NASA Student Launch

2014-2015 PDR for Maxi-MAV

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Section 1. Summary of PDR 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 carbon fiber airframe, fiberglass, 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)	38.3
Motor Choice	CTI 3147-L935-IM-P
Recovery System	Dual deployment

Table 1: Launch vehicle overview.

Section 2. Changes Made Since Proposal

1) Vehicle Criteria

The launch vehicle has seen two major changes since the proposal. These changes had effect on the overall dimensions and mass of the launch vehicle. The changes made since the proposal are as follows:

- The autonomous door that opens to allow for the cache payload to be inserted into the launch vehicle will now open rotationally.
- The launch vehicle's motor is now selected to be a Cesaroni 3147-L935-IM-P.

To save weight, the track system for the door's actuation was changed from a linear design to one which allows for rotational actuation. In the linear design, extra airframe was needed to allow for the door to fit when retracted up and into the launch vehicle. This was deemed to be a waste of space. By designing the track system to follow the curvature of the airframe, the door assembly can now be fully housed on the same plane and open about the launch vehicle's axis.

This change in payload insertion design, coupled with a more in-depth mass analysis of various launch vehicle building materials and fasteners caused a shift in the launch vehicle's mass and center of gravity. The new motor was chosen to bring our launch vehicle closer to the required 3,000 ft altitude. Minor adjustments to the fin dimensions were made to keep the launch vehicle near the same level of aerodynamic stability.

2) AGSE Criteria

The AGSE has seen 7 major design changes since the proposal. These changes have affected the overall mass and dimensions of the system.

- The arm has been completely redesigned
- The ground station has been completely redesigned
- An auto platform leveling system has been implemented
- The launch platform has been lengthened to 120.39 inches and anti-friction tape has been added
- The ignition system has had tensioners included
- The drive motor for the vehicle erection system has been sized
- A weather station is being incorporated into the AGSE
- Bluetooth communication is being incorporated to communicate between the vehicle and the payload cache system

The payload arm has been almost completely redesigned since the proposal. The four major changes to payload arm are as follows:

- Instead of using a rack and pinion system to move the payload vertically and horizontally, a thread less ball screw system has been implemented.
- Instead of using a servo to rotate the gripper assembly horizontally, a timing belt system will be used.
- The towers on each side of the arm will be made out of 8020 posts instead of the off-the-shelve U-channels
- The gearing on the payload gripper has changed to only use three gears.

The rack and pinion system was abandoned due to being less reliable. The thread less ball screw system was chosen as it's been proven to work in 3D printers and is cheaper than a traditional ball screw. A timing belt system has been chosen to rotate the gripper assembly due to its higher reliability compared to using a servo. The two towers will be made out of 8020 posts due to its higher flexibility in adjusting the payloads height. Finally, the gearing on the gripper has changed to its simpler design compared to the proposal.

The ground station was changed to increase structural rigidity. Two separate frames enclose the vehicle and are supported by eight support rails. Four of these rails are at structural break points and are 1.5 x 3 inch t-slotted aluminum extrusions, the other four rails are the mounting points for the vehicle erection system and consist of 1.5 x 1.5 inch t-slotted aluminum extrusions.

To ensure safe exit velocity, the guide rails on the launch platform have been lengthened. This came at the results of mathematical analysis. In addition to added length, anti-friction tape will be used on the inside portion of the guide rails to reduce the frictional losses during takeoff.

To ensure consistent tension on the igniter wire during vehicle erection system actuation and igniter installation, two tensioner systems have been added. These consist of a threaded rod with two nuts, a spring, and a brass sleeve bearing. During setup, the wire will be inserted by sliding the two driven wheels out, placing the wire, and then allowing spring tension to ensure proper grip.

Analysis was performed on the vehicle erection system to determine the motor torque requirement at a required rpm. The rpm was chosen to ensure that the system would finish its required function within the required time frame and the torque was sized such that the system could drive the vehicle at the required rpm.

The system architecture has been changed from the central PC network outlined in the proposal. We will now be using an I2C network connecting the microcontrollers in the AGSE. Using I2C allows us to interface multiple controllers together in the place of communication being transferred through USB protocol.

Another change to the ground station is the weather data collection. The weather system consists of multiple, identical sensor clusters. Each board will read temperature, light, and air speed data from the immediate environment. The weather data recording has been added to increase the science value of the project and add environmental feedback into the AGSE.

Bluetooth communication has been added to communicate with the rocket capsule. A wireless connection removes the need for a physical wire disconnect from the AGSE to the capsule. The wireless communication allows for data logging after launch up to 1000 meters.

Section 3. Launch Vehicle Criteria

1) Design and Verification of Launch Vehicle

Design Overview

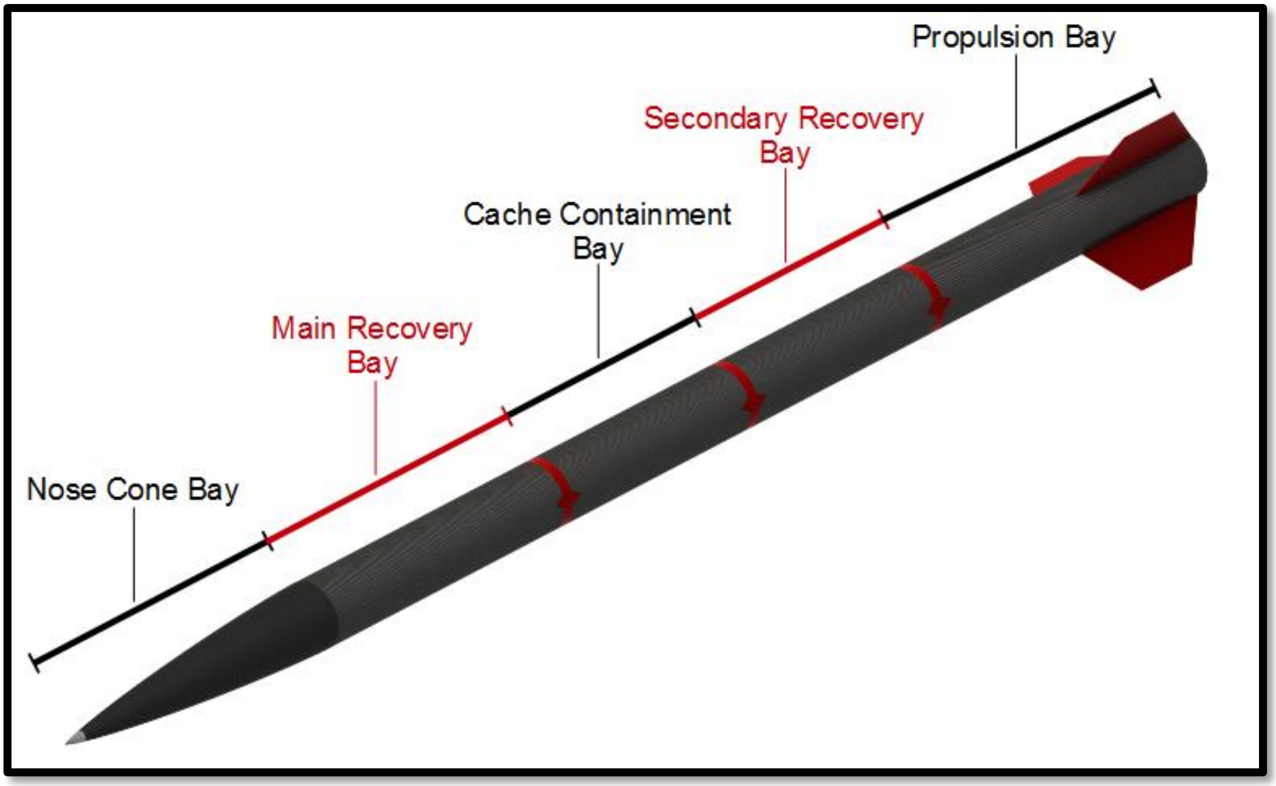


Figure 1: Layout of the primary launch vehicle sections.

