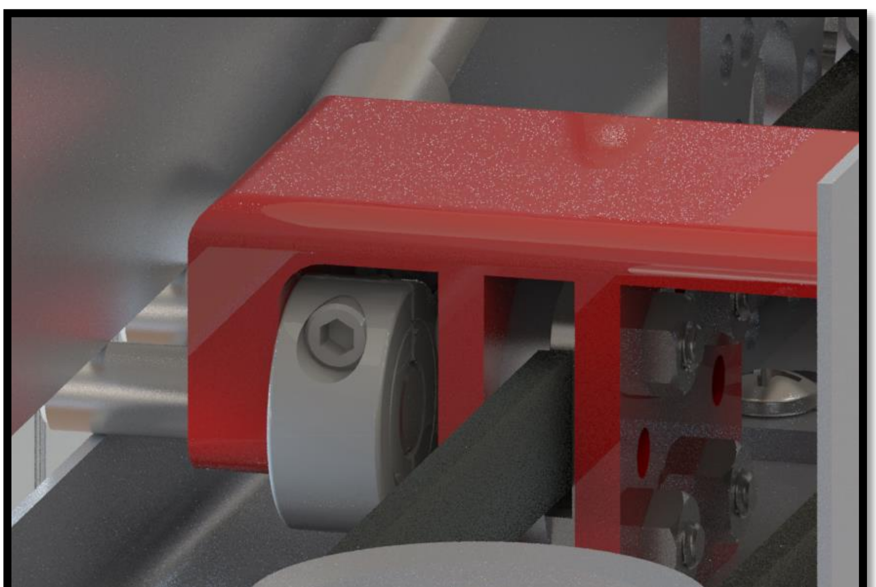

Figure 95. Another view of the slider.

The slider will have flanges on each side where two 0.25in shafts will be located. Each shaft will be held in place using an aluminum clamping collar. The shafts will go through a slot on the sides of the main U-channel. The shafts will keep the weight of the slider off the belt so that it will only experience a tension force in the direction of motion. Push rods will be used to connect the slider with the L-bracket at the front of the payload arm. The push rods have a flange with a 0.25in hole at each end. One end will go through the front shaft of the slider and the other end will go through the shaft on the top of the L-bracket. The push rods will be placed near the sides of the U-channel so that they are out of the way of the shafts on the gripper assembly when it rotates horizontally.

The Arduino Uno that will be controlling the payload arm will be placed in a 3D printed case with a clear acrylic cover at the end of the U-channel. The driving pulley for the timing belt will be mounted directly to the shaft of a 12VDC motor. This motor will be mounted underneath the U-channel as shown in Figure 96.

Figure 96. Side view of payload arm assembly.

Once the gripper assembly is rotated horizontally, the timing belt will stop moving. Then, the motor on the gripper assembly will begin to rotate in the opposite direction which will cause it to extend towards rocket. Currently gripper assembly is expected to have to travel 12in horizontally to reach the clips inside the rocket. Once inside the rocket, a hall-effect sensor will probably be used to detect when it has reached the clips that will 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 will be mounted in between two 80/20 aluminum posts. The posts are currently going to be 18in tall but can be cut to any length as necessary. The U-channel will have two brackets that support it underneath using 5/16-18 UNC socket screws and nuts. The same type of screw will then be used to attach the bracket to a special 80/20 fastener on the 80/20 posts which is held in place using a set screw. Two other 5/16-18 UNC screws will be used near the top of the U-channel sides to prevent rotation.

A 0.25in thick 6061 aluminum plate will be used to mount the two towers holding the U-channel as shown in Figure 97.

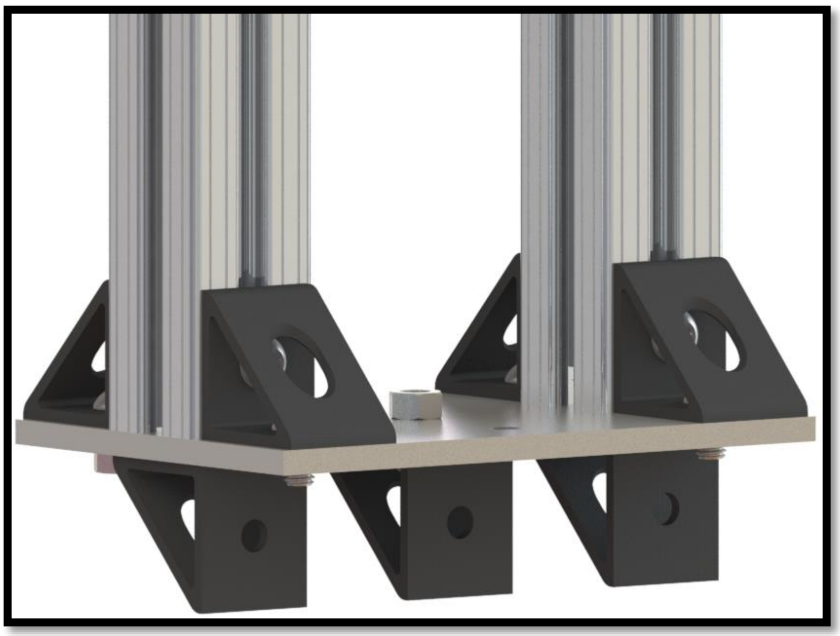

Figure 97. Payload arm mounting plate.

The same brackets used to hold the U-channel will be used to support the 80/20 towers on each side. 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.

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 horizontally to deposit the payload inside the rocket. A SolidWorks Simulation was therefore done to see how much deflection is expected on the shafts due to the weight of the gripper assembly. Figure 98 shows the constraints and loads that were applied to the shaft during the simulation.

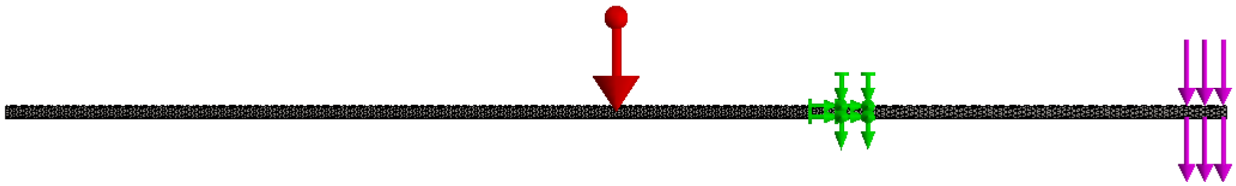

Figure 98. Constraints and loads on shaft.

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 98. The shaft was analyzed at its maximum extended length of 12in. In Figure 98 the red arrow represents the gravity vector and the purple arrow 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 the properties and loads applied shown in

Table **39**.

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 39. 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 somehow the middle shaft is the only one carrying the load due to some unforeseen problem. Figure 99 and Figure 100 show the resulting plots from the simulation.

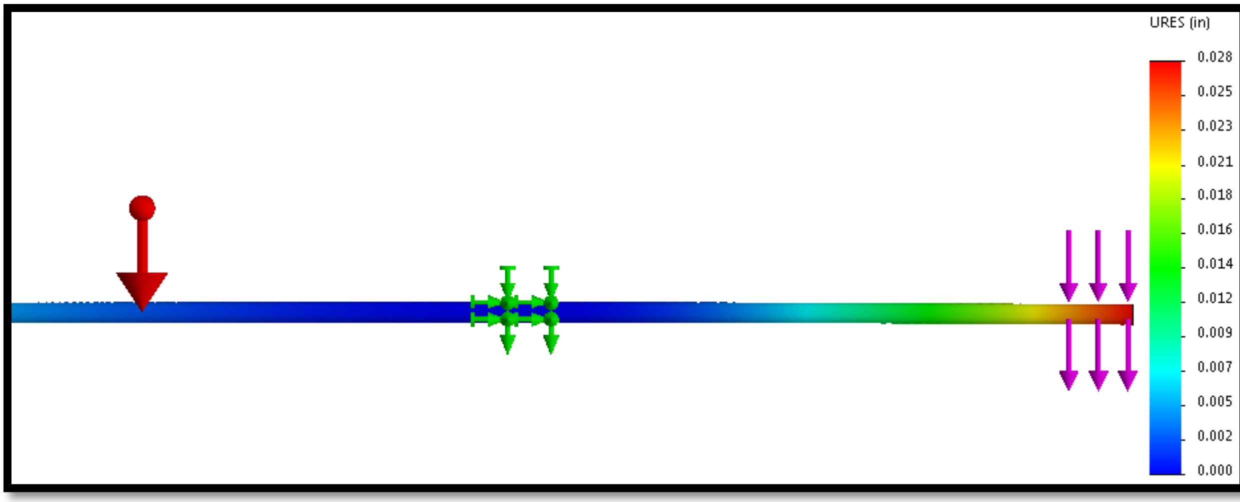

Figure 99. Vertical displacement plot.

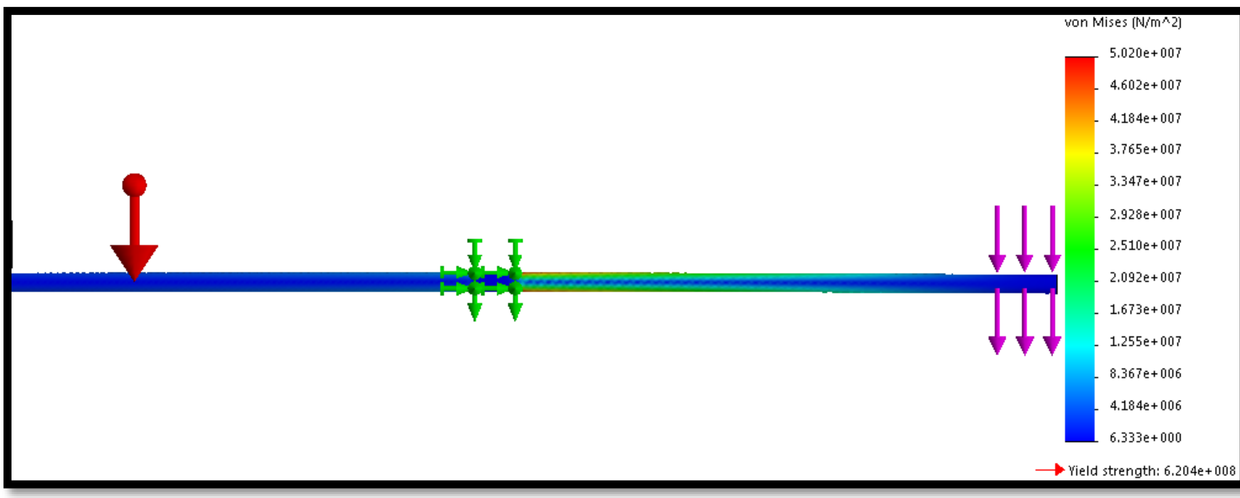

Figure 100. VonMises stress plot.

Assuming the worst case scenario where the entire weight of the gripper assembly is on one shaft and the gripper assembly is fully extended, the results shown in

Table **40** were obtained.

Maximum Vertical Displacement (in)	Maximum VonMises Stress (MPa)	Yielding Factor of Safety
0.028	50.2	12.4

Table 40. Results from cantilever analysis.

From the results, the team is confident that the weight from the gripper assembly on the shafts are negligible on the vertical displacement. When the payload arm is built, the team will still verify that there is no noticeable shaft deflection.

Schematics

The overall dimensions of the payload arm from the base plate are 15.975in x 6.625in x18.25in starting from the base plate and not including the length of the shafts that the gripper assembly is on. Figure 101 shows the general dimensions of the payload arm.

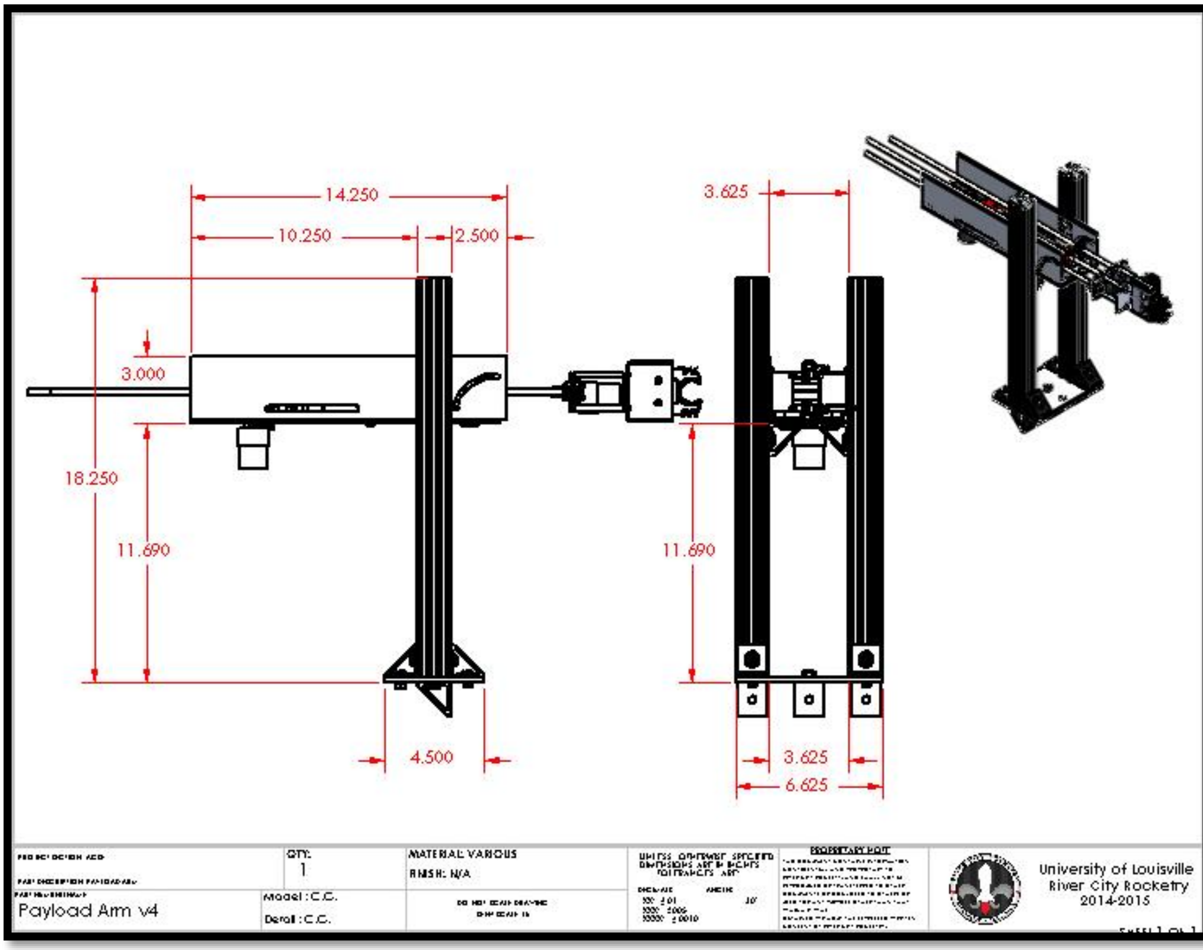

Figure 101. General dimensions of payload arm.

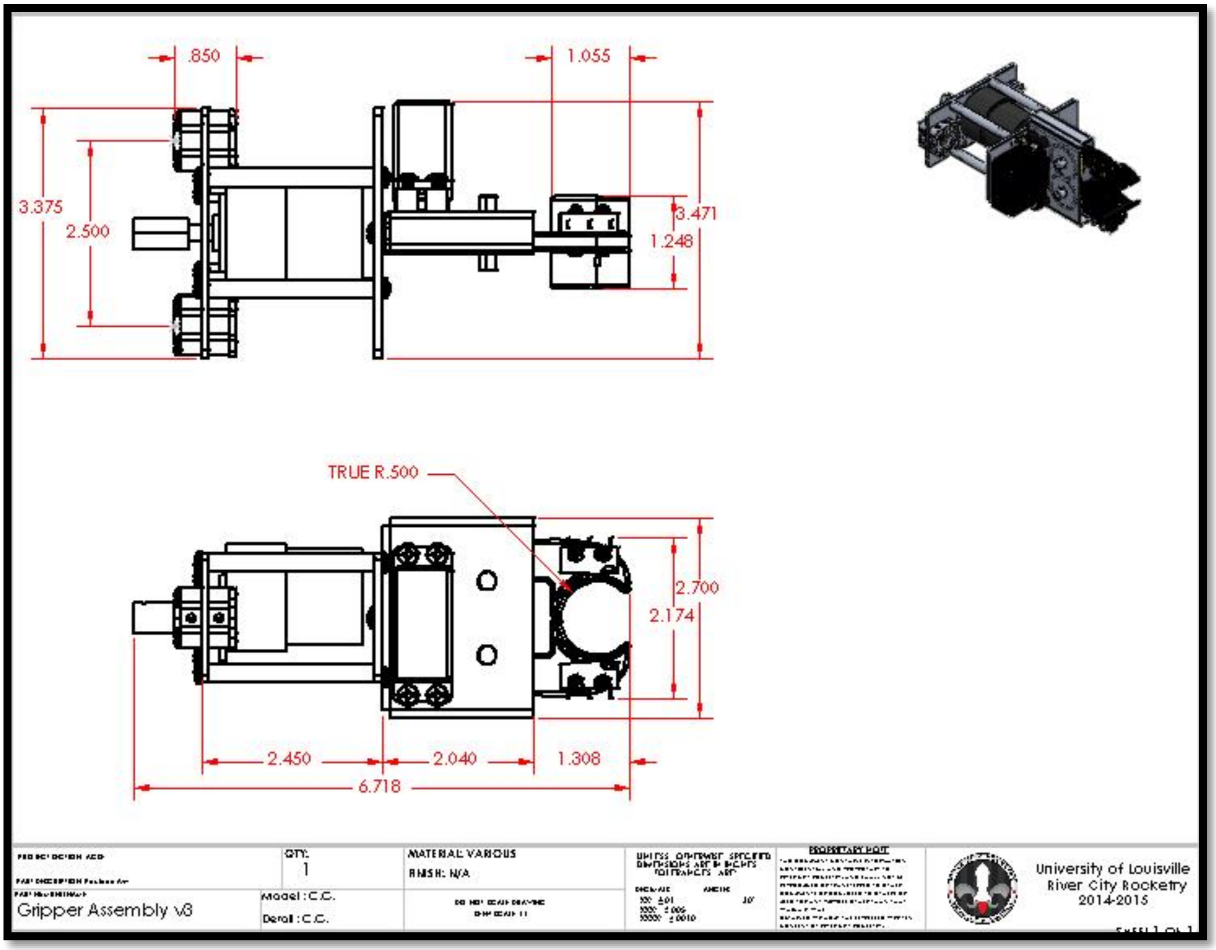

Figure 102. General dimensions of gripper assembly.

Controls

The payload arm will operate on a series of checks to see if it is ready to go to the next step. An Arduino Uno is currently expected to control the system which will in turn be connected to the laptop. A general overview of how this system will operate is shown in Figure 103.

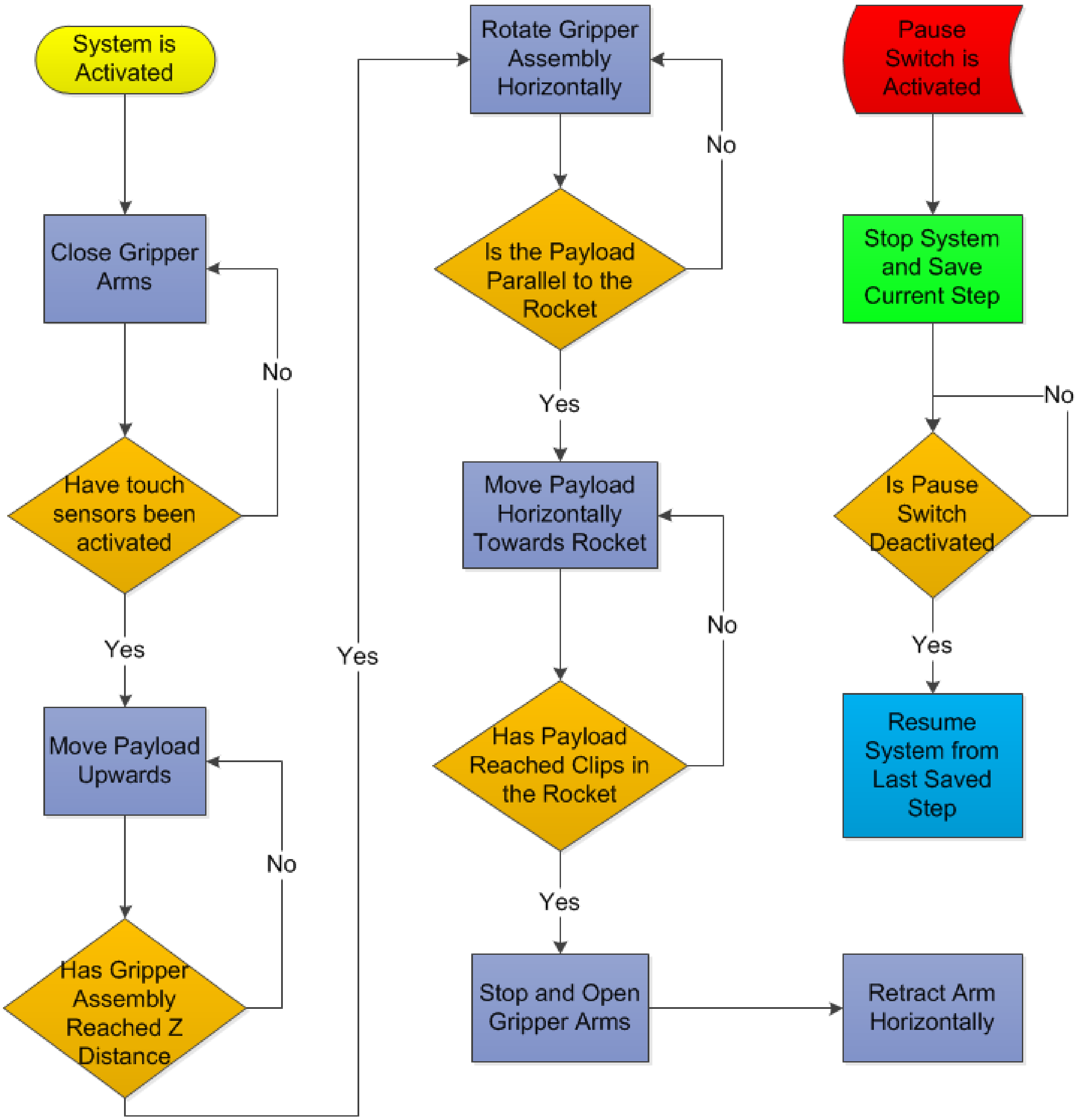

Figure 103. Flowchart for payload capture system.

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.

Challenges

Table **41** shows the foreseen design challenges for the payload capture system and their chosen solutions.

Design Challenge	Solution
Detect when the payload has been captured the by the payload arm.	A touch sensor will be 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 Z distance from the ground at a low cost.	A threadless ball screw system will be implemented. A regular shaft will be more cost effective than a threaded rod at larger lengths.
Rotate the gripper assembly to be parallel with the rocket.	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 motor that operate the payload arm will be chosen such that they are able to drive their components fast enough while still having enough torque 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 41. 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 **42** shows the verification plan to meet these requirements as well as any others set forth by the team.

Requirement	Method of Completion	Method of Verification
Each Maxi-MAV team must capture and contain a payload.	The team will design and build an arm system to pick up a payload from the	Each subsystem of the payload arm will be tested

	ground and place it inside the rocket.	to insure it can operate without any problems.
If the pause switch is re-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.	The pause switch will be tested at various phases of the payload capture process.
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.	The entire system will be timed to insure it falls within its allotted time.
All AGSE system shall be fully autonomous.	The payload arm will be completely controlled by an Arduino Uno.	The system must operate successfully without any team member intervening while testing.

Table 42. Verification plan for payload arm.

Tests and Measurements

To make sure that the payload arm will function without flaws during the actual competition, the system will undergo several tests which are described in

Table **43**.

Tests	Success Qualification
Verify that the payload arm can detect when the payload is secured.	The system must correctly sense the payload whenever it is grabbed.
Verify that the payload can be grabbed and held securely by the gripper assembly.	The payload is grabbed and does not fall out at least 5 times in a row.
Verify that the threadless ball screw system works correctly by running the motor and shaft connected to it.	The gripper assembly must be able to move upwards without problems at least 5 times in a row.
Verify that the arm is able to rotate horizontally using the belt system.	The arm must successfully rotate 90 degrees at least 5 times in a row.
Verify that the arm is able to move horizontally towards and away from the rocket.	The payload must be able to move horizontally without moving more than 0.028in vertically.

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.
Verify that the payload arm is stable.	The payload arm must not wobble whenever it is in motion. It must also stay perpendicular to the side rail.
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.
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.

Table 43. Test Plan for the Payload Arm

3) 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 44.

Overall Height (in)	Tower Height (in)	Overall Width (in)	Overall Thickness (in)	Overall Mass (lb_m)
126.78	120.36	30.97	22.65	104.265

Table 44: Launch platform general dimensions.

Figure 104: Launch platform.

Changes since Proposal

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

Table 45

Change	Justification for Change
The spacing between the vehicle and the guide rails has been lowered from 0.125 inches to 0.050 inches.	Better control of launch angle
The anti-friction tape has been removed and replaced with a spray on Teflon coating.	More cost effective
The material for the lower plates has been determined to be AISI 1020.	Required detail for fabrication

Table 45: Changes made since proposal.

Design

The launch platform consists of three t-slotted aluminum extrusions which guide the vehicle until the vehicle has reached a designated safe velocity. Along the rails will be sprayed with a Teflon spray coating which dries as a solid to lower the frictional losses between the vehicle and the rails. The gap between the guide rails and the vehicle is 0.050 inches.

Figure 105: Launch platform base.

The guide tower rests upon a base, shown in Figure 105, made from two machined 0.375 inch thick, and one 0.250 inch thick steel triangular plates with each plate serving a specific purpose. The bottom most plate, shown in Figure 106, is where three 18.375 inch aluminum extrusions that stabilize the primary guide rails and is the base mounting plate for the ignition system.

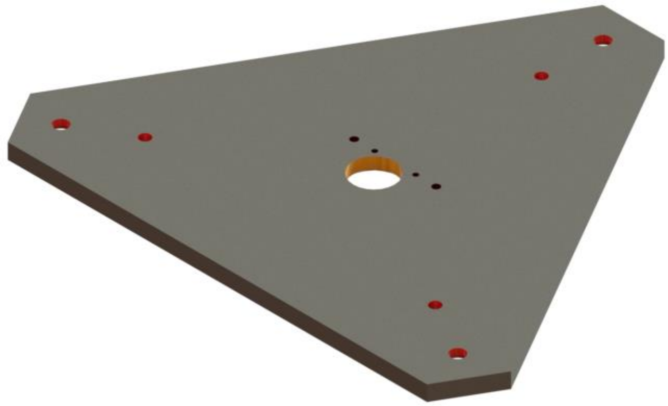

Figure 106: Platform bottom plate.

The middle plate, shown in Figure 107 , is the plate in which the guide rails mount. The guide rails mount the same way as the support rails. The rails then are attached via rectangular connecting plate that is fastened to both support and guide rail.

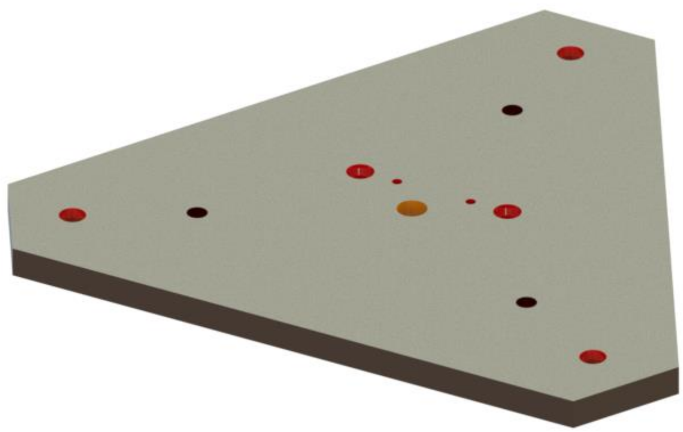

Figure 107: Middle base plate.

The uppermost plate, shown in Figure 108, is where the vehicle rests pre-flight. This is constrained by two sets of plates that connect and stabilize the support and guide rails. The plate also features three clearance holes for the screws that hold the motor retainer into the vehicle.

Figure 108: Uppermost base plate.

To ensure correct vehicle position during payload insertion, an alignment plate, shown in Figure 109, will hold one of the fins in the correct orientation and will only allow for translation along the axis of the launch platform.

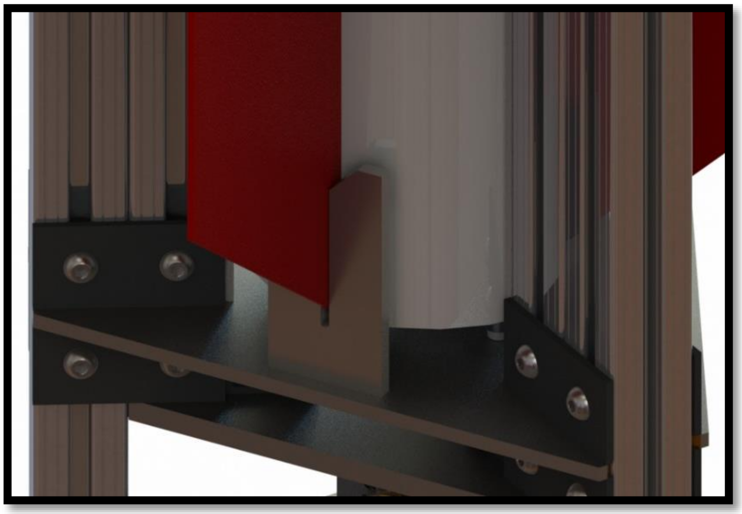

Figure 109: vehicle alignment plate.

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 will have a connecting rod and a fastening plate mounted on three sides of the extrusion, shown in Figure 109. The connecting rod is an 8 inch rod with the bottom half being threaded and the upper half being the same diameter as the t-slotted extrusion.

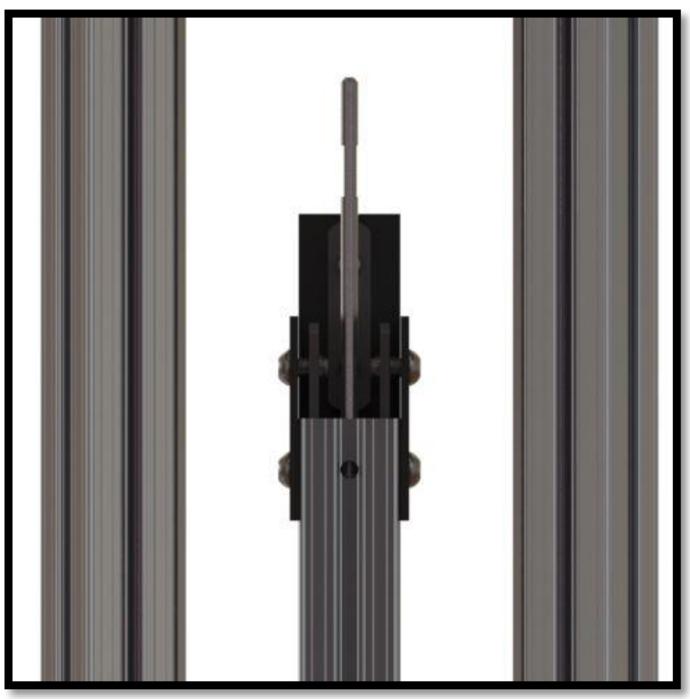

Figure 110: Tower connection joint.

To maintain structural rigidity during vehicle erection and provide the mounting locations for the ground station and the vehicle erection system, three ring assemblies will be used. To avoid any incidental contact between the vehicles 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 111. These rings connect to three t-slotted aluminum extrusions which are 6.5 inches long.

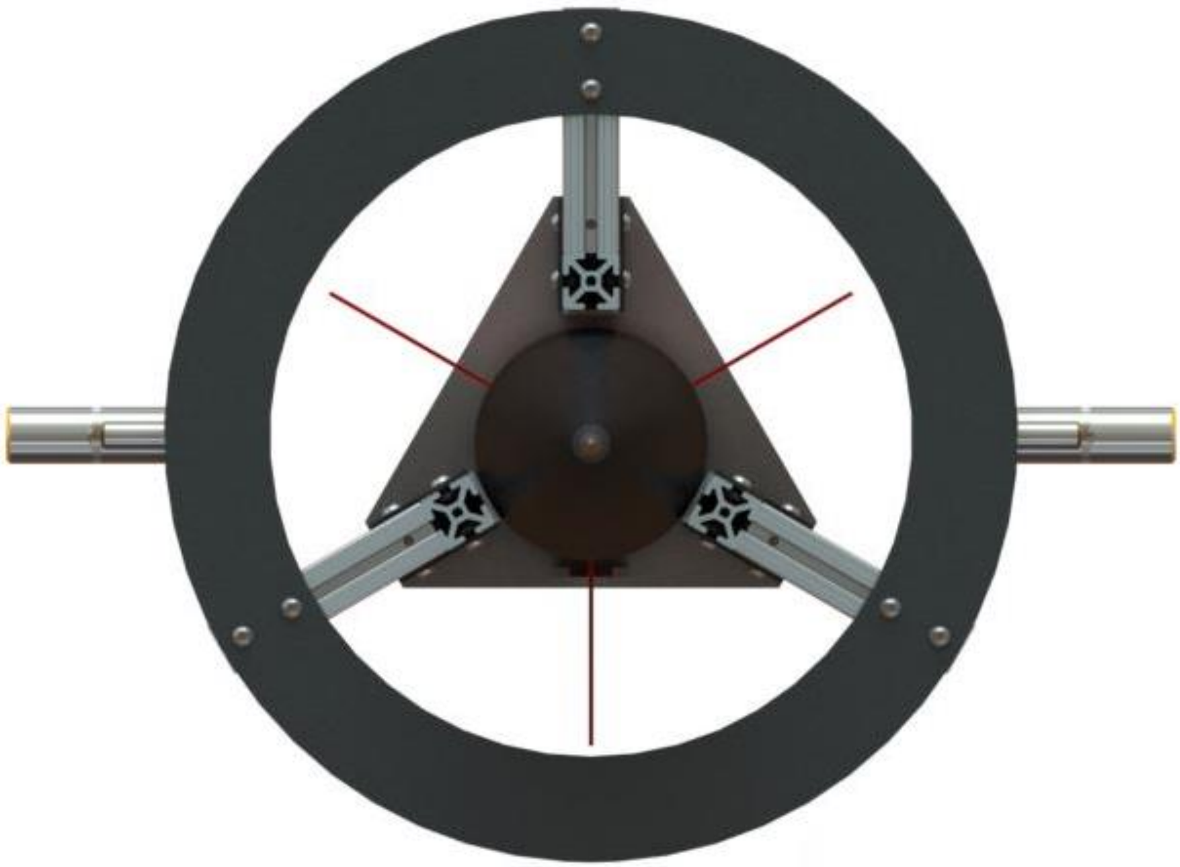

Figure 111: Worst case alignment.

The bottom most stability ring assembly, shown in

Figure 112, 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 22.65 inches. The placement of this ring assembly is 24.000 inches from the bottom of the station.

Figure 112: 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 dowel holes will be part of the connecting shaft, shown in

Figure 113, and the tower rings.

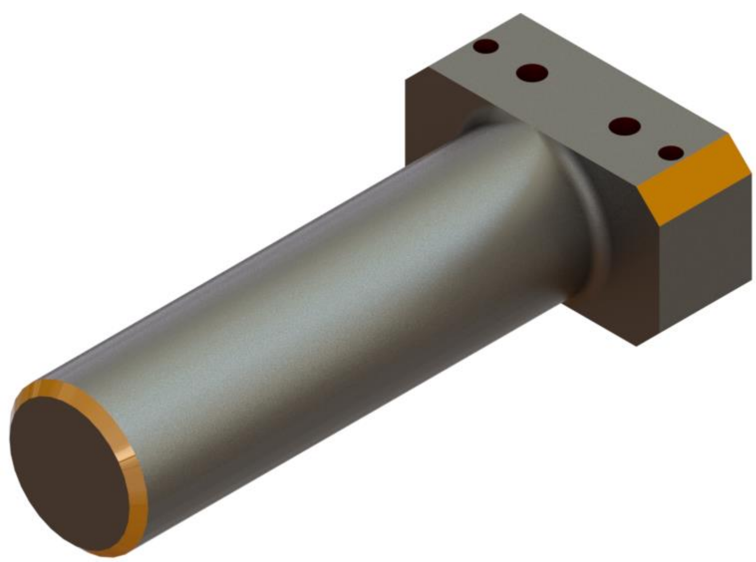

Figure 113: Vehicle connection shaft.

The secondary ring assembly, shown

Figure 114, 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 40.350 inches.

Figure 114: 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 115. These will also be held in proper alignment via two ¼ inch dowels through both the connection shaft and the rings.

Figure 115: V.E.S. and platform connection joint.

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

$$h = \int_{0}^{t_e} \mathrm{Vdt} \tag{27}$$

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 116.

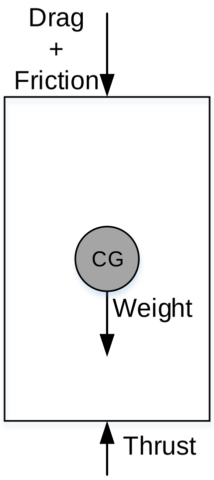

Figure 116: Vehicle takeoff F.B.D.

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

$$+\uparrow \sum \mathrm{F} = \mathrm{ma} \tag{28}$$

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

$$+\uparrow \sum \mathrm{F} = \mathrm{T} - \mathrm{mg} - \mathrm{F_d} - \mathrm{F_f} \tag{29}$$

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

$$\mathrm{F_d} = \frac{1}{2}\rho \mathrm{C_d} \mathrm{A} \mathrm{V}^2 \tag{30}$$

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

$$\mathrm{m} = \mathrm{m_w} - \mathrm{b_r t} \tag{31}$$

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 (31) can be combined to determine the acceleration of the vehicle and the resulting equation is shown below.

$$a_i = \frac{T_i - (m_w - b_r t)g - F_f - \frac{1}{2}\rho C_d A V_{i-1}^2}{m_w - b_r t} \tag{32}$$

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

$$k_1 = a_i(V_{i-1})$$ (33 26)

$$k_2 = a_i\left(V_{i-1} + \frac{h}{2}k_1\right) \tag{34}$$

$$k_3 = a_i\left(V_{i-1} + \frac{h}{2}k_2\right) \tag{27}$$

$$k_4 = a_i\left(V_{i-1} + \frac{h}{2}k_3\right) \tag{28}$$

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

$$V_i = V_{i-1} + \frac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{37}$$

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 46 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 46: Trail 1 parameters.

Figure 117 shows the recorded flight data during the competition launch from the vehicles primary Raven altimeter.

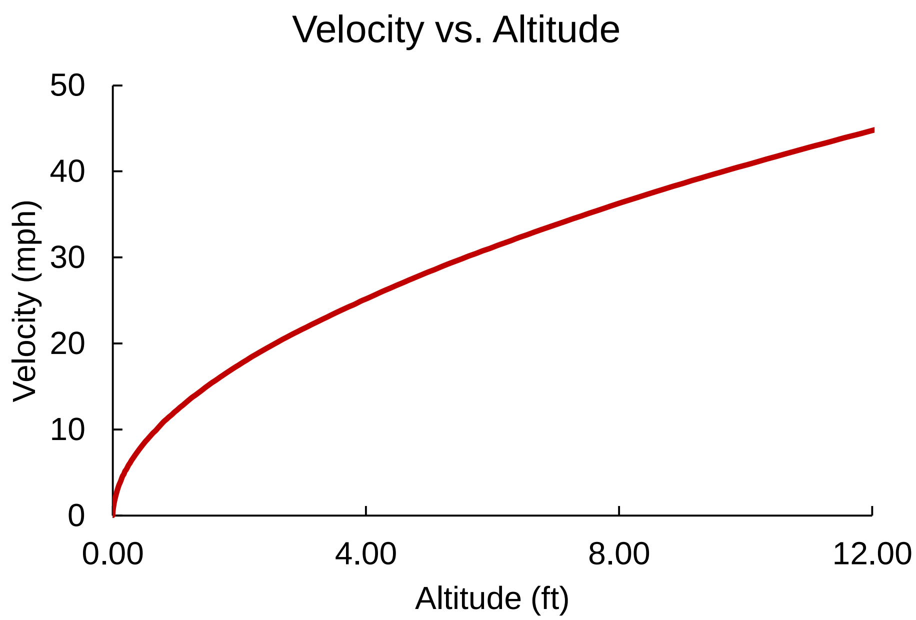

Figure 117: Velocity vs. altitude in tower.

The flight data was then compared vs. the predicted flight profile shown in Figure 118.

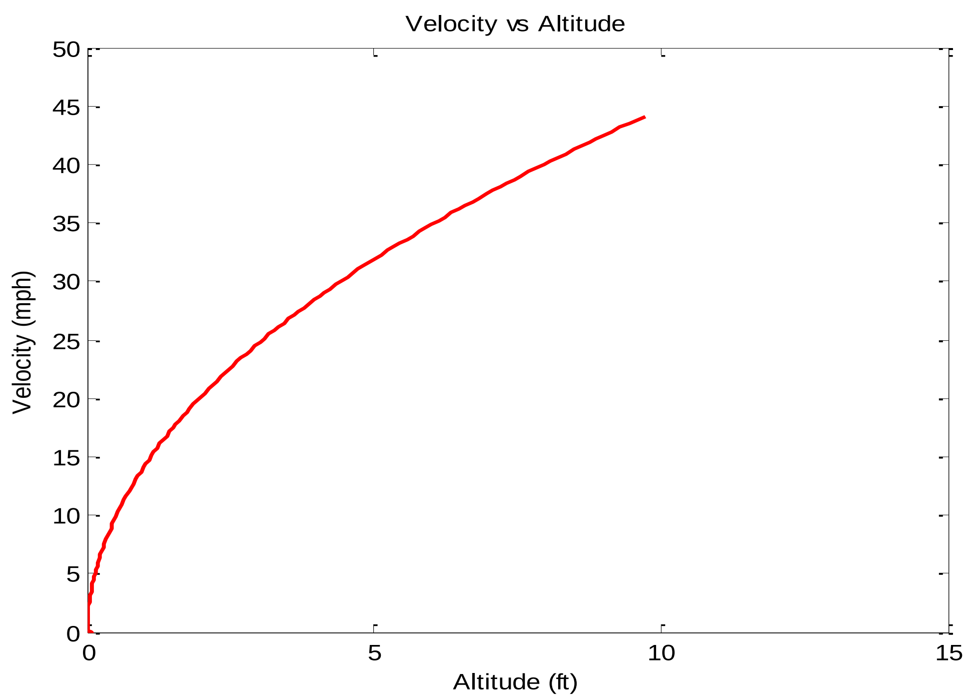

Figure 118: Predicted velocity vs. altitude in tower.

The exit velocities and percent error are shown in

Table 47.