The team is focusing on overall efficiency of the vehicle design 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 carbon fiber airframe, to feature a removable fin system, to have no wasted internal space, 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 55 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 carbon fiber, 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.

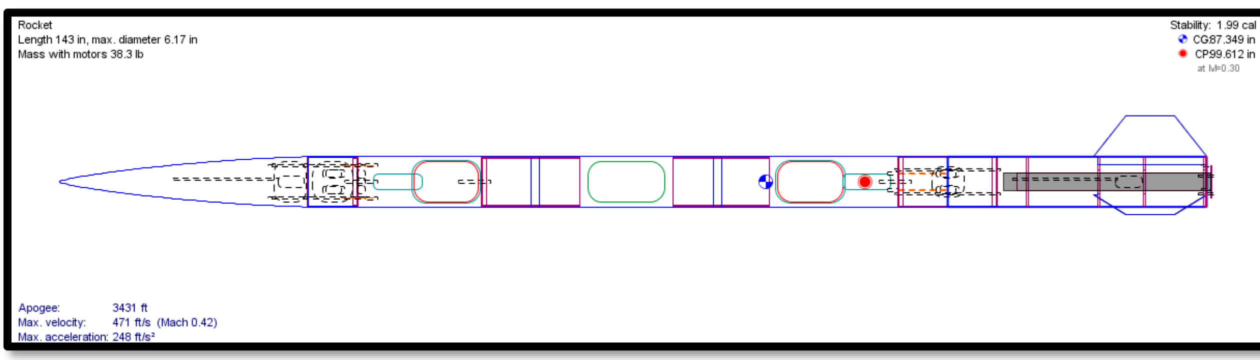


Figure 2: OpenRocket simulation of the launch vehicle.

Figure 2 shows the OpenRocket schematic of the launch vehicle. The vehicle is designed such that the cache capsule system 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.

Nose Cone Design

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

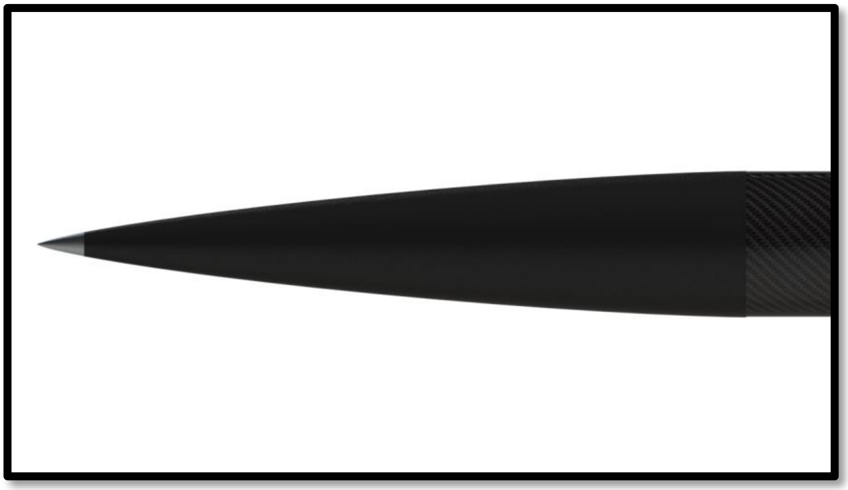


Figure 3: Von Karman nose cone modeled in SolidWorks.

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.

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 18.

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.

Ballast System Design

Until the launch vehicle is 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.

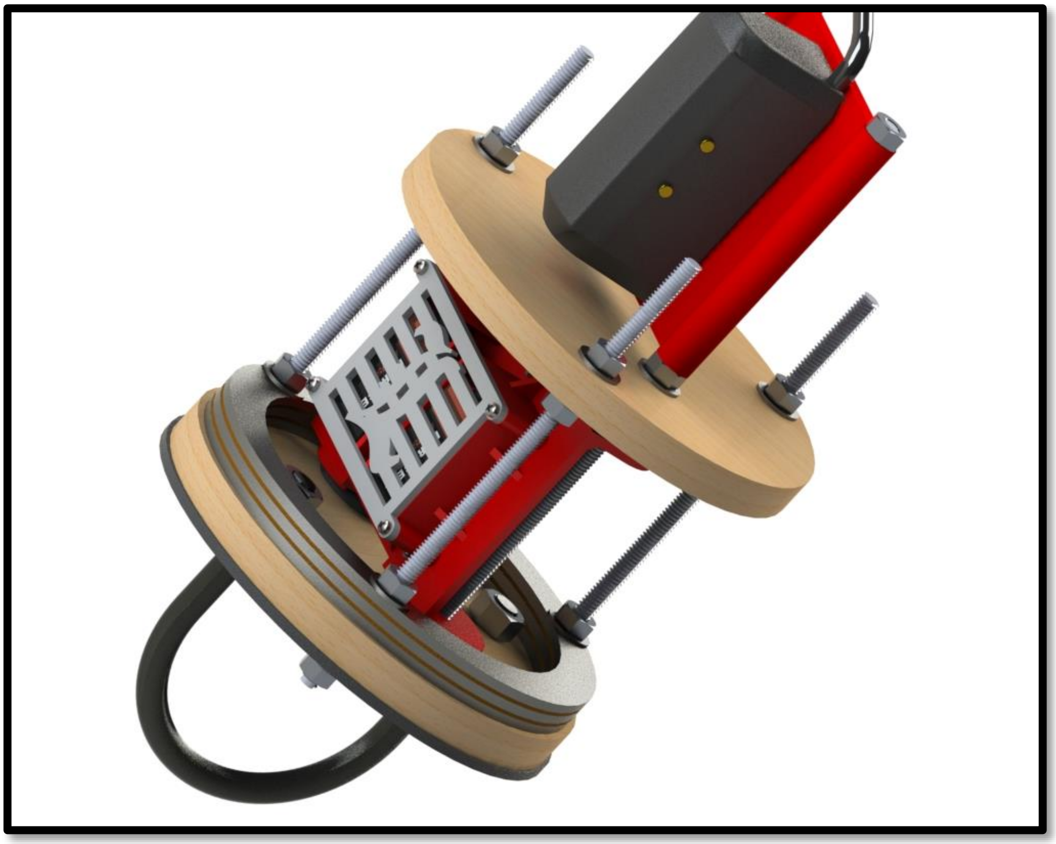


Figure 4: Rendered image of the nose cone's ballast system.

The primary goal in the design of the ballast system was to ensure it did not interfere with any other systems. Figure 4 shows a rendered representation of the nose cone's avionics bay and the inclusion of the 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.