True Velocity (mph)	Predicted Velocity (mph)	Percent Error
40.712	44.6263	9.61%

Table 47: 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 48: Error adjusted exit velocity.

Figure 119 shows the predicted flight profile until rail exit.

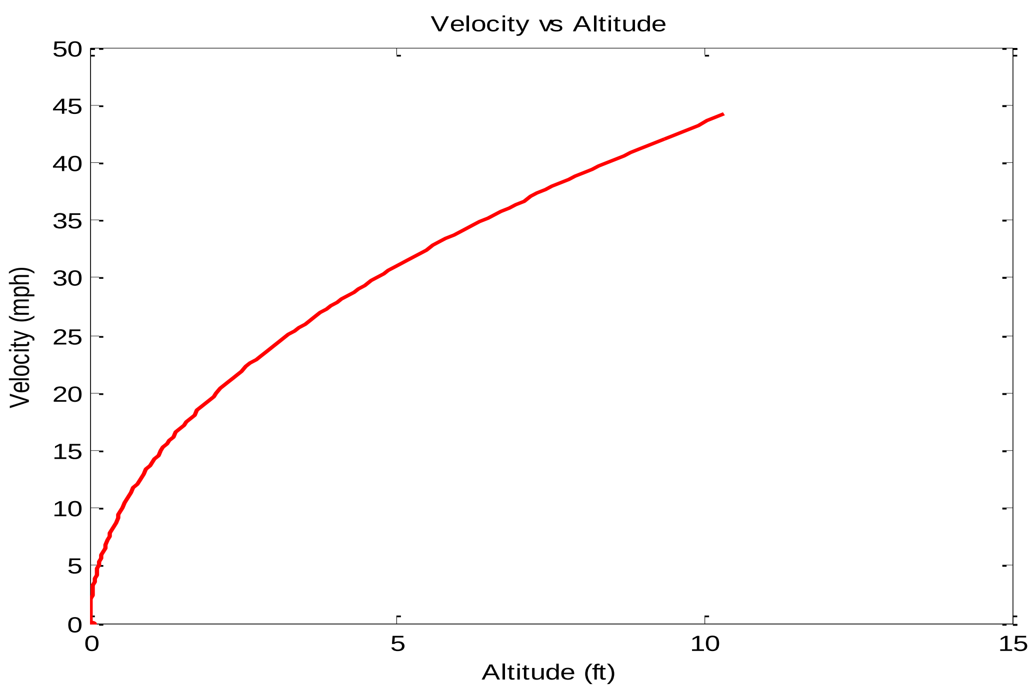

Figure 119: Predicted flight profile.

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

Table 44.

Construction

The t-slotted aluminum extrusions will be cut at the station shown in Figure 120.

Figure 120: Milder saw cutting station.

The pieces will then be planed and cut to length using a mill.

The stability rings will have the preliminary cut using the waterjet shown in Figure 121.

Figure 121: Waterjet cutter.

To maintain the tight tolerances needed for the connection joints and the dowels in the rings. CNC technology will be used to create the connection shafts and a secondary wire EDM process will be done on the rings for proper dowel locations.

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 two alignment pins. These pins 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 49: Launch Platform Design Challenges.

4) 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 PDR

The changes since preliminary design review are shown in

Table 50.

Change	Justification for change
Articulating arm internal fastening changed.	A more cost effective and more defined fastening option was determined.
Dowel holes added to carriage.	Dowel holes will assist in alignment of the completed assembly
Power screw nut interface with carriage changed.	Nut was reflected across the mount plate to allow for additional travel.
Motor mount redesigned.	A more rigid fastening option was determined.

Table 50: Vehicle erector changes since preliminary design review.

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 122.

Figure 122: 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 123.

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Figure 123: 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

$$y = \frac{Wx^2}{48EI}(3l - 4x) \tag{3929}$$

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 51.

Modulus of elasticity ($\frac{lb_f}{in^2}$)	**Moment of inertia (in^4)**	**Max deflection (in)**
10,200,000	1.8042	0.006

Table 51: 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 124.

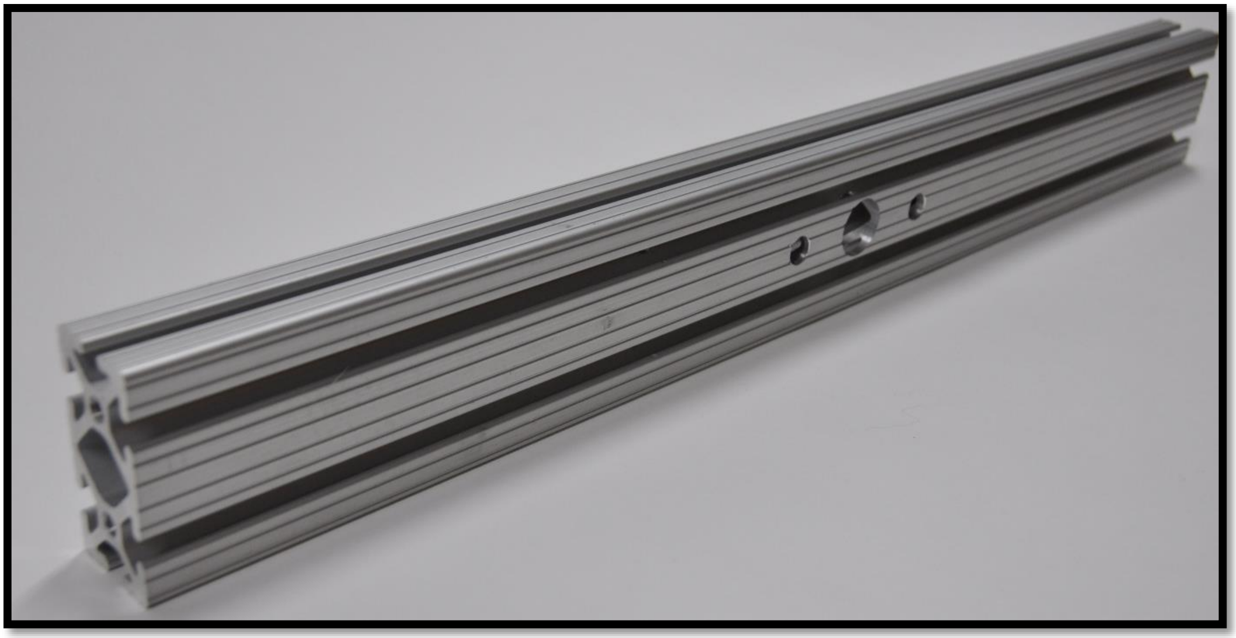


Figure 124: Bearing support cross bar.

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 125.

Figure 125: Ampflow brushed DC-E30-150-G gearmotor.

The motor will be mounted to the track system via the motor mount plate shown in Figure 126.

Figure 126: 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. Alignment of the motor plate will be controlled by two ¾” long ¼” dowel pins. One dowel hole has been included in the motor mount plate as shown in Figure 126. The second dowel hole will be added during the assembly phase. 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 127. The bearing will be mounted using two 2 inch 7/16”-14 UNC 2A thread socket head cap screws with appropriate 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 127: Power screw support ball bearing.

The carriage assembly is shown in Figure 128.

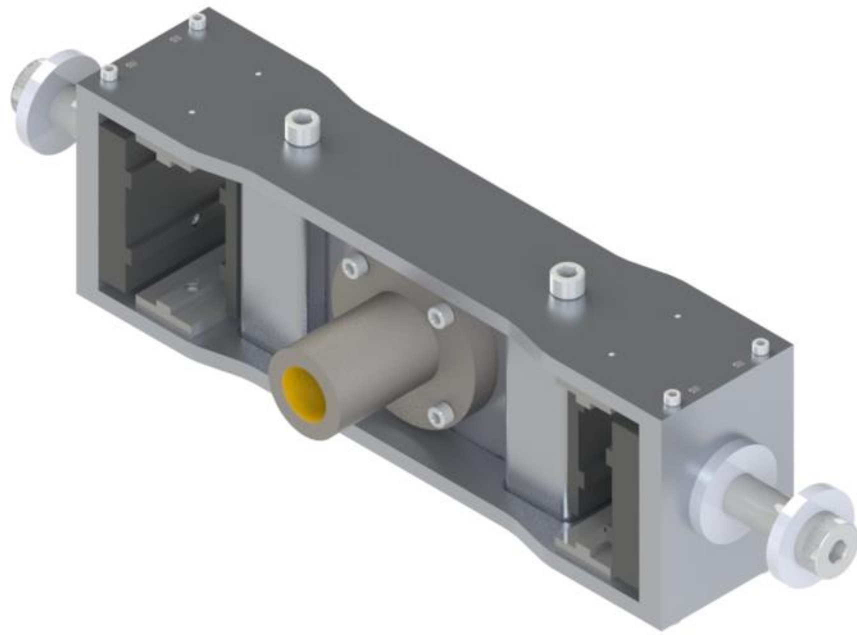


Figure 128: Vehicle erector carriage assembly.

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 129.

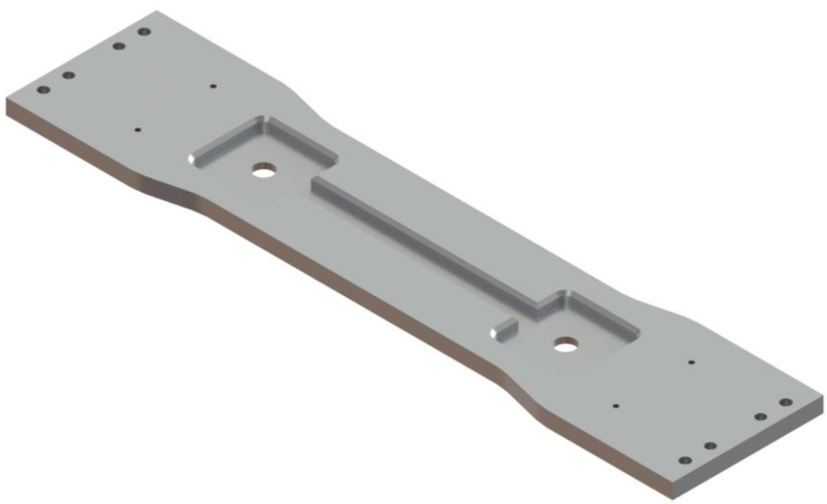


Figure 129: Carriage bottom plate.

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 130.

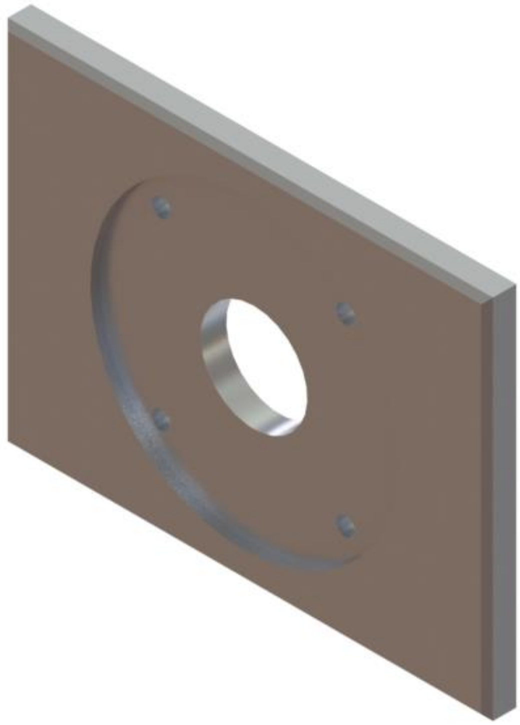


Figure 130: Carriage vertical mount plate.

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 131.

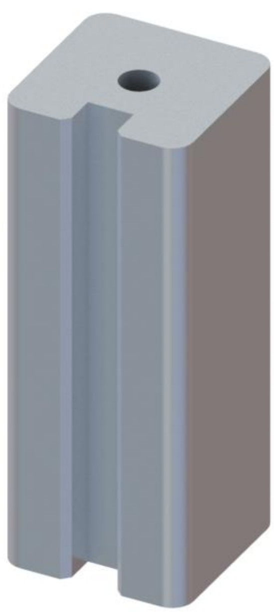


Figure 131: Carriage vertical upright.

Two vertical side plates also connect the top and bottom plates and are used to interface the carriage with the articulating arms. The articulating arms are connected to the side plates via a ¾" diameter 1 inch long shoulder bolt with 5/8"-11 UNC 2A 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. In order 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 X axis direction. Fixed geometry in the Z 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 52.

Configuration	Vehicle angle (deg)	Load bar angle (deg)	Load (lbf)	Factor of safety
1	0	14.0	120	2.208
2	45	47.0	60	2.717
3	85	68.5	4	N/A

Table 52: 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 132.

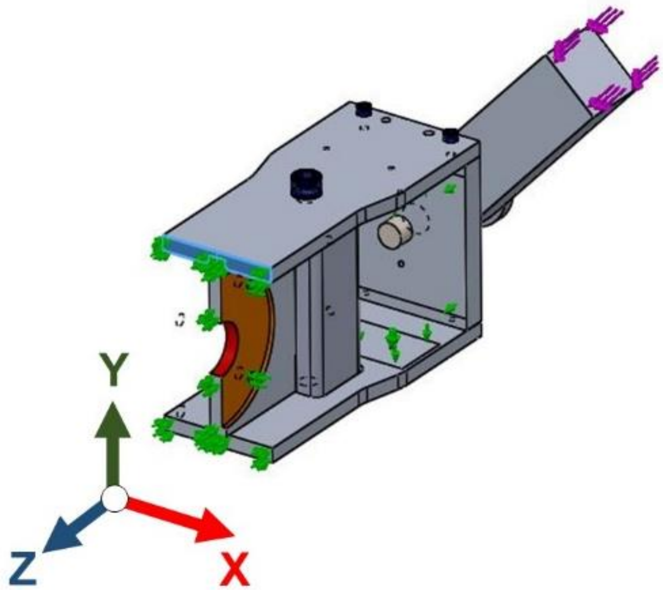


Figure 132: Carriage boundary conditions for configuration 1.

A stress distribution plot for configuration 1 is shown in Figure 133.

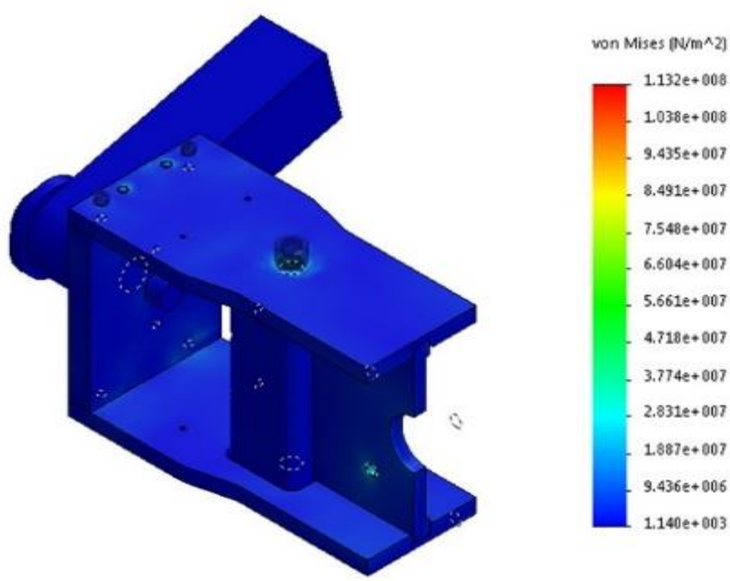


Figure 133: Carriage stress distribution for configuration 1.

The factor of safety distribution for configuration 1 is shown in Figure 134.

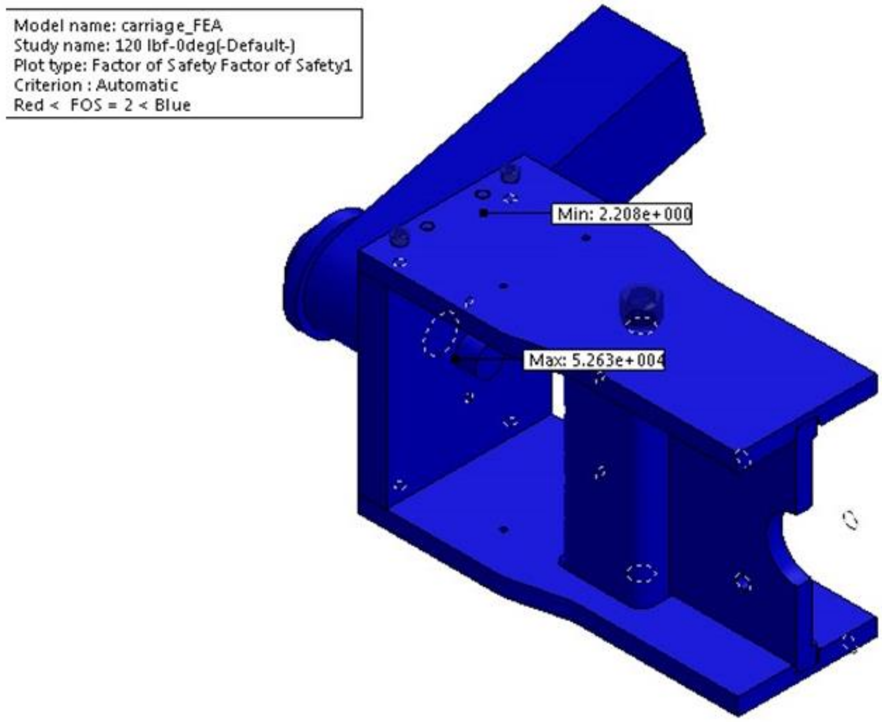


Figure 134: Carriage factor of safety distribution configuration 1.

As shown in Figure 134 the minimum safety factor was 2.208.

The factor of safety distribution for configuration 2 is shown in Figure 135.

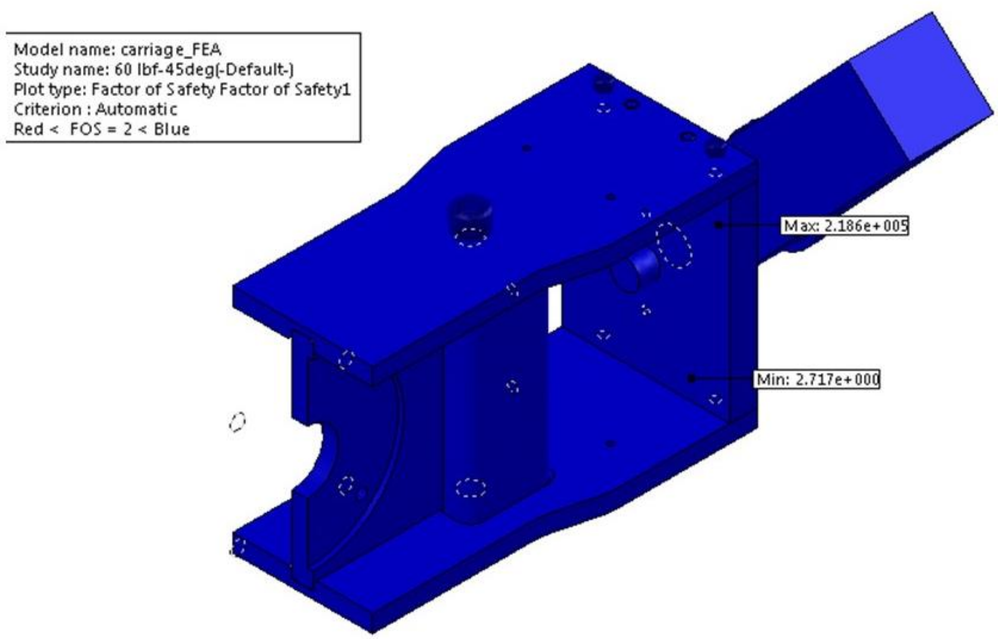


Figure 135: Carriage factor of safety distribution configuration 2.

The articulating arms will be made out of t-slotted aluminum extrusion. One articulating arm is shown in Figure 136.

Figure 136: 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 welded and bolted together at the mid arm joint. The bolted connection is the primary mode of transferring load through the articulating arm, welding was included to control axial rotation of the aluminum extrusions and add additional structural integrity to the joint. An exploded view of the bolted connection is shown in Figure 137.

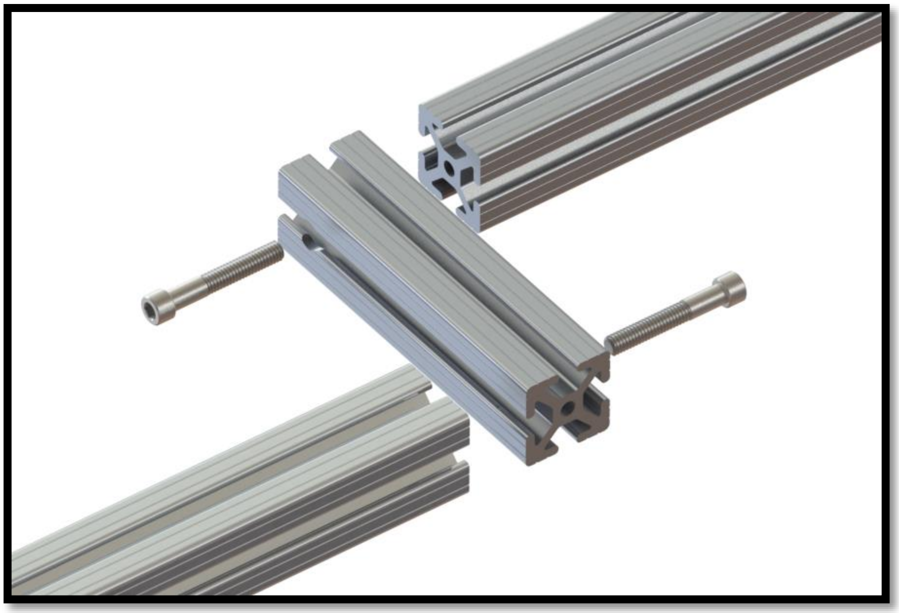


Figure 137: Articulating arm joint connection without weld.

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 a 11/16 inch 5/16”-18 UNC 2A flanged button head cap screw. A completed end cap is shown in Figure 138.

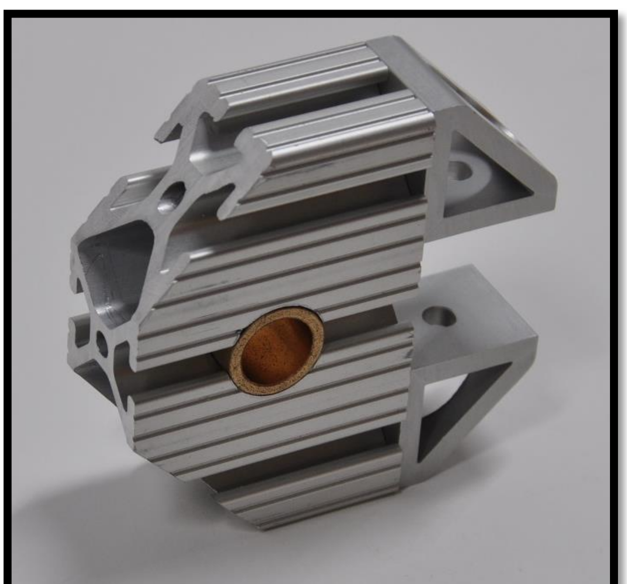


Figure 138: Articulating arm end cap.

Geometry Selection

The geometry of the vehicle raising system is shown in Figure 139

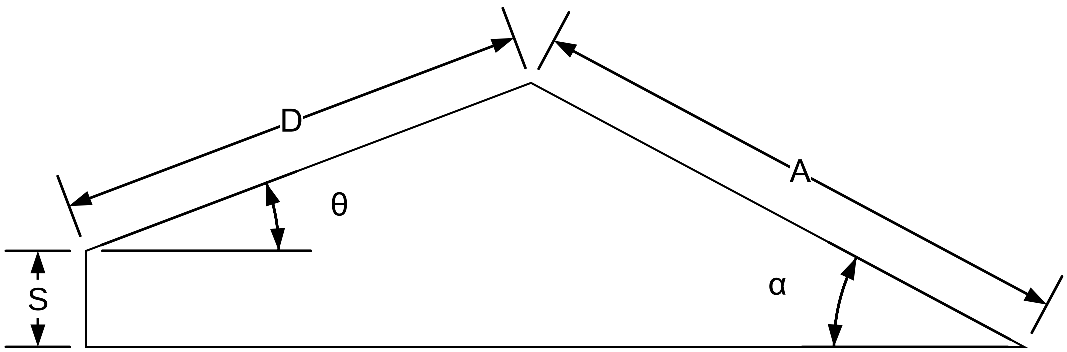


Figure 139: Vehicle erection system geometry.

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. This geometry can be extended into that shown in

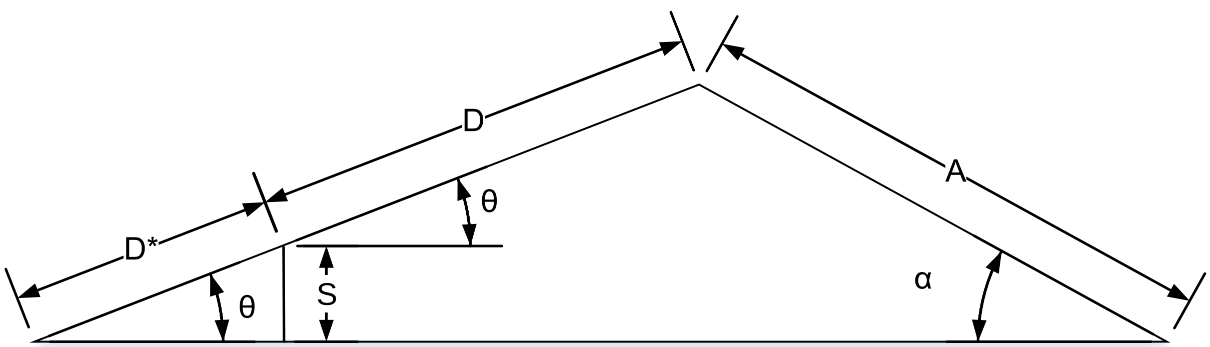


Figure 140: Extended geometry.

D* is the additional length added by the new triangle seen in the lower left. The triangle that results in the extension is seen in Figure 141

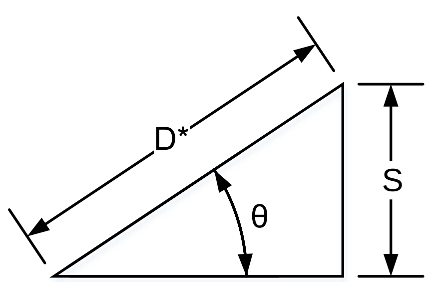


Figure 141: Extension triangle.

This triangle is then used to calculate the length of D* via

$$D^* = \frac{S}{\sin\theta} \tag{40}$$

Using the law of sines, it can be shown that

$$\sin\alpha = \frac{\sin(\theta)\,(D + D^*)}{A} \tag{41}$$

By combining equations (40) and (41), the sin of α is calculated using

$$\sin\alpha = \frac{\sin\theta\left(D + \frac{S}{\sin\theta}\right)}{A} \tag{42}$$

The geometry of the system is different when θ equals zero. This initial state geometry is shown in Figure 142.

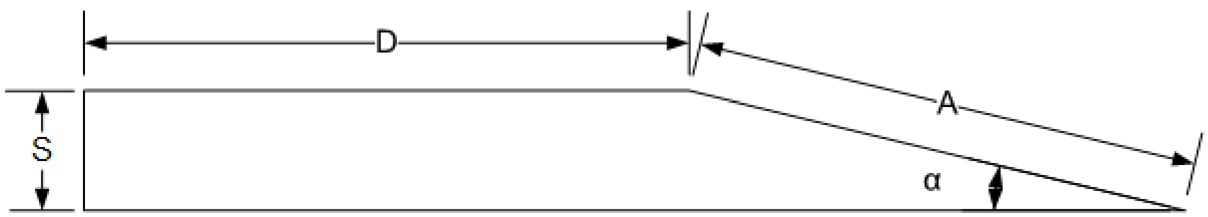


Figure 142: Stating geometry.

The triangle that consists of the raising arm and angle α is shown in Figure 143.

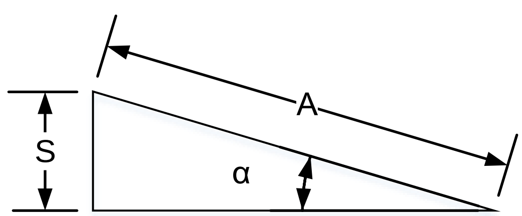


Figure 143: Initial state arm geometry.

From this geometry, the sin of α is determined using

$$\sin\alpha = \frac{S}{A} \tag{43}$$

By combining equations (42) and (43) α is determined using

$$\alpha = \begin{cases} \sin^{-1}\left(\frac{S}{A}\right), & \theta = 0 \\ \sin^{-1}\left(\frac{\sin\theta\left(D + \frac{S}{\sin\theta}\right)}{A}\right), & \theta > 0 \end{cases} \tag{44}$$

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 53 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 53: 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 initial distance the carriage has to be relative to the pivot point is calculated using

$$X_i = D + \sqrt{A^2 - S^2} \tag{30}$$

The final distance from the vehicle pivot point to the carriage is determined via

$$X_f = A\frac{sin(\pi - \theta - \alpha)}{\sin\theta} - \frac{S}{\tan\theta} \tag{46}$$

The total amount of carriage travel is then calculated using

$$Travel = X_i - X_f \tag{47}$$

The total geometry including forces is shown in Figure 144.

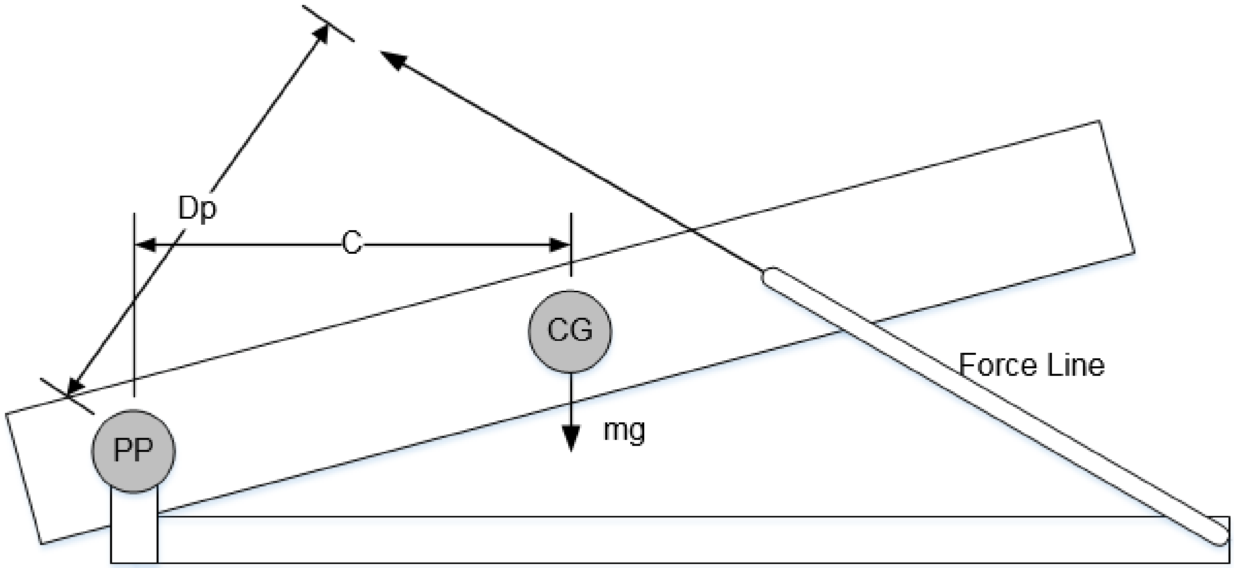


Figure 144: Total system description.

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 is calculated by

$$+\circlearrowleft \sum M_{PP} = F_a D_p - mgC \tag{48}$$

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 is then calculated via

$$F_a = \frac{mgC}{D_p} \tag{319}$$

D_p is calculated using

$$D_p = \frac{S}{\sin\left(\frac{\pi}{2} - \alpha\right)} \tag{50}$$

The horizontal center of gravity distance is calculated via

$$C = C_0 \cos\theta \tag{51}$$

Combining equations (319) through (51), the raising force is determined using

$$F_a = \frac{mgC_o \cos\theta \sin\left(\frac{\pi}{2} - \alpha\right)}{S} \tag{52}$$

The initial opening force calculations were performed in addition to the carriage travel distance and plotted against each other in Figure 145. This is useful to see the different force, vs. travel relationships available to further determine the optimum solution.

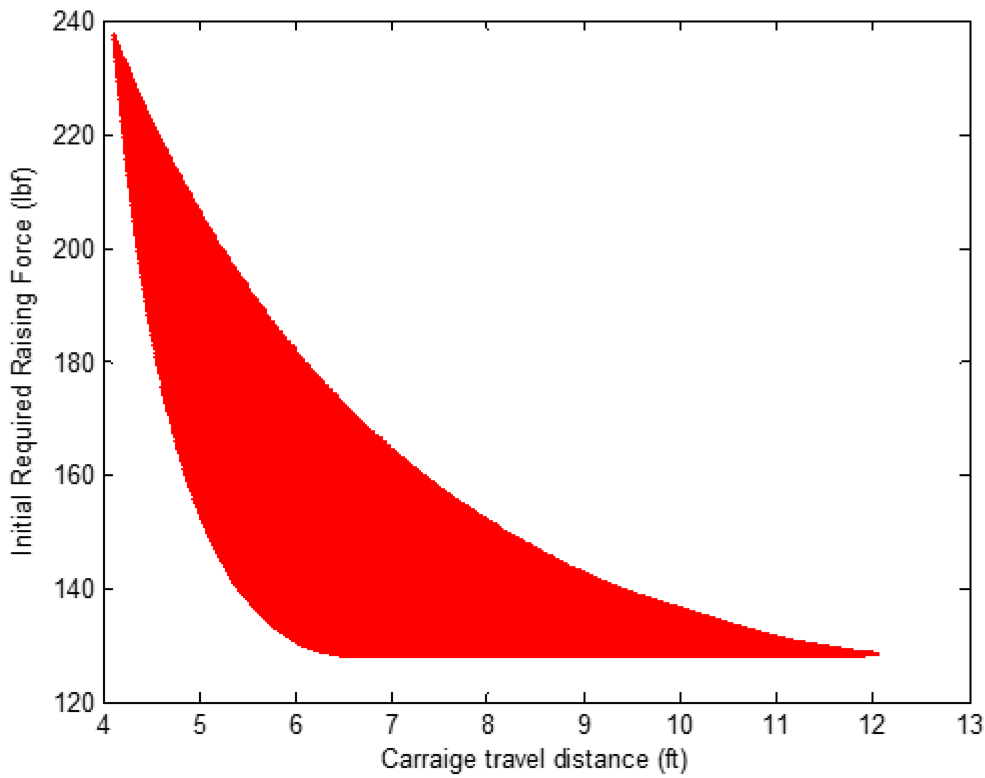


Figure 145: Initial Raising Force vs. Carriage Travel Distance.

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.
3. The initial opening force must not be greater than 160 lb_f

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

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

Table 54: Optimized Selections.

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

$$F_s = F_a \cos\alpha + F_f \tag{53}$$

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

$$F_f = \mu F_a \sin \alpha \tag{324}$$

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

$$T = \frac{F_s l}{2\pi v} \tag{55}$$

where l is the screw lead and v is the screw efficiency, typically 90% for ball screws.

Table 55 shows the calculation parameters.

μ	m (lb_m)	C_o	l (in)
0.35	133.9	25.6717	0.5

Table 55: Calculation Parameters.

Figure 146 shows the required raising force vs. vehicle angle.

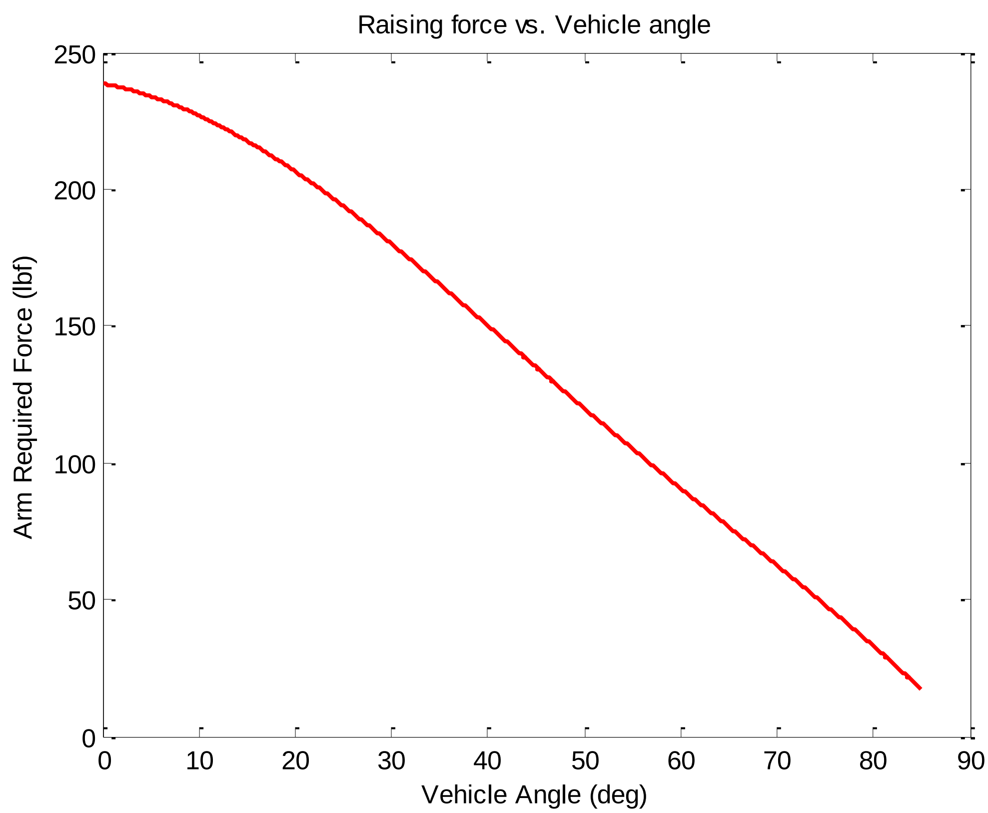


Figure 146: Raising Force vs. Vehicle Angle.

Figure 147 shows the screw drive force vs the vehicle angle.

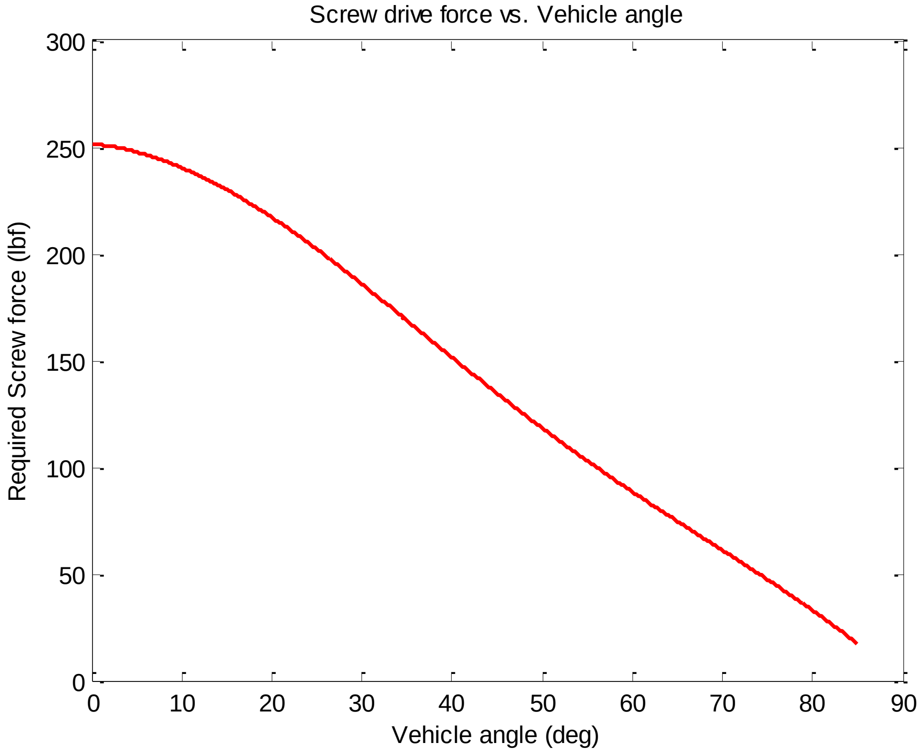


Figure 147: Screw Drive Force vs. Vehicle Angle.

Figure 148 shows the required motor torque vs. vehicle angle.

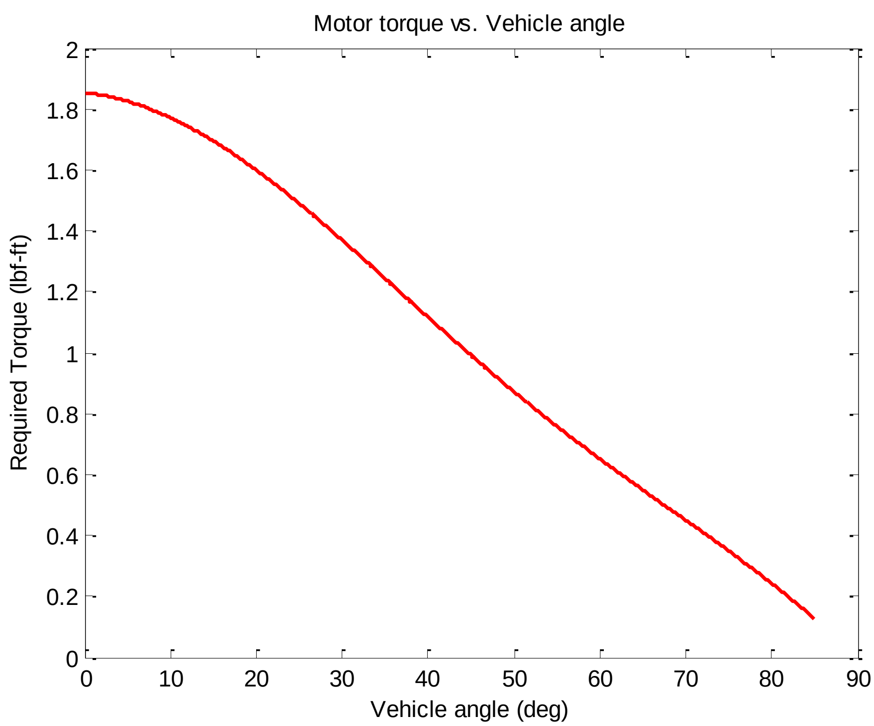


Figure 148: Required Motor Torque vs. Vehicle Angle.

Controls

When the model is finalized, a control strategy (e.g., proportional-integral) will be utilized to achieve the required behavior of the system.

We are going to model the system using black-box system identification method. Using the behavior of the erector system, we determine a mathematical relation between the system and the model. After recording data from the system, different models will be compared to find out the best method of capturing the dynamical behavior of the erector system.

We will have a compact equation that relates the dynamic relation between the motor input voltage and the vertical angle of the erector system. This equation will be in the form of Laplace transfer function, H(s), shown Figure 149.