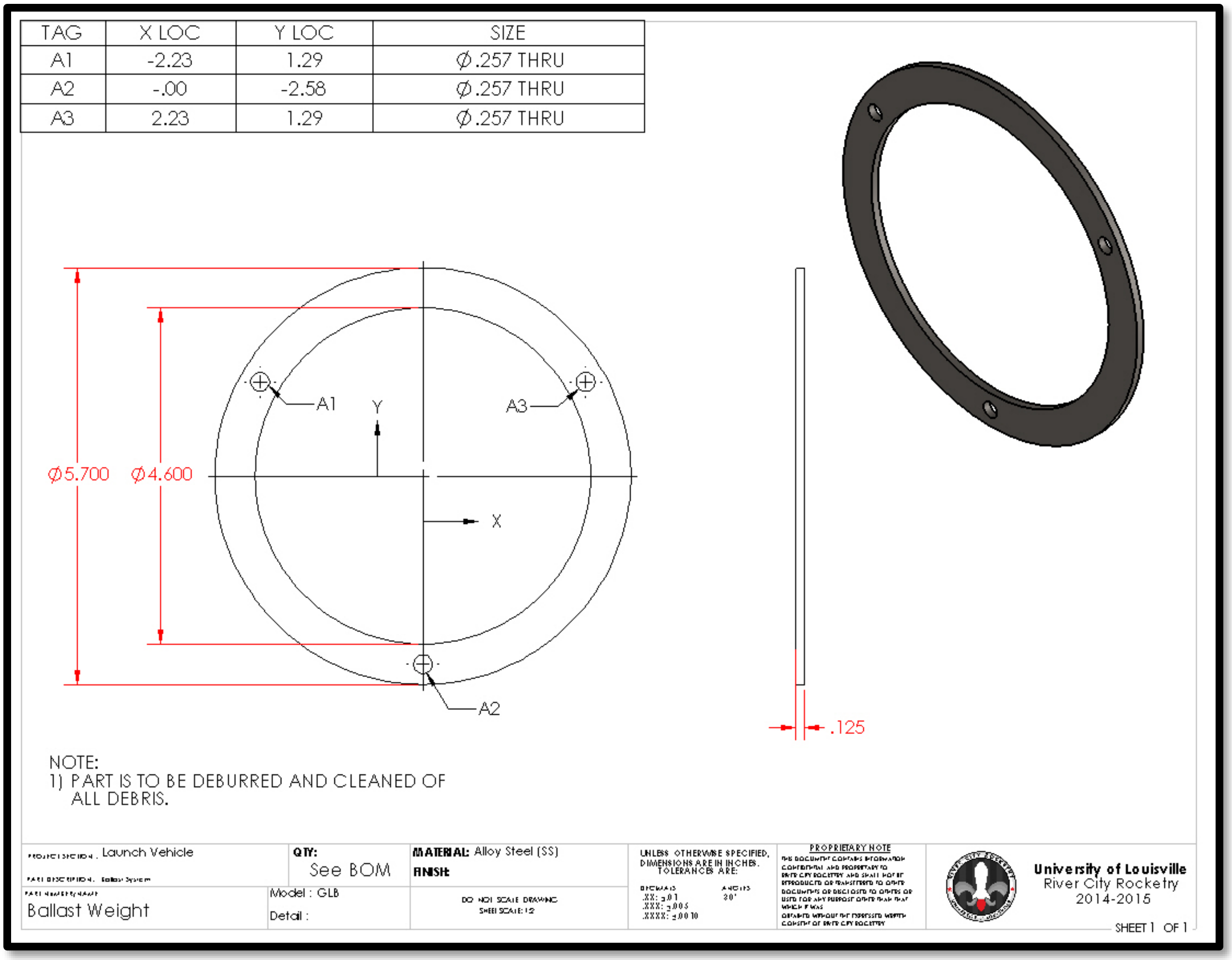


Figure 5: Detailed drawing of the ballast weight.

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

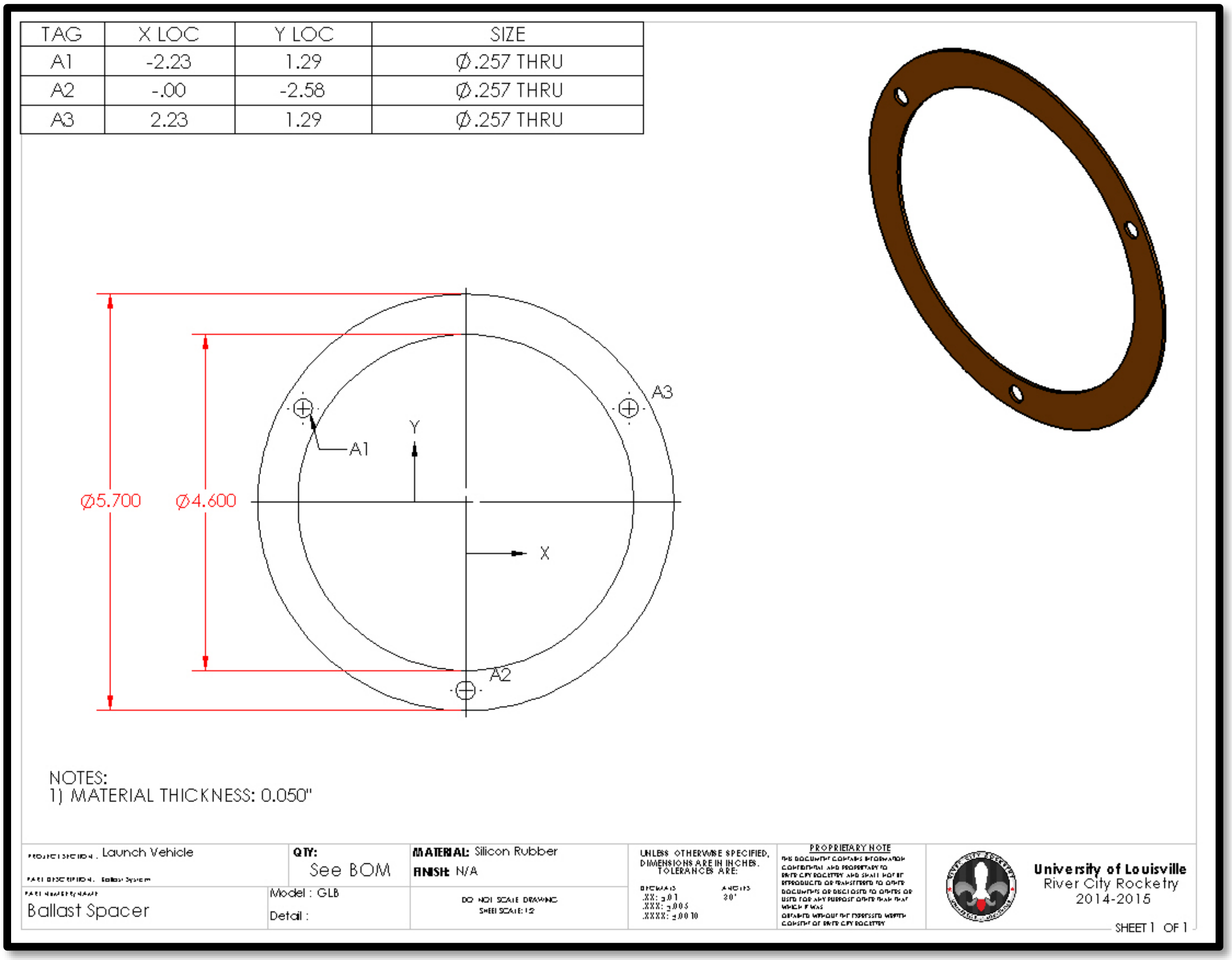


Figure 6: Detailed drawing of the ballast spacer.

The inclusion of the silicone rubber spacers was 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