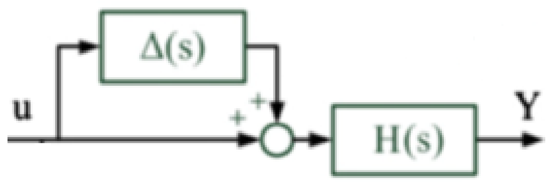


Figure 149: Process block diagram.

In this representation, u is the system input (the motor's input voltage), Y is the system output (the erector system's angle with horizon), and Δ(s) is the uncertainty of the model. A controller will be designed using frequency-based approaches to achieve steady-state error, settling time, etc. The closed-loop system is shown in Figure 150.

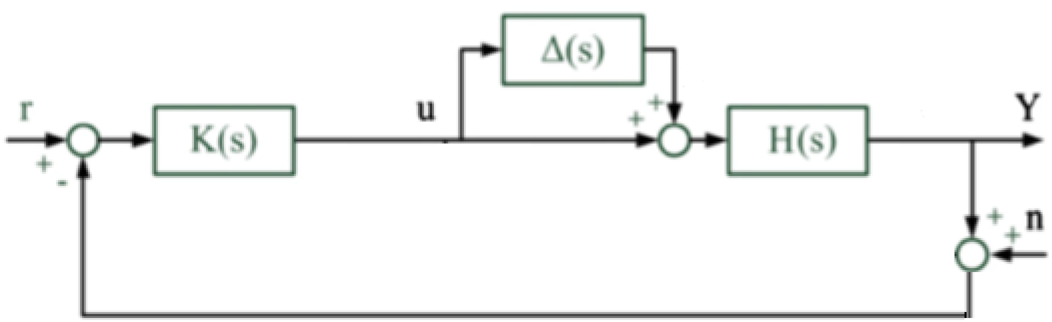


Figure 150: System block diagram.

In this figure, n represents the measurement noise, r is the reference (command) signal, and K(s) is the designed compensator. The reference signal, r, represents the desired values of angle in upward and downward command (i.e. 85 and 0 degrees).

The microcontroller we are going to use in this project is an Esplora from Arduino microcontroller family. The Esplora will also be used as an interface between the laptop computer and the rest of the hardware. The controller will await commands from master controller through serial communication. The Esplora provides sensory information as and a process-completion flag for the central controller for data-logging.

A variety of sensor types can be used for the feedback control system including accelerometers, encoders, and tilt sensors. An accelerometer will be used to directly measure the angle. There is an on-board accelerometer on the Esplora that we are using for the implementation of the control. The microcontroller-sensor and sensor are integrated into unit.

The motor controller translates the digital commands from the microcontroller to voltages and currents for the motors. The motor controller is an interface between the microcontroller (which is able to provide low-power signals) and the battery capable of powering 24V instead of varying voltages.

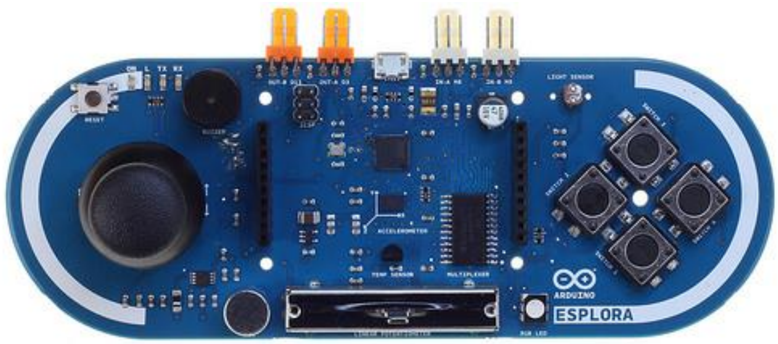
We are going to use the Sabertooth motor controller (Dimension Engineering). The controller implements soft current limiting and thermal protection for the driver. It is driven through serial communication with the Esplora. The list of the items is as follows:

Motor driver: Sabertooth 60A motor driver

Figure 151: 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. Sabertooth features screw terminal, and has a built in 5V 1A Switch-mode BEC that can supply power for our microcontroller.

Arduino Esplora



The Arduino Esplora is a microcontroller board derived from the Arduino Leonardo. The Esplora differs from all preceding Arduino boards because it provides onboard sensors for interaction. The Esplora has onboard sound and light outputs to be used for alarm and monitoring purposes of our erector system. The controller has several input sensors, including a joystick (which can be used for manually setting the angle of the erector system at a desired value) and an accelerometer.

Challenges

Challenge	Solution
T-slotted Aluminum extrusions in the carriage design at proposal failed FEA.	T-slotted extrusions were replaced with aluminum machined components.
The dual power screw configuration at proposal could cause jamming issues during carriage actuation.	A single power screw was selected to mitigate jamming. The screw was sized to adequately handle the load of the system.
All components must be able to be easily transported to and from launches.	All components will be designed to fit into the back of a standard minivan. All components must fit with-in a 4ft x 8ft x 4ft volume.
Cross section of launch platform must be clear when platform is in the loading or launch position.	Articulating arms were designed to clear the launch platform cross section at all times.
Optimizing erector geometry.	Dimensions were optimized by iterating over multiple solutions with a custom computer algorithm and selecting the best configuration after constraints were determined.

Table 56: Various design challenges and solutions.

5) 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 actuation 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

Overall Height (in)	Overall Thickness (in)	Overall Width (in)	Overall Mass (lb_m)
4.00	3.00	4.20	4.17

Table 57: Ignition System Overall Dimensions.

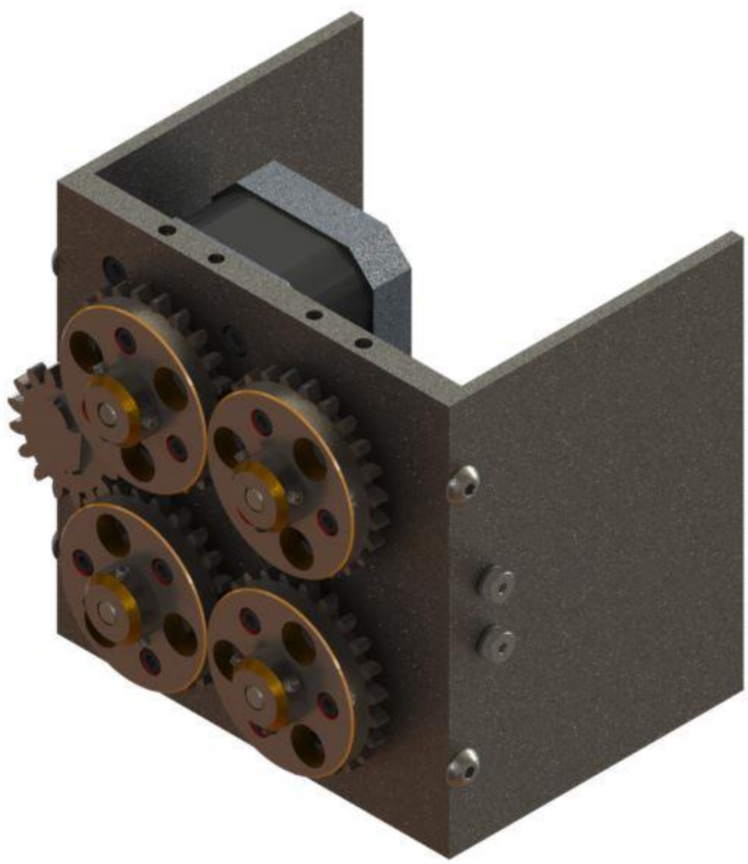


Figure 152: Ignition station.

Changes since PDR

The changes since preliminary design review are shown in

Table 58.

Change	Justification for change
The drive wheels have a groove added.	To prevent the igniter from moving outside of the system.
One drive motor has been removed.	To simplify the controls of the system.
An idler gear was added.	The get all drive wheels to turn in sync with each other.
The extrusion wheel was combined with the shaft collars.	Part count reduction.
The spring tensioner has been redesigned.	To keep constant tension of the igniter wire during system operation and to make instillation easier.
Dowel augmentation has been changed to include only one dowel for initial insertion.	Potential for damage to a motor grain during installation if multiple dowels are used.
Added interrupt pin functionality to the Arduino Uno.	To ensure safety in the event of an abort during igniter insertion.

Table 58: Ignition station changes since preliminary design review.

Design

The design of the ignition station is similar to a cable extruder. Two titanium printed wheels grab the igniter wire from two different points to maintain cable linearity. The wheels grab the igniter due to heat shrink sleeve being placed around the wire increasing the coefficient of friction between the printed titanium and the cable. To keep the wire in the correct alignment, grooves will added to keep the cable properly placed within the wheels. Figure 153 shows the exploded drive wheel assembly.

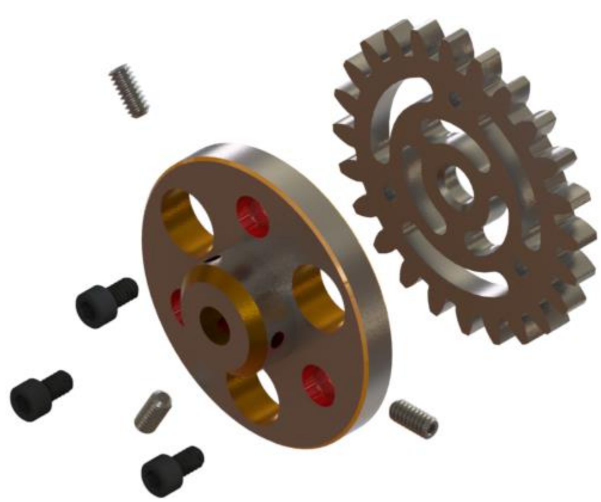


Figure 153: Exploded extrusion wheel assembly.

The wheel itself connects to the driving gear via three 4-40 3A socket head cap screws and to the shaft via three 4-40 3A socket head set screws. One wheel is driven by a stepper motor and the others are driven via gear train. The gear train consists of four drive gears and an idler gear shown in Figure 154, and then more drive gears.

Figure 154: Idler gear.

The drive gears are mounted to a single plate along with a spring tension system and three custom nylon bushings to keep the shaft rotation smooth. Prints for these components can be found in Appendix IV – Technical Drawings.

For ease of igniter wire installation, the two drive wheels not meshed to the motorized wheel or the idler rest in slots and springs are used to keep constant tension on the wheel and thus the igniter wire. The tension assembly is shown in Figure 155.

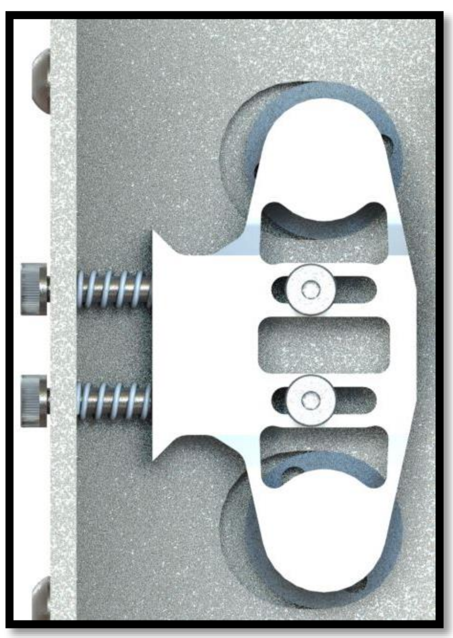


Figure 155: Spring tensioner.

The primary component of the tension assembly is a 3D printed ABS part that holds the rear end of the shafts in proper place and has pockets for the springs to distribute the stress evenly. Two shoulder screws hold the tensioner in the proper alignment so that the shafts are vertical at all times. The drawing for the mounting plate is shown in Figure 156 and Figure 157.

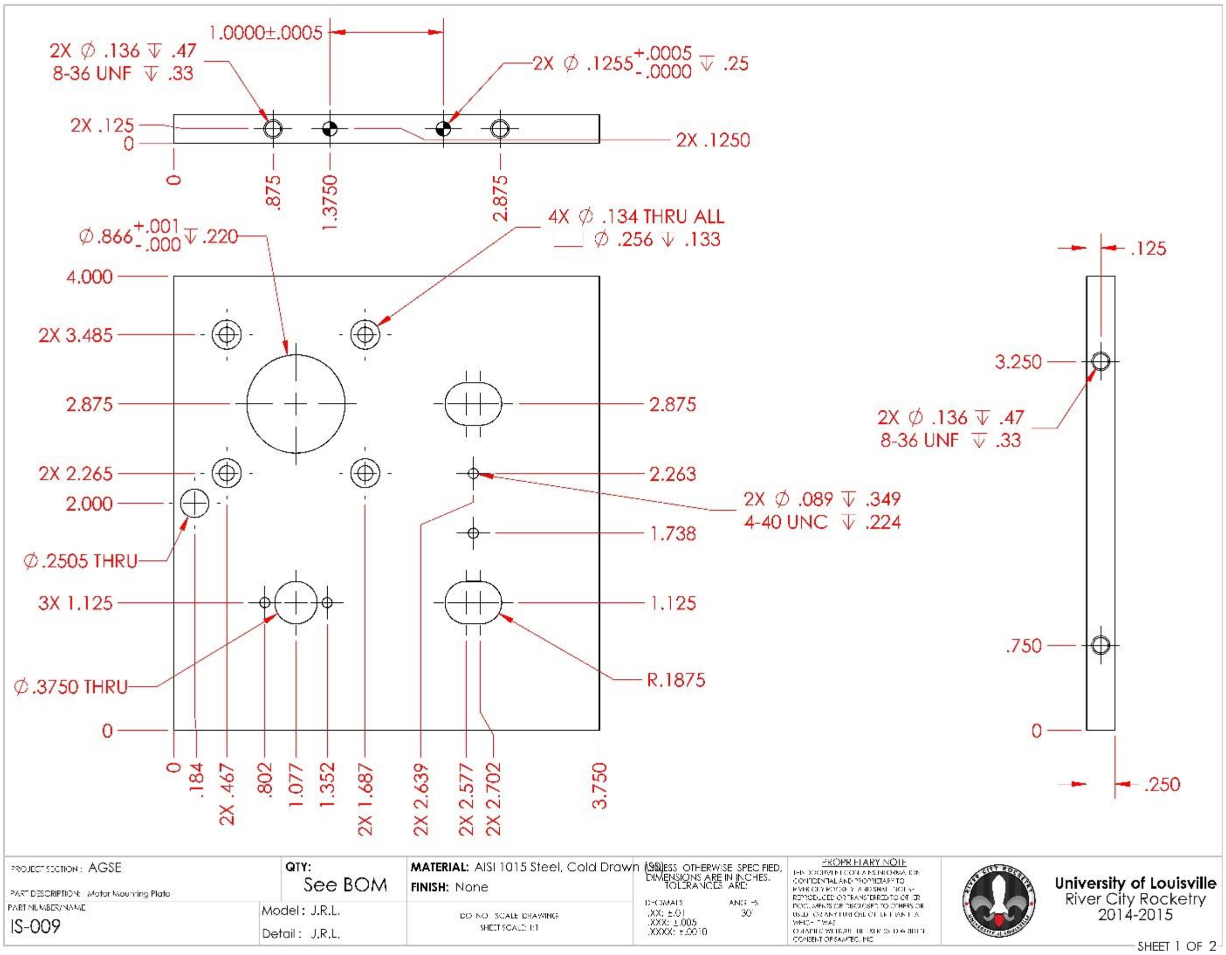


Figure 156: Mounting plate page 1.

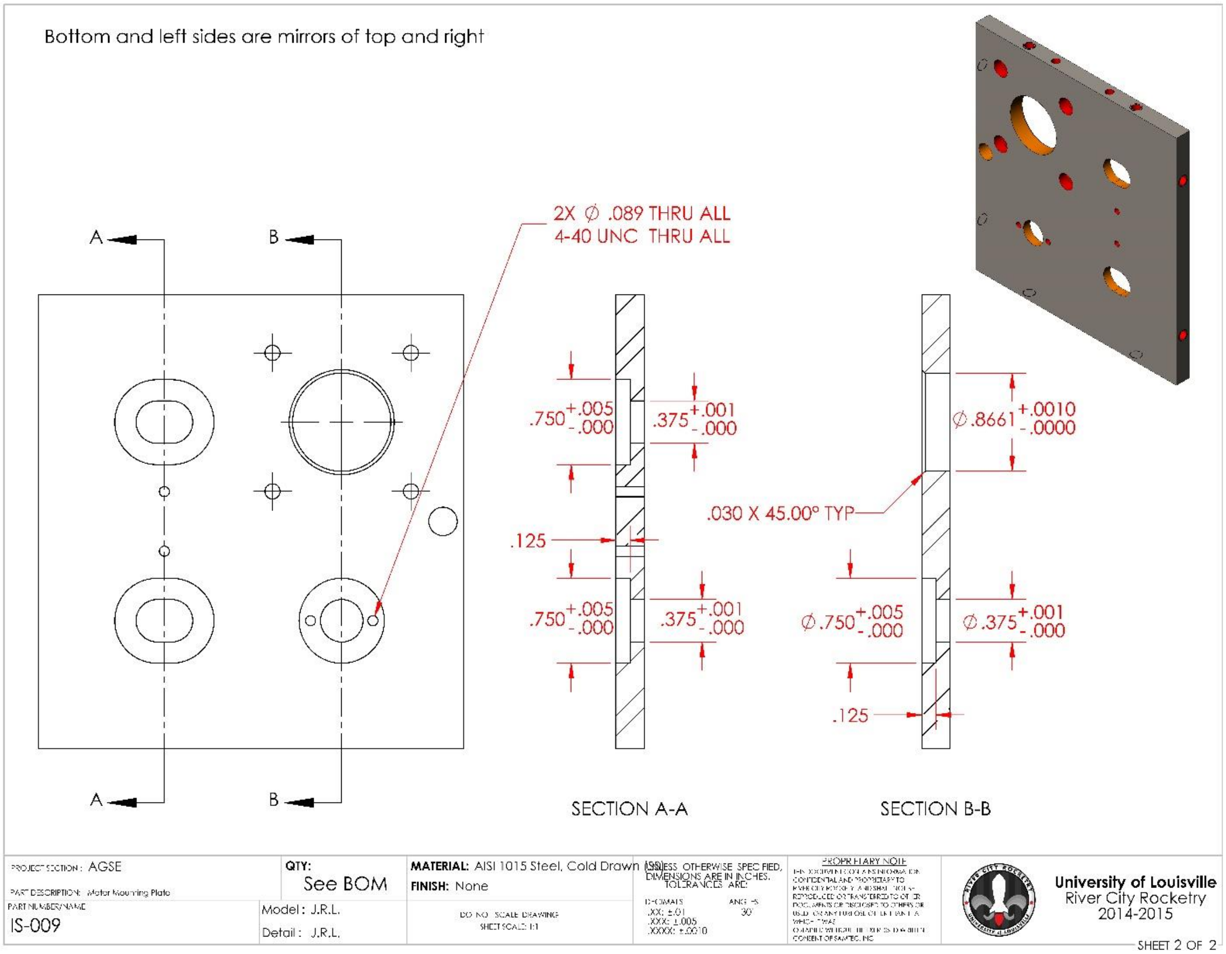


Figure 157: Mounting plate sheet 2.

Due to the possibility of wire-less signal during competition, the igniter is to be wrapped in shielding similar to the way the altimeters on the launch vehicle are shielded. The length of the igniter will be wrapped in aluminum tape to form a Faraday cage around the igniter conductor wire.

The igniter is going to be protected from potential damaging signals, a Faraday cage will be built around the igniter during launch. This will consist of running a 1/32 dowel along one side of the wire, adding aluminum tape around the length of the wire, and then using shrink sleeve to protect the tape. This will not need to happen over the entire length of the wire, instead it will protect only exposed wire and the rest of the igniter wire will be housed in a protected environment. The cross-section of the wire is shown in Figure 158.

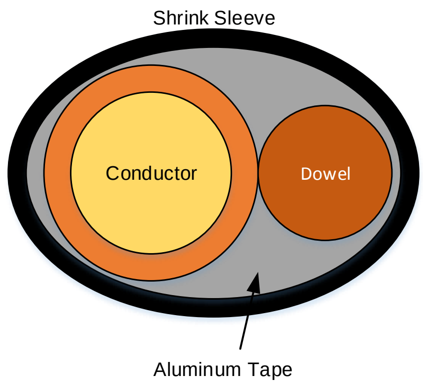


Figure 158: Augmented igniter.

The dowel was changed to one due to potential damage if an edge of a dowel caught on a motor grain during insertion.

Controls

Figure 159 shows the operational flow chart.

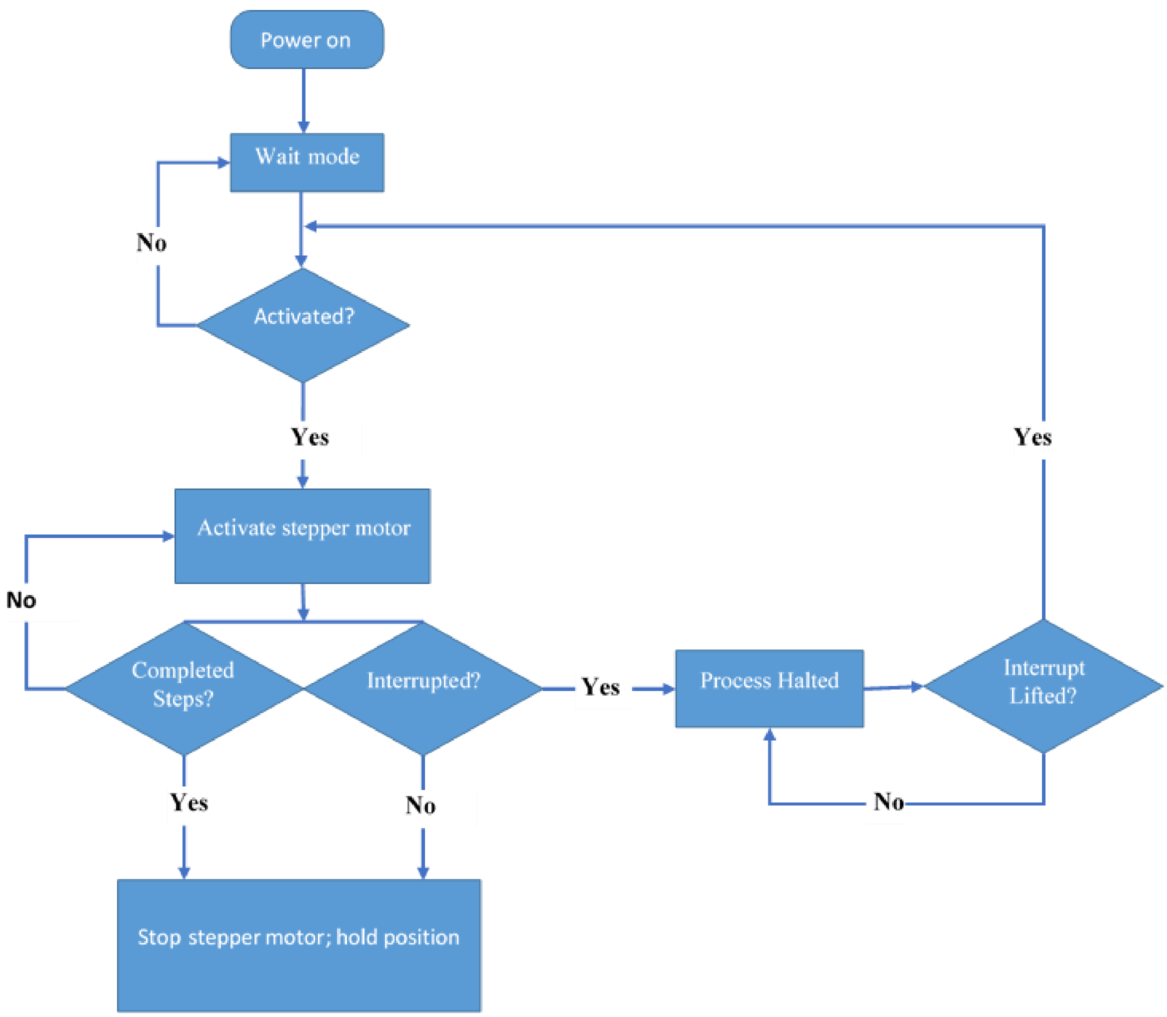


Figure 159: Operational flow chart.

The enable ignition power switch was added to the system. This is a competition requirement to ensure that no person on the launch field has their safety compromised through premature ignition of the igniter.

The interrupt feature of the Arduino Uno was also implemented. Upon the interrupt pin being switched logic low by the central controller, the stepper motor is immediately stopped halting the progress of the igniter. This is a safety feature that will be used in the event of an abort.

The components used in controlling the ignitions station are the Arduino Uno microcontroller, a corresponding Adafruit motor shield, and the stepper motor. Each component is described below. The open source licensing and documentation of the Uno were deciding factors in choosing the microcontroller. The libraries for stepper motor are included in the microcontroller software. The Arduino Uno provides the implementation for the I2C bus used in the igniter station communications.

Arduino Uno

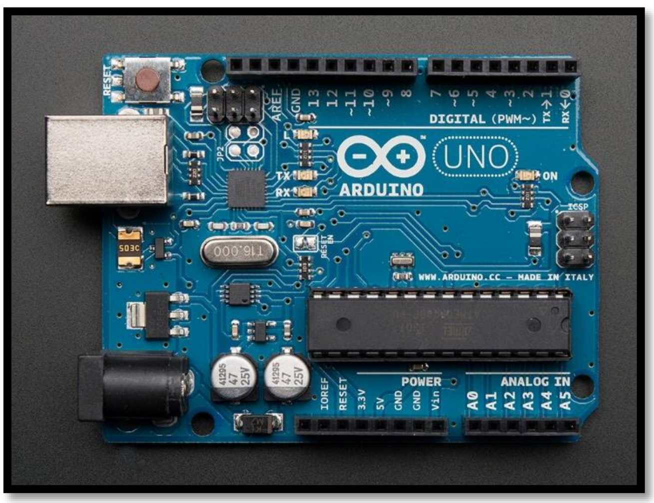


Figure 160: Arduino Uno microcontroller.

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. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

Adafruit motor shield

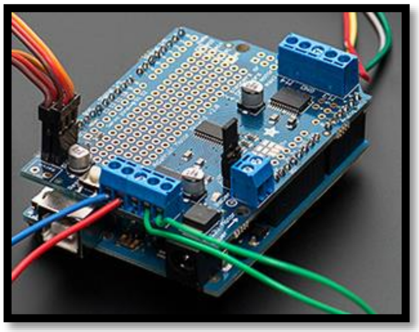


Figure 161: Corresponding motor shield.

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

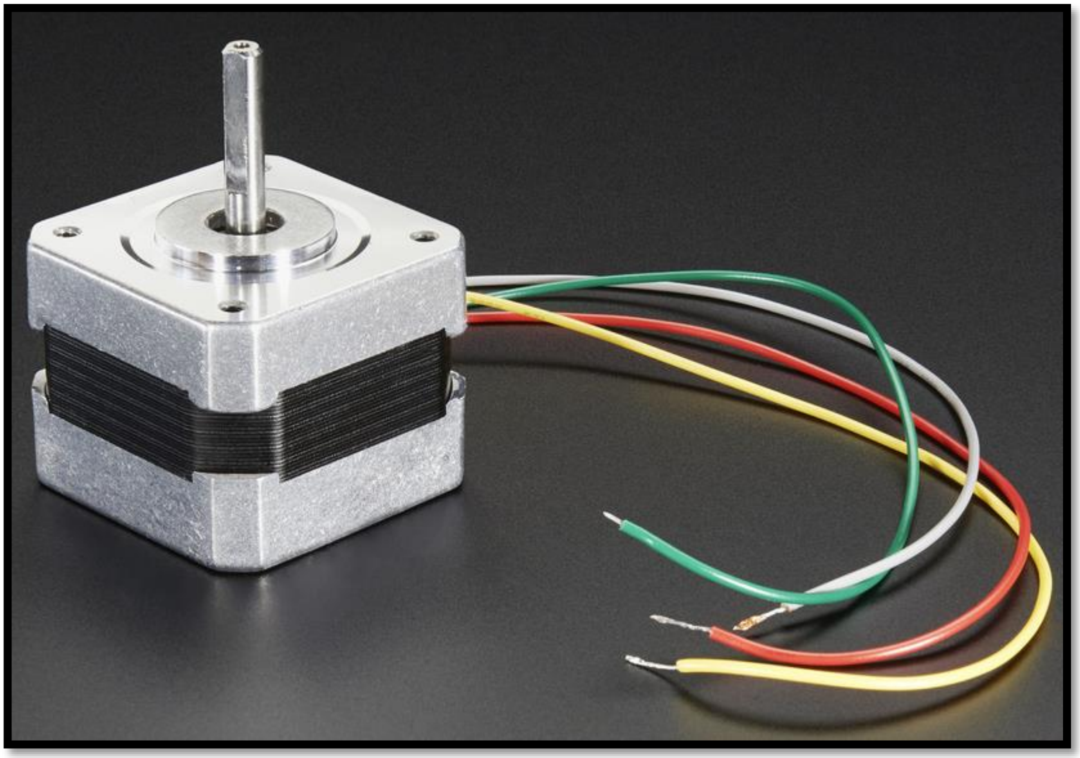


Figure 162: Stepper motor.

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 communications flowchart between the components is shown in Figure 163.

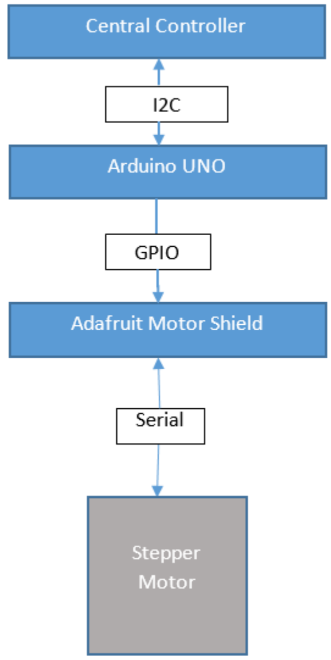


Figure 163: Component communications.

The central controller will send an activation to the Arduino Uno of the igniter station over the I2C bus. The Uno, connected through the on-board GPIO pins, drives the stepper motor to install the igniter into the motor.

Performance Characteristics

The circumference of the drive wheel is calculated using

$$C = 2\pi r \tag{56}$$

where r is the radius of the drive wheel. The number of revolutions needed to complete installation is determined via

$$N = \frac{L}{C} \tag{57}$$

where L is the total distance the igniter must move. The amount of time required is then calculated using

$$t = \frac{N}{\omega} \tag{58}$$

where ω is the rotational speed of the motor.

Table 59 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 59: Performance evaluations.

To accurately control the system, the number of total turns must be known. The number of turns is calculated using

$$N_s = \frac{L}{D} \quad (59)$$

where D is the distance traveled per motor step which is calculated using

$$D = F_c C \quad (69)$$

where F_c is the fraction of the circumference that the wheel travels per motor step. F_c is determined using

$$F_c = \frac{A_s}{360} \quad (61)$$

where A_s is the angle traveled per motor step. Figure 66 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 60: 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 3 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 3 consecutive successful cycles.
Stepper motor movement speed	Confirm speed is 60 RPM with stopwatch and taped flag passing marker. Verified after 3 consecutive successful attempts.
Igniter travel distance	Physical measurement of yellow tapped mark on igniter is visible above housing.
Abort functionality	Verify interrupt state by halting at any point during insertion.

Table 61: Test plan.

The stepper motor interaction with the Arduino has been tested thoroughly using a 12 volt power supply and using supplied libraries for the stepper motor. The interrupt functionality is tested using an active low button attached to the interrupt pin. It has been observed that the stepper motor halts when the button is depressed (which is logic low on pin) and resumes when button is released. This confirms desired functionality of interrupt pin and ensures safety

Additional testing needs to be done to ensure proper entry and exit out of interrupt state from each possible initial mode. Such as power on during abort, abort during every part of code execution and abort after igniter installation is complete. This will ensure proper behavior upon a cleared abort status. Below is a figure depicting how the interrupt pin was tested.

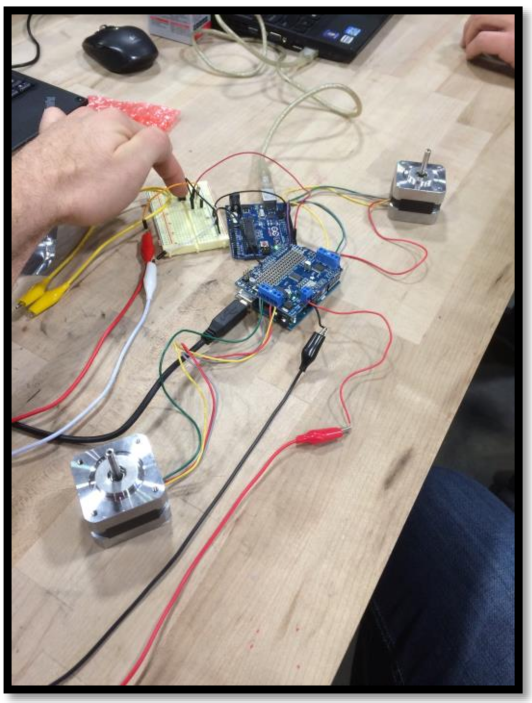


Figure 164: Igniter installation interrupt pin testing

6) Fabrication

Instead of describing the manufacturing of components for each subsection, it was determined that the type of component, needed precision, and required manufacturing type, would be a better method of

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 62: 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 165: Flat plate example.

Components classified as flat plates will be produced using the waterjet located at G.E. Firstbuild. The waterjet advertises a tolerance of +/- 0.008 inches and all parts have been designed with this in mind. Figure 166 shows the waterjet cutter which will be used. It has a cutting area of 48”x 96”.

Figure 166: The waterjet.

To take advantage of the high material efficiency potential of the cutting method, nesting software is being used to minimize material usage. An example is shown in Figure 167.

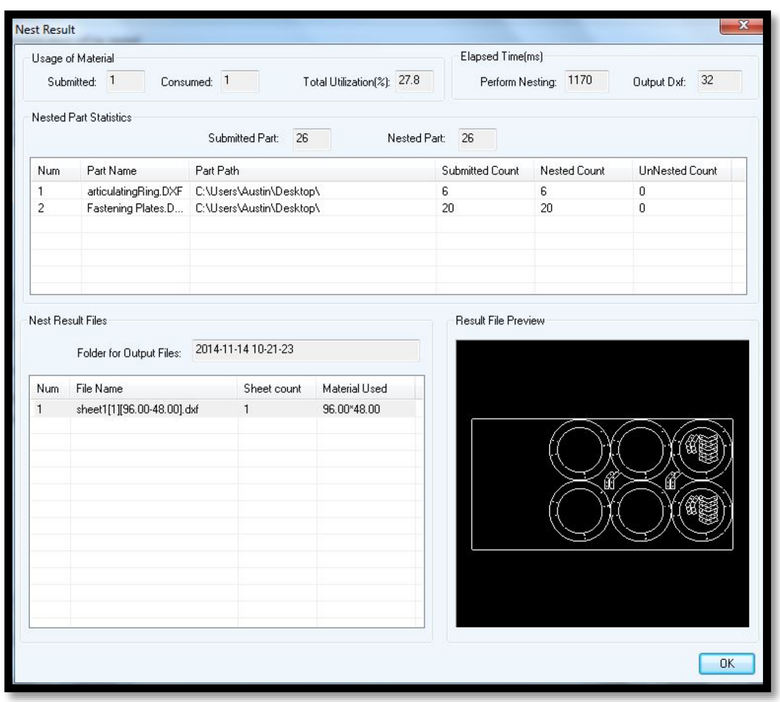


Figure 167: Nesting software.

Parts cut using the waterjet do not have flat exterior edges and thus two edges which have been cut cannot mate accurately. Figure 168 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 168: 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 169.

Figure 169: 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.

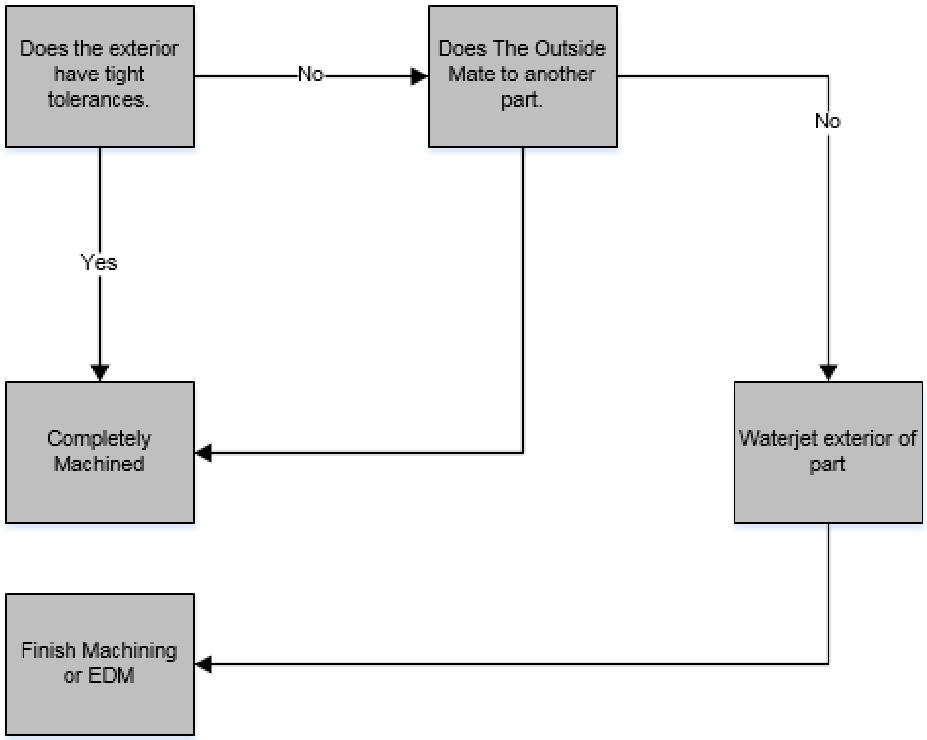


Figure 170: Flowchart depicting whether or not a part can start with a looser process.

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 G.E. 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 G.E. Firstbuild, and complex machining operations will be performed by ATLAS Machine and Tool. Below are images of machined precision components.

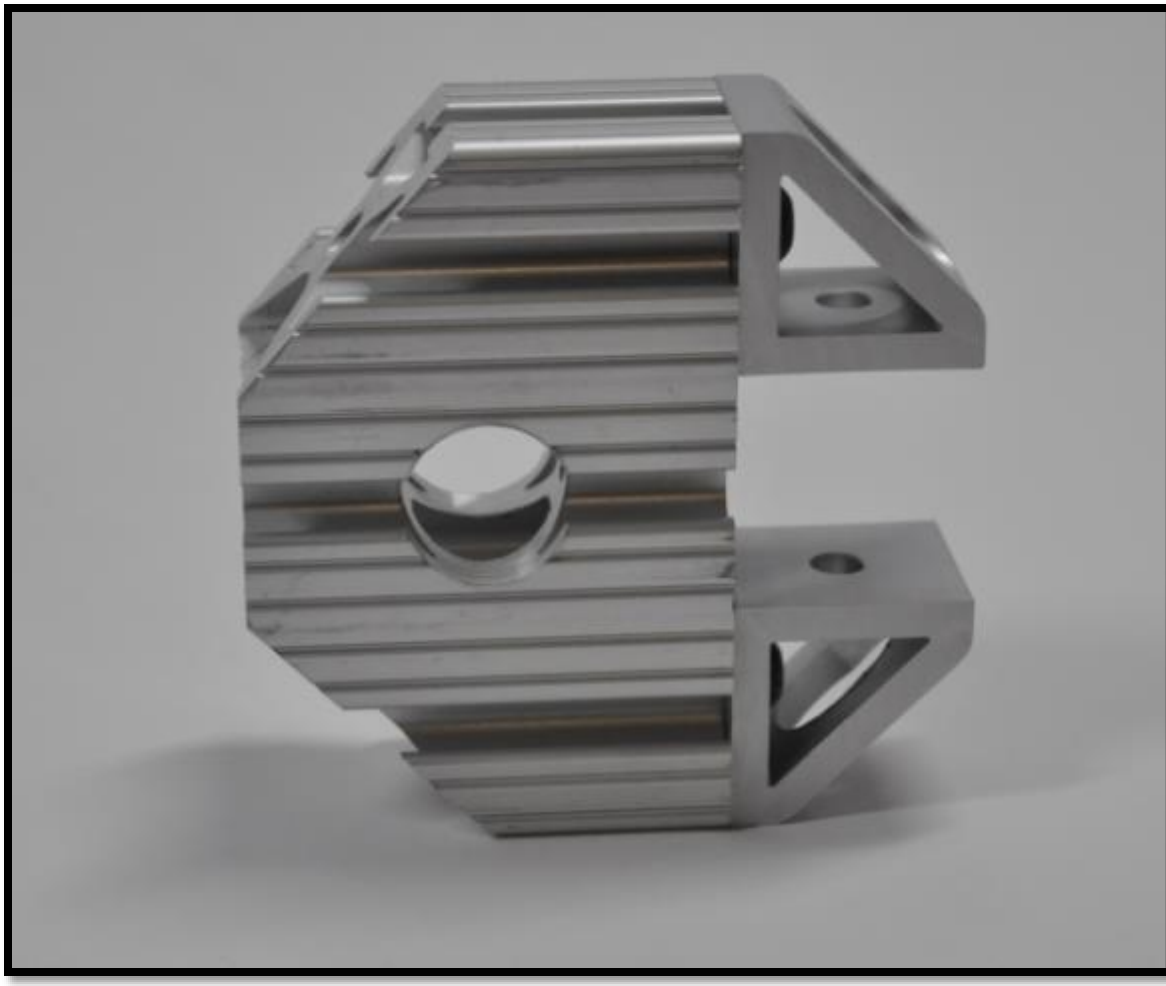


Figure 171: Arm connection component.

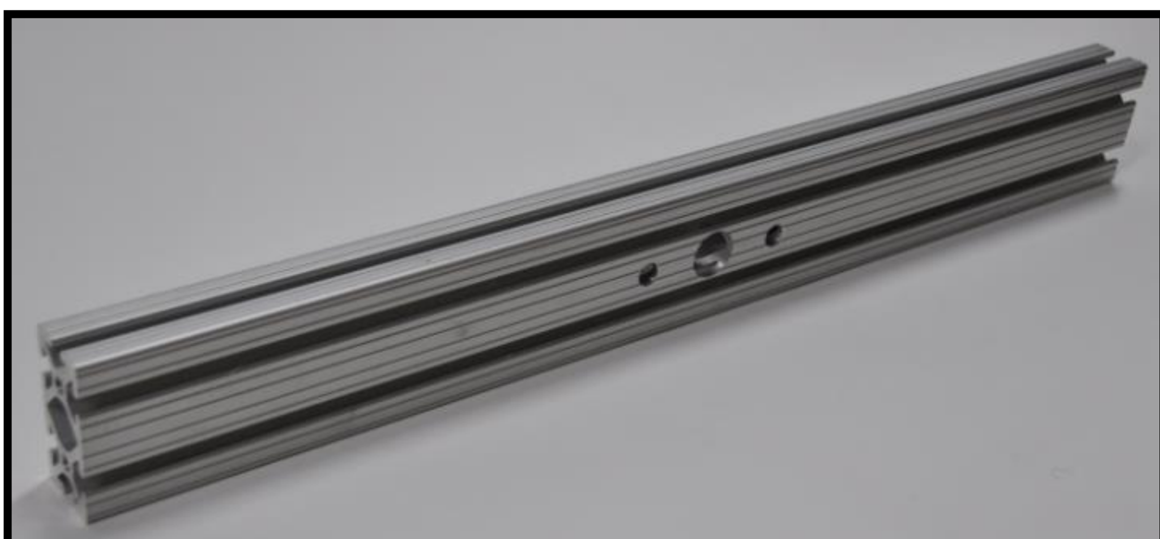


Figure 172: Rear track support for vehicle erection system.

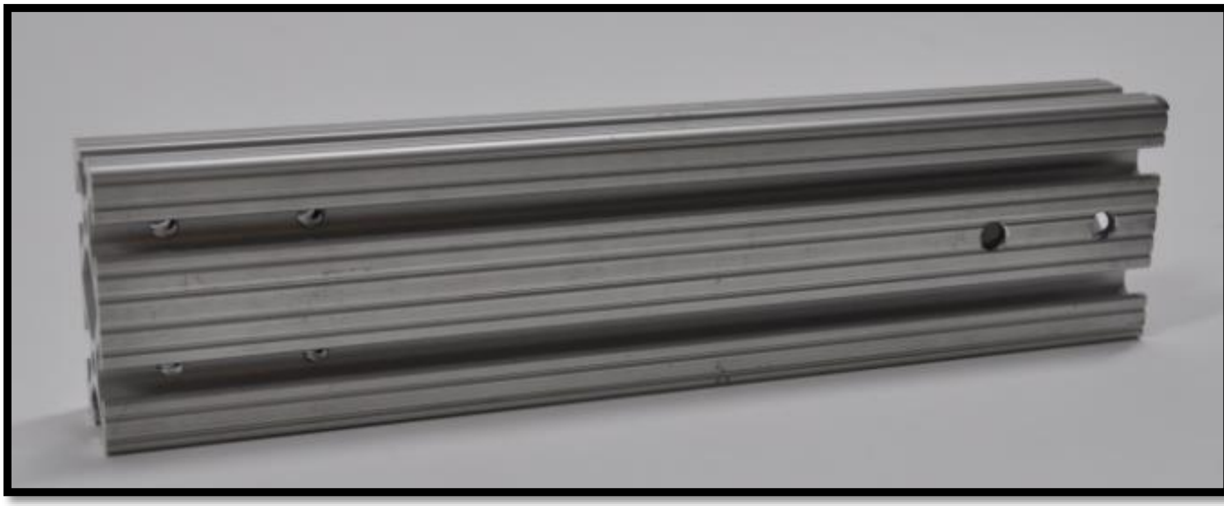


Figure 173: Ground station support beam.

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 174: Spring tensioner.

Figure 175: Threadless ball screw nut.

Figure 176: Gripper arm.

7) Electronics Systems

Overview

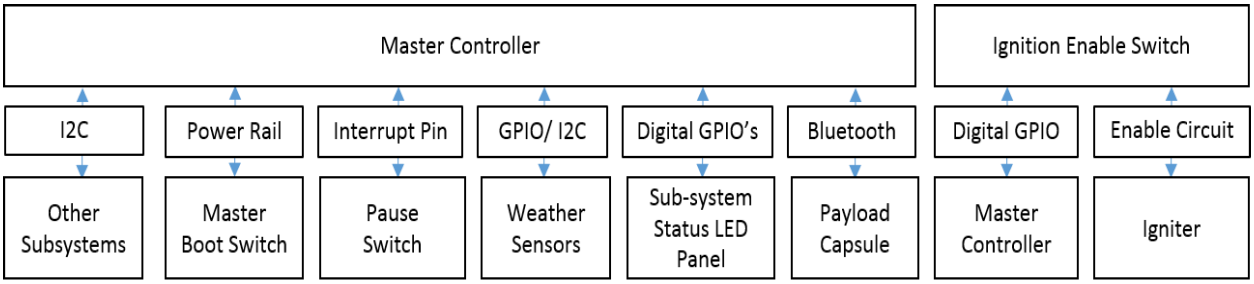


Figure 177. Housing electronics overview.

The electronics housed within the ground station are illustrated above in Figure 177. As the figure shows, the electronics of the ground station consist of a collection of microcontrollers, sensors, and interconnections between. All system monitoring is provided through the housing electronics via an indication/control panel (shown later in

Figure **178**) that is accessed from the side of the AGSE. The user interface provides a HMI (human machine interface) for the launch setup team and field safety officer. The power distribution is discussed in the "Power distribution" section of the ground station.

Integration

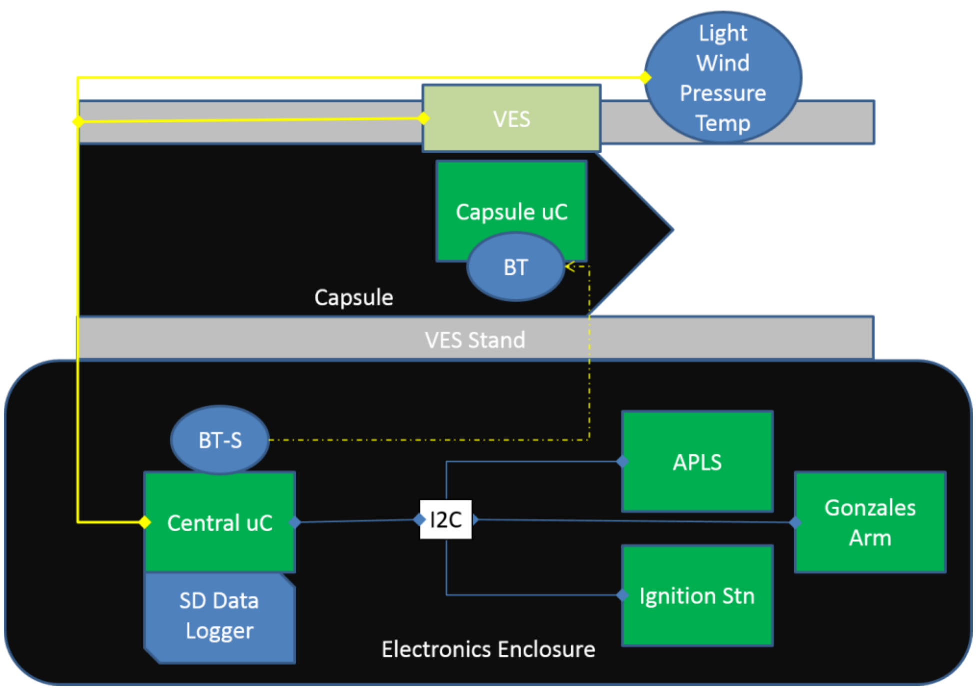


Figure 178. System connections.

Illustrated in

Figure **178**, 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 (blue lines), Bluetooth (dotted yellow lines), and GPIO interface (solid yellow lines). The central controller initiates all subsequent processes including: station power, device boot sequence, manual halt procedures, weather data collection, wireless communication and logging system status to SD card for later review.

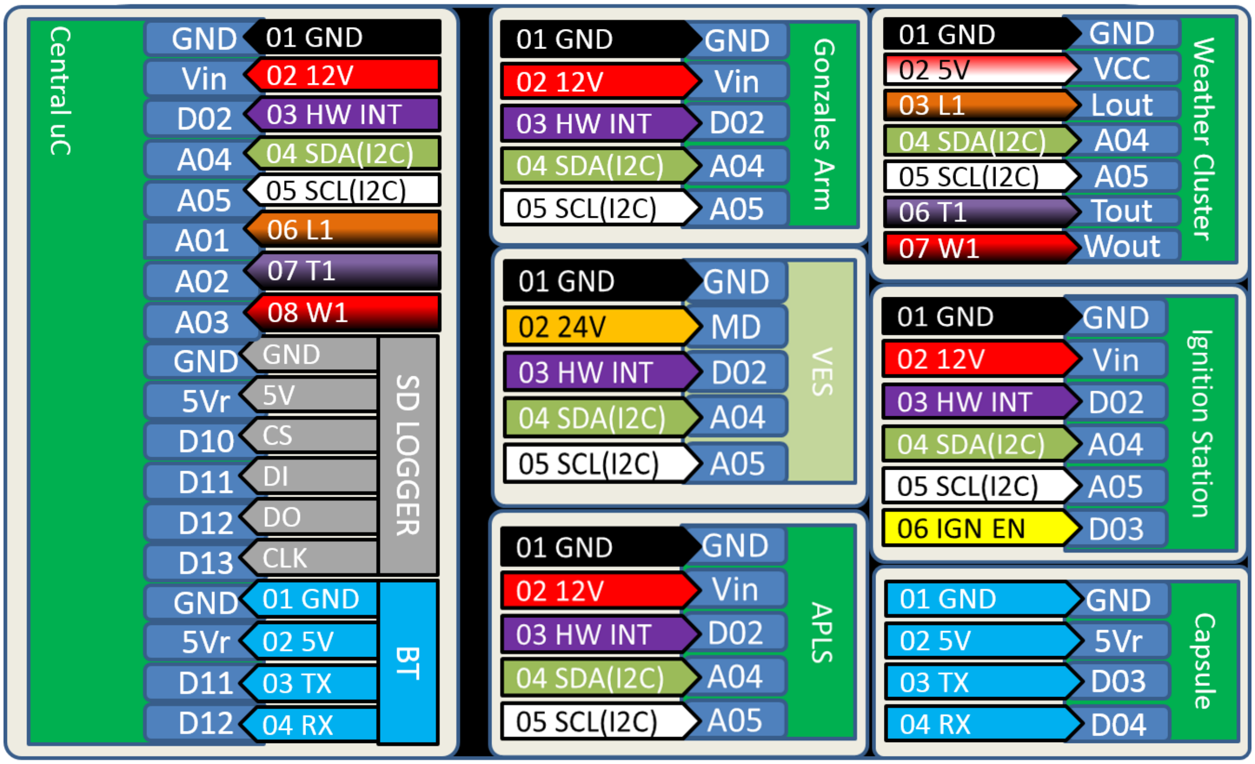


Figure 179. Wire harness and pin allocation.

The integration of electronic subsystems is physically done by means of connectivity. The wire harness outline in Figure 179 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 beige section represents the external connections from the VES system. 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 below). 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.

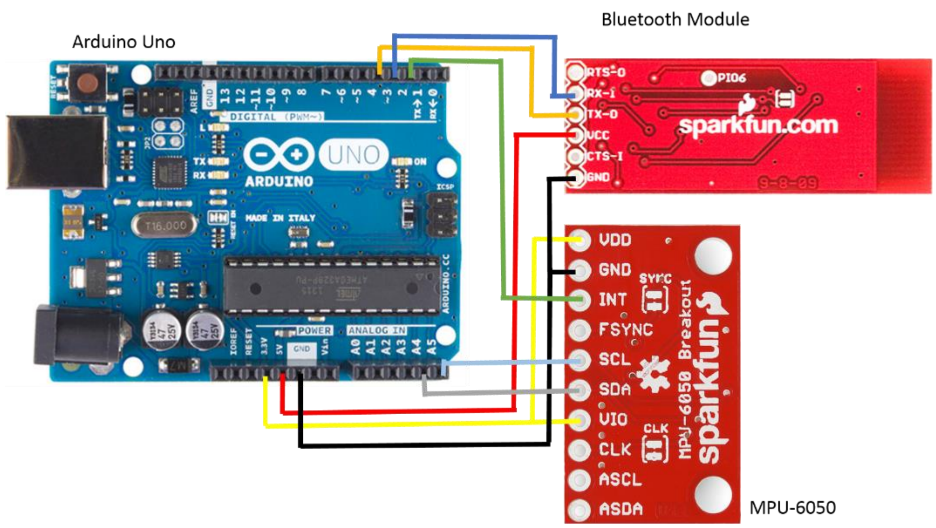


Figure 180. Subscale Bluetooth connections.

A harness was constructed for subscale testing to connect the microcontroller, gyroscope, and Bluetooth module during the subscale launch. The harness design is shown above in Figure 180. A similar wire harness will be made to fly with the full scale subsystem.

AGSE Power Distribution

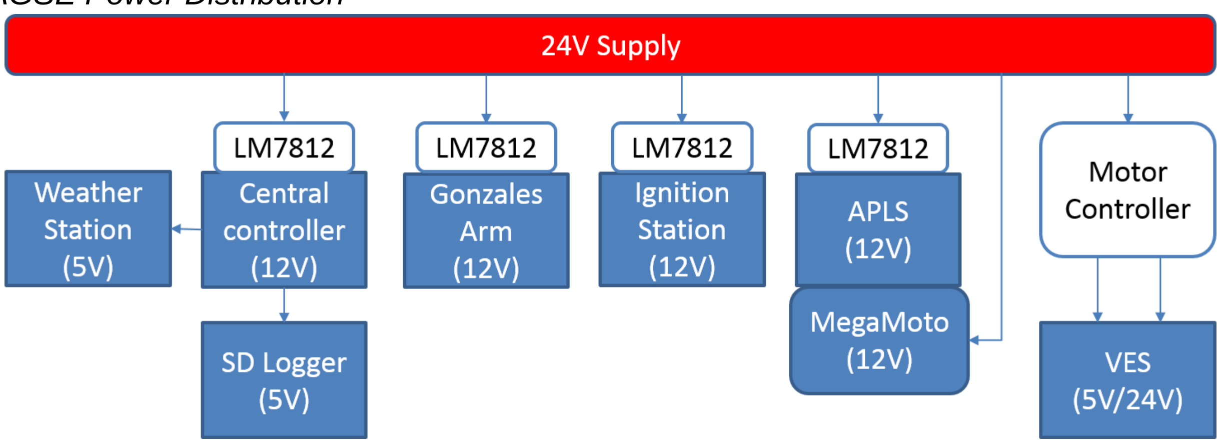


Figure 181: AGSE voltage lines.

Power is provided to the system by regulating the power contained in the dual battery (24V) supply. The regulated line path is shown in Figure 181. 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. It will power the VES (Arduino Esplora) microcontroller. All other microcontrollers in the AGSE use a regulated 12V line provided by the commercially available 7812 IC; the IC removes unwanted noise in the processing electronics.

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. The

APLS system will be programmed to run each outrigger motor separately to avoid premature power drain.

Weather station

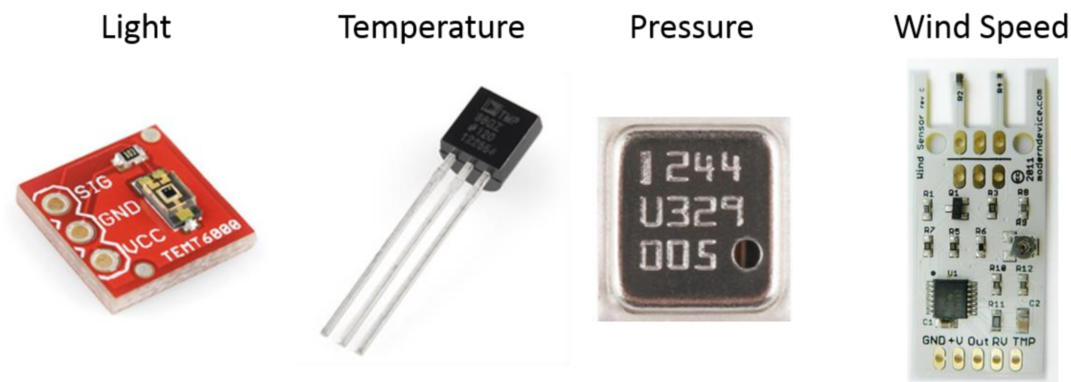


Figure 182. The weather cluster sensors.

The weather station is a cluster of four sensors. The cluster will be placed at the free-swinging end of the VES launch rail. The cluster reads temperature, light, air speed, and pressure with sensors shown in Figure 182. The light sensor is the TEMT6000 that outputs a voltage that changes with intensity of light incident to the sensor. The temperature sensor is the TMP36, and outputs a voltage that is dependent on the ambient temperature surrounding the sensor. The sensor reads temperature at a resolution of 10mV per degree Celsius. 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 VCC depending on the air speed acting on it. The light, temperature, and wind speed will be read through analog pins A00, A01, and A02.

The fourth sensor is the *Bosch* BMP180. The BMP180 is a barometer that measures pressure and relays the data through the I2C bus to the central controller. Features of the BMP180 include low noise measurement and low power consumption. The barometer requires no calibration for expected operation.

The weather station sensors will be tested discretely for expected functionality before being integrated onto proto-board or custom PCB. Each sensor will be exercised in accordance to the expected sense. The temperature sensor will be tested against a calibrated thermometer to acknowledge drift and error in the sensor. The light sensor will be tested to sense light vs. dark. A binary value is expected as the sensor will output a logic value depending on the illumination present. The wind speed will be tested in various air speeds. The lowest speed being “0” to detect calm weather, and the highest being safe wind speed for launch. The barometer will be tested against a calibrated barometric pressure sensor. The barometer is the most complex sensor in the cluster and was implemented in the 2014 competition launch. It is expected to have the least amount of error in the cluster.

SD Logger

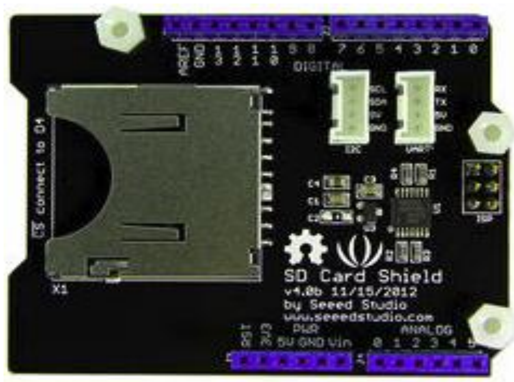


Figure 183. Seeed SD card shield V4.0

A data logging SD card board (shown in Figure 183) is attached to the central controller through the SPI bus. The board is stacked directly to the central controller without external wiring or power. As Figure 179 shows, the SPI bus for the Arduino Uno is implemented 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.

The SD logger will first be tested to log the MPU-6050 data stream available from the subscale launch setup. After validating the data logging capability, the board will be added to the AGSE central controller to log the weather station data.

Communication

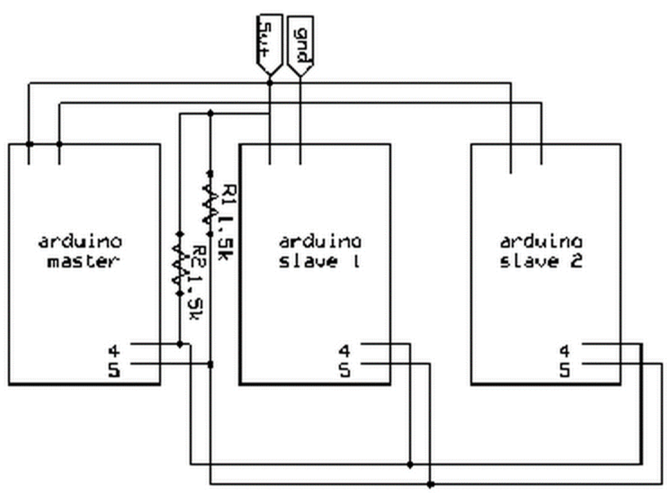


Figure 184. Example I2C network

The AGSE communication operates as a distributed architecture; multiple microcontrollers communicate through an I2C bus like the example configuration shown in Figure 184. As shown in the harness diagram, each controller allocates analog pins

A04 (SDL) and A05 (SDA) to communicate on the bus. The bus requires two pull-up resistors to function properly.

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 *wire* library handles all "low-level" communication operations. To implement the protocol, an address is needed with the data to send. Microcontroller communication will be 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 63. I2C commands

As outlined in

Table **63**, 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.

Wireless Communication Overview

The rocket capsule requires ground station communication for status updates and data transmission. The communication scheme will ensure transmission of the following: payload capture signal (to close the payload bay doors) and launch data (up to 10m). To meet the transmission needs, Bluetooth communication has been implemented. (A separate option included direct wire communication that forcefully separated with vehicle launch. The wired connection introduced structural risks to the vehicle launch and would have the added risk of disconnection when raising the rocket. Both issues are avoided with the use of Bluetooth.)

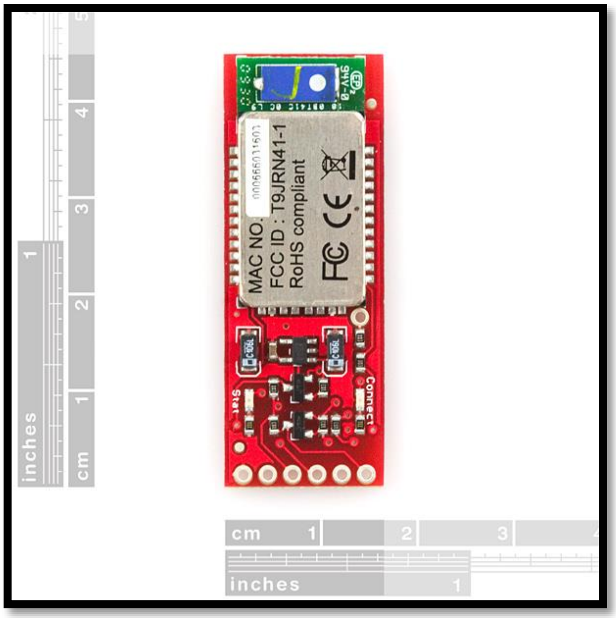


Figure 185. SparkFun Bluetooth mate gold.

The station-capsule communication interface consists of two identical Bluetooth transceivers. Both transceivers are the module shoe above in Figure 185. The Bluetooth Mate Gold is a commercially available Bluetooth module from the SparkFun online electronics company. Each module transmits and receives data between the AGSE microcontroller and the capsule microcontroller.

As illustrated in Figure 186 below, the Bluetooth module makes use of 2 digital pins on the microcontroller. The module acts as a virtual transmit/receive line from the station to the capsule. The "data pipe" design keeps all Bluetooth specific functions in the background, while the Arduino only interacts with a virtual serial output. The AGSE software only deals with sending and receiving serial data, rather than dealing in frequency-hopping protocol that Bluetooth requires. At the highest level, the capsule and station become connected when the AGSE is powered. The connection stays active until the AGSE is powered down or the capsule goes out of range during liftoff.

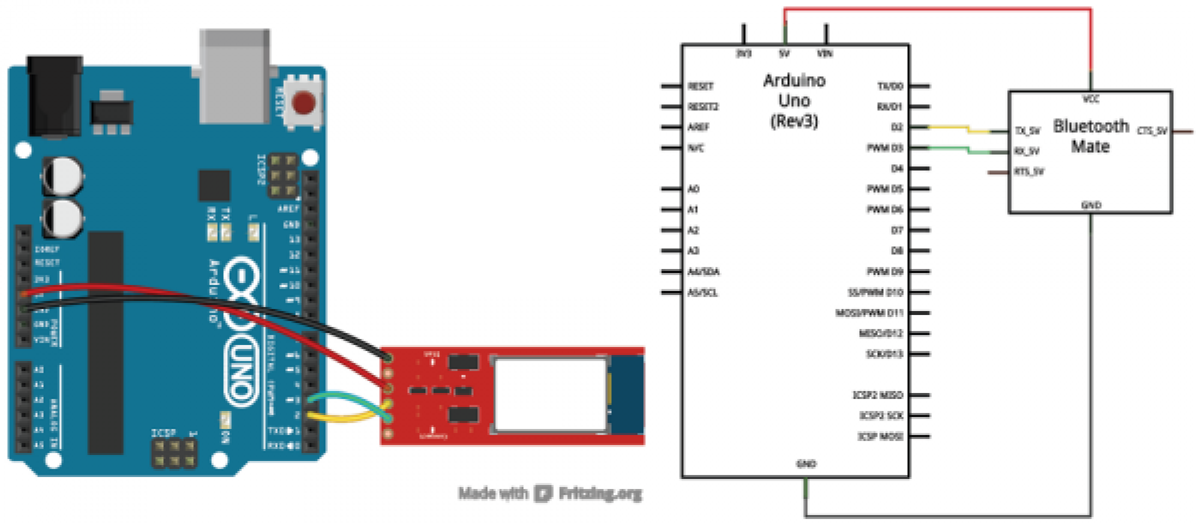


Figure 186. Uno hardware hookup.

Operation

The capsule module operates as a “slave” on the Bluetooth network. The capsule module must be in “slave” mode as it will be powered before the AGSE module is powered on. The capsule will be powered when installed into the rocket. Then, the rocket will be installed into the AGSE. The AGSE will then be powered on and will power the “master” Bluetooth module.

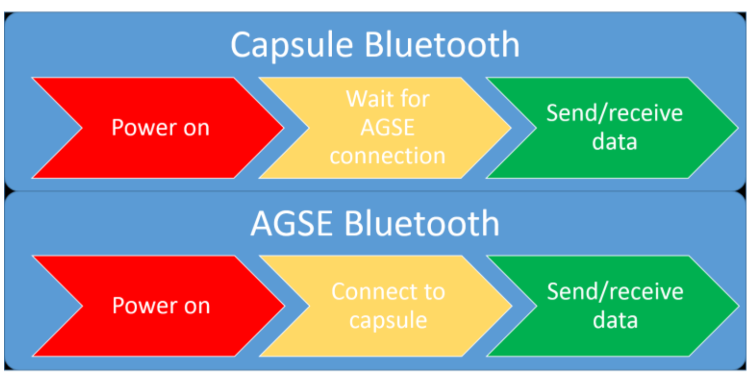


Figure 187. Bluetooth startup operation

As outlined in Figure 187, the capsule waits for the AGSE to be powered to connect. Then, the “master” module will connect 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. In the case that the connection is lost, the slave will return to a “waiting for connection” status. The AGSE will then time-out after 60 seconds where the ground station will reconnect to the waiting capsule.

The Bluetooth modules serve only as “data pipes” illustrated in Figure 188. The modules have no part in calculations; they are used to relay information. 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.

Figure 188. Data pipe operation.

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 189. 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.

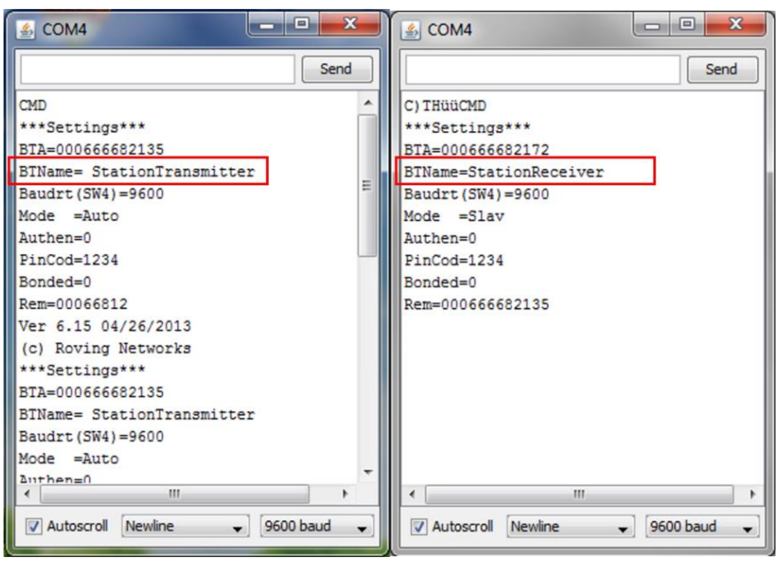


Figure 189. Bluetooth serial interface (unique names)

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 was the "SY" command to set the transmit/receive power output. The device has the ability to attenuate the output power in order to conserve supply battery life. Our device is 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

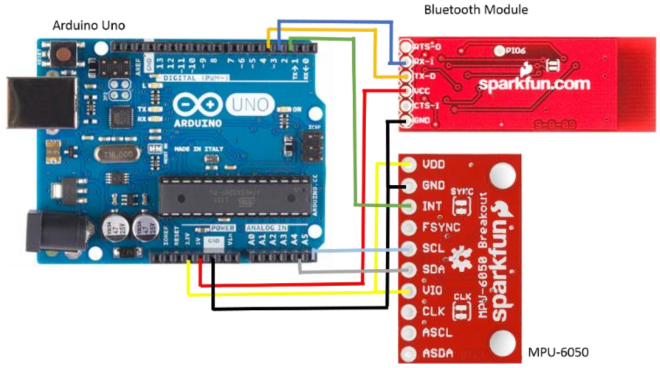


Figure 190. Bluetooth orientation transmitter.

The Bluetooth communication has been tested and validated to receive and transmit serial data. The pair of transceivers were functionally tested to wirelessly transmit 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 (shown in Figure 190 above) read the orientation data from the MPU-6050 and broadcast the data through Bluetooth. A receiver setup (shown in Figure 191 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. Further testing of the Bluetooth modules will be done with the devices installed in fiberglass.

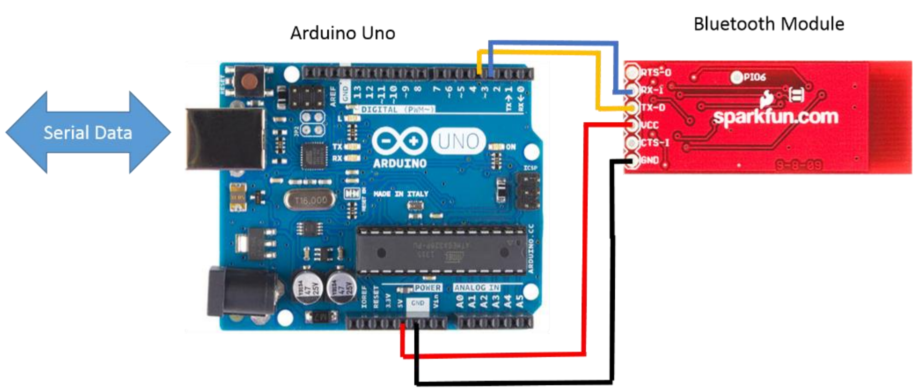


Figure 191. Bluetooth receiver.

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 192 below) was taken of a cell phone that was able to pair with the Bluetooth transmitter. The data shown in the screenshot is the received YPR values from the accelerometer. 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.

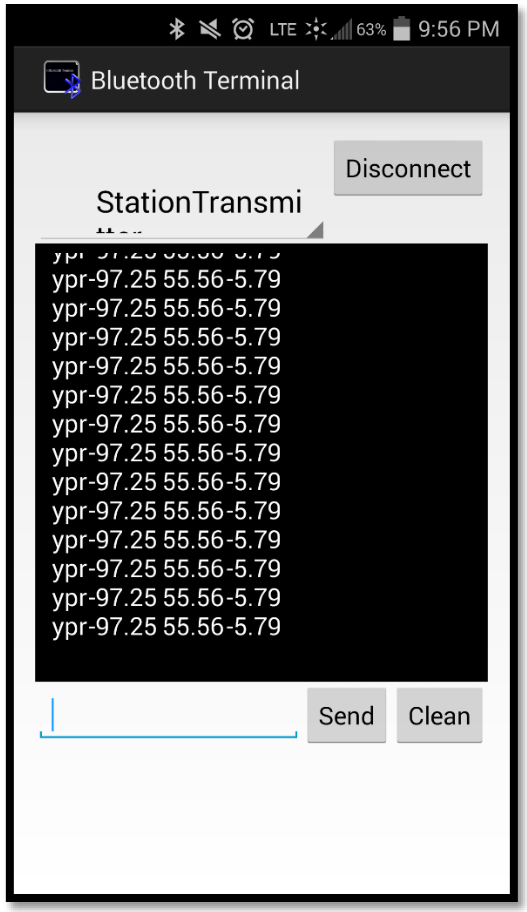


Figure 192. Cell phone screenshot.

The communication setup was tested at the first sub scale launch in Memphis, TN. The communication dropped out early due to the modules not being configured correctly. As mentioned above, the new setup allows for automatic connection between the transceivers. We will test this functionality in the next test launch of the rocket. We expect to keep constant communication of acceleration data streaming between the modules. We predict that the module will communicate post launch for a maximum distance of 10m into liftoff. This will be verified by use of a time stamp in the transmitted orientation data, to map disconnect.

Wireless Integration

The module will be installed in all coming test launches. During subscale, the gyroscope transmitter is installed in the rocket while the receiver is connected to a test PC on the ground to live monitor the data stream. For the full scale testing, the communication device is placed in, or near, the capsule and will be connected to the capsule microcontroller to relay the required information. There will be opportunity to communicate the orientation data on competition day as well.

User interface

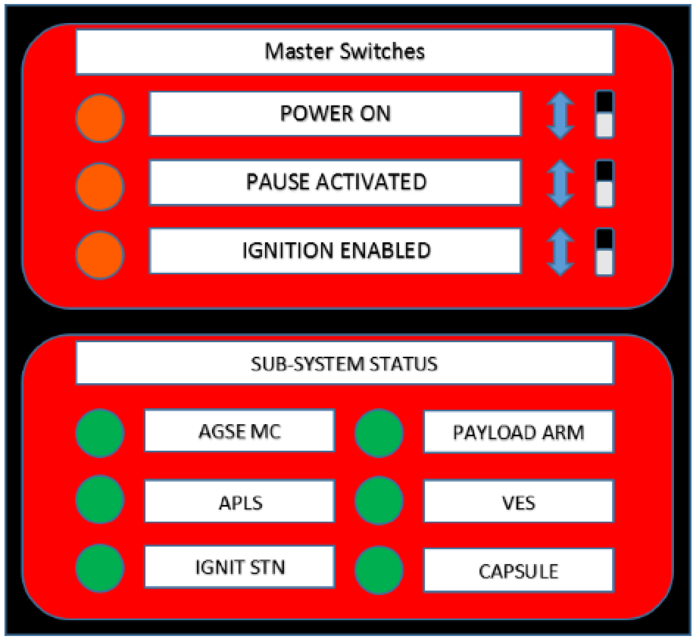


Figure 193: AGSE User Interface.

As shown above in Figure 193: AGSE User Interface., the launch staff will have access to an external user interface. The interface includes master boot, pause, and ignition toggle switches. As outlined in Figure 194 below, 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 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 194. 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 so that the igniter will not energize without the approval of the field safety officer.

Testing

Testing will be conducted to qualify gauge of wire used in each harness. This testing will include powering a static load on the harness with the intended supply voltage regulator. Success will qualify the wire harnessing, connectors, and regulators used in the ground station. We expect to correctly size the wire harness by matching the rating of the wire to the observed power needs of each subsystem.

The I2C bus will be tested for correct “call and response” to system commands at each phase of launch set up. A test sequence of transmissions will be sent and scanned on the bus of each subsystem controller to verify communication in testing and competition.

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.

The pause interrupt will be tested to immediately pause upon activation of the master pause switch. The test will be performed after the master boot test is repeatable and successful. All systems will be powered on and allowed to boot to a pause. The pause will be deactivated, and all systems will follow the predetermined startup sequence. The pause will be cycled (off for 10 seconds) at 15 second intervals. 15 second intervals allows the behavior of the pause to be observed in each stage of the competition. For a successful test, all electronics must pause to a recoverable state to resume process upon deactivation of the switch. Any malfunction resulting in unfinished routine will be considered a failure.

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.

8) Statement of Work Verification

Table 64 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 platform will start 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 into the AGSE supply line. “Golden Rule” interrupt will be assigned in software to ensure enable/disable has priority in system execution.
After the master switch is turned on, a pause switch will be activated, temporarily	A secondary toggle switch will be implemented on the AGSE to halt all

halting all AGSE procedure and subroutines. This will allow the other teams at the pads to set up, and do the same.	operations for safety and setup. The second toggle having all e-stop priority aside from the master switch.
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 a master arming switch. Once payload is stored/rocket raised, the system will enter a scheduled halt status. Power will be supplied to ignition station microcontroller, but not to actuating motors. This will ensure the highest safety margin for rocket ignition. The master arming switch activation will allow the microcontroller to continue with automated igniter instillation. The master arming switch shall have possibility of arming a TBD distance away from AGSE to further ensure safety of arming staff.
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 AGSE systems will be controlled autonomously by PC/Microcontroller systems. All launch processes will be automated, except 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	All components and procedures will fail safely in a recoverable state if pause sequence is initiated. Specific fail-safe implementation will be outlined in future failure mode evaluations. Communication will exist between AGSE and vehicle to ensure vehicle does not close while arm is inside the vehicle.
The system must complete all tasks within 10 minutes	The time requirement has been separated by sub-station and the amount of time will be factored into the detailed design.
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 has been designed with remote payload retrieval in mind. Payload capture will be able to reach pre-determined area below ground station and outside vehicle mold line.

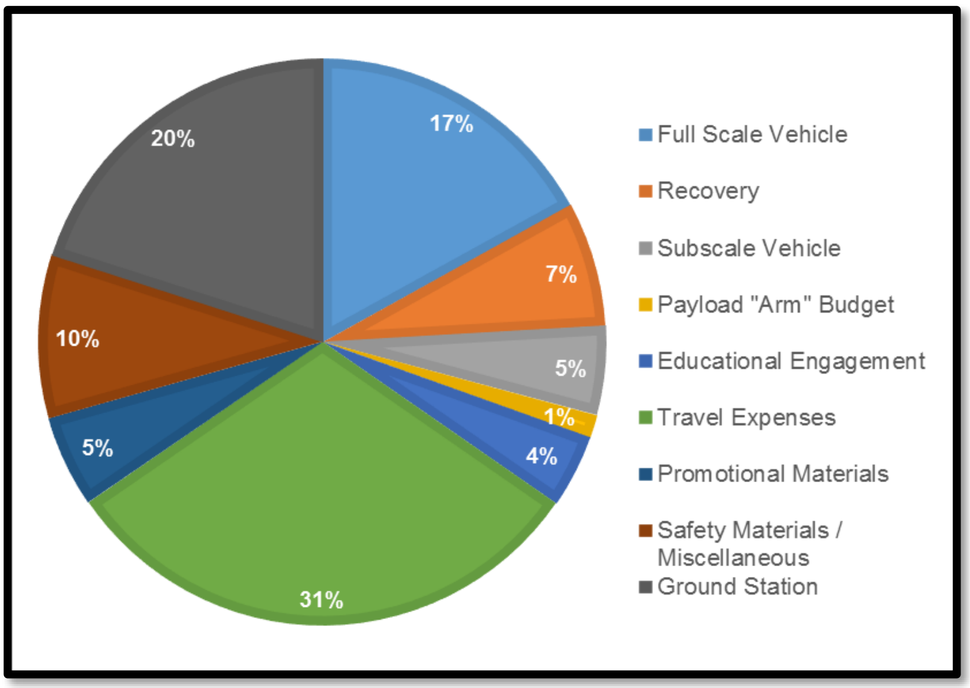
No forbidden technologies will be utilized	No forbidden technologies will be used.
A master switch to power all parts of the AGSE, the switch must be easily accessible and hardwired into the AGSE	A fused power block will isolate all devices from power supply.
A pause switch to temporarily terminate all 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 PC/microcontroller will have control of indicating power/pause status through an Amber LED panel indicator. The LED flashing will be implemented through PWM control from microcontroller with inputs from both power switch and pause switch.
An all systems go light to verify all systems have passed safety verifications and the rocket system is ready to launch	"All Systems Go" LED indicator will be implemented on launch station to verify LCO's approval.

Table 64: AGSE SOW verification.

Section 5. Project Plan

1) Budget Plan

Overall Tentative 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**



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

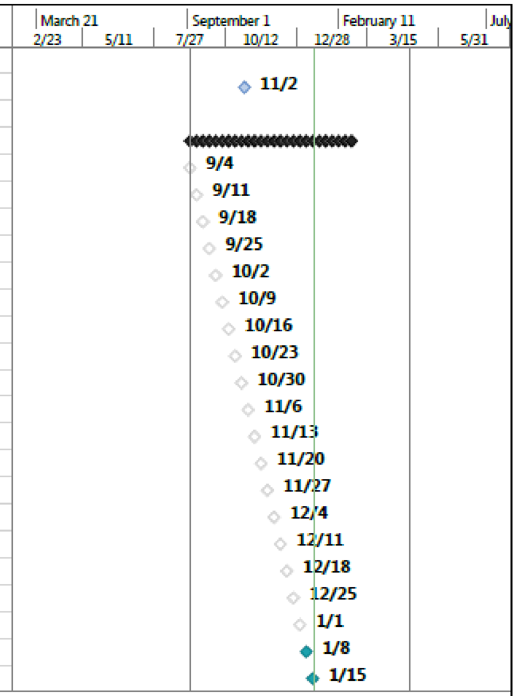
Kickstarter: For the past three competition years, River City Rocketry launched a Kickstarter site to connect with the community and gain support. Kickstarter is a fundraising platform that allows creative projects to find support from people near and far. River City Rocketry offered various rewards to its supporters such as custom science boards, team t-shirts, and even advertisement or logo space on the rocket so that sponsors have a personal connection to the team and project. The site was a huge success for the team over the years. By having a presence on Kickstarter, River City Rocketry has been able to share with the community their passion for science and rocketry.

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	
24	Design Meeting 20	0 days	Thu 1/15/15	Thu 1/15/15	



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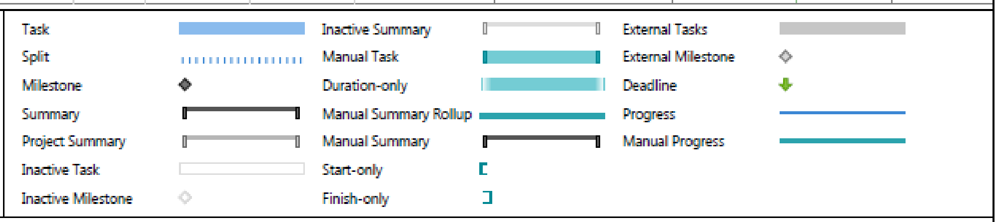

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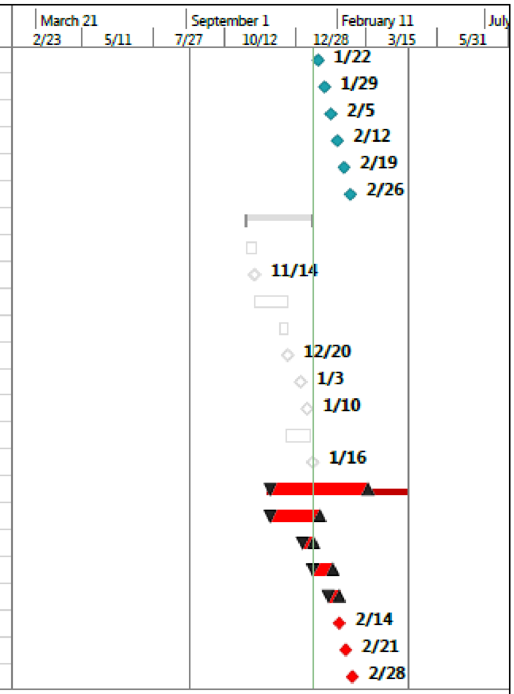
Figure 195: Overall project timeline. Page 1.