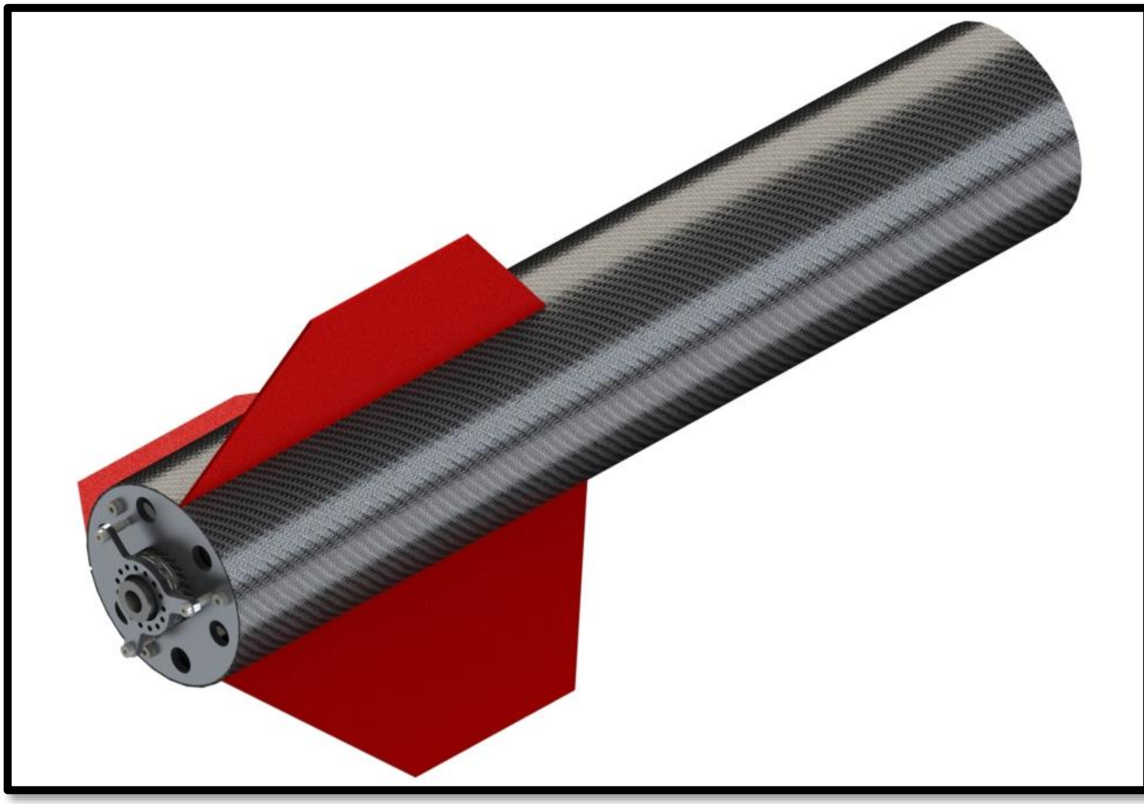


Figure 7: Assembled propulsion bay.

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 carbon fiber tubing. The slots will be precision cut to ensure correct alignment of fins during installation. To do this, the team will develop a jig for ease of manufacturing.

Motor Tube

The motor tube will consist of 2.13” diameter carbon fiber tubing. The motor tube will be cut to house the launch vehicle’s motor with two inches of motor overhang. An aluminum centering ring will be epoxied two inches below the foremost 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.

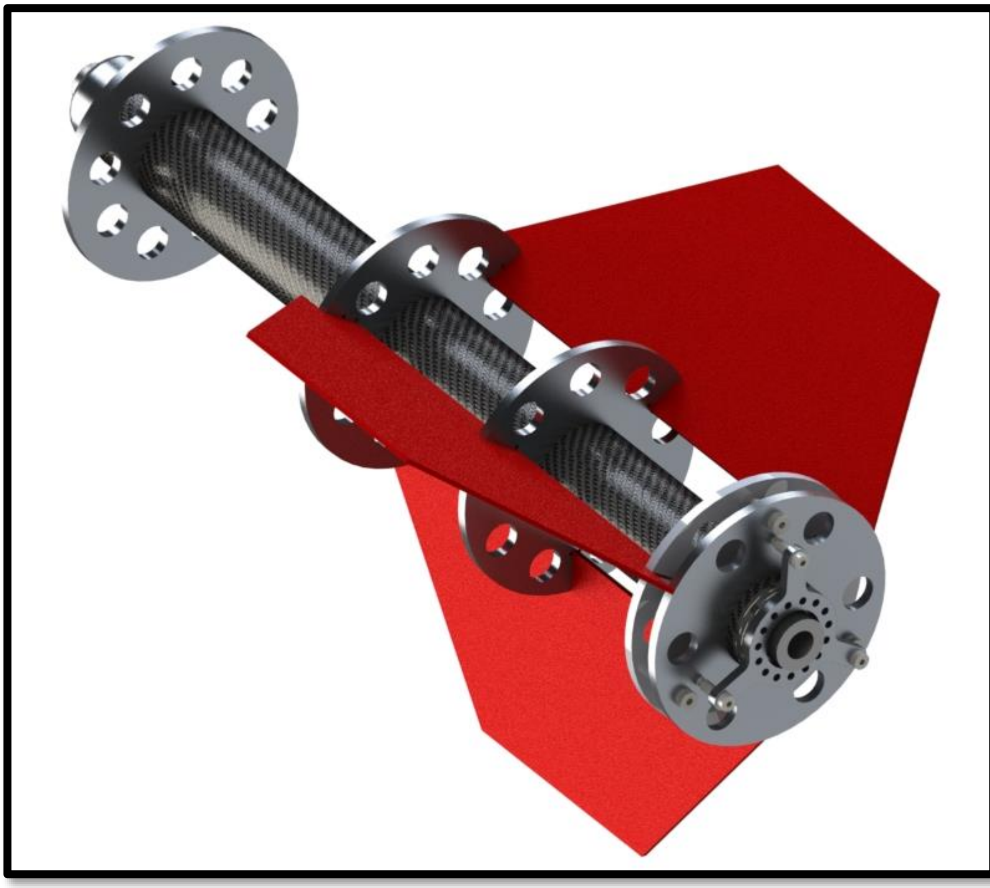


Figure 8: Propulsion bay's removable fin assembly.

Figure 8 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 9.

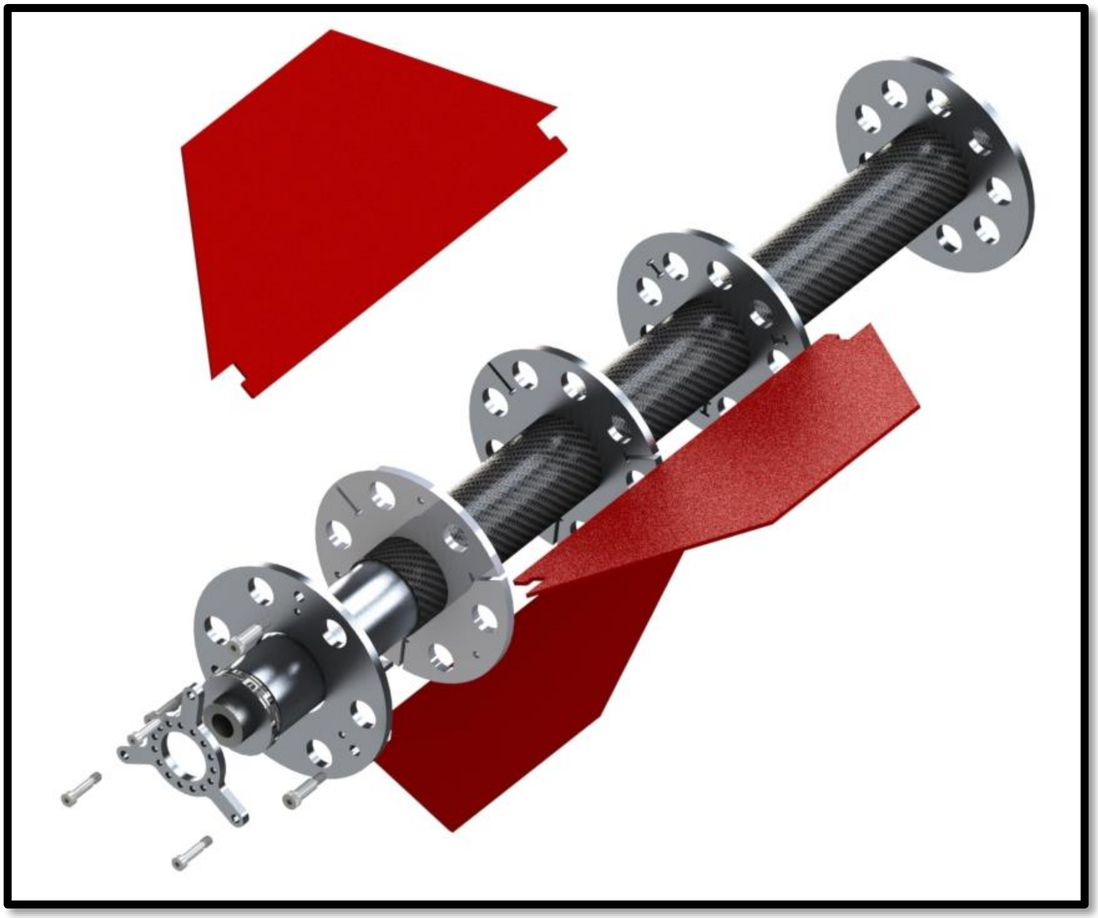


Figure 9: Exploded view of removable fin system.