ID	Task Name	Duration	Start	Finish	Predecessors
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 12/1/14	Mon 3/16/15	
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	0 days	Sat 2/14/15	Sat 2/14/15	
47	Secondary full scale launch	0 days	Sat 2/21/15	Sat 2/21/15	
48	Final full scale launch	0 days	Sat 2/28/15	Sat 2/28/15	



Project: OverallSchedule.mpp
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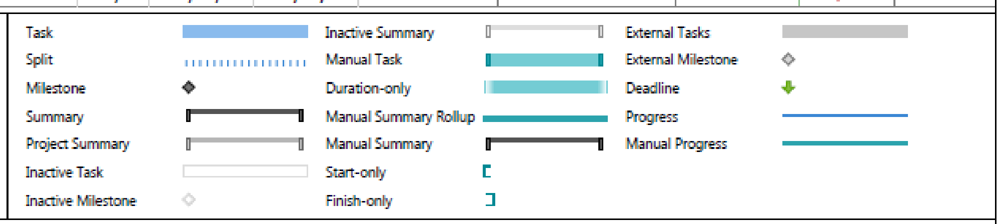
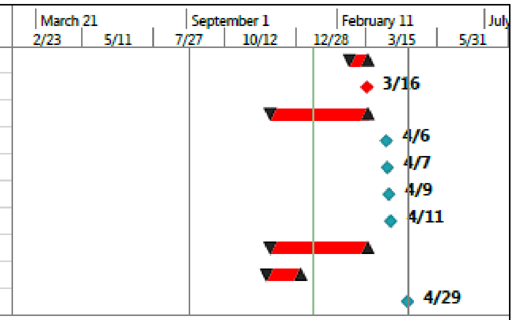


Page 2

Figure 196: Overall project timeline. Page 2.

ID	Task Name	Duration	Start	Finish	Predecessors
49	Write FRR	14 days	Wed 2/25/15	Mon 3/16/15	
50	FRR Due	0 days	Mon 3/16/15	Mon 3/16/15	
51	FRR	76 days	Mon 12/1/14	Mon 3/16/15	
52	Travel to Huntsville	0 days	Mon 4/6/15	Mon 4/6/15	
53	LRR	0 days	Tue 4/7/15	Tue 4/7/15	
54	Rocket Fair	0 days	Thu 4/9/15	Thu 4/9/15	
55	Launch	0 days	Sat 4/11/15	Sat 4/11/15	
56	PLAR	76 days	Mon 12/1/14	Mon 3/16/15	
57	Write PLAR	27 days	Thu 11/27/14	Fri 1/2/15	
58	PLAR Due	0 days	Wed 4/29/15	Wed 4/29/15	



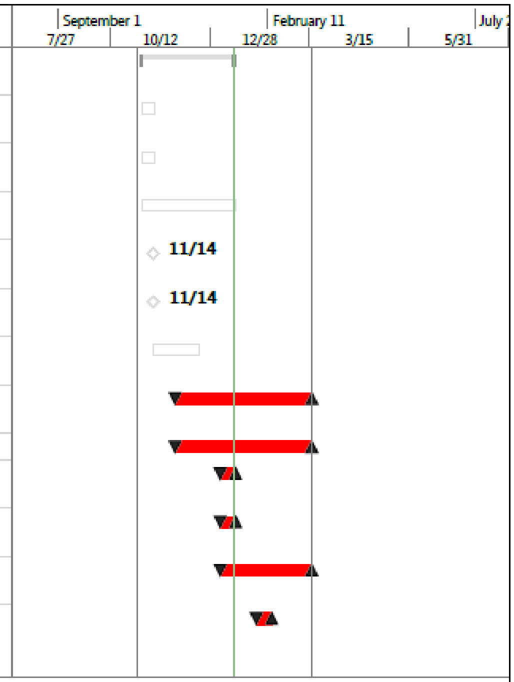
Project: OverallSchedule.mpp
Date: Fri 1/16/15

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 197: Overall project timeline. Page 3.

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 12/1/14**	**Mon 3/16/15**	
9	**FRR**	**76 days**	**Mon 12/1/14**	**Mon 3/16/15**	
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	



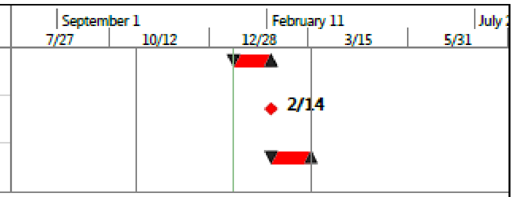
Project: SafetySchedule.mpp
Date: Fri 1/16/15

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 198: Safety 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	



Project: SafetySchedule.mpp
Date: Fri 1/16/15

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	

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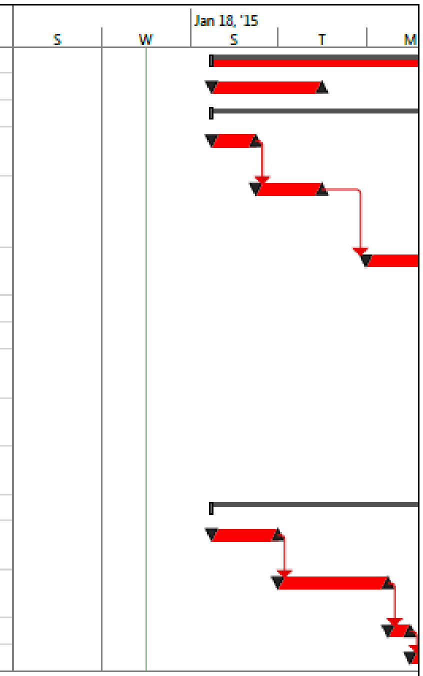
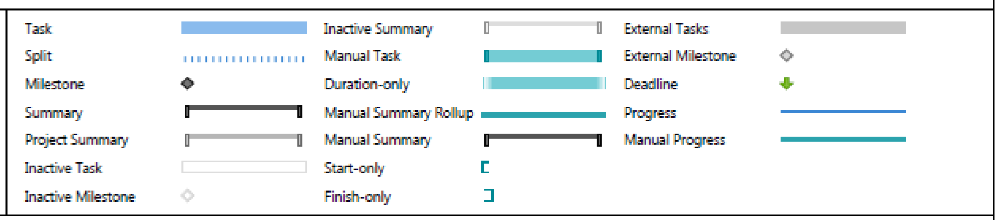
Figure 199: Safety timeline. Page 2.

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



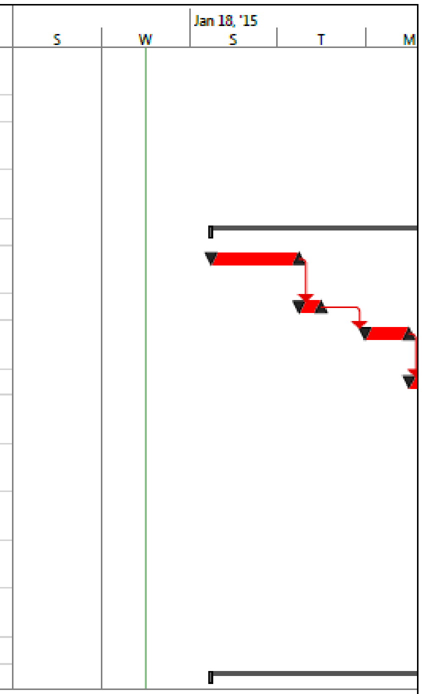
Project: VehicleSchedule.mpp
Date: Fri 1/16/15



Page 1

Figure 200: 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**	**30 days**	**Mon 1/19/15**	**Fri 2/27/15**	
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 1/28/15	Wed 1/28/15	24
26	Machine foam inserts on ShopBot	2 days	Thu 1/29/15	Fri 1/30/15	25
27	3D print all fairing ABS components	1 day	Mon 2/2/15	Mon 2/2/15	26
28	Construct door and cache capsule assemblies	5 days	Tue 2/3/15	Mon 2/9/15	27
29	Install door and cache capsule assemblies	5 days	Tue 2/10/15	Mon 2/16/15	28
30	Epoxy foam inserts in fairing halves	2 days	Tue 2/17/15	Wed 2/18/15	29
31	Test fairing actuation	7 days	Thu 2/19/15	Fri 2/27/15	30
32	**Avionics**	**30 days**	**Mon 1/19/15**	**Fri 2/27/15**	



Project: VehicleSchedule.mpp
Date: Fri 1/16/15

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	

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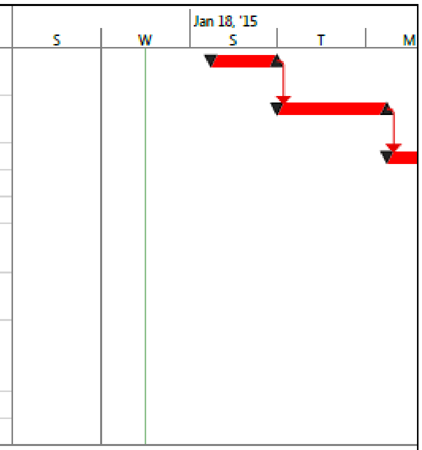
Figure 201: Vehicle project timeline. Page 2.

ID	Task Name	Duration	Start	Finish	Predecessors
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 2/28/15	Sat 2/28/15	
42	Final Revisions beofre FRR Proposal	10 days	Mon 3/2/15	Fri 3/13/15	



Project: VehicleSchedule.mpp
Date: Fri 1/16/15

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 3

Figure 202: Vehicle project timeline. Page 3.

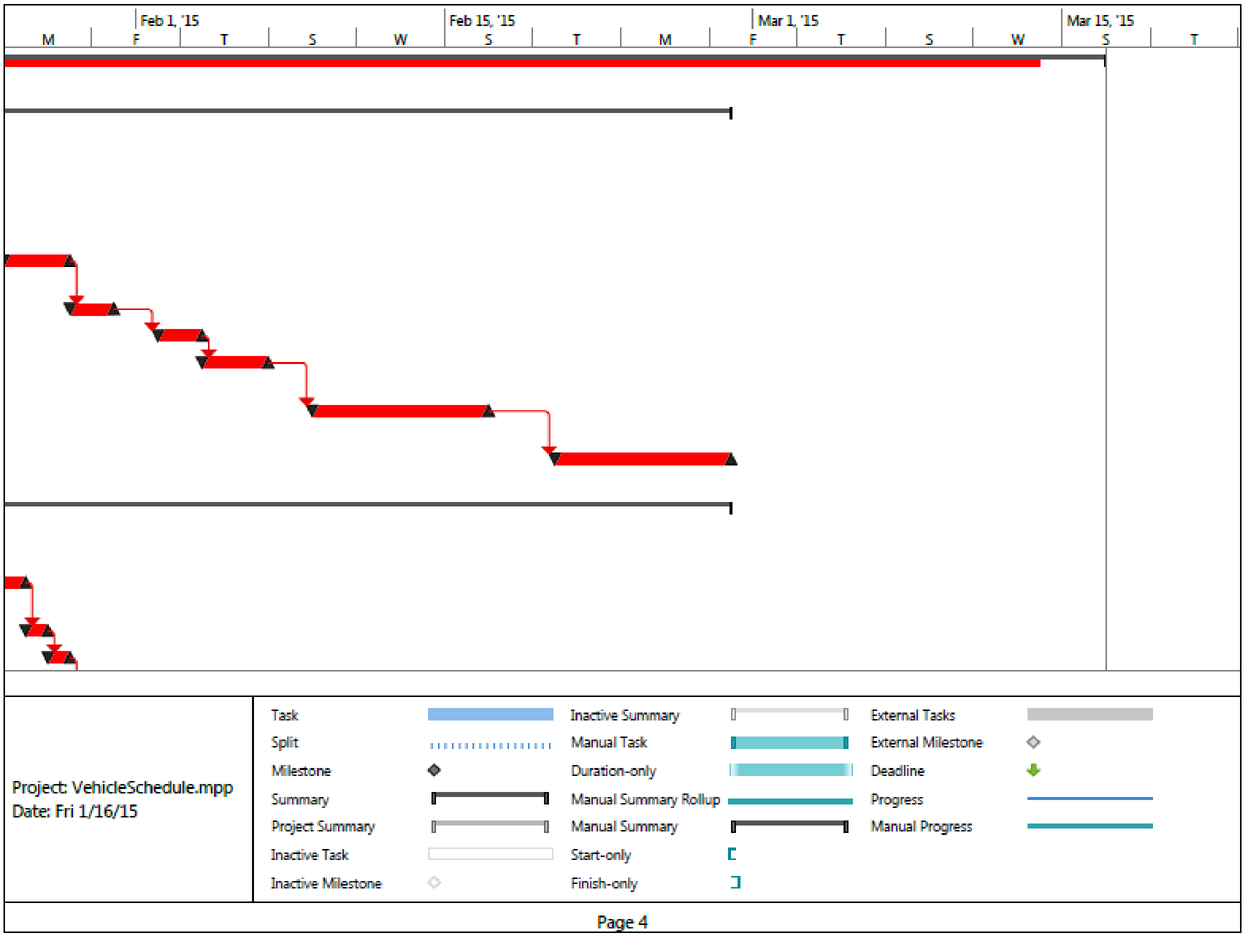


Figure 203: Vehicle project timeline. Page 4.

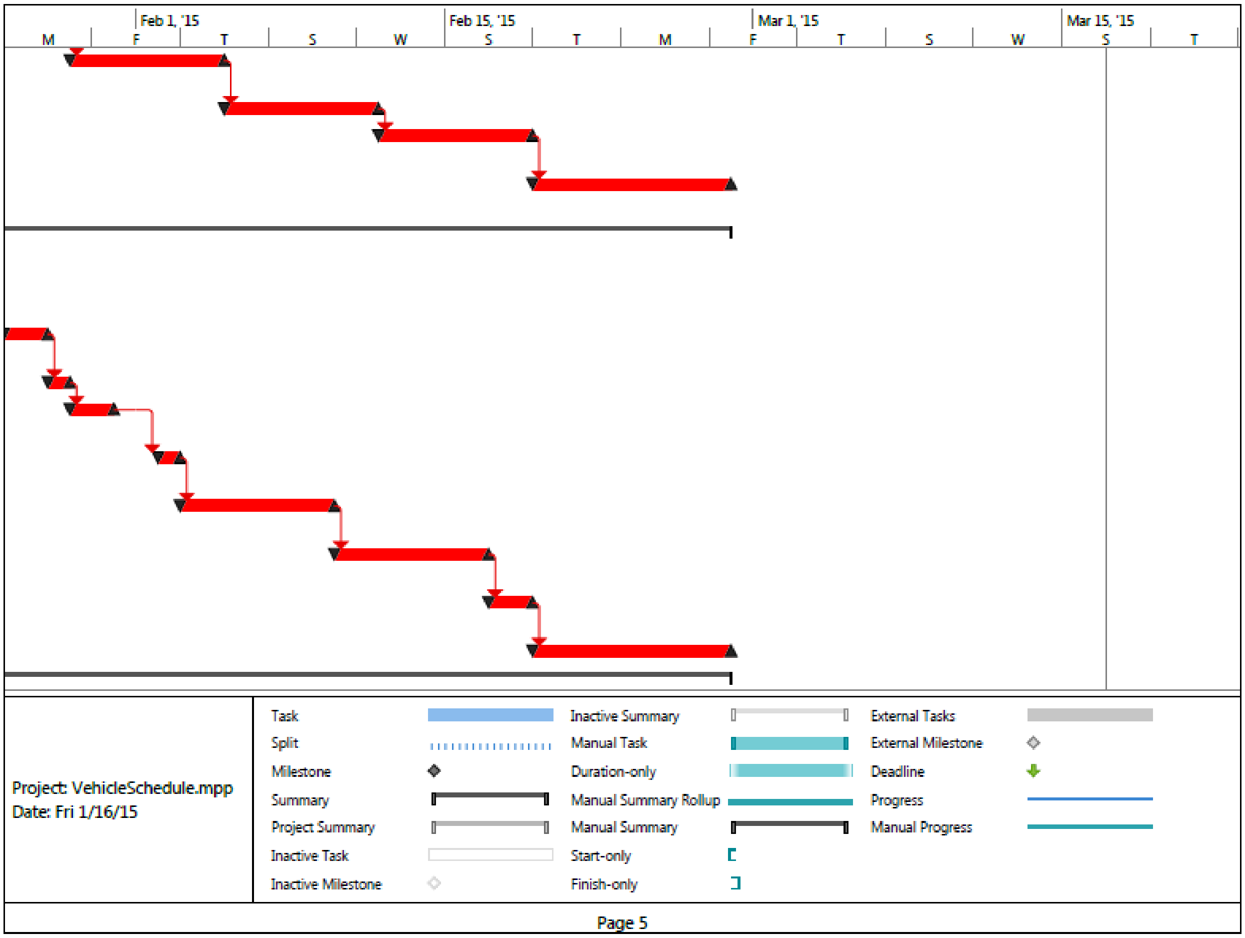


Figure 204: Vehicle project timeline. Page 5.

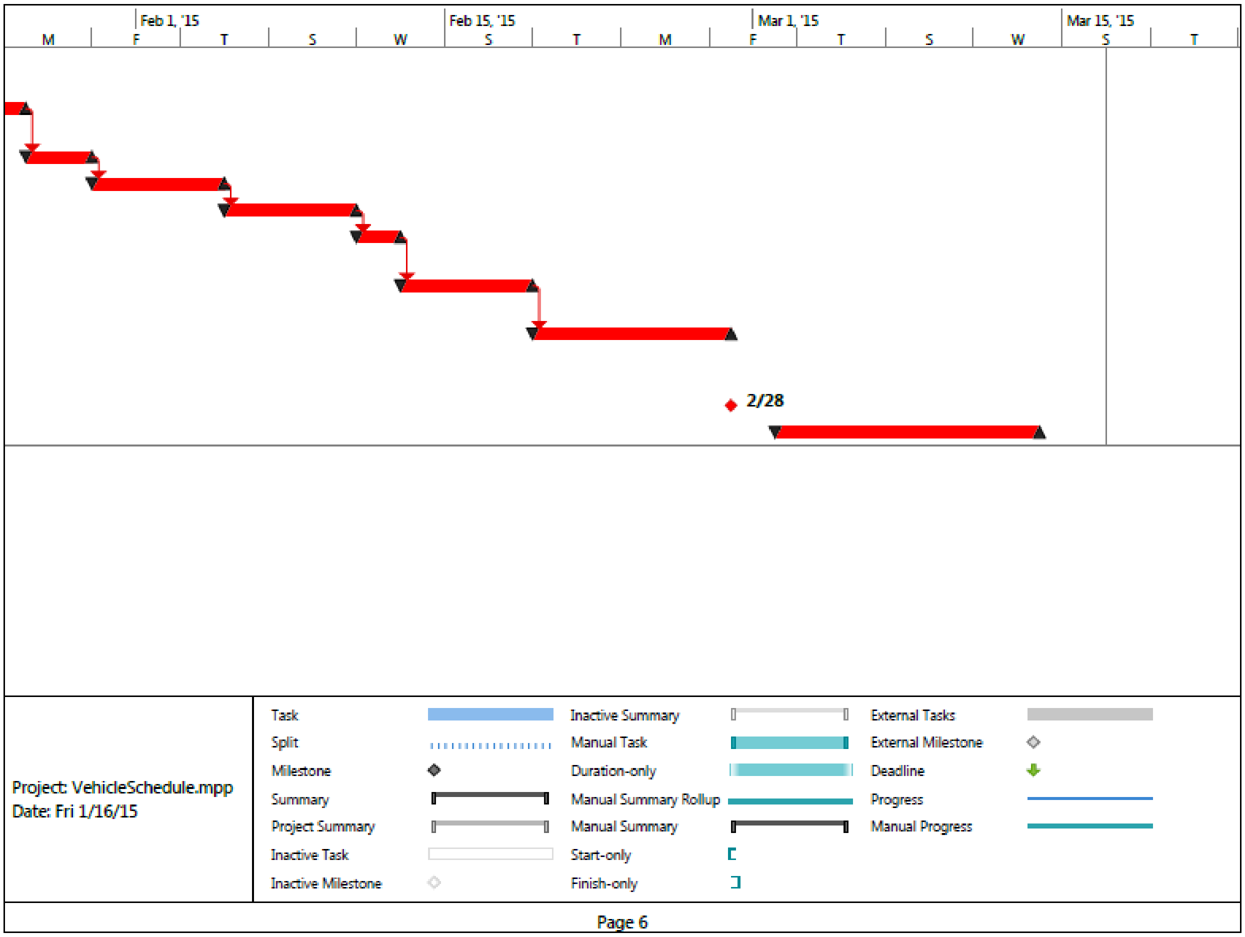


Figure 205: Vehicle project timeline. Page 6.

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.

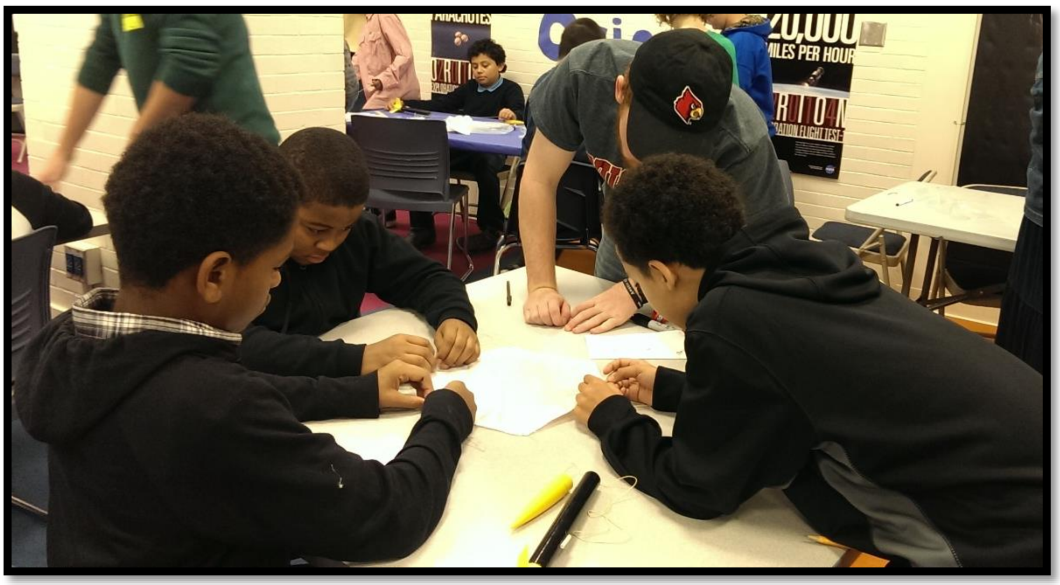


Figure 206: Ross assisting students in assembling their parachute.

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 either participated in already this season, or has plans to do so this year.

6 Day Program Curriculum

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 will continue 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 is looking to offer a similar program for robotics and basic programming. The details are still being worked out but we look to have this program released by January. The curriculum for the aerospace program is detailed below.

Figure 207: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, from 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 208: 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 209: Emily helping a student at last summer's College for a Day event.

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 210: Carlos helping a student prep her rocket for launch.

Figure 211: 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 a 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.

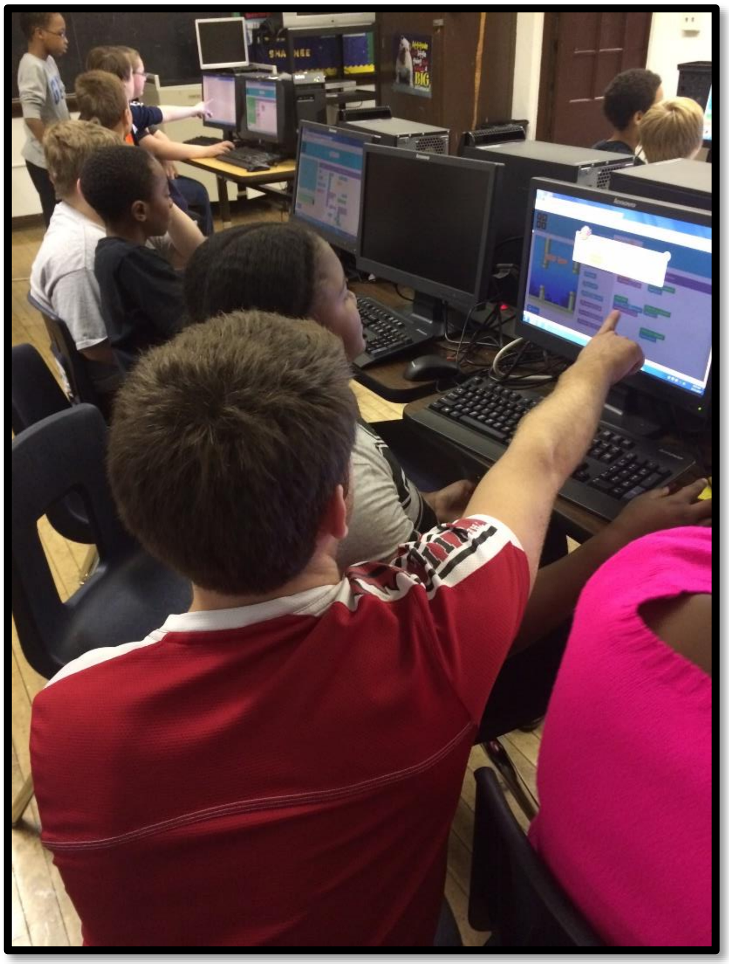


Figure 212: David teaches students how to program a game on code.org.

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.

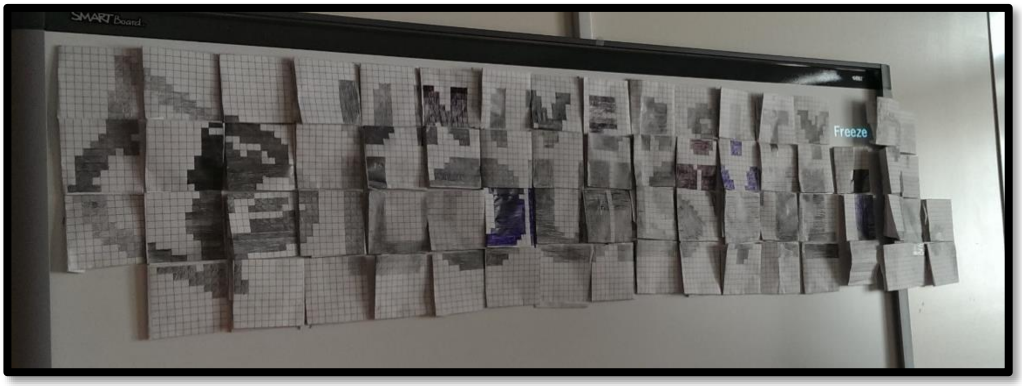


Figure 213: The satellite message that students decoded.

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 give a presentation to teach students at the Shawnee Academy 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.

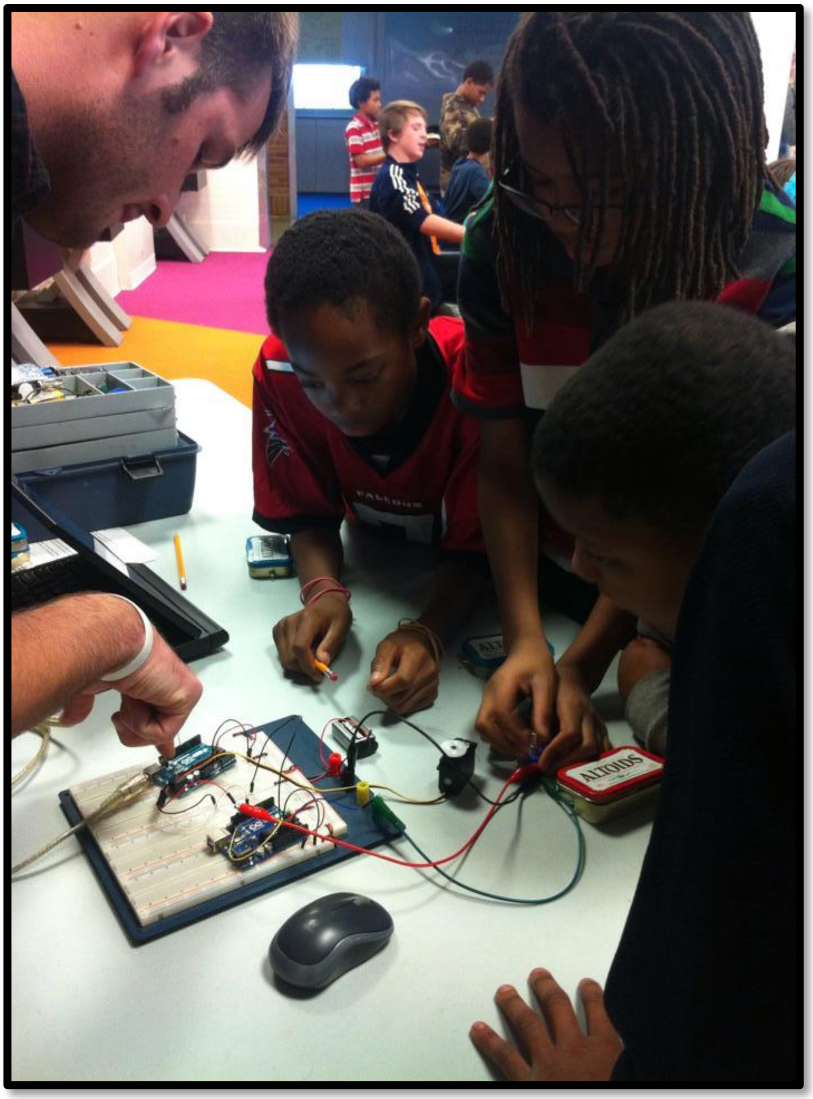


Figure 214: Sherman shows students a circuit that he built and how it works.

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.

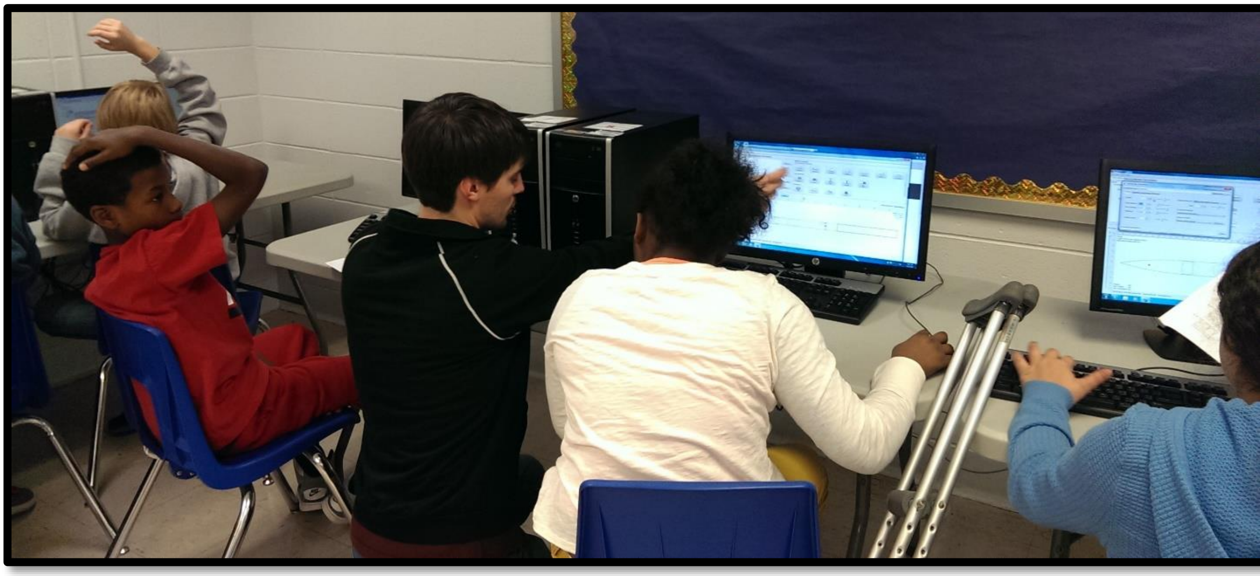


Figure 215: Gregg helps student with her OpenRocket simulation.

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 working 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.

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.

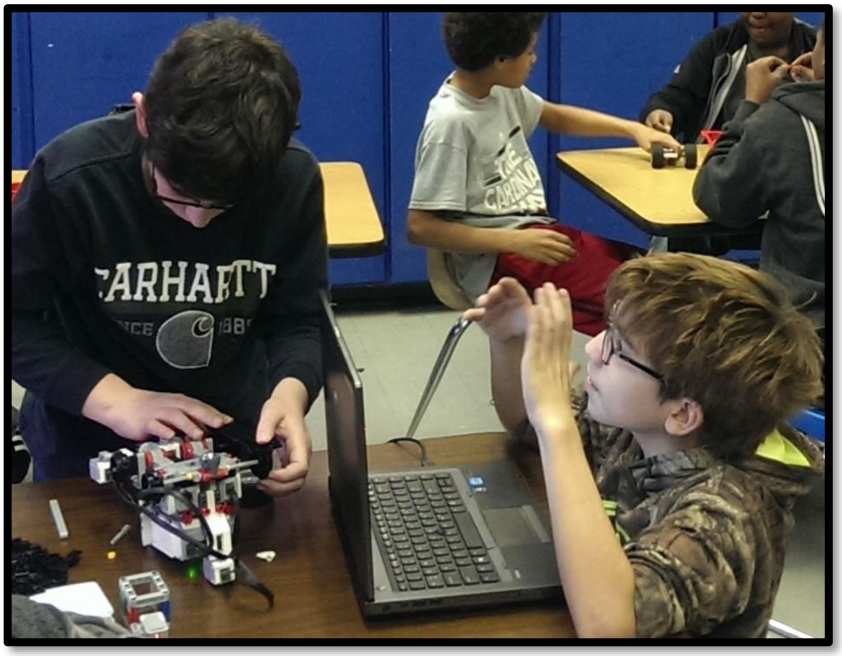


Figure 216: Students discuss designs and modifications to their program.

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 of 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 217: 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.

<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.

<u>Louisville Science Center Partnership:</u>

In the Louisville metropolitan area, the Louisville Science Center has heavily promoted STEM topics. The University of Louisville River City Rocketry Team plans to participate in Engineering Week at the science center for the third year running. The team will set up an interactive booth to discuss rocketry and to build and launch paper rockets with any visitors.

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 218: 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 219: 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 there are still many events planned, we have been able to work with 868 students already. This puts us well on our way of meeting our goal of working with 1500 students this year while still bringing some of the most exciting, hands-on STEM programs to our local schools and community.

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

I. Appendix 2 – Full Scale Launch Procedures

Safety Checklist: Vehicle Erector

To be checked and initialed by AGSE Safety representative.

Vehicle Erector Assembly:

AGSE Representative Signatures:

1. ______________________________ *2.* ______________________________

Required Equipment:

- *Track extrusions (x2)*
- *Motor mount cross member*
- *Bearing mount cross member*
- *Ball screw*
- *Carriage assembly*
- *Ball screw nut*
- *Ampflow Gearmotor with mounting assembly*
- *Ball screw coupler*
- *Ball screw bearing block*
- *Articulating arm (2x)*
- *Extrusion end cap fasteners (8020 PN# 3380) (8x)*
- *5/16"-18 UNC 2A button socket head cap screws 1 inch long (8x)*
- *3/16" T-handled Allen Wrenches (4x)*
- *Additional fasteners*
- *Carpenter's square*
- *Motor bench-top testing unit*

Prior to leaving for launch site:

1. ___ Ensure ball screw is clean and free of debris.
2. ___ Ensure ball screw nut is clean and free of debris.
3. ___ Inspect nylon guide pads on carriage for excessive wear.
   Note: If any damage is identified, **immediately** inform both of the team captains and the safety officer. The launch pad will be deemed safe to use or a corrective action will be decided upon and implemented.
4. ___ Check all carriage fasteners are securely tightened.

5. ___ Fasten two track extrusions to the motor mount cross member.
6. ___ Verify that track extrusions are square using a carpenter's square.
7. ___ Attach gearmotor to motor mount cross member.
8. ___ Install ball screw with coupler to gearmotor output shaft.
9. ___ Thread the ball screw nut one foot down the length of the ball screw. Thread the nut so that the boss is pointed towards the motor.

   ⚠WARNING Ensure that the nut rotates freely along the entire length of the ball screw. If there is any resistance, failure could occur when trying to erect the launch platform, resulting in a mission failure.
10. ___ Slide carriage onto track.
11. ___ Ensure carriage slides without resistance down the entire length of the track.

    ⚠WARNING Launch pad is not to be cleared for launch until the carriage moves freely along the track. If the carriage does not slide freely, failure could occur when trying to erect the launch platform, resulting in a mission failure.
12. ___ Insert ball screw into bearing block and attach bearing block to cross bar.
13. ___ Verify track extrusions are square with carpenter's square.
14. ___ Verify carriage moves without resistance across its entire length of travel.
15. ___ Fasten ball screw nut to carriage assembly.
16. ___ Test gearmotor actuation of carriage over the entire travel using the motor bench-top testing unit.

    ⚠WARNING If carriage does not move over the entire range of motion freely, immediately inform the team captains and safety officer. The launch pad will be deemed safe to use or a corrective action will be decided upon and implemented.

At launch site:

1. ___ Verify track extrusions are square with cross members and parallel with each other over their entire length of the track.
2. ___ Check that the ball screw, ball screw nut, and carriage guides are clean and free of debris.
3. ___ Test gearmotor actuation of carriage over the entire travel using the motor bench-top testing unit.

   ⚠WARNING If carriage does not move over the entire range of motion freely, immediately inform the team captains and safety officer. The launch pad will be deemed safe to use or a corrective action will be decided upon and implemented.
4. ___ Fasten vehicle erector system to ground station.
5. ___ Verify track is square and parallel over entire length.
6. ___ Connect power leads to motor.
7. ___ Verify AGSE control system actuates carriage.
8. ___ Fasten articulating arms to carriage using ¾" shoulder bolts.

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.* _______________________________

<u>*Launch Day Procedures:*</u>

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: Fairing Payload

To be checked and initialed by Fairing Payload Safety representatives.

Fairing Payload Representative Signatures:

1. ___________________________ *2.* ______________________________

Prior to leaving for launch site:

Fairing Assembly:

Required Equipment:

- *Shock absorption plates (x2)*
- *Tape*

1. ___ Check that the airframe is not deformed.
2. ___ Check for cracks in the epoxy fillets to ensure the structural integrity of all bulk plates.
3. ___ Tape shock absorption plates to the lower bulk plate. Ensure that foam side of the absorption plates are in contact with the lower bulk plate.

Launch day procedures:

Fairing Deployment Mechanism and Foam Inserts:

Required Equipment

- *U-bolts (x2)*
- *Springs (x2)*
- *Washers (x8)*
- *Nuts (x8)*
- *Hinge*
- *Socket cap screws (x8)*
- *Nuts (x8)*
- *Foam inserts*
- *Tape*

1. ___Inspect that springs have not been warped.
2. ___ Ensure that the hinge is free of debris and opens smoothly.
3. ___ Thread 2 springs onto the two U-bolts
4. ___ Install U-bolts to upper bulkhead using nuts and washers.
4. ___ Ensure that springs rest in the grooves on the U-bolts.
5. ___ Ground test to ensure springs open fairing to an angle large enough to deploy the cache capsule.

6. ___ Inspect the foam inserts and ensure there is no play or deformations in them.
7. ___ Tape foam inserts securely into place.
8. ___ Ensure that the fairing can smoothly open and close.

    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.

Pyro Cap Assembly:

Required Equipment:

- *Precision flathead screwdriver*
- *3 components of pyro cap*
- *Black powder*
- *E-matches (x4)*
- *4-40 shear pins (x2)*
- *Duct tape*
- *Eye-bolt*
- *Nylon chord*

Required PPE:

- *Nitrile gloves*
- *Safety glasses*

1. ___ Inspect shells for bends or cracks that would cause clearance conflicts or mechanical failure of the pyro cap assembly.
2. ___ Install eye-bolt into pyro cap.
3. ___ Remove green plastic cover from each e-match and install into each of the four holes in the cap.
4. ___ Secure e-matches and ensure that the pyrotechnic tip is completely inside the chamber of the pyro cap. Cover holes on top of cap with duct tape. Cut any excess tape off so that there is no overhanging tape.
5. ___ Fill the two wells of the cap with black powder and cover base with duct tape. Cut any excess tape off so that there is no overhanging tape.

    ⚠WARNING If the cap is not completely sealed, black powder will leak. Leakage could potentially result in the charges being too small to shear the pins, resulting in the payload being unable to deploy.
6. ___ Mount cap to base plates using 2, 4-40 shear pins.

Fairing Final Assembly:

Required Equipment:

- *Packed cache capsule deployment bag*
- *Nylon chord*
- *Cache capsule*
- *4-40 countersunk screws (x4)*

1. ___ Tie the nylon cord from the deployment bag to the appropriate eyebolt on the upper bulk plate.
2. ___ Tie nylon cord from the pyro cap's eyebolt to the appropriate eyebolt in the adjacent bulk plate.
3. ___ Mount pyro cap assembly to lower bulk plate using 2, 4-40 countersunk screws.
4. ___ Ensure lower fairing altimeter housings have been completely assembled and ready for launch according to the recovery checklist. Obtain approval to close off fairing from the recovery representative.
5. ___ Close fairing.
6. ___ Install remaining two4-40 countersunk screws to hold the fairing closed and to secure the pyro cap in place.

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:

9. ___ Make sure the arm is lined up with the rocket's payload bay.
10. ___ Make sure the payload arm is securely attached to the AGSE side rail.
11. ___ Lower the gripper assembly right above the payload with the arms in the open position.
12. ___ 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*
- *Anti-friction tape*
- *Fasteners*
- *Pivot point bearings (2x)*

Prior to leaving for launch site:

1. ___ Ensure launch platform is clean and free of debris.
2. ___ Inspect anti-friction tape for damage and replace any damaged sections.

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*
- *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 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.
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*

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. ___ Slide motor casing fully into the motor mount tube.
6. ___ 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:

18. ___________________________ *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.
19. ___ Unwind one e-match.
20. ___ 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.
21. ___ 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.
22. ___ 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.
23. ___ Repeat steps 2 through 4 four times.
24. ___ 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 cap screws (x4)*
- *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.
9. ___ Install lower sustainer door using socket cap screws.

Safety Checklist: Recovery

To be checked and initialed by Recovery Safety representatives.

Recovery Representative Signatures:

2. ___________________________ *2.* ______________________________

<u>Prior to leaving for launch site:</u>

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. 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, 3-36 Phillips head screws.
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. ___ 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*

1. ___ Attach shock chord to swivel.
2. ___ Attach swivel shock chord from the upper airframe.
3. ___ Attach second length of shock chord to U-bold on nosecone.
4. ___ Attach parachute to shock chord.
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*

1. ___ Attach fairing to the upper airframe using 4-40 shear pins. Ensure that all shear pins are tight fitting and will not fall out during ascent.
2. ___ Attach upper sustainer to fairing using 4-40 shear pins. Ensure that all shear pins are tight fitting and will not fall out during ascent.
3. ___ 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 achived.
4. ___ Attach nose cone to upper sustainer using 4-40 socket cap screws.
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 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.				Low	
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 65: 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 will 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, Teflon coating spray 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. The Teflon coating will be inspected prior to each launch and any damaged portions will be replaced.
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	3	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	3	Moderate	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	3	Moderate	All fasteners will be properly tightened during assembly and will be checked prior to launch. 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	1	4	Low	All personnel will be required to maintain a minimum safe distance away from the AGSE when in

		transporting ground station. Ground station will collapse under weight and not function				operation. During assembly this failure mode will be tested to ensure doesn't happen.

Table 66: 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 specified and 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 nut, causing vehicle erector to be motionless.	1	3	Moderate	Analysis has been performed to determine the minimum bolt and mounting plate specifications based on the maximum loads the interface will encounter.
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	1.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. 3. Possible short to exterior parts.	1	3	Moderate	Electrical redundancy measures will be implemented.

Table 67: 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	1,2. 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.	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 small dowel rods will be attached to igniter.

Damage to igniter	Wheels smash and damage insulation.	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.Ignitior 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 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	High strength materials are used for installing the igniter

Table 68: 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 with proper lubrication to prevent galling
Improper outrigger pad orientation.	1.Uneven terrain	Unbalanced ground station, possible damage	3	2	Moderate	Terrain will be inspected prior to placing ground station and the landing locations of the outrigger

	2.Object obstructs pad from contacting ground 3. Pad jams in outrigger	to surroundings/terrain				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 determine coefficient of friction between pad and terrain 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. Testing will be completed to verify the sizing of the pads. 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 3.Unstable ground	Ground station falls possibly injury to personnel surround ground station.	1	3	Moderate	System interlocks will track progress of ground station leveling and determine if outriggers are out of sync. If the stability of the ground station reaches a critical point the system

	4. Ground station footprint					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 69: 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	Arm fails to retrieve and load payload.	1	3	Moderate	Testing will be completed to verify grips close consistently on payload.

	2. Grips do not close to specific position 3. Gripping motor does not have enough torque					
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 70: 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	AGSE fails to operate.	1	3	Moderate	Testing will be completed to ensure all components maintain

	2. Break in communication line					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 71: 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 72: 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 2. Communication failure between switch and controller 3. Code error	Damage to AGSE. Personal injury to personnel working near or around AGSE.	1	3	Moderate	All personnel will be required to maintain a minimum safe distance 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	Undesired launch sequence/ personal injury/ Disqualification	1	3	Moderate	Redundancies will be implemented to ensure the igniter safety system performs as expected.

	switch and controller 3. Code error					
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 73: 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.	1,3,4. 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.	1,2. 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 graphite prior to each launch in order to minimize friction. 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 adhesion 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. Examine external epoxy beads for cracks prior to launch.
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 will be designed to withstand the force from takeoff with an acceptable factor of safety. 1. Electrical components will be 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.
Fins are not properly aligned.	Fins are not mounted straight or do not have equal radial spacing.	Rocket becomes unstable or spins	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 will be

		excessively during flight.				aligned within a tolerance that will not negatively affect the flight of the rocket.
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 previously by the team without any signs of failure. Analysis will be done to validate that the current design is strong enough to withstand forces seen during flight.

Table 74: 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.	1,2. Rocket follows ballistic path, becoming unsafe.	1	5	Low	1. The separation section of the rocket will be designed to ensure that the black powder charge provides sufficient pressurization, allowing the rocket to separate and deploy its recovery system. 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, becoming unsafe.	1	5	Low	Multiple altimeters and e-matches are included into systems for redundancy to eliminate this 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	4	Moderate	Deployment bags will be 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. 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	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

		the rocket to be damaged.				parachutes will be 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 will be performed to verify the coefficient of drag is approximately that which was used during analysis. Should the coefficient of drag be too large, the parachute will have to be resized.
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 should 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	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.

		the rocket to be damaged.				
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 become ballistic.	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 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	3	High	A custom deployment bag will be designed for the vortex ring parachute to ensure that the lines do not tangle during deployment. Ground testing will be 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	4	Moderate	Since the vortex ring parachute is a rotational parachute and the cruciform parachute is prone to rotation, swivels will be used to allow the parachute to rotate, without translating that 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 will be

						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 will be done to ensure that the vortex ring rotates as it should. If it does not rotate, line lengths can be altered to achieve the necessary rotation to generate lift.
Vortex ring parachute oscillates.	Improper length of centerline.	Unclean deployment of cache capsule and lower airframe.	2	4	Moderate	The vortex ring will be ground tested to ensure that does not oscillate prior to utilizing during a flight. l

Table 75: 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	4	Moderate	1. Black powder charges will be designed to overcome the shear strength of the shear pins, allowing the rocket to separate easily. 2. The coupling between the two sections will be 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.	1,2. Ejection charges will not fire, preventing	2	5	Low	Batteries will be checked for sufficient charge during launch day preparations. If the launch is

	2. Extremely cold weather	the rocket from splitting and the rover being deployed.				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	

Table 76: 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 serious safety threat to	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.

		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. 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 77: 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 salt flats being extremely soft, as well as local launch sites, 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 moist 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 rocket must be worked on for long

	for long periods of time.	materials or adhesives.				periods of time, shelter should be sought.

Table 78: 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 environments 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.

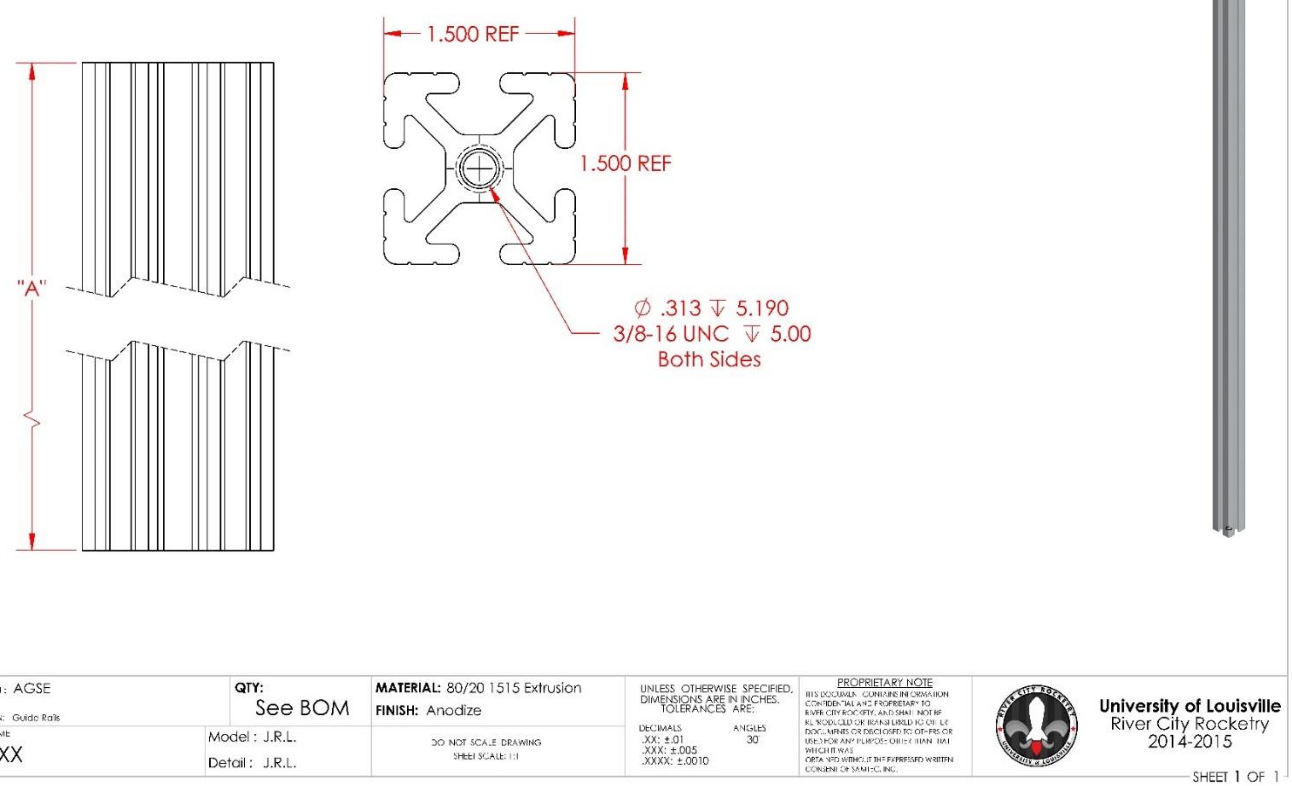
Release of toxic fumes in the air.	Burning of ammonium perchlorate motors	Biodegradation.	4	1	Moderate	Ammonium perchlorate will be burned in small quantities and infrequently. The amount of toxins released will cause minimal degradation.
Production of styrene gas.	Through the use of fiberglass in the 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.

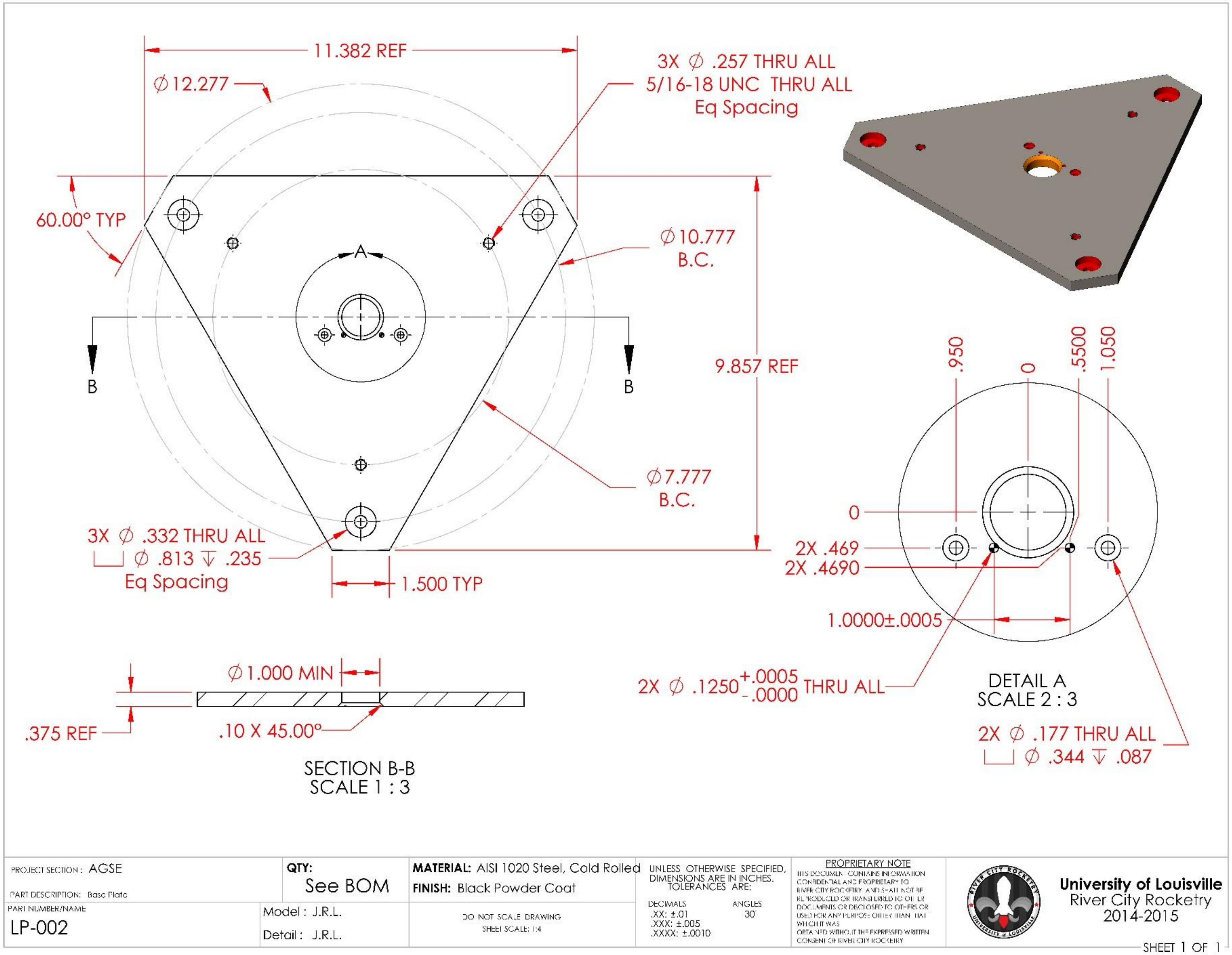
		potentially cause a fire.				
Plastic waste material.	Plastic using in the production of electrical components and wiring.	1. Sharp plastic material produced when shaving down plastic components could harm animals if ingested by an animal. 2. Plastic could find its way down a drain and into the water 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 79: Hazards to environment risk assessment

Section 9. Appendix IV – Technical Drawings

Part Number	Dim "A"
LP-001-01	18.375
LP-001-02	60.000
LP-001-03	8.000
LP-001-04	6.500
LP-001-05	48.870
LP-001-06	72.870





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B.C.
B
B
9.857 REF
Ø7.777
B.C.
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Eq Spacing
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0
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2X .4690
1.0000±.0005
Ø1.000 MIN
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DETAIL A
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⌴ Ø .344 ↧ .087
PROJECT SECTION: AGSE
PART DESCRIPTION: Base Plate
PART NUMBER/NAME
LP-002
QTY:
See BOM
Model : J.R.L.
Detail : J.R.L.
MATERIAL: AISI 1020 Steel, Cold Rolled
FINISH: Black Powder Coat
DO NOT SCALE DRAWING
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UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
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.XXX: ±.005
.XXXX: ±.0010
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30'
PROPRIETARY NOTE
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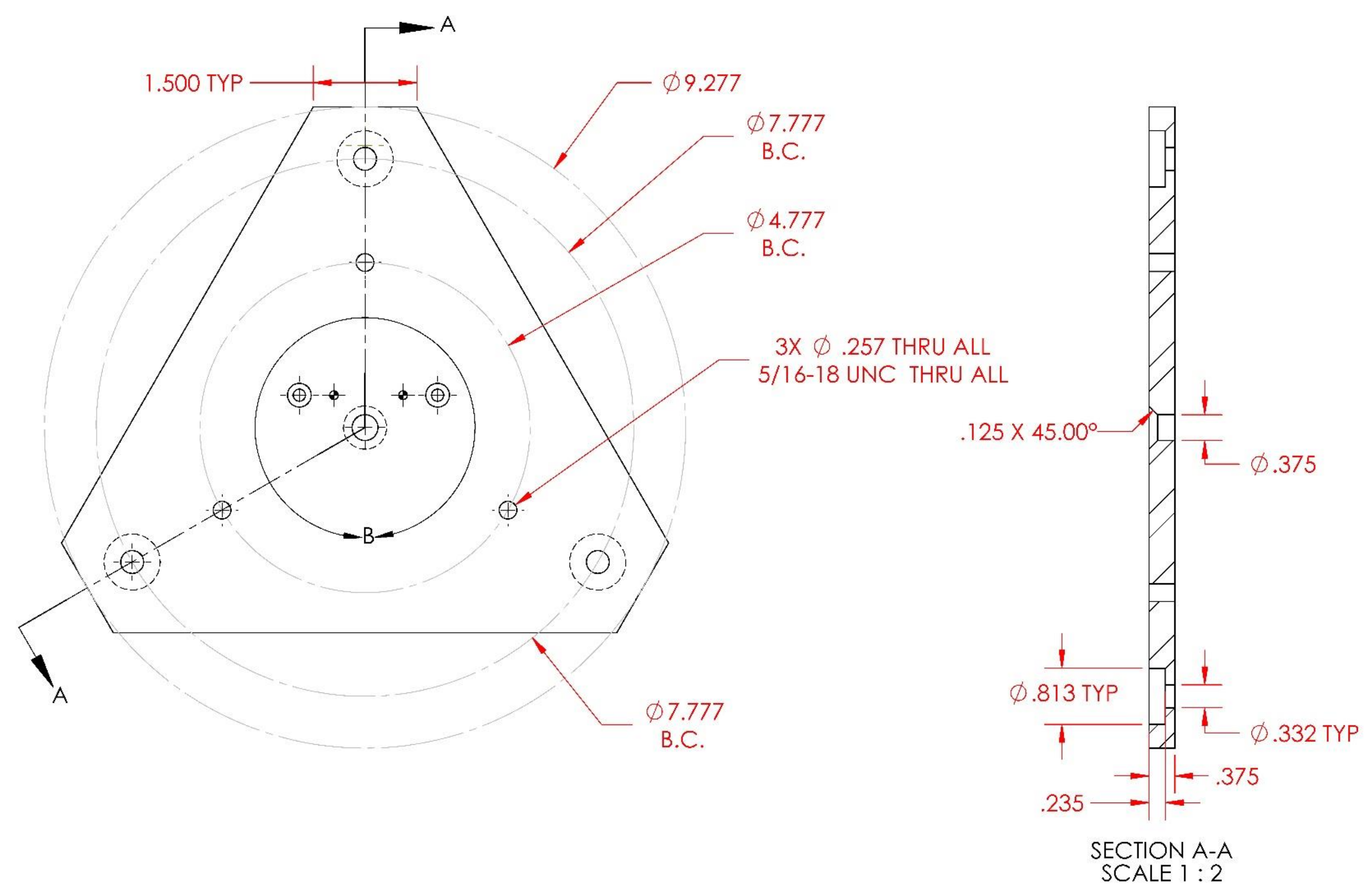
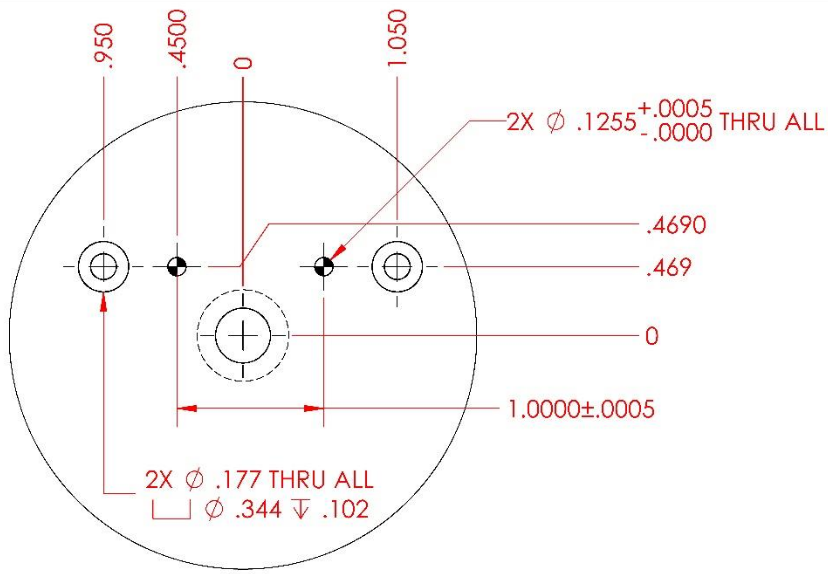


PROJECT SECTION: AGSE PART DESCRIPTION: Secondary Plate	QTY: See BOM	MATERIAL: AISI 1020 Steel, Cold Rolled FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETY, AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF SAMTEC, INC.	University of Louisville River City Rocketry 2014-2015
PART NUMBER/NAME LP-003	Model: J.R.L. Detail: J.R.L.	DO NOT SCALE DRAWING SHEET SCALE: 1:1			

SHEET 1 OF 2



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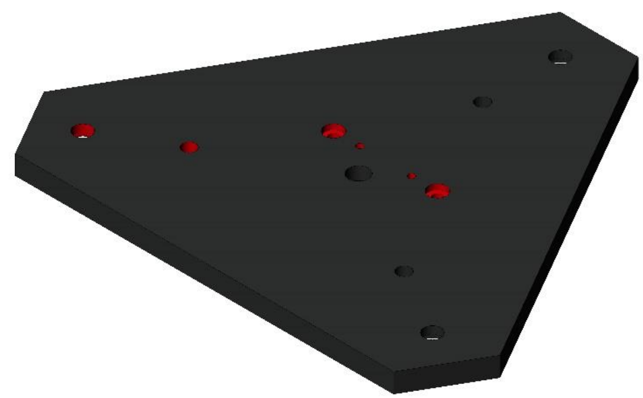

PROJECT SECTION : AGSE PART DESCRIPTION: Secondary Plate	QTY: See BOM	MATERIAL: AISI 1020 Steel, Cold Rolled FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETY, AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF SAMTEC, INC.
PART NUMBER/NAME LP-003	Model : J.R.L. Detail : J.R.L.	DO NOT SCALE DRAWING SHEET SCALE: 1:1	DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	

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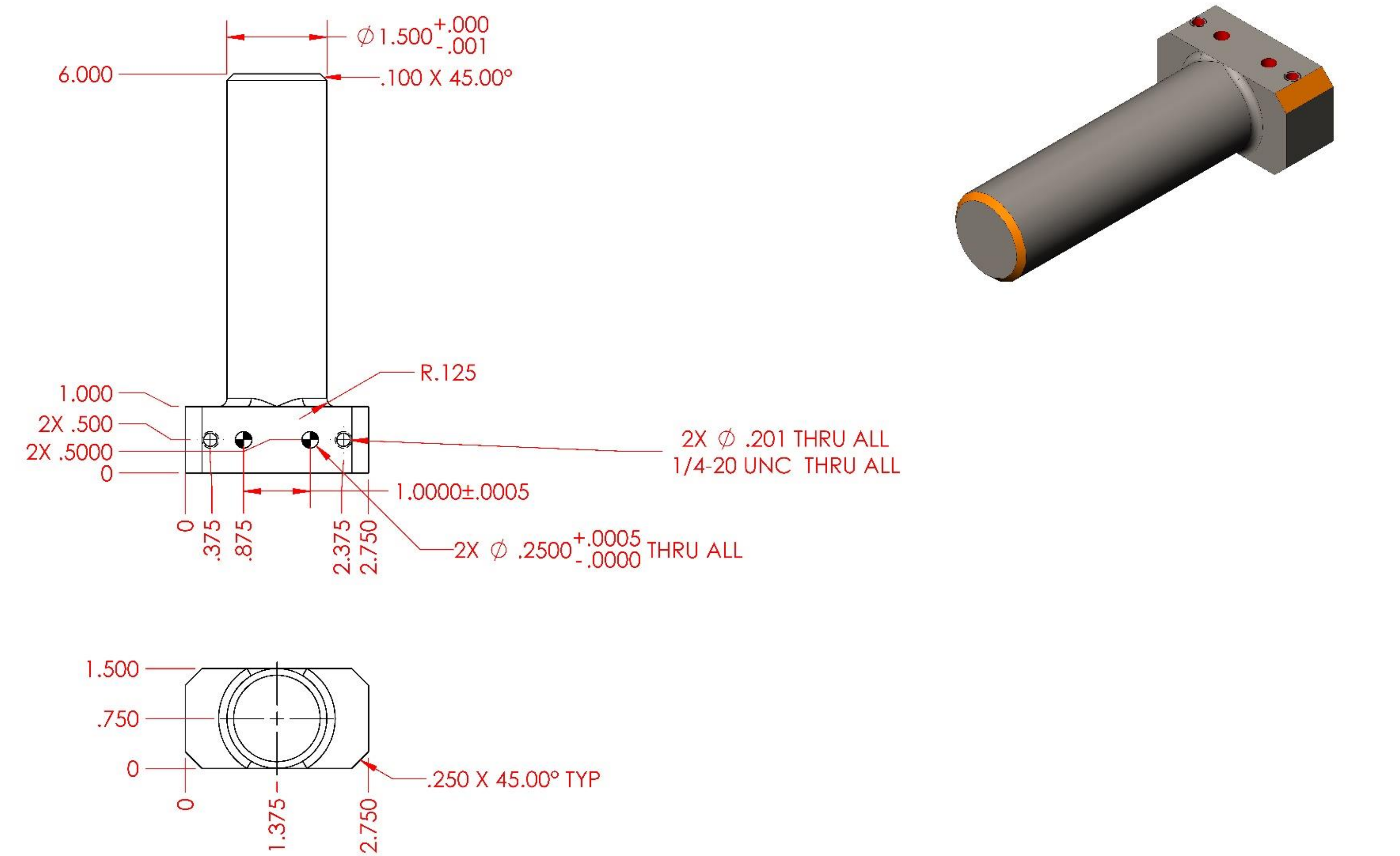
SHEET 2 OF 2



PROJECT SECTION: AGSE

PART DESCRIPTION: Pivot Shaft Block

PART NUMBER/NAME

LP-008

QTY: See BOM

Model: J.R.L.

Detail: J.R.L.

MATERIAL: AISI 4130 Steel, annealed at 865C

FINISH: Flash Chrome

DO NOT SCALE DRAWING

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DECIMALS
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ANGLES
30'

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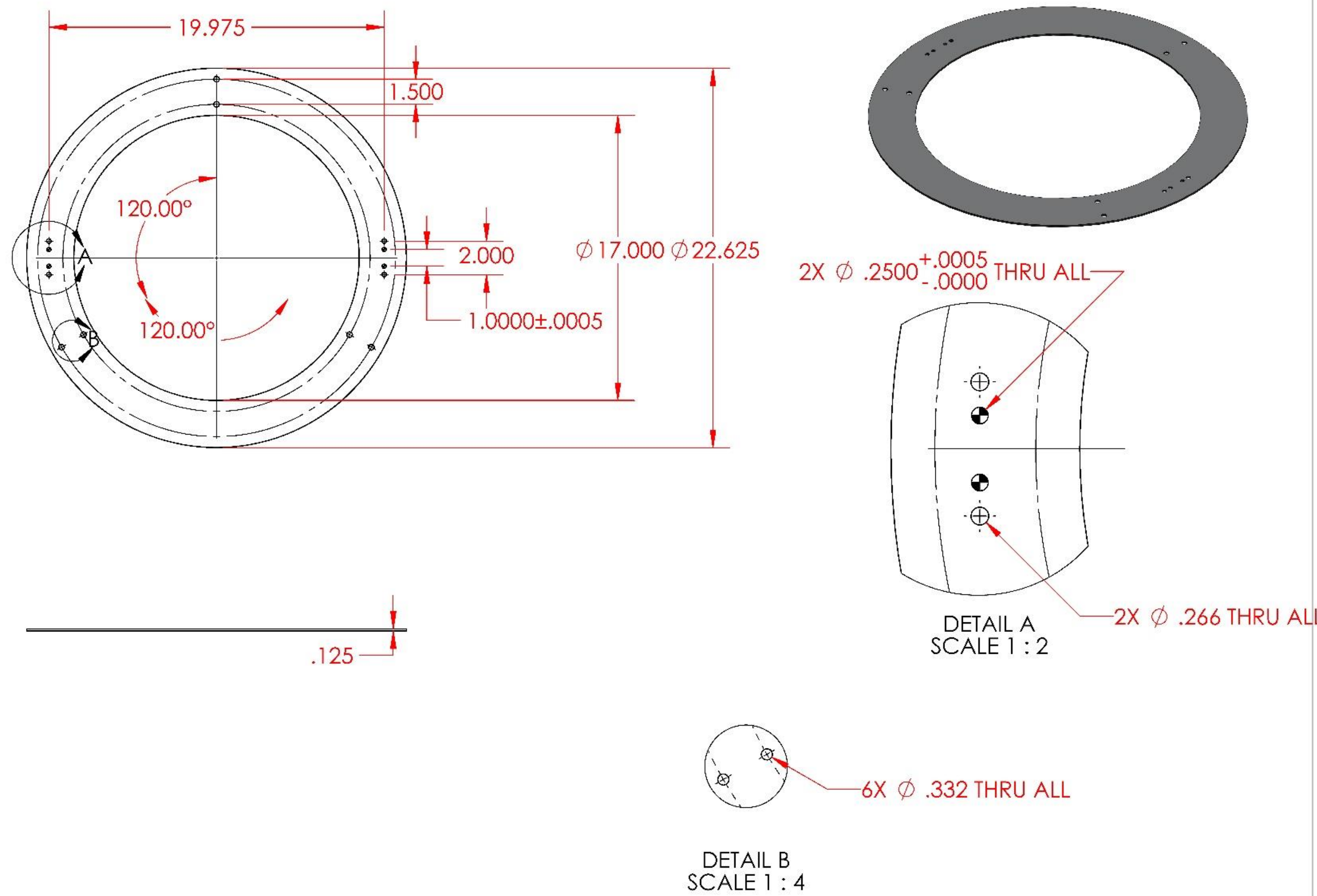

PROJECT SECTION: AGSE PART DESCRIPTION: Mounting and Stability Ring	QTY: See BOM	MATERIAL: 1060 Alloy FINISH: PowerCoat	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETY, AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF SAMTEC, INC.
PART NUMBER/NAME LP-005	Model: J.R.L. Detail:	DO NOT SCALE DRAWING SHEET SCALE: 1:1		

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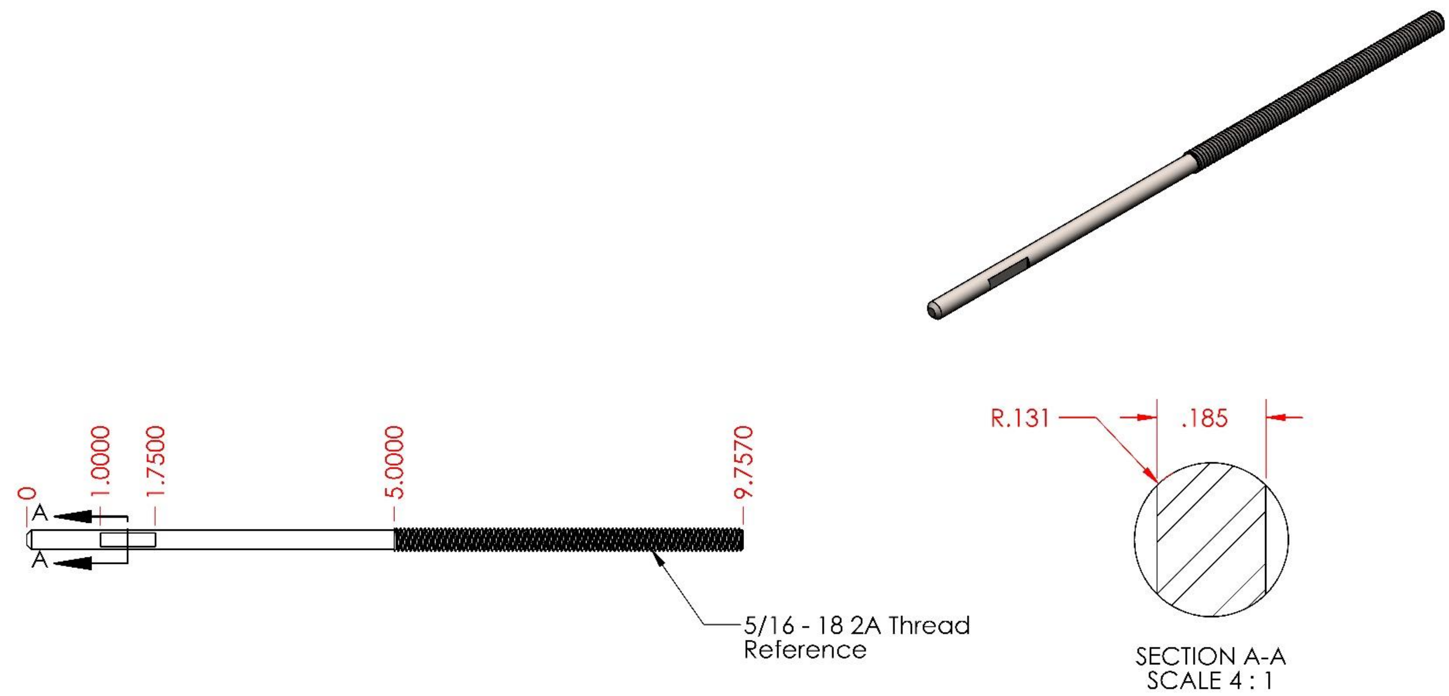
SHEET 1 OF 1



PROJECT SECTION: Launch Platform PART DESCRIPTION: Alignment Screw	QTY: See BOM	MATERIAL: Stainless Steel (ferritic) FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30°	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY.		**University of Louisville** River City Rocketry 2014-2015
PART NUMBER/NAME LP-006	Model: JRL Detail: JRL	DO NOT SCALE DRAWING SHEET SCALE: 1:4				

SHEET 1 OF 1

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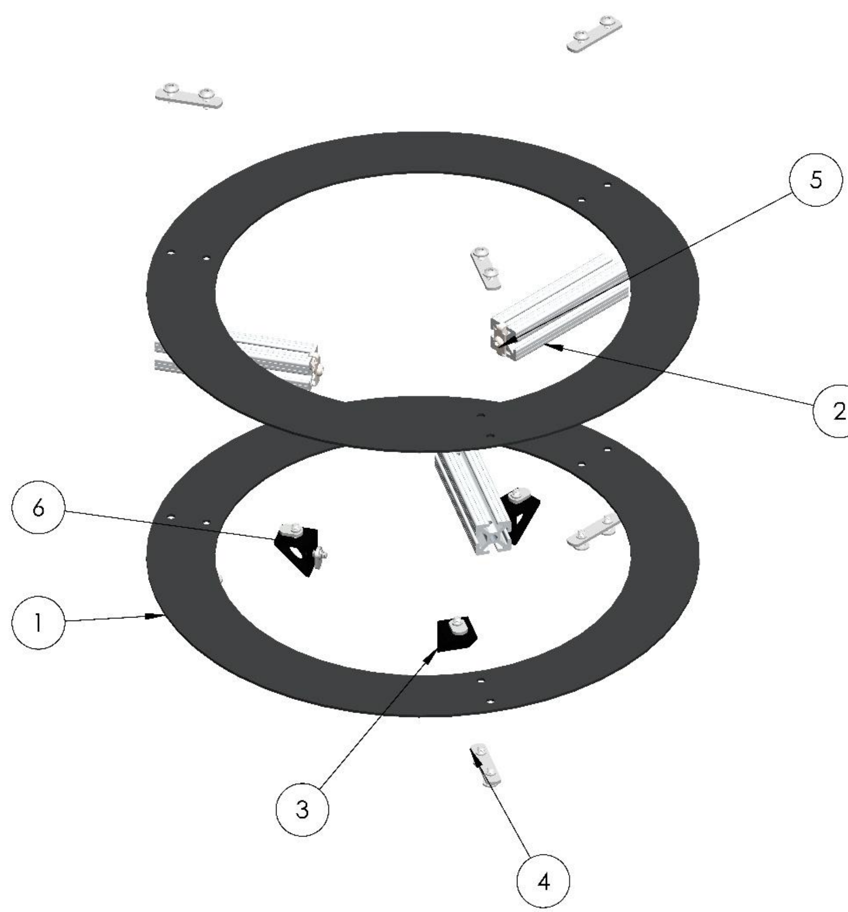
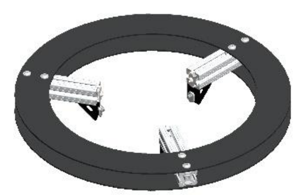
4	47065T149	6
5	47065T156	3
6	47065T97	6





PROJECT SECTION: Launch Platform

PART DESCRIPTION: Upper tower ring

PART NUMBER/NAME: Tower Ring

QTY: See BOM

Model: JRL

Detail:

MATERIAL: None

FINISH: None

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.XXX: ±.005
.XXXX: ±.0010

ANGLES
30'

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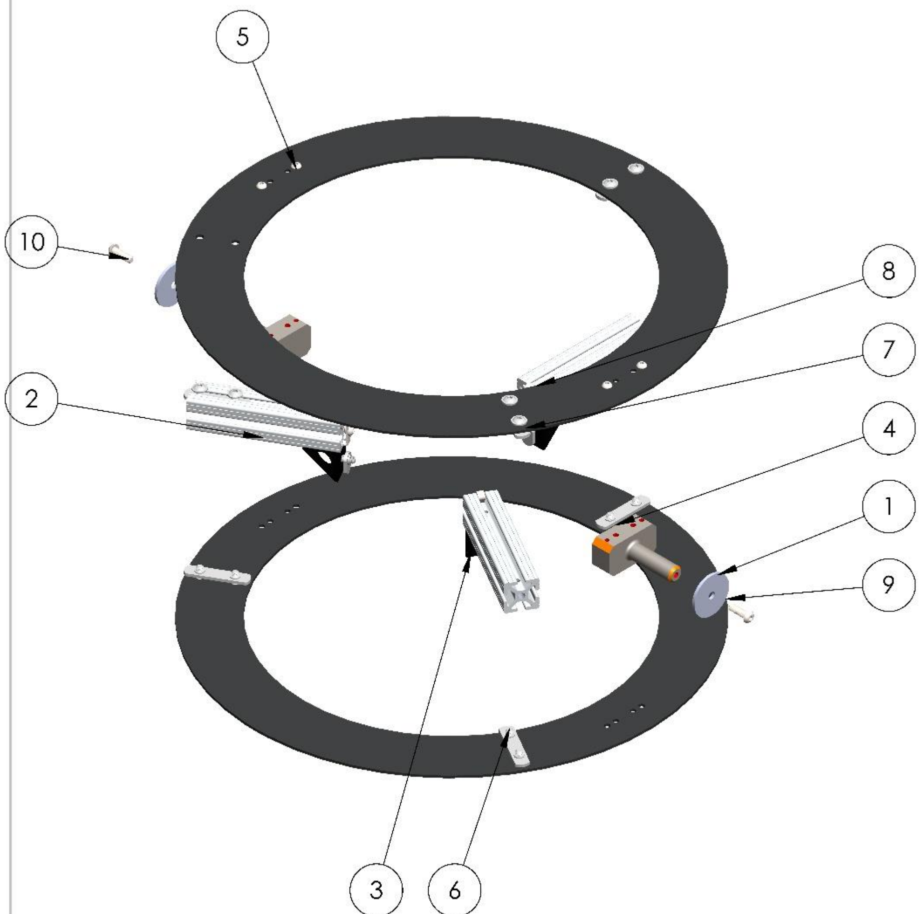

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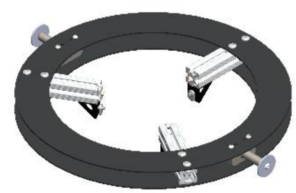
1	LP-005	2
2	LP-001-04	3
3	4332	3
4	LP-010	2
5	92949A564	4
6	47065T149	6
7	47065T97	6
8	47065T156	3
9	92303A103	2
10	92949A582	2



PROJECT SECTION: Launch Platform

PART DESCRIPTION: Arm connection joint

PART NUMBER/NAME

Tower_Arm_Connection

QTY: See BOM

Model: JRL

Detail: JRL

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

PROPRIETARY NOTE

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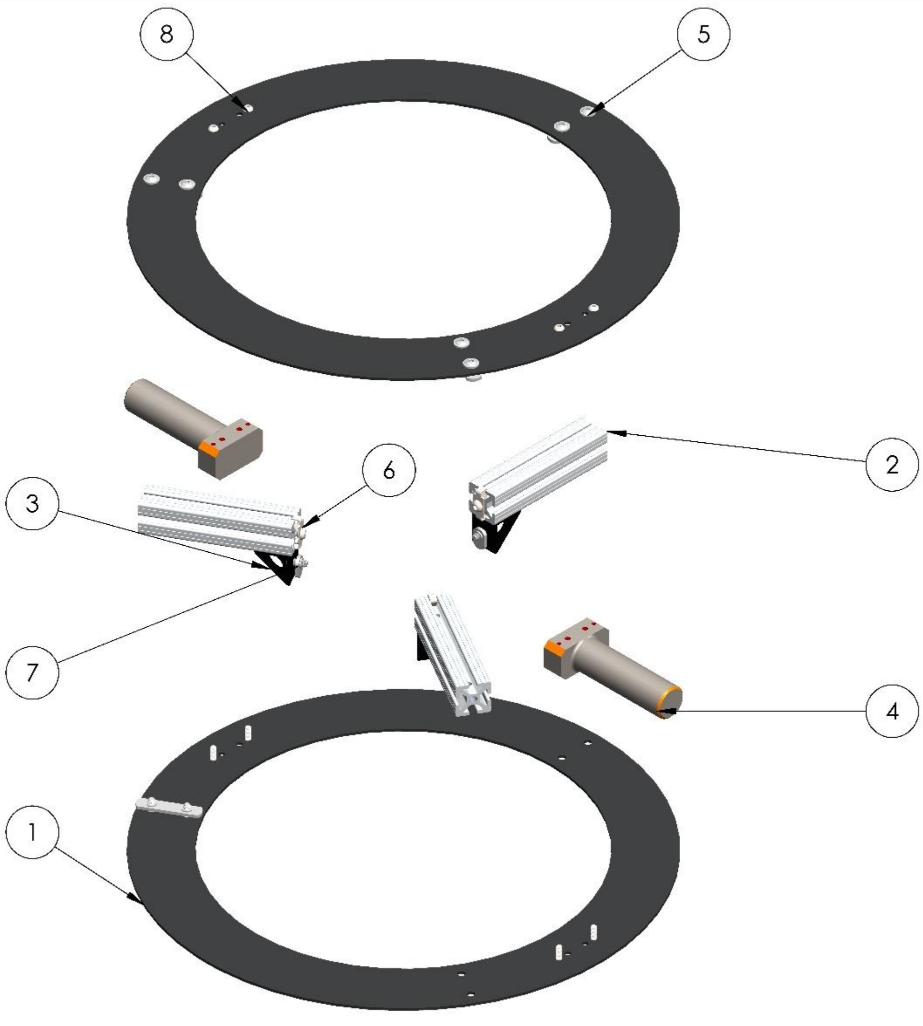
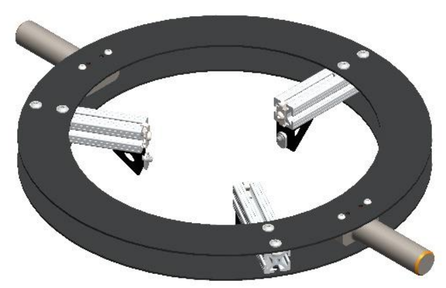
SHEET 1 OF 1





ITEM NO.	PART NUMBER	QTY.
1	LP-005	2
2	LP-001-04	3
3	4332	3
4	LP-008	2
5	47065T149	4
6	47065T156	3
7	47065T97	6
8	92949A564	8

PROJECT SECTION: Launch Platform

PART DESCRIPTION: Tower connection joint

PART NUMBER/NAME

Tower_Ring_Connection

QTY: See BOM

Model: JRL

Detail: J.R.L.