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.

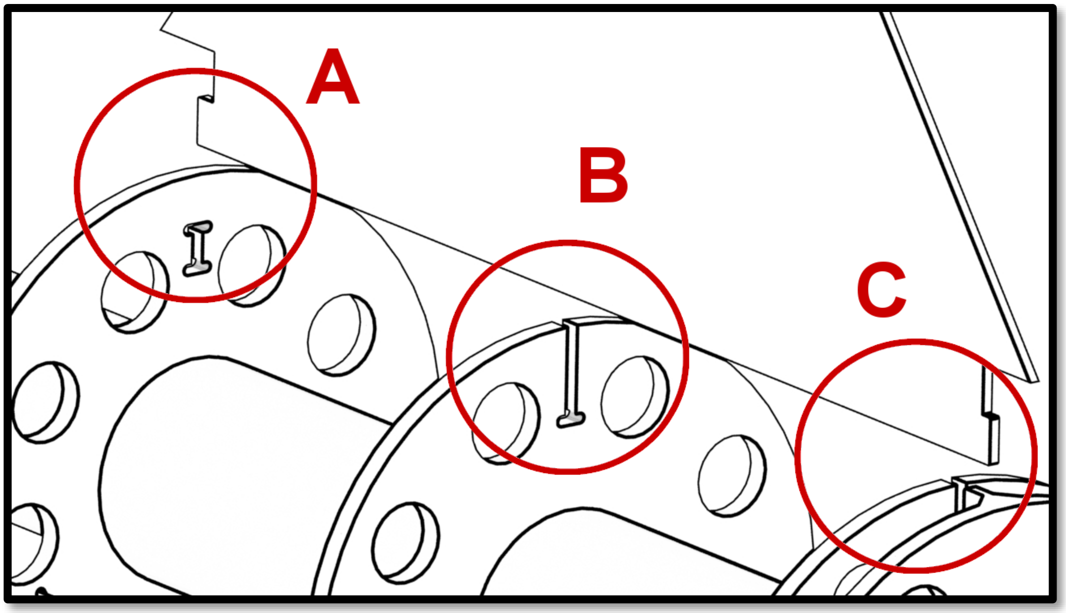


Figure 10: Highlighting the three connections between the fins, centering rings, and fin retainer.

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

During installation, the fin is inserted through the airframe, and into the slots at points B and C. Once bottoming the fin at the base of the slot, the fin is pushed forward until the forward fin tab slides through the slot in the fore centering ring at point A. The rear fin retainer can then be assembled into the rear of the launch vehicle. The standoff on the fin retainer should be aligned with the fin tab. The shoulder screws are then installed through the fin retainer and into the aft centering ring. The launch vehicle's fins will be rigidly in place at this point, and fully constrained in place.

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 OMAX Abrasive Waterjet. Figure 11, below, shows the detailed drawing of the launch vehicle's fin.

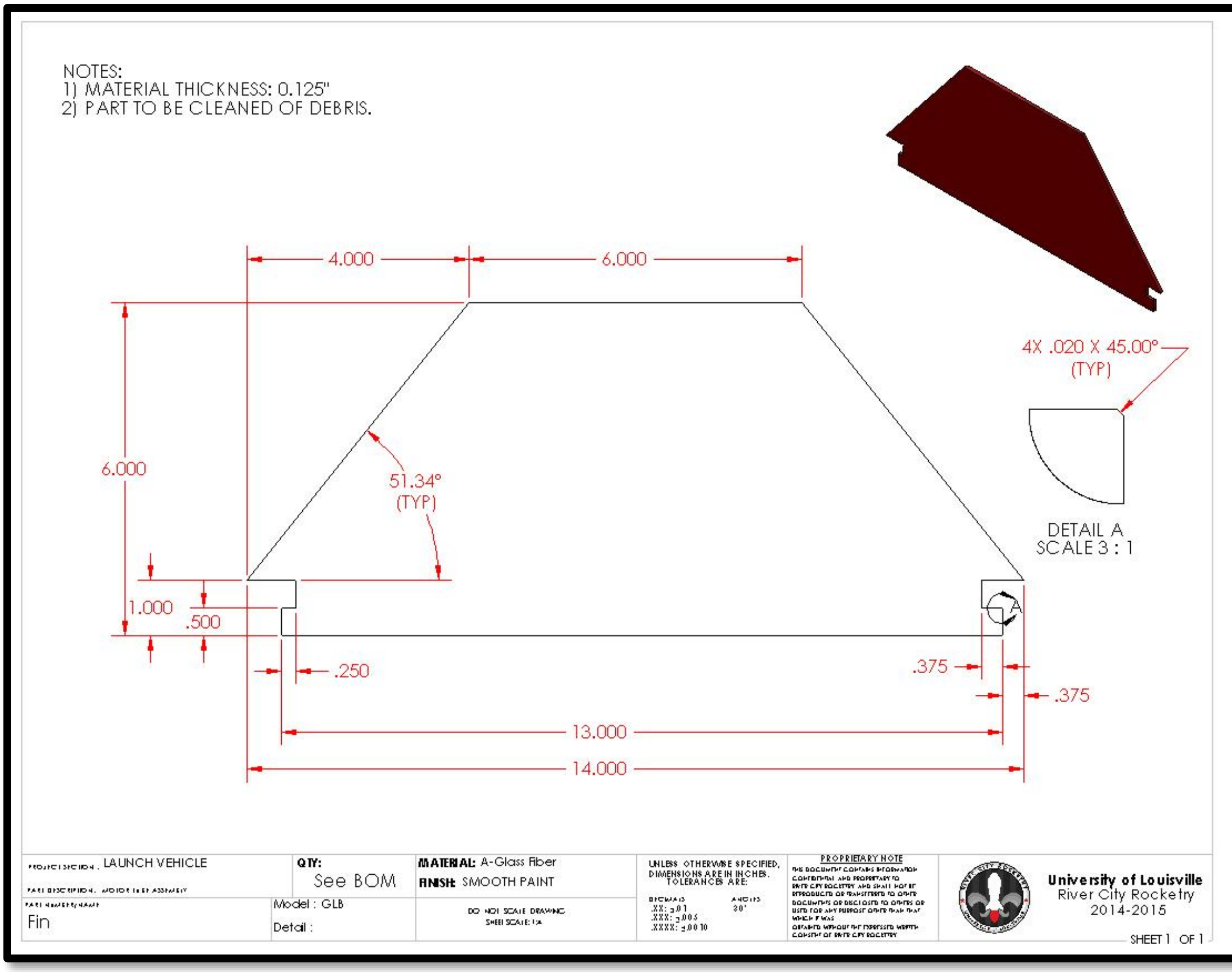


Figure 11: Detailed drawing of the launch vehicle's fin.

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 maintain tolerances within the thousandth of an inch. Blanks will be cut out using an OMAX 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 between the fin slots and the fin. To save weight, each centering ring has excess material removed, as seen in Figure 12. Sets of equally spaced holes of 0.80” diameter will be cut in between each of the machined fined slots.