MATERIAL: None

FINISH: None

DO NOT SCALE DRAWING

SHEET SCALE: 1:16

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:

DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010

ANGLES 30

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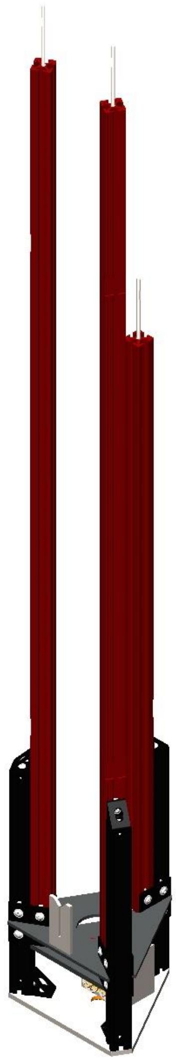
SHEET 1 OF 1



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

Model: JRL

Detail: JRL

MATERIAL: None

FINISH: None

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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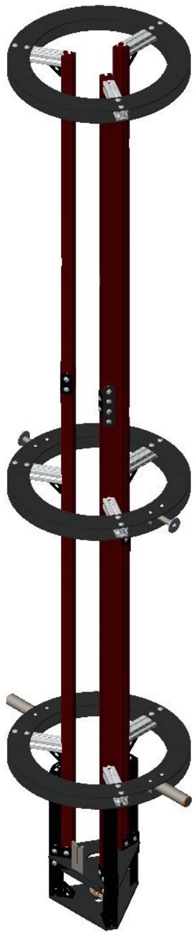
SHEET 1 OF 1

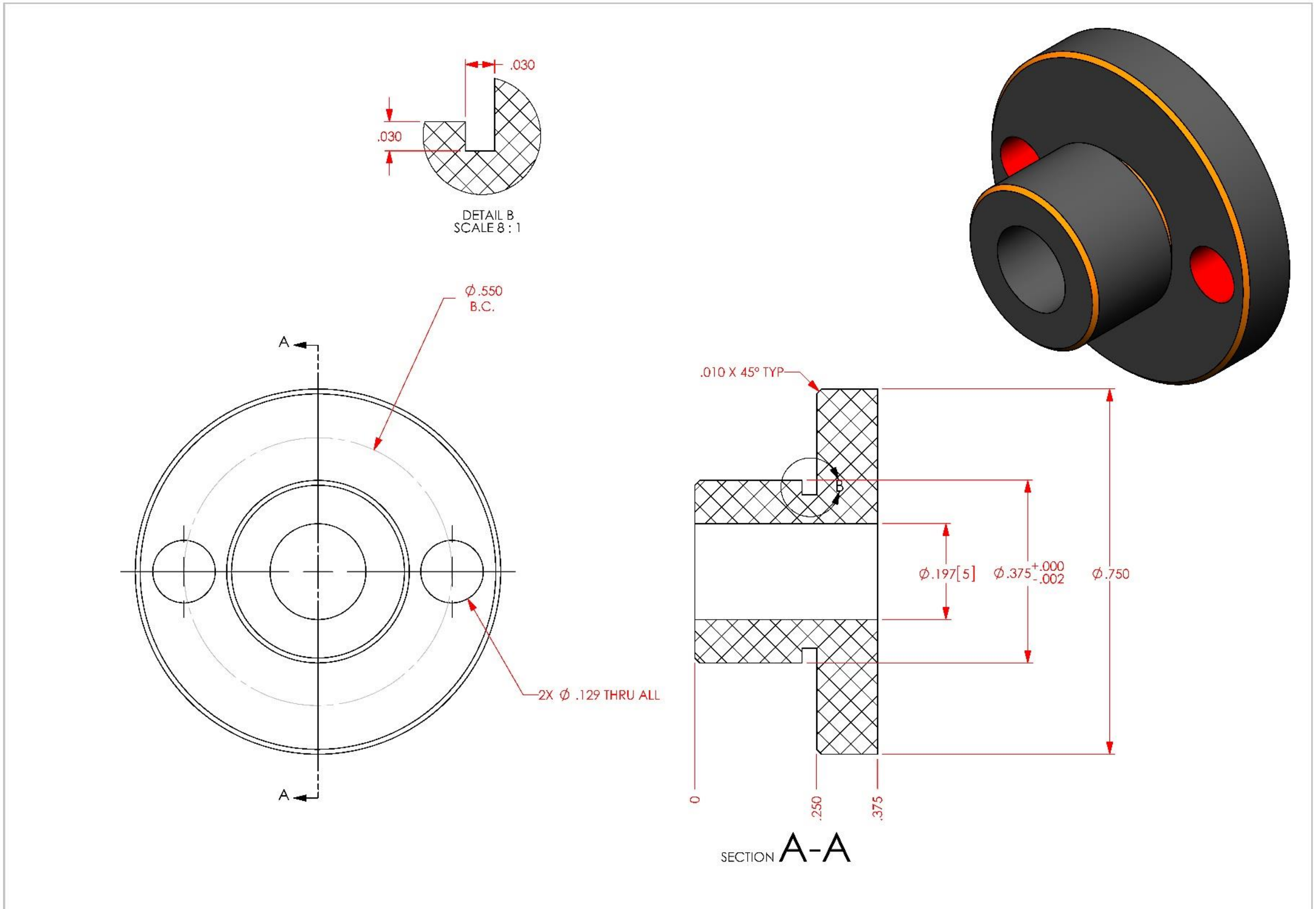
ITEM NO.	PART NUMBER	QTY.
1	Tower Ring	1
2	LP-001-06	1
3	LP-001-05	2
4	Guide Fasteners	3

PROJECT SECTION: Launch Platform PART DESCRIPTION: Launch platform upper section.	QTY: See BOM	MATERIAL: None FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY.	University of Louisville River City Rocketry 2014-2015
PART NUMBER/NAME Launch Platform Upper Section	Model : JRL Detail : JRL	DO NOT SCALE DRAWING SHEET SCALE: 1:24			SHEET 1 OF 1

ITEM NO.	PART NUMBER	QTY.
1	Base	1
2	Launch Platform Upper Section	1
3	Tower_Arm_Connection	1
4	Tower_Ring_Connection	1



PROJECT SECTION: AGSE PART DESCRIPTION: Launch Platform	QTY: See BOM	MATERIAL: None FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY.	**University of Louisville** River City Rocketry 2014-2015
PART NUMBER/NAME Launch Platform	Model: JRL Detail: JRL	DO NOT SCALE DRAWING SHEET SCALE: 1:48			SHEET 1 OF 1



PROJECT SECTION :

PART DESCRIPTION:

PART NUMBER/NAME
IS-001

QTY: See BOM

Model :

Detail :

MATERIAL: NYLON 6/6
FINISH: None

DO NOT SCALE DRAWING
SHEET SCALE: 4:1

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:

DECIMALS	ANGLES
.XX: ±.01	30'
.XXX: ±.005	
.XXXX: ±.0010	

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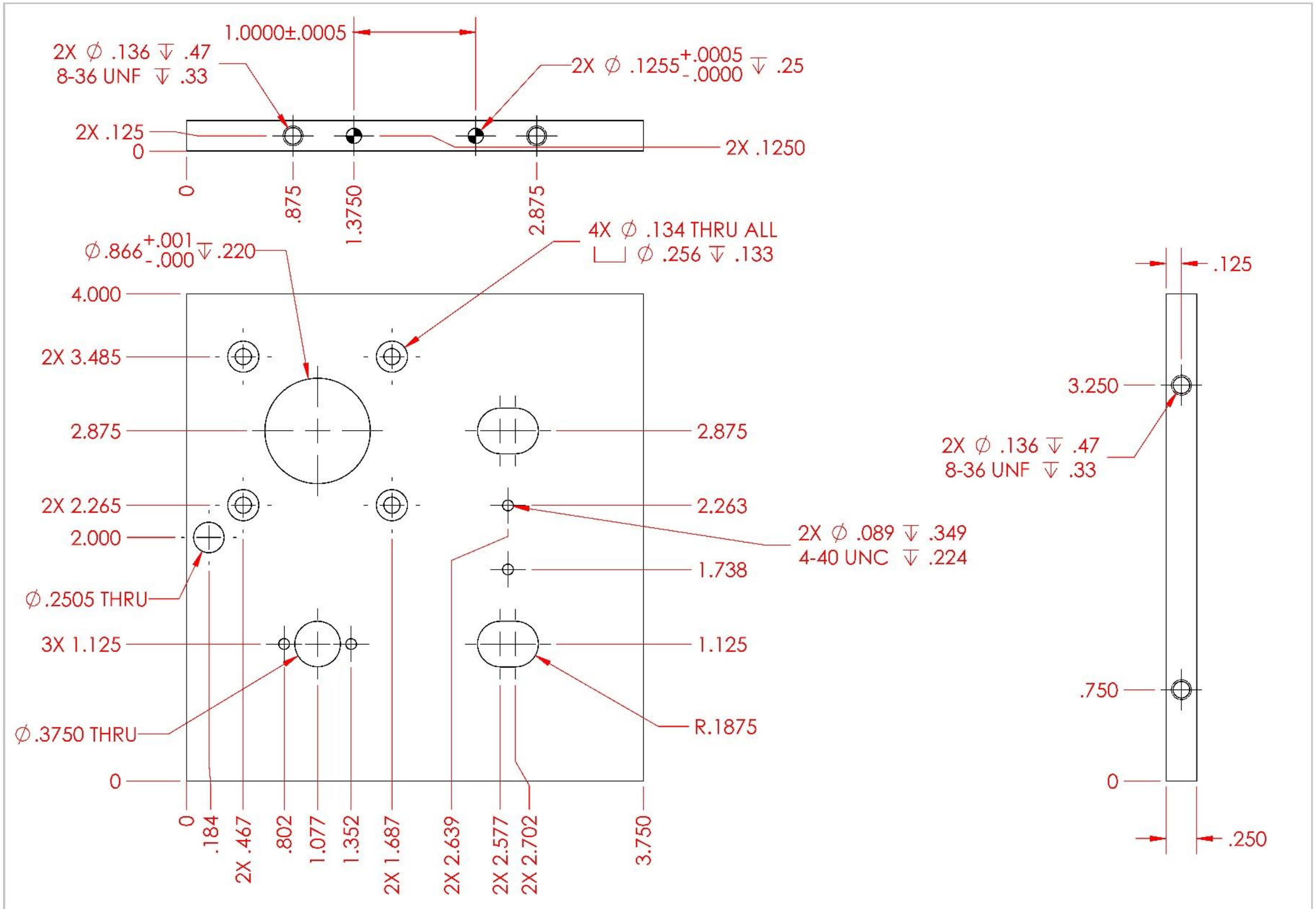
SHEET 1 OF 1



PROJECT SECTION: AGSE

PART DESCRIPTION: Motor Mounting Plate

PART NUMBER/NAME: IS-009

QTY: See BOM

Model: J.R.L.

Detail: J.R.L.

MATERIAL: AISI 1020 Steel, Cold Rolled

FINISH: None

DO NOT SCALE DRAWING

SHEET SCALE: 1:1

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:

DECIMALS: .XX: ±.01, .XXX: ±.005, .XXXX: ±.0010

ANGLES: 30'

PROPRIETARY NOTE

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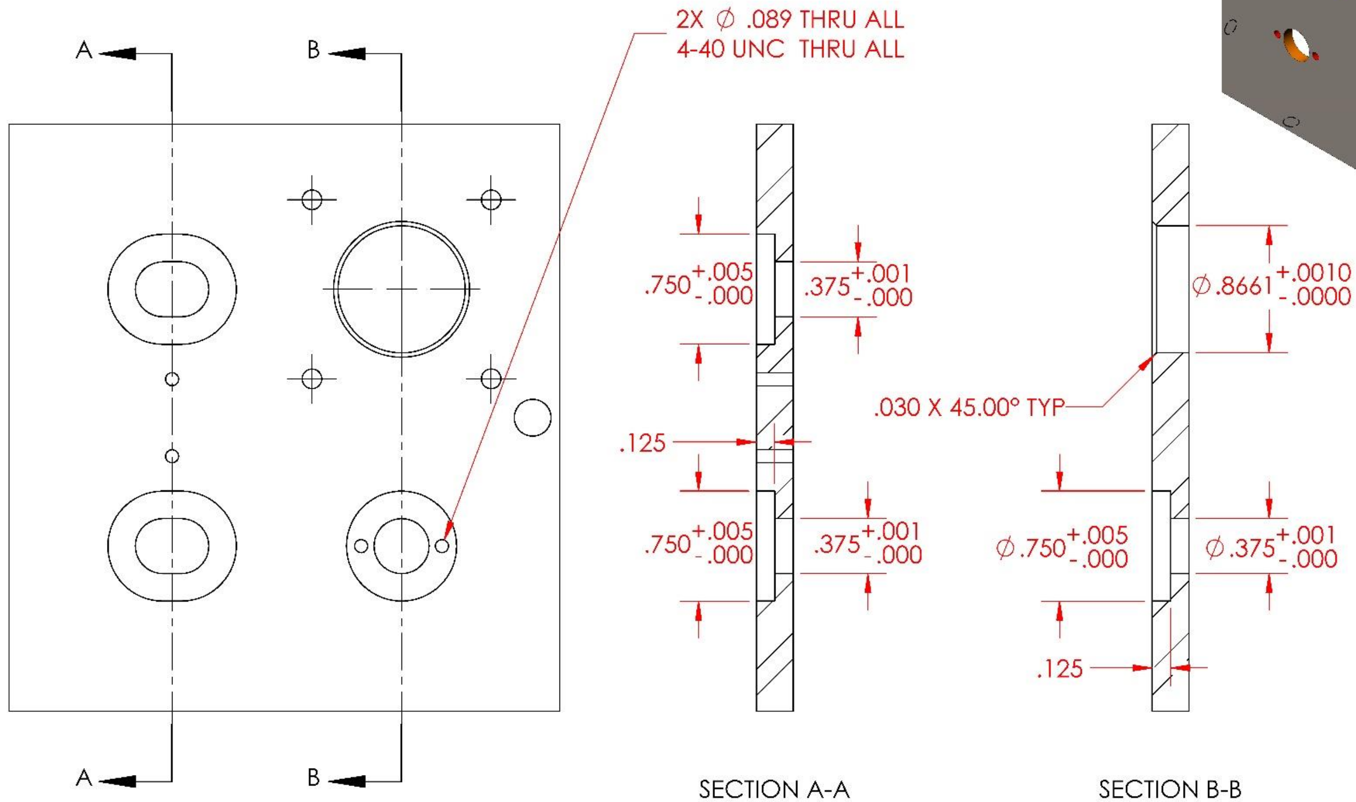
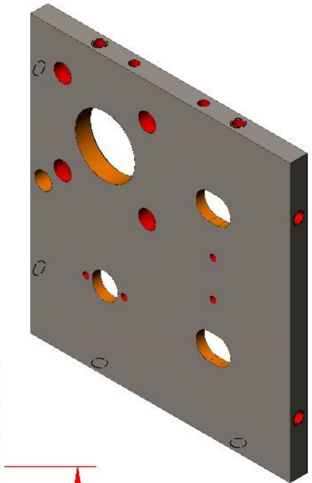
2014-2015

SHEET 1 OF 2

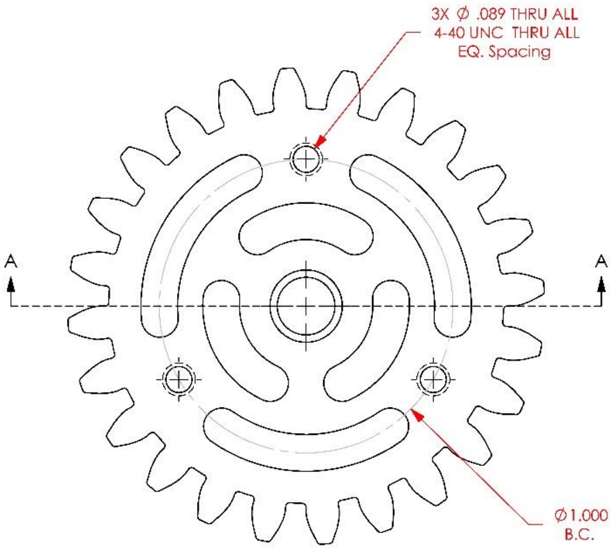
Bottom and left sides are mirrors of top and right

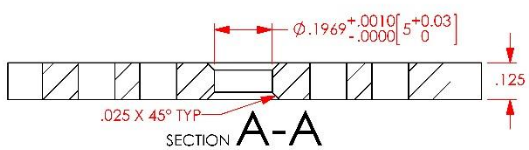


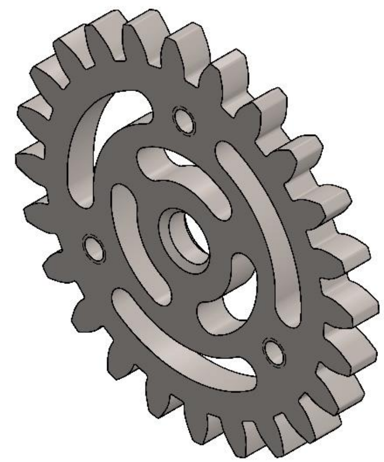


PROJECT SECTION: AGSE PART DESCRIPTION: Motor Mounting Plate	QTY: See BOM	MATERIAL: AISI 1020 Steel, Cold Rolled FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:	PROPRIETARY NOTE		**University of Louisville** River City Rocketry 2014-2015
PART NUMBER/NAME IS-009	Model : J.R.L. Detail : J.R.L.	DO NOT SCALE DRAWING SHEET SCALE: 1:1	DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETY, AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF SAMTEC, INC.		

SHEET 2 OF 2







Gear Parameters	
Parameter	**Value**
Dimetrical Pitch (teeth/in)	16.000
Number of Teeth	24.000
Pressure Angle (deg)	20.000
Addendum Circle (in)	1.625
Pitch Circle (in)	1.500
Base Circle (in)	1.410
Dedendum Circle (in)	1.344

PROJECT SECTION : AGSE PART DESCRIPTION: Drive gear	QTY: See BOM	**MATERIAL:** Titanium Ti-8Mn, Annealed **FINISH:** None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY
PART NUMBER/NAME IS-003	Model : J.R.L. Detail :	DO NOT SCALE DRAWING SHEET SCALE: 2:1		

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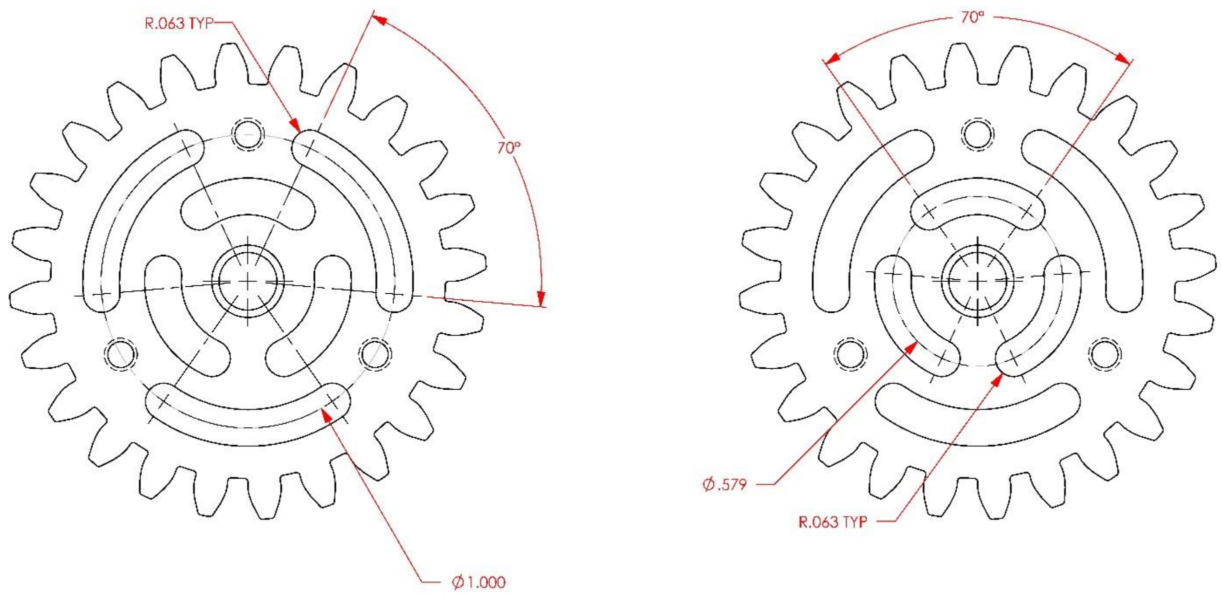
SHEET 1 OF 2

Notes:
Slotes are all equally spaced



PROJECT SECTION: AGSE PART DESCRIPTION: Drive gear	QTY: See BOM	**MATERIAL:** Titanium Ti-8Mn, Annealed **FINISH:** None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY	**University of Louisville** River City Rocketry 2014-2015
PART NUMBER/NAME IS-003	Model : J.R.L. Detail :	DO NOT SCALE DRAWING SHEET SCALE: 2:1			

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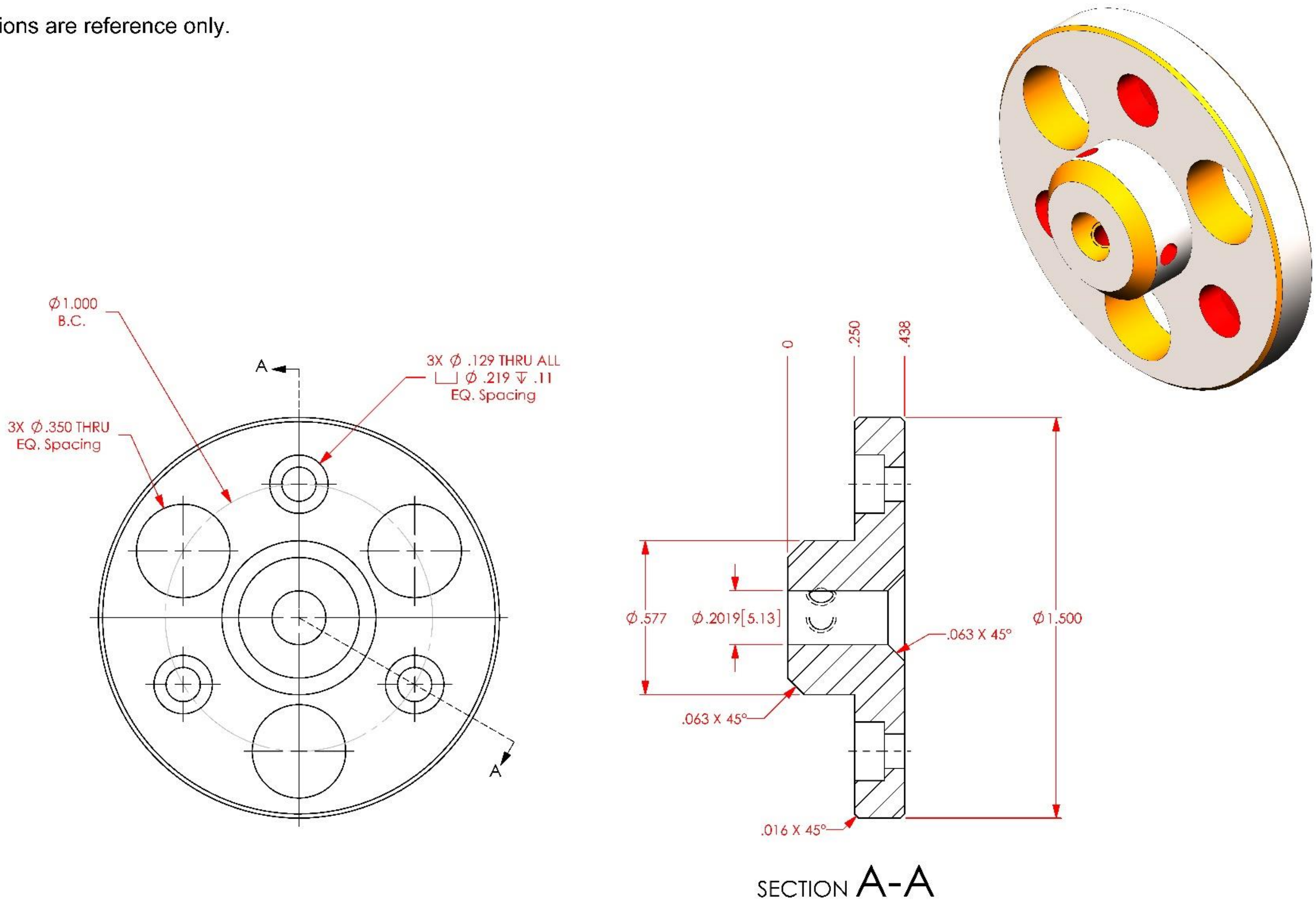
SHEET 2 OF 2

Note:
Dimensions are reference only.



PROJECT SECTION: AGSE PART DESCRIPTION: Drive wheel	QTY: See BOM	MATERIAL: Titanium Ti-8Mn, Annealed FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY, AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY.	University of Louisville River City Rocketry 2014-2015
PART NUMBER/NAME IS-005	Model : J.R.L. Detail :	DO NOT SCALE DRAWING SHEET SCALE: 2:1	DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'		

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SHEET 1 OF 1

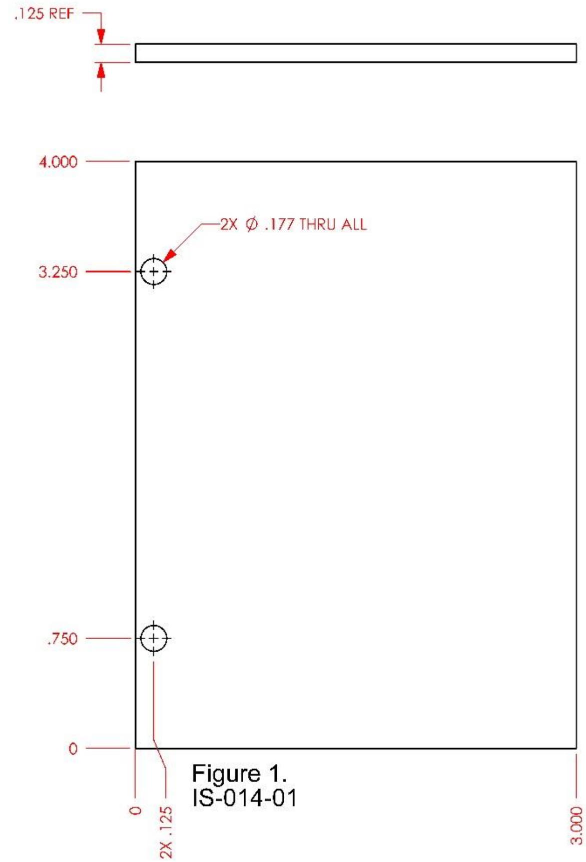
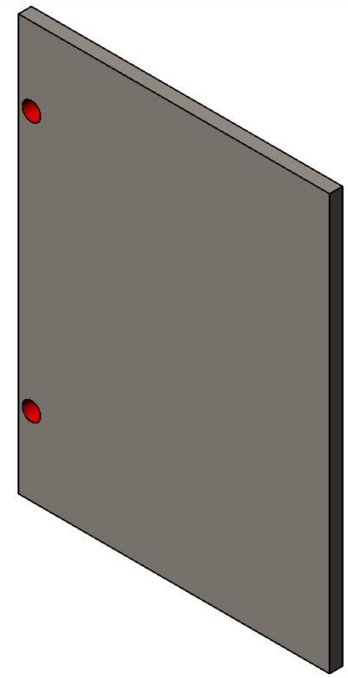
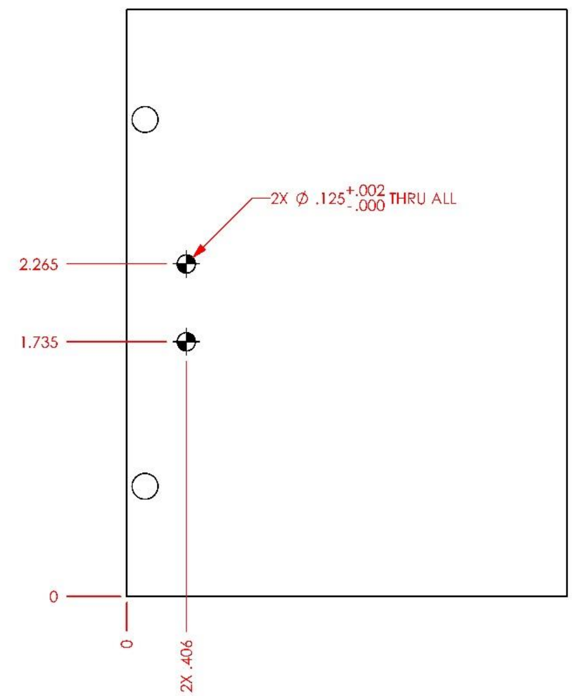


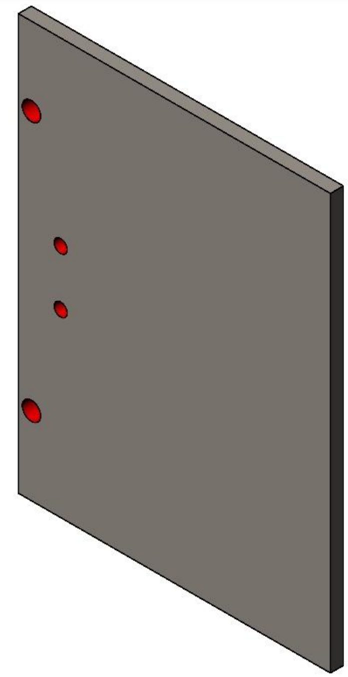
Figure 1.
IS-014-01



PROJECT SECTION: AGSE PART DESCRIPTION: Side deflection plate	QTY: See BOM	MATERIAL: AISI 1020 Steel, Cold Rolled FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY, AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY.		University of Louisville River City Rocketry 2014-2015
PART NUMBER/NAME IS-014-XX	Model : J.R.L. Detail :	DO NOT SCALE DRAWING SHEET SCALE: 1:1	DECIMALS: .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES: 30'			SHEET 1 OF 2

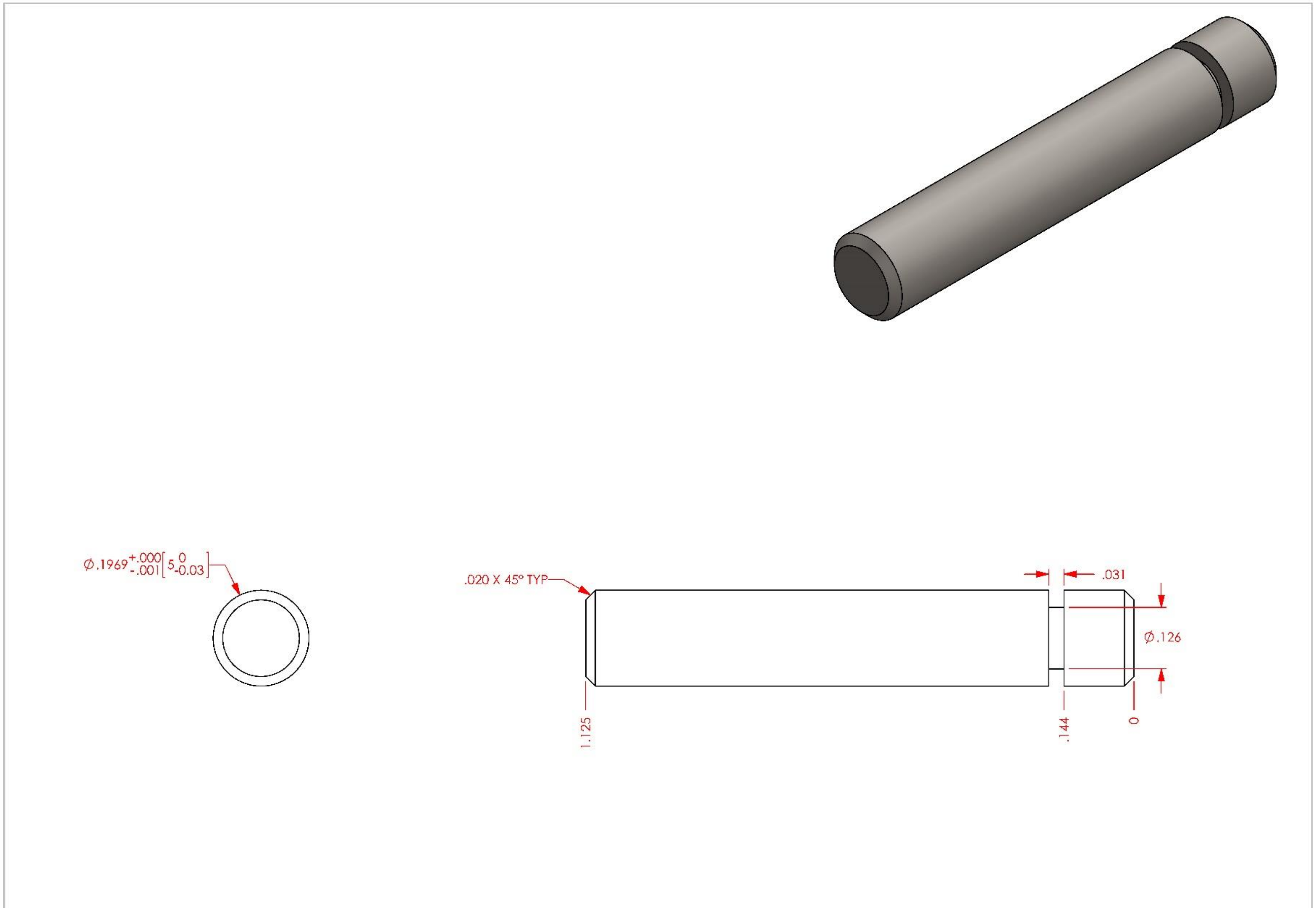
IS-014-02. Same as Figure 1 except as shown





PROJECT SECTION: AGSE PART DESCRIPTION: Side deflection plate	QTY: See BOM	MATERIAL: AISI 1020 Steel, Cold Rolled FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:	PROPRIETARY NOTE		University of Louisville River City Rocketry 2014-2015
PART NUMBER/NAME IS-014-XX	Model : J.R.L. Detail :	DO NOT SCALE DRAWING SHEET SCALE: 1:1	DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY, AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY.		

SHEET 2 OF 2



PROJECT SECTION :

PART DESCRIPTION:

PART NUMBER/NAME
IS-015

QTY:
See BOM

Model :

Detail :

MATERIAL:

FINISH:

DO NOT SCALE DRAWING
SHEET SCALE: 2:1

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UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN INCHES.
TOLERANCES ARE:

DECIMALS	ANGLES
.XX: ±.01	30'
.XXX: ±.005	
.XXXX: ±.0010	

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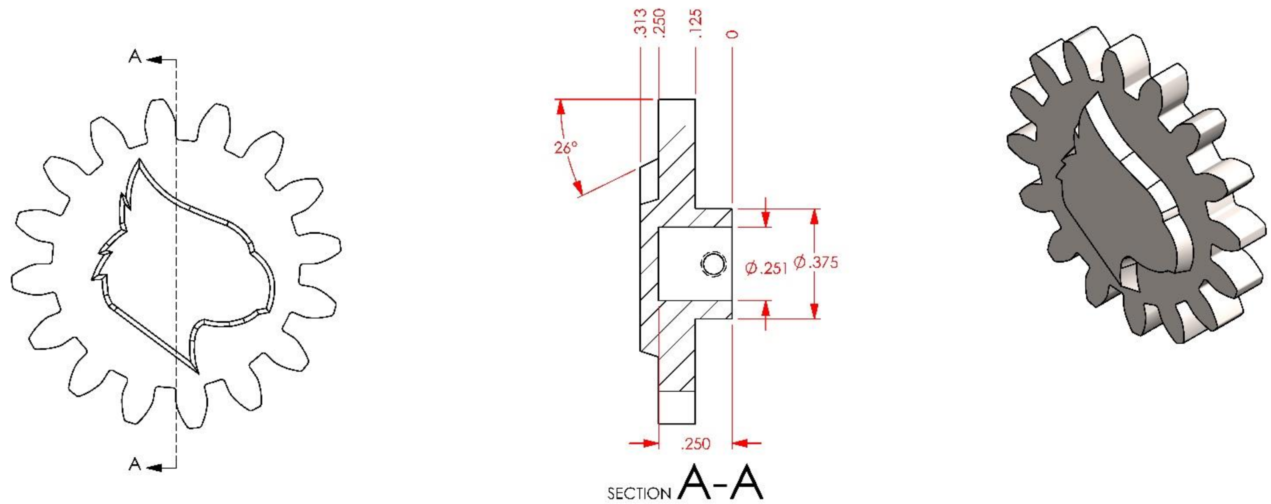
SHEET 1 OF 1



Note:
Dimensions are reference only.

Gear Parameters	
Parameter	**Value**
Dimetrical Pitch (teeth/in)	16
Number of Teeth	16
Pressure Angle (deg)	20
Addendum Circle (in)	1.13
Pitch Circle (in)	1
Base Circle (in)	0.94
Dedendum Circle	0.84

PROJECT SECTION :
PART DESCRIPTION:
PART NUMBER/NAME
IS-020

QTY: See BOM

Model :
Detail :

MATERIAL:
FINISH:

DO NOT SCALE DRAWING
SHEET SCALE: 2:1

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:

DECIMALS	ANGLES
.XX: ±.01	30'
.XXX: ±.005	
.XXXX: ±.0010	

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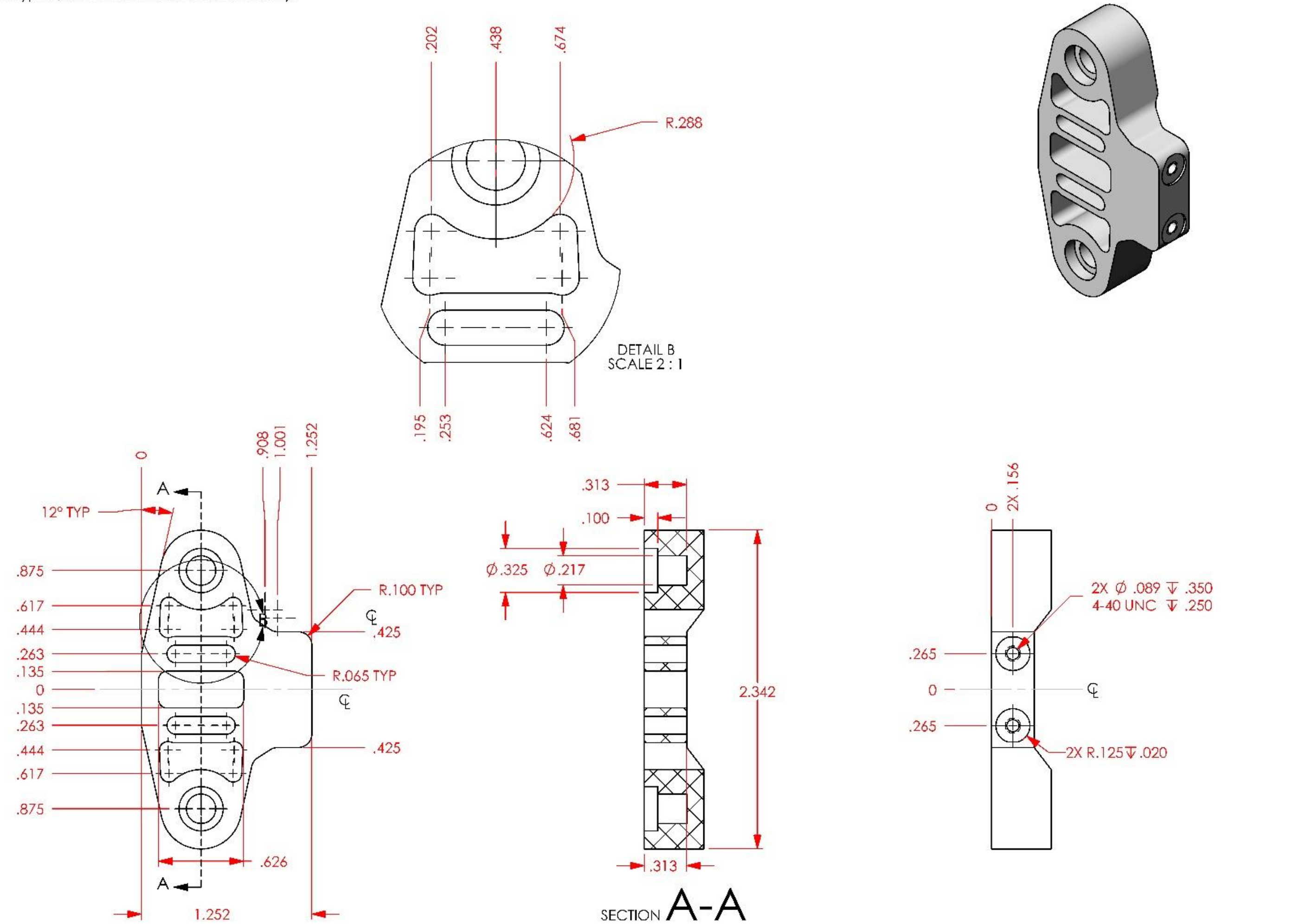
SHEET 1 OF 1

Notes:
Part to be rapid prototyped, all dimensions for reference only.



PROJECT SECTION: AGSE PART DESCRIPTION: Spring tensioner pressure plate	QTY: See BOM	MATERIAL: ABS FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY	**University of Louisville** River City Rocketry 2014-2015
PART NUMBER/NAME IS-021	Model : J.R.L. Detail :	DO NOT SCALE DRAWING SHEET SCALE: 1:1			SHEET 1 OF 1

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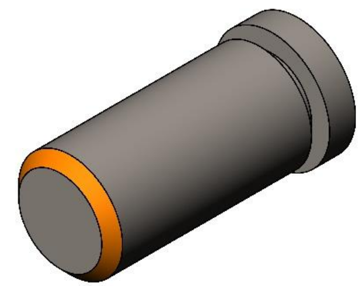

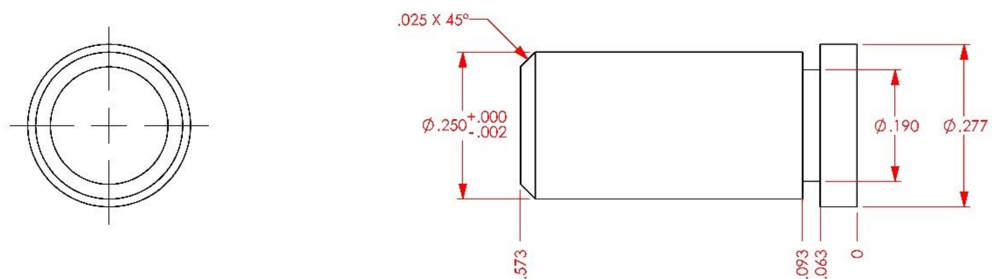

PROJECT SECTION : AGSE PART DESCRIPTION: Idler shaft	QTY: See BOM	MATERIAL: AISI 1020 Steel, Cold Rolled FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY
PART NUMBER/NAME IS-022	Model : J.R.L. Detail :	DO NOT SCALE DRAWING SHEET SCALE: 4:1		

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ITEM NO.	PART NUMBER	QTY.
1	IS-003	1
2	IS-005	1
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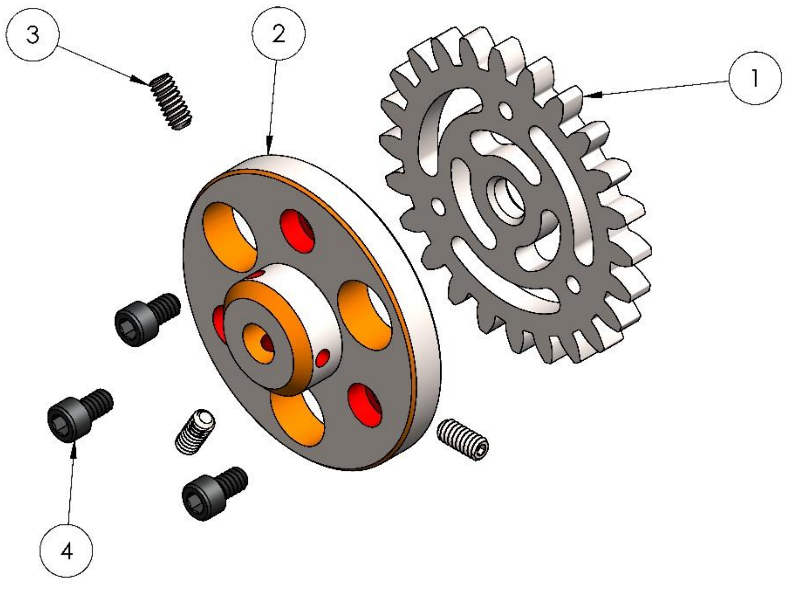
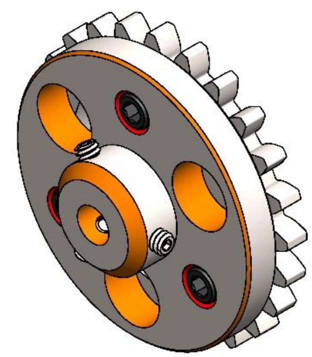
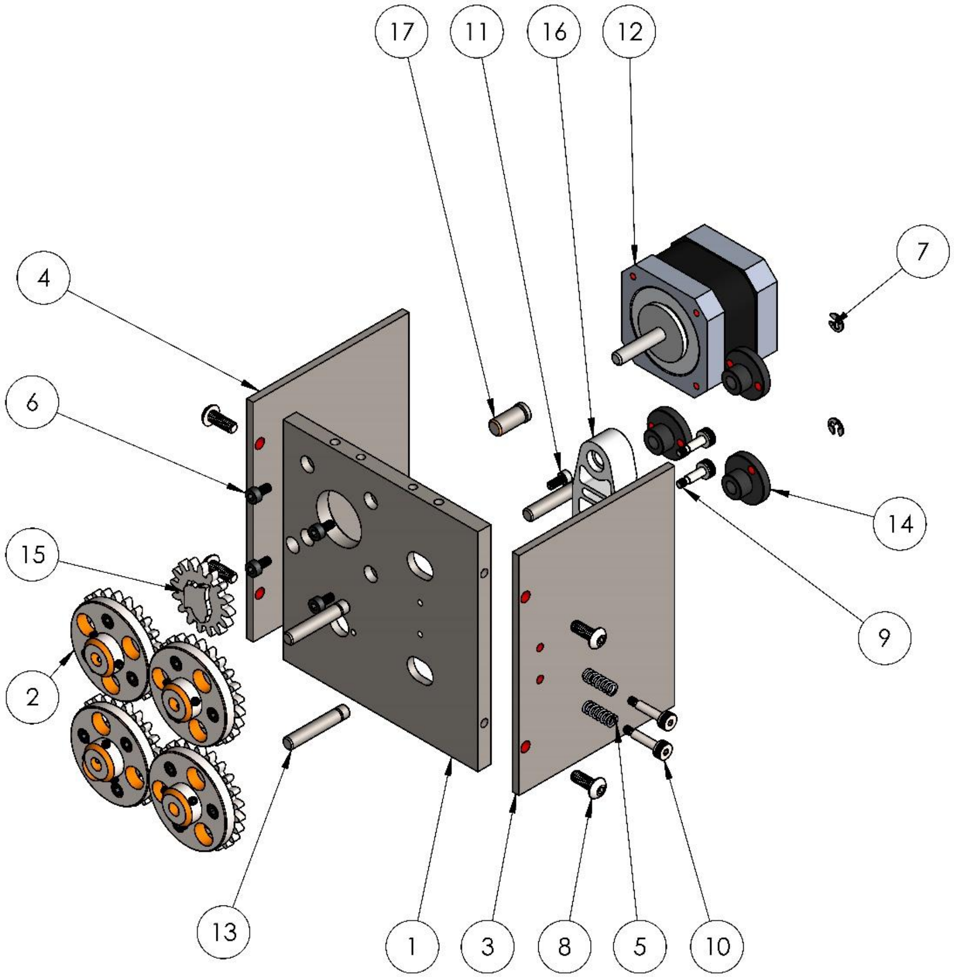
4	91251A105	3





PROJECT SECTION: AGSE PART DESCRIPTION: Extrusion Wheel	QTY: See BOM	MATERIAL: "SW-Material@Part1.SLDPRT" FINISH: N/A	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETY, AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF SAMTEC, INC.	University of Louisville River City Rocketry 2014-2015
PART NUMBER/NAME Extrusion Wheel	Model: J.R.L. Detail: J.R.L.	DO NOT SCALE DRAWING SHEET SCALE: 1:1			SHEET 1 OF 1



ITEM NO.	PART NUMBER	QTY.
1	IS-009	1
2	Extrusion Wheel	4
3	IS-014	1
4	IS-014	1
5	9657K268	2
6	91290A111	4
7	98317A211	3
8	92949A193	4
9	97345A419	2
10	91259A157	2
11	90128A106	2
12	Stepper motor - NEMA-17 size, 200 stepsrev 12V 350mA	1
13	IS-015	3
14	IS-001	3
15	IS-020	1
16	IS-021	1
17	IS-022	1

PROJECT SECTION : AGSE
PART DESCRIPTION: Ignition Station
PART NUMBER/NAME
Ignition Station

QTY: See BOM
Model : J.R.L.
Detail : J.R.L.

MATERIAL: "SW-Material@Part1.SLDPRT"
FINISH: N/A
DO NOT SCALE DRAWING
SHEET SCALE: 1:1

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010
ANGLES 30'

PROPRIETARY NOTE
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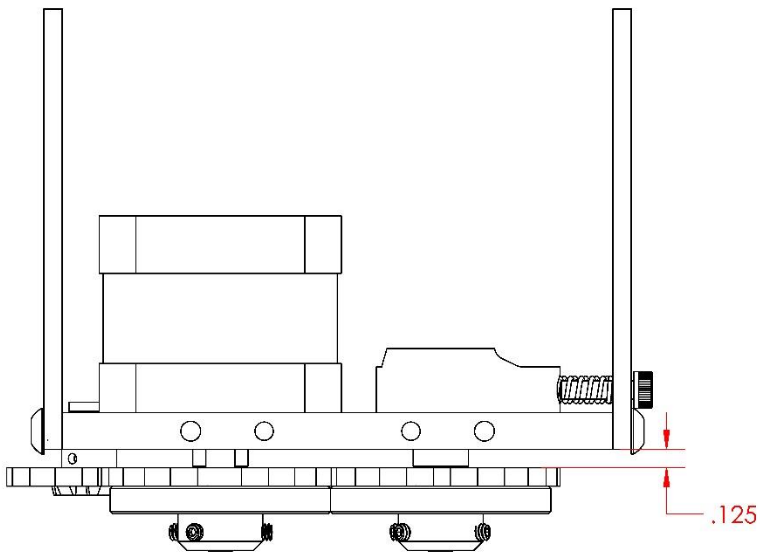
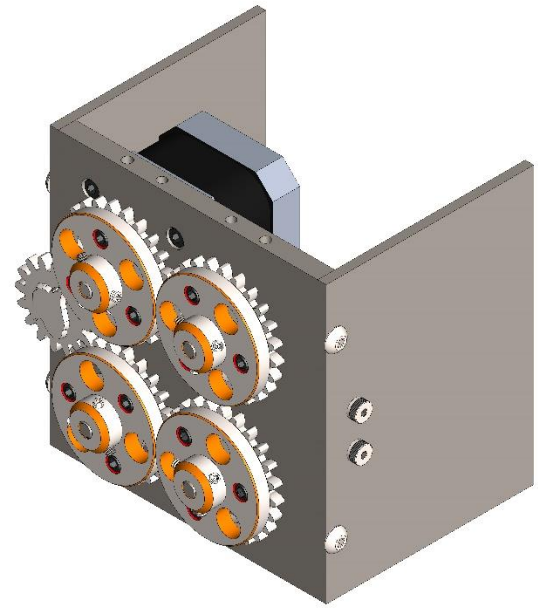
2014-2015

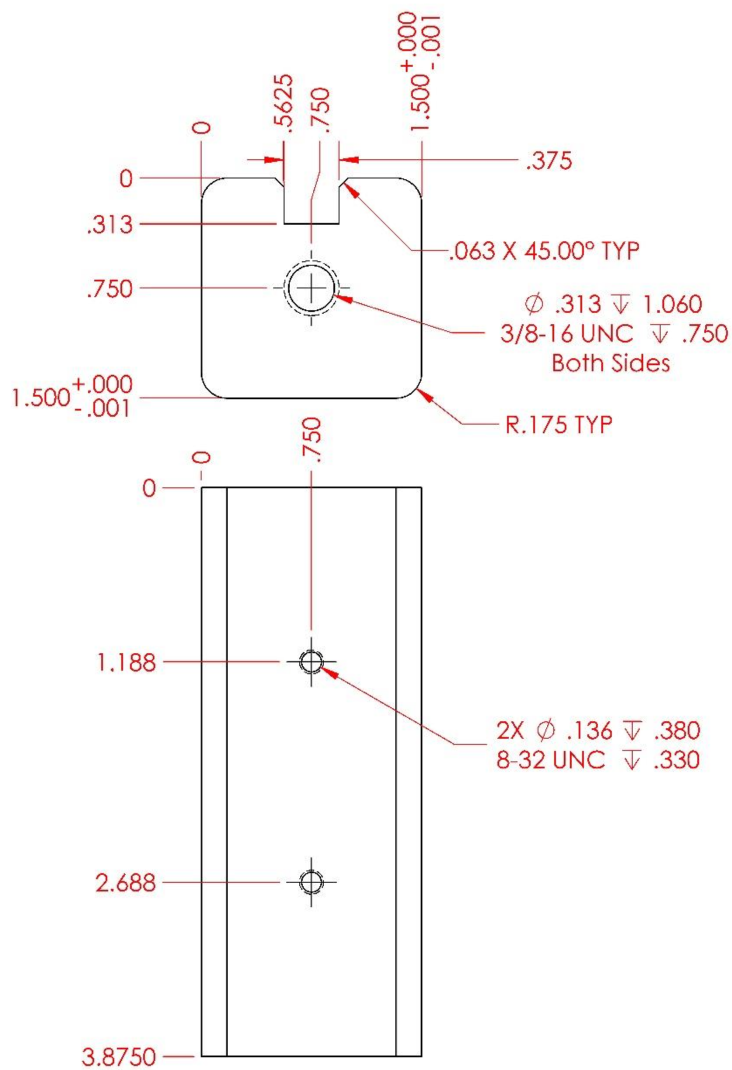
SHEET 1 OF 2

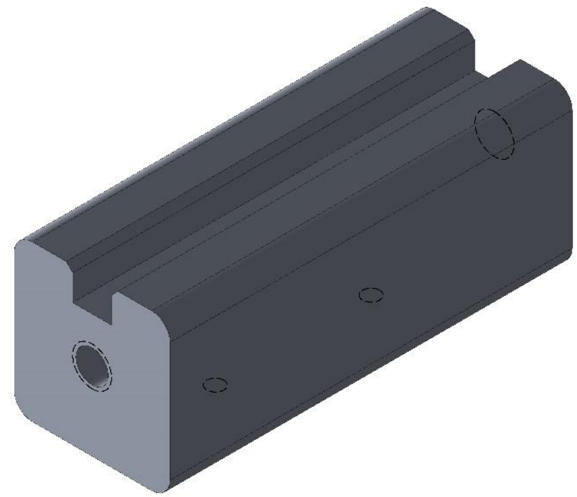




PROJECT SECTION: AGSE PART DESCRIPTION: Ignition Station	QTY: See BOM	MATERIAL: "SW-Material@Part1.SLDPRT" FINISH: N/A	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY.	**University of Louisville** River City Rocketry 2014-2015
PART NUMBER/NAME Ignition Station	Model : J.R.L. Detail : J.R.L.	DO NOT SCALE DRAWING SHEET SCALE: 1:4	DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'		

SHEET 2 OF 2





PROJECT SECTION :

PART DESCRIPTION:

PART NUMBER/NAME
carriageUprightMachined

QTY:
See BOM

Model :

Detail :

MATERIAL: 6061-T6 (SS)

FINISH:

DO NOT SCALE DRAWING
SHEET SCALE: 1:2

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:

DECIMALS
.XX: ±.01
.XXX: ±.005
.XXXX: ±.0010

ANGLES
30'

PROPRIETARY NOTE

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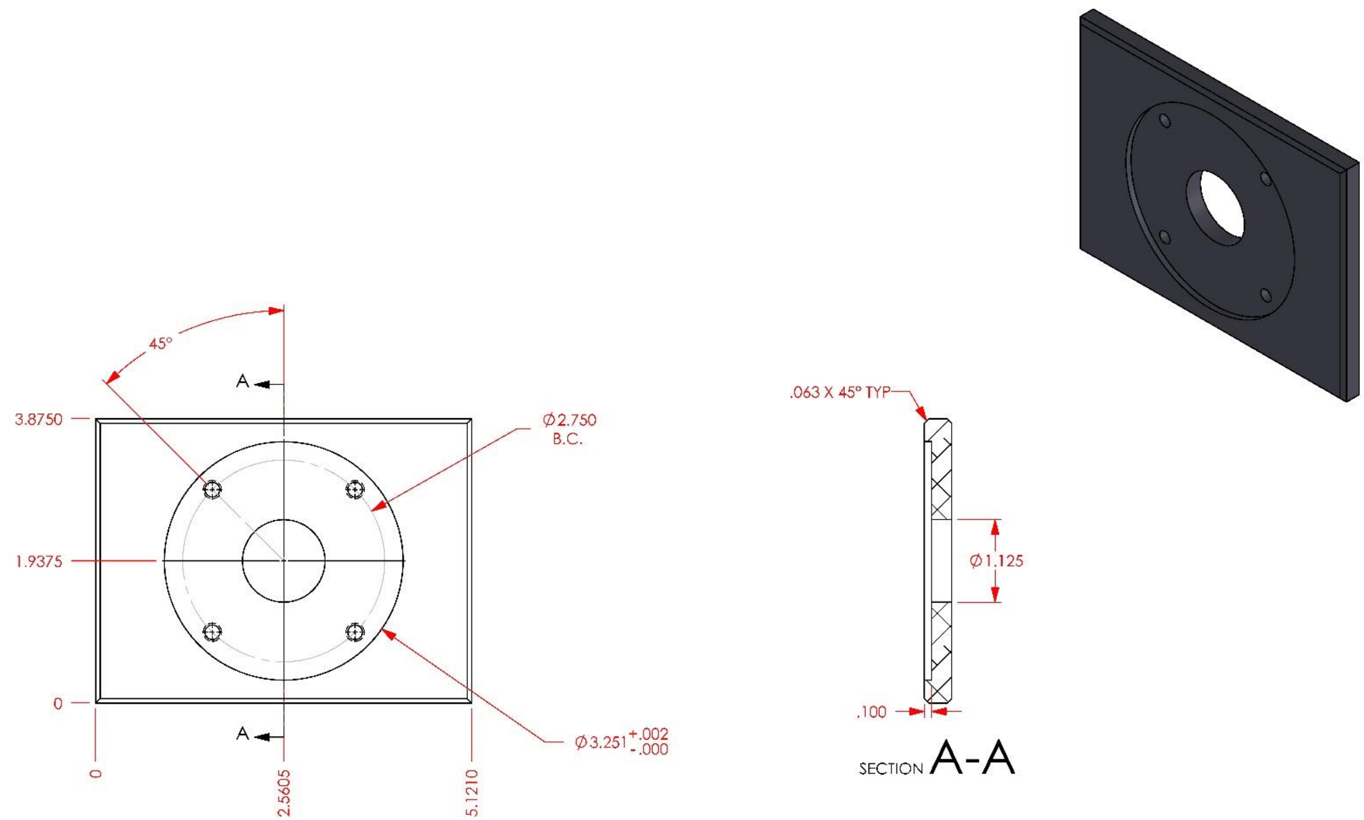
2014-2015

SHEET 1 OF 1



PROJECT SECTION : AGSE PART DESCRIPTION: Power screw mount plate	QTY: See BOM	MATERIAL: 6061-T6 (SS) FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN	**University of Louisville** River City Rocketry 2014-2015
PART NUMBER/NAME Carriage Screw Plate	Model : J.R.L. Detail :	DO NOT SCALE DRAWING SHEET SCALE: 1:2			

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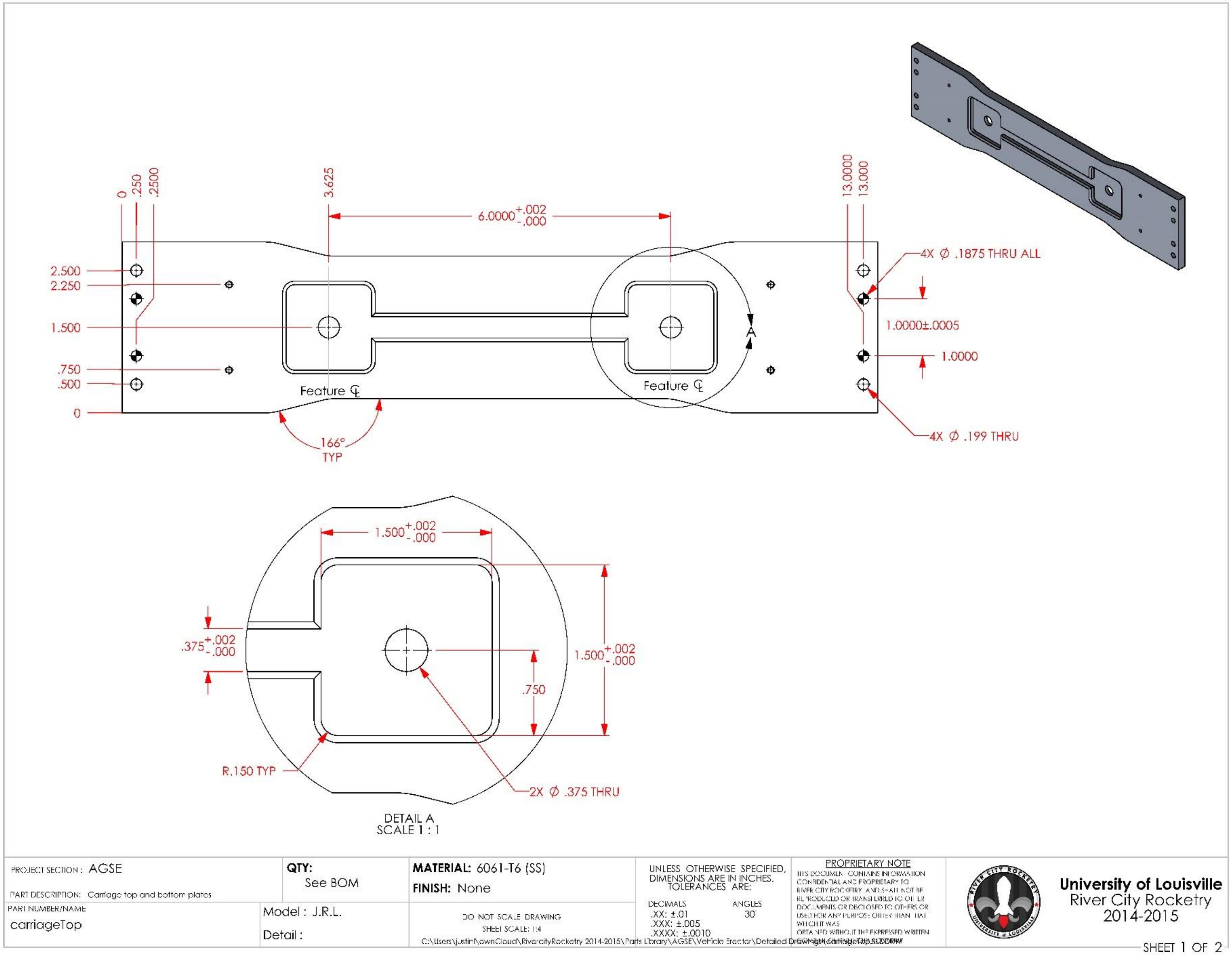
SHEET 1 OF 1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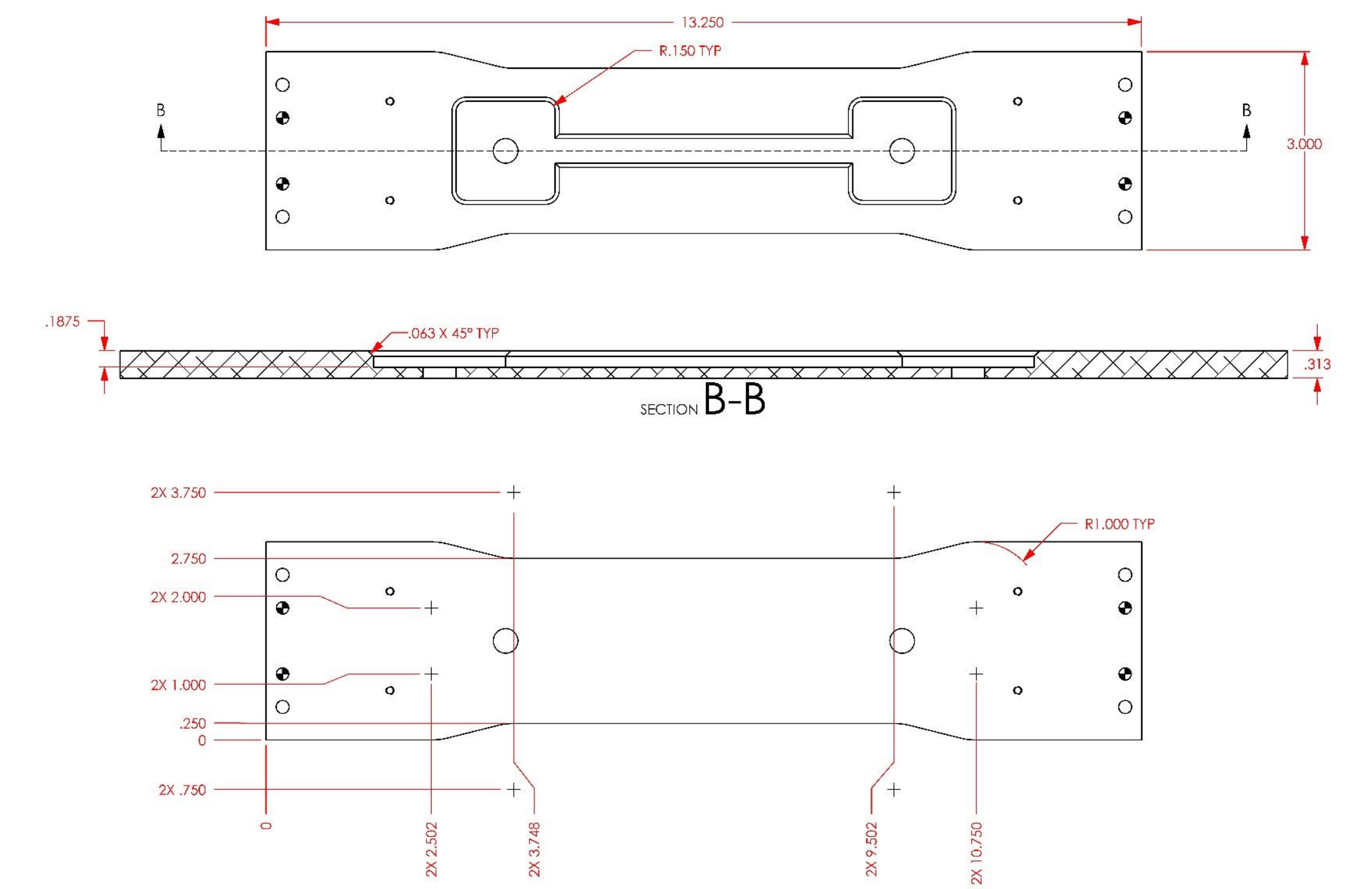
13.0000
13.000
6.0000 +.002 -.000
2.500
2.250
1.500
.750
.500
0
4X Ø .1875 THRU ALL
1.0000±.0005
1.0000
4X Ø .199 THRU
A
Feature ℄
Feature ℄
166° TYP
1.500 +.002 -.000
.375 +.002 -.000
1.500 +.002 -.000
.750
R.150 TYP
2X Ø .375 THRU
DETAIL A
SCALE 1 : 1
PROJECT SECTION : AGSE
PART DESCRIPTION: Carriage top and bottom plates
PART NUMBER/NAME
carriageTop
QTY:
See BOM
Model : J.R.L.
Detail :
MATERIAL: 6061-T6 (SS)
FINISH: None
DO NOT SCALE DRAWING
SHEET SCALE: 1:4
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
DECIMALS
.XX: ±.01
.XXX: ±.005
.XXXX: ±.0010
ANGLES
30'
PROPRIETARY NOTE
University of Louisville
River City Rocketry
2014-2015
SHEET 1 OF 2

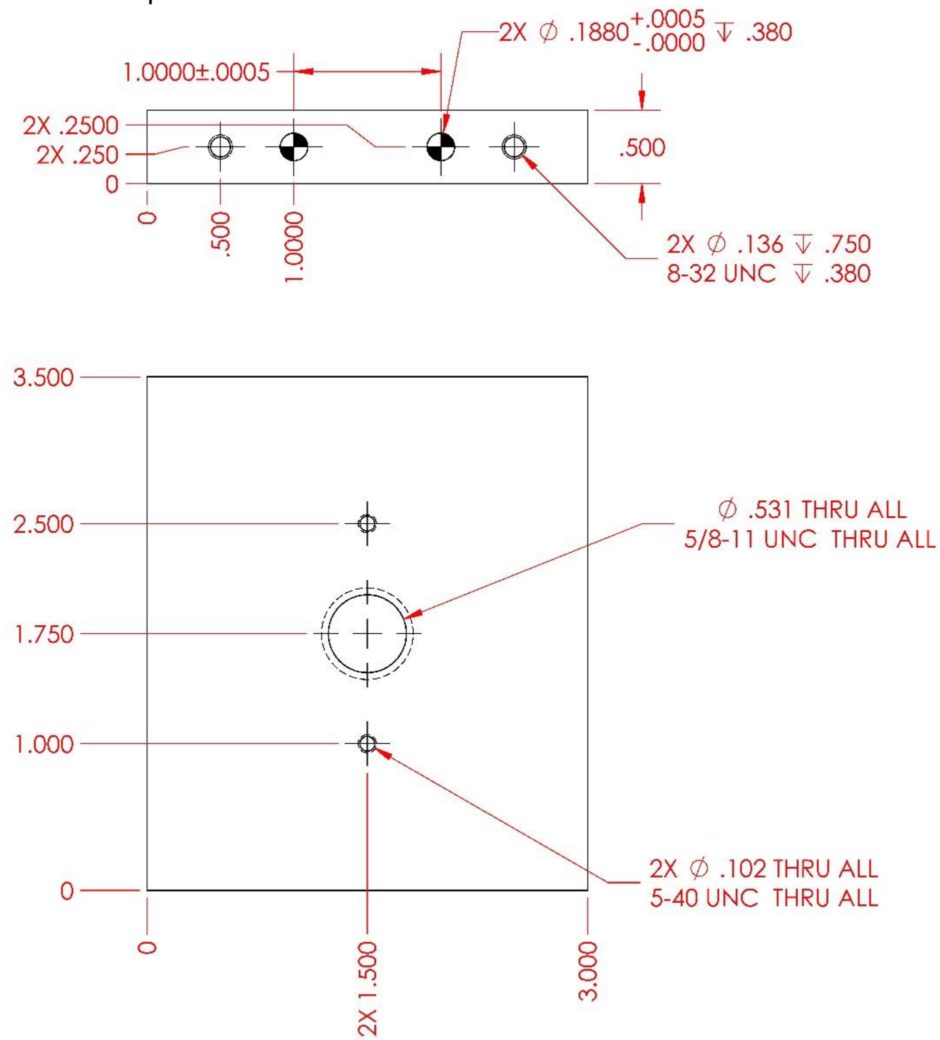


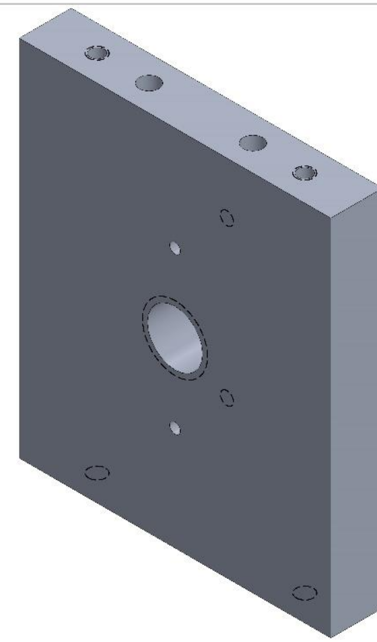
PROJECT SECTION: AGSE PART DESCRIPTION: Carriage top and bottom plates	QTY: See BOM	MATERIAL: 6061-T6 (SS) FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN	University of Louisville River City Rocketry 2014-2015
PART NUMBER/NAME carriageTop	Model: J.R.L. Detail:	DO NOT SCALE DRAWING SHEET SCALE: 1:4			

C:\Users\justin\ownCloud\RivercityRocketry 2014-2015\Parts Library\AGSE\Vehicle Erector\Detailed Drawings\carriageTop.SLDDRW

SHEET 2 OF 2

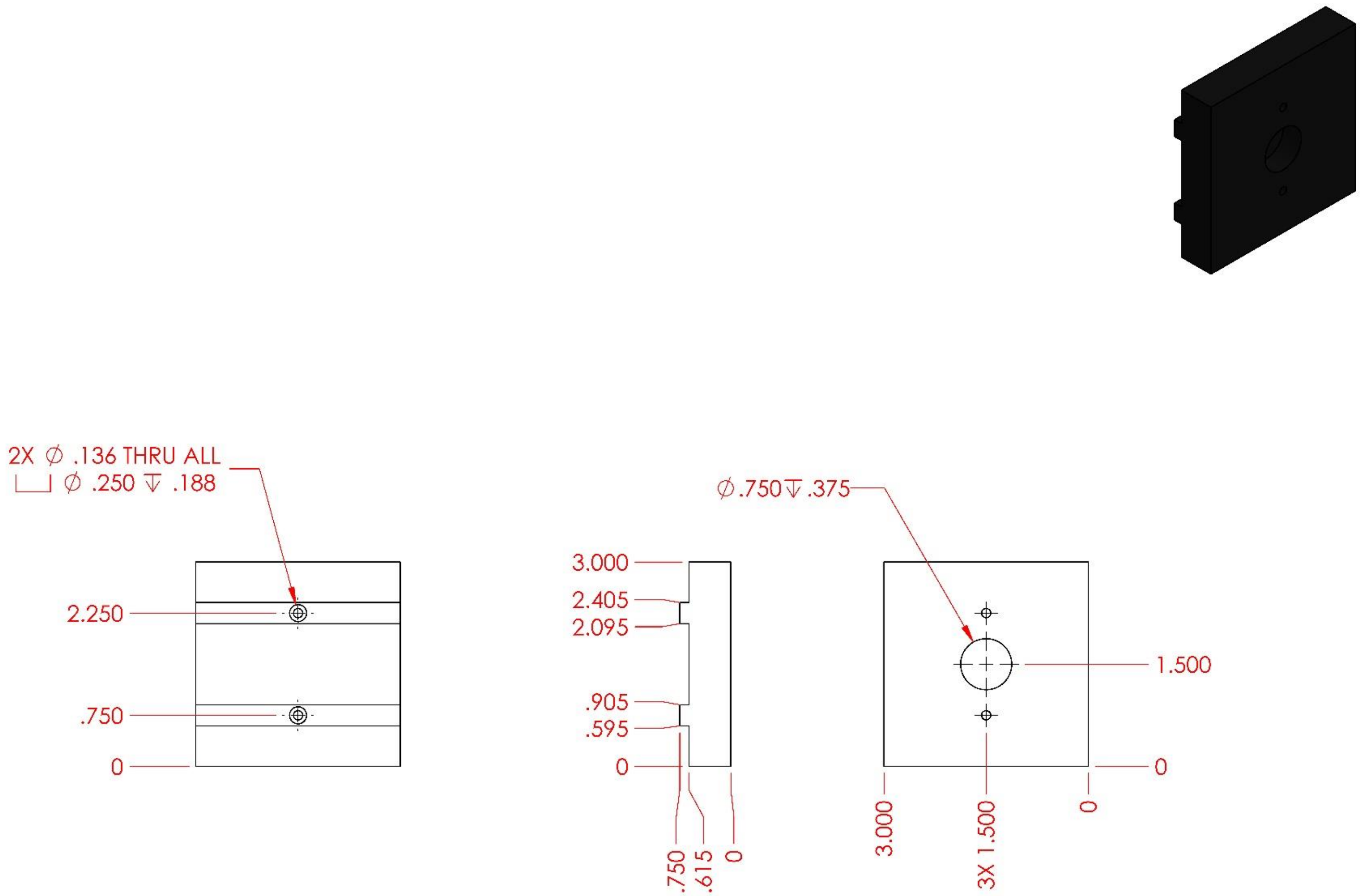
Note:
Bottom is mirror of top





PROJECT SECTION : AGSE PART DESCRIPTION: Carriage side plates	QTY: See BOM	MATERIAL: 6061-T6 (SS) FINISH: None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE: DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30	PROPRIETARY NOTE THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY.	University of Louisville River City Rocketry 2014-2015
PART NUMBER/NAME articulationCarriagePlate	Model : J.R.L. Detail :	DO NOT SCALE DRAWING SHEET SCALE: 1:1			

SHEET 1 OF 1



PROJECT SECTION: AGSE PART DESCRIPTION: Outer nylon guide	QTY: See BOM	**MATERIAL:** Nylon 101 **FINISH:** None	UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES ARE:	PROPRIETARY NOTE
PART NUMBER/NAME carriageInnerUprightOuterSlider	Model : J.R.L. Detail:	DO NOT SCALE DRAWING SHEET SCALE: 1:2	DECIMALS .XX: ±.01 .XXX: ±.005 .XXXX: ±.0010 ANGLES 30'	THIS DOCUMENT CONTAINS INFORMATION CONFIDENTIAL AND PROPRIETARY TO RIVER CITY ROCKETRY AND SHALL NOT BE REPRODUCED OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY PURPOSE OTHER THAN THAT WHICH IT WAS OBTAINED WITHOUT THE EXPRESSED WRITTEN CONSENT OF RIVER CITY ROCKETRY.

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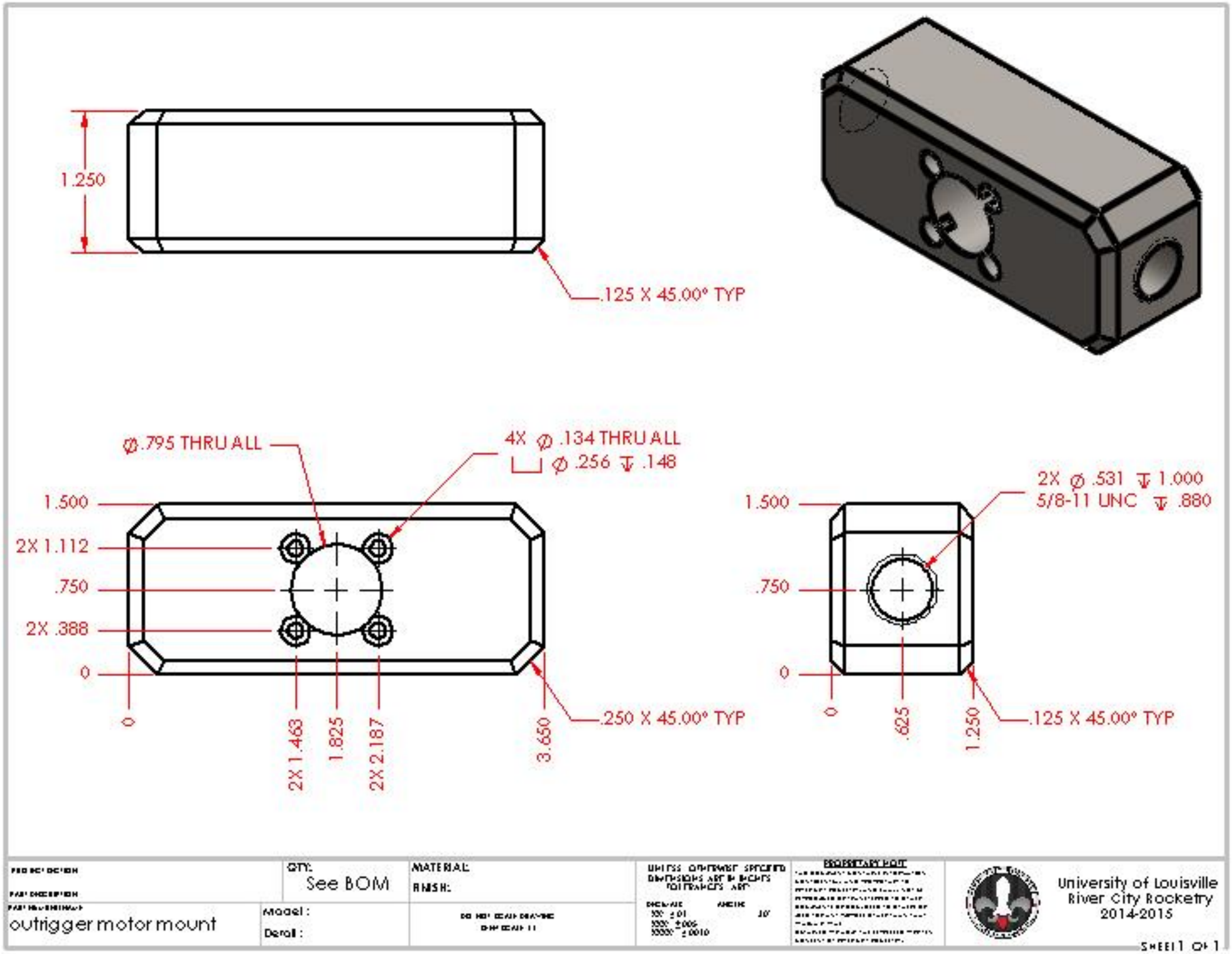
SHEET 1 OF 1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Ø.795 THRU ALL
4X Ø .134 THRU ALL
⌴ Ø .256 ↧ .148
1.500
2X 1.112
.750
2X .388
0
0
2X 1.463
1.825
2X 2.187
3.650
.250 X 45.00° TYP
2X Ø .531 ↧ 1.000
5/8-11 UNC ↧ .880
1.500
.750
0
0
.625
1.250
.125 X 45.00° TYP
QTY:
See BOM
MATERIAL:
FINISH:
outrigger motor mount
Model :
Detail :
University of Louisville
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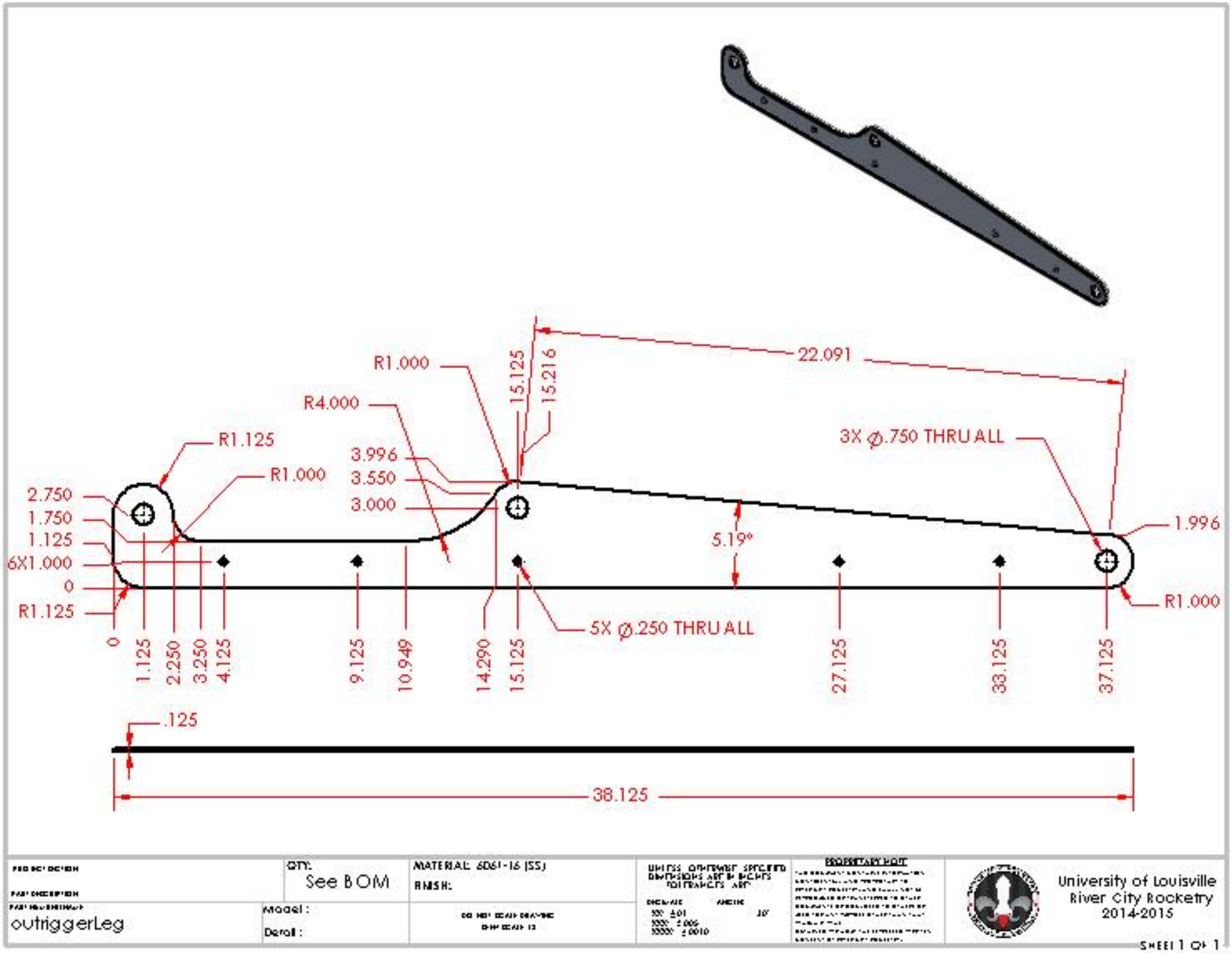
2014-2015
SHEET 1 OF 1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R1.125
R1.000
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2.750
1.750
1.125
6X1.000
0
R1.125
5.19°
1.996
R1.000
5X ⌀.250 THRU ALL
0
1.125
2.250
3.250
4.125
9.125
10.949
14.290
15.125
27.125
33.125
37.125
.125
38.125
QTY:
See BOM
MATERIAL: 6061-T6 (SS)
FINISH:
outriggerLeg
Model :
Detail :
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SHEET 1 OF 1