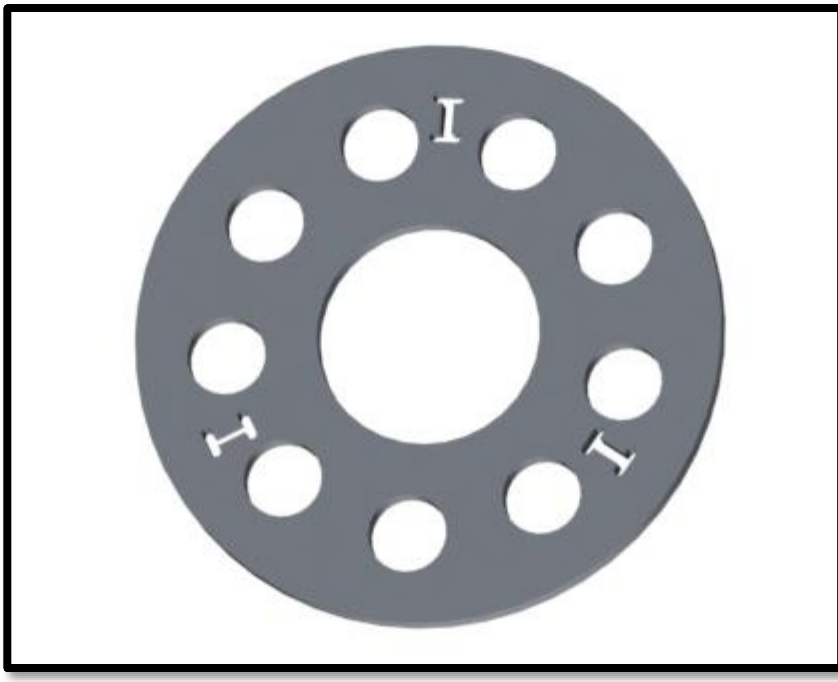
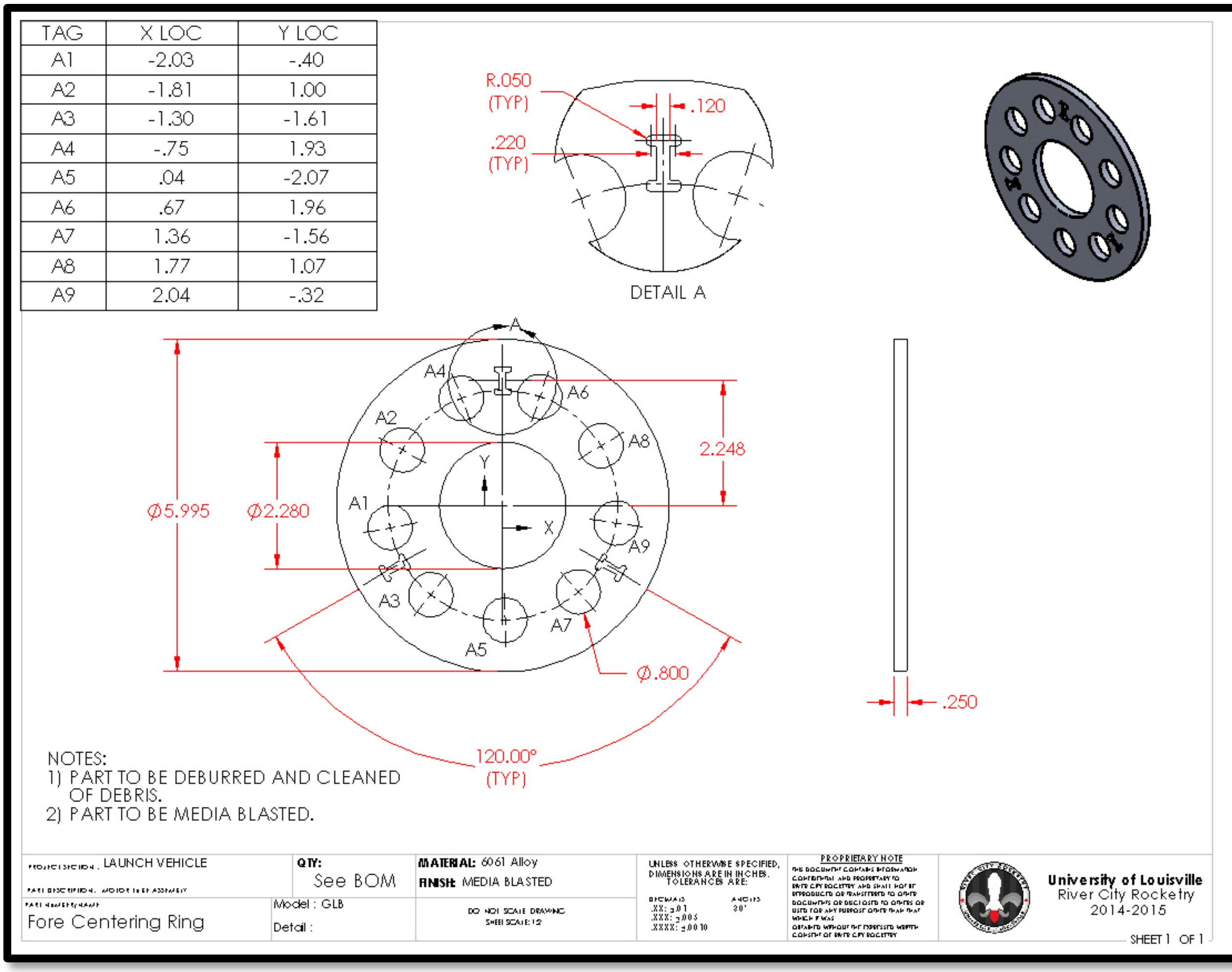


Figure 12: View of the fore centering ring in the removable fin system.

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 13, shows the general geometry of the centering rings.



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

Figure 13: 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 14, below, shows the detailed geometry of the casing retainer.

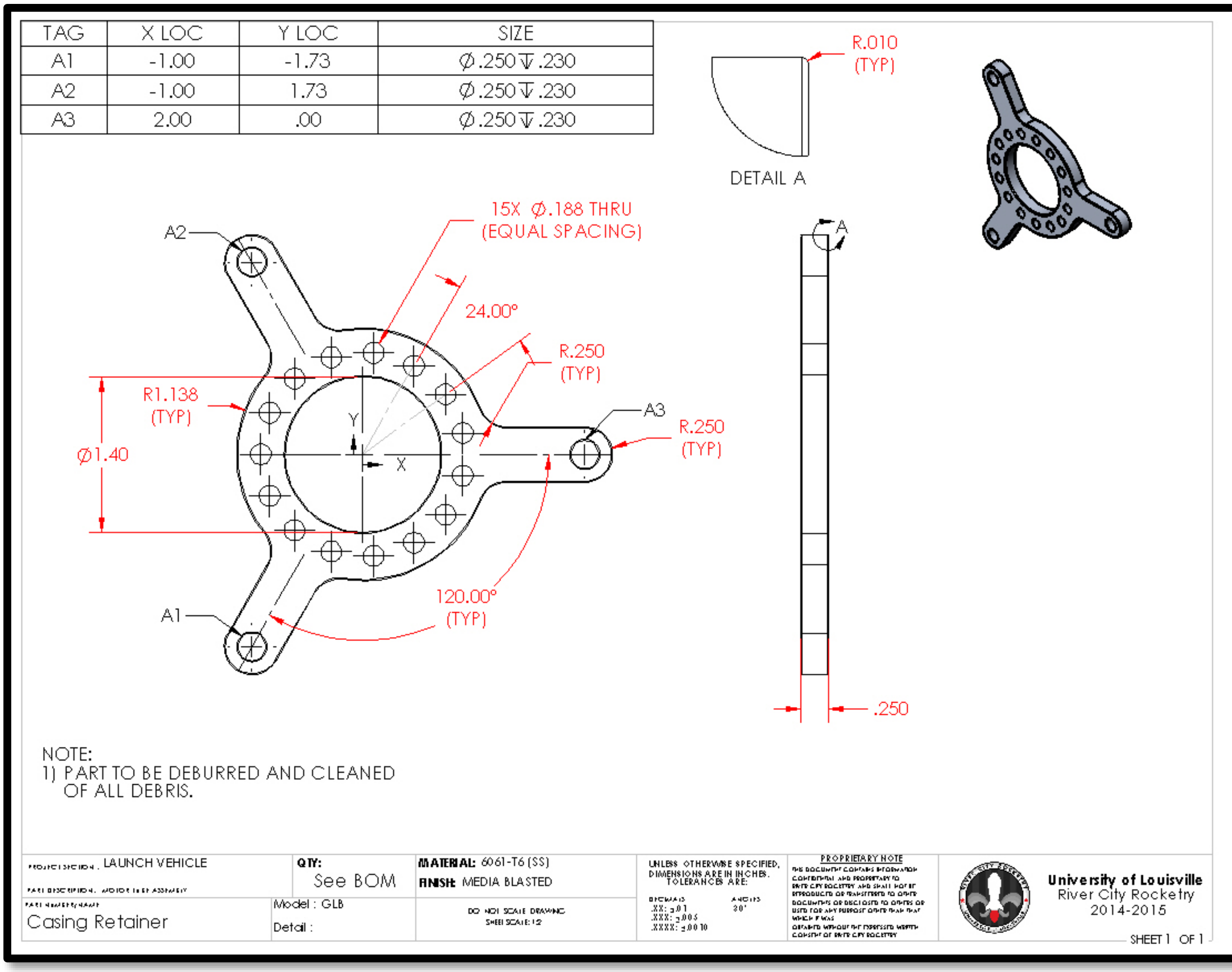


Figure 14: Detailed drawing of the motor casing retainer.

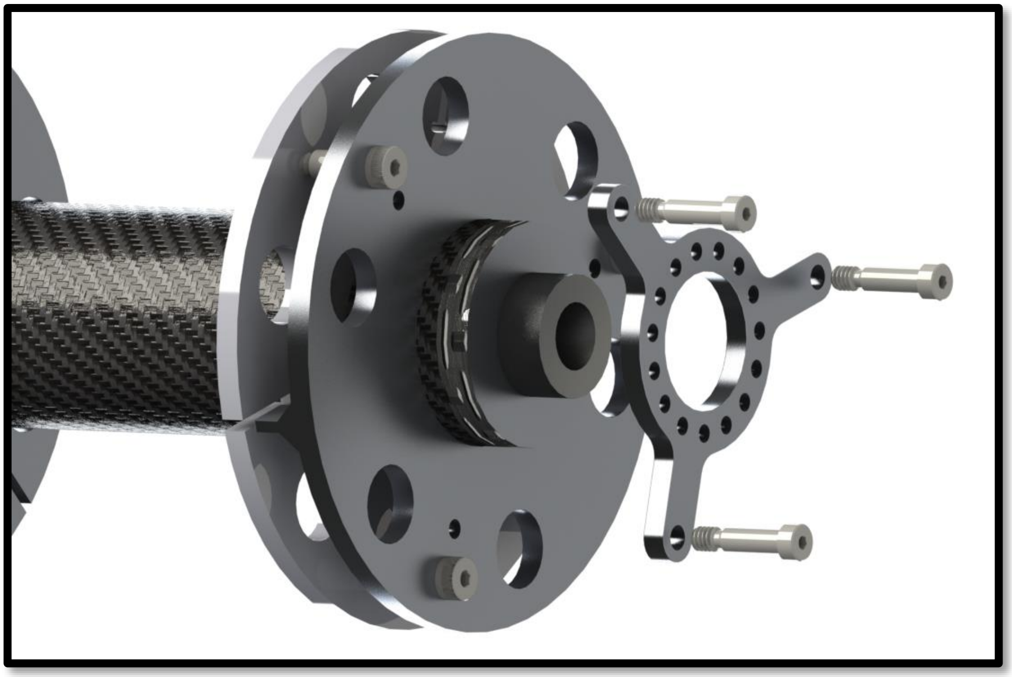


Figure 15: Motor retention components exploded view.

Prior to installation, the fins and rear fin retainer must be installed. As seen above in Figure 15, the motor casing retainer 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.

Subscale Testing

A subscale version of the full scale competition rocket has been designed to test the aerodynamic properties of the launch vehicle's design. The subscale launch vehicle, shown below in Figure 16, is designed to be a one-half scale model of its full scale counterpart.

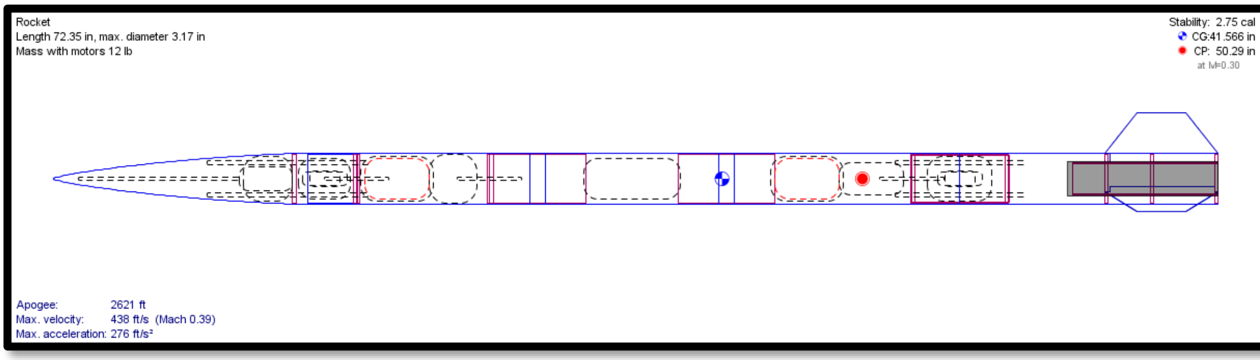


Figure 16: Subscale launch vehicle OpenRocket schematic.

The primary goal of the subscale is to allow the team to test various design criteria and systems incorporated into the full scale launch vehicle. The three tests the team plans on conducting are:

1. Aerodynamic properties and stability of the launch vehicle.
2. Custom vortex parachute design, and other recovery devices.
3. Range of on-board live Bluetooth feed from the launch vehicle to the ground station.

It is imperative for the launch vehicle's flight verification that the subscale vehicle's flight see's similar aerodynamic stresses. The team designed the subscale to have a higher peak velocity and a similar maximum acceleration, as seen below in Table 5.

Property	**Full Scale**	**Subscale**
Diameter (in)	6	3
Length (in)	143	72.35
Mass (lbs)	38.3	12
Motor Selection	CTI 3147-L935-IM-P	CTI 821-J430-WT-18A
Stability Caliber	1.99	2.75
Maximum Velocity (ft/s)	471 (Mach 0.42)	438 (Mach 0.39)
Maximum Acceleration (ft/s^2)	248	276

Table 5: Comparison of properties between the full scale and subscale launch vehicles.

Designing the subscale in this manner will ensure the subscale will see higher aerodynamic stresses than the full scale. This verification of the subscale will be a justification for the design of the full scale launch vehicle.

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 17.

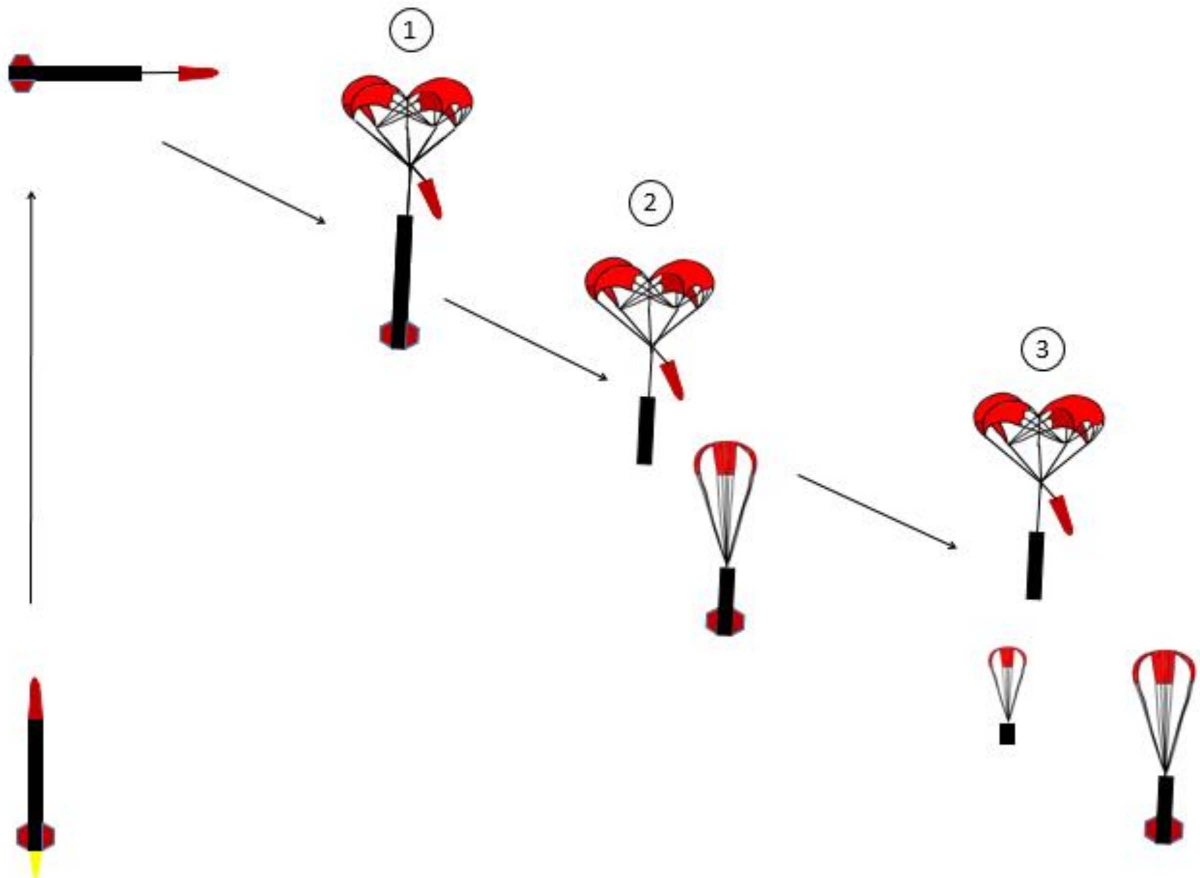


Figure 17: Recovery sequence of events.

A description of the recovery sequence and the altitude at which each event occurs is described in Table 6.

Event	Altitude (ft.)	Description
1	3,000	Apogee. Nose cone ejection. Entire rocket under main parachute acting as drogue.
2	1,250	Eject lower airframe. Both upper and lower airframes now falling under main parachutes.
3	1,000	Cache capsule ejection. All independent sections now under main parachutes.

Table 6: Recovery events and descriptions.

Drift calculations have been performed for the upper airframe at various wind speeds, yielding the results shown in Table 7

Wind speed (mph)	Distance drift from launch pad (ft)
0	0
5	242.9
10	485.7
15	728.6
20	971.4

Table 7: Drift calculations.

These drifts are 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 18.

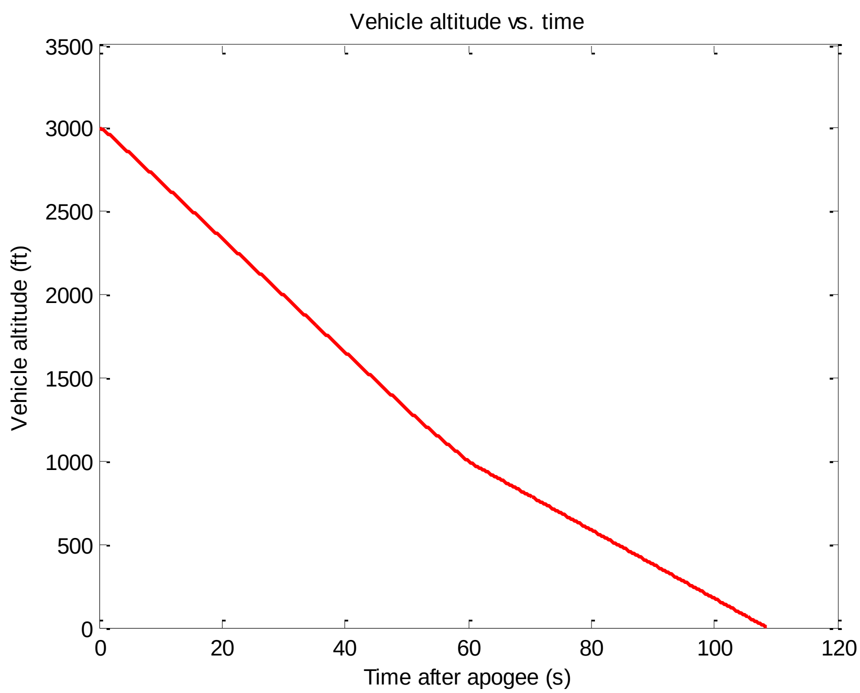


Figure 18: Upper airframe altitude versus time plot.

The decent velocity versus time is shown in Figure 19 for the vortex ring.

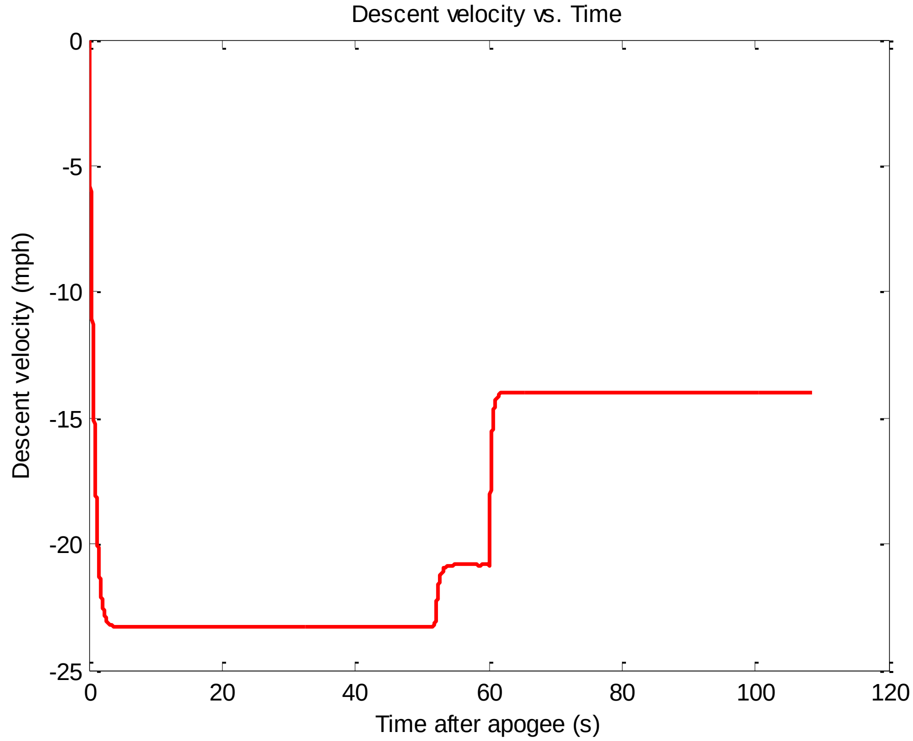


Figure 19: Upper airframe decent velocity versus time.

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 8.

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.
Oscillation reduction	Excessive oscillation of upper airframe during ejection of cache capsule could result in cache capsule not deploying correctly.

Table 8: 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 9.

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 9: Parachute performance characteristics comparison.

The vortex ring was selected for the main parachute for the upper airframe due to the efficiency of the parachute and the low opening force and 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 slightly 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 10.

Section of rocket	Mass (lb_m)	Area (ft^2)	Diameter (ft)	Velocity (ft/s)	E (lb_f-ft)
Upper airframe	11.4	17.5	4.7	18.40	60
Lower airframe	13.8	58.4	8.6	16.73	60
Cache capsule	6.28	24.2	5.6	17.53	30

Table 10: 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 panels for the vortex ring will be manufactured in accordance with the panel layout shown in Figure 20.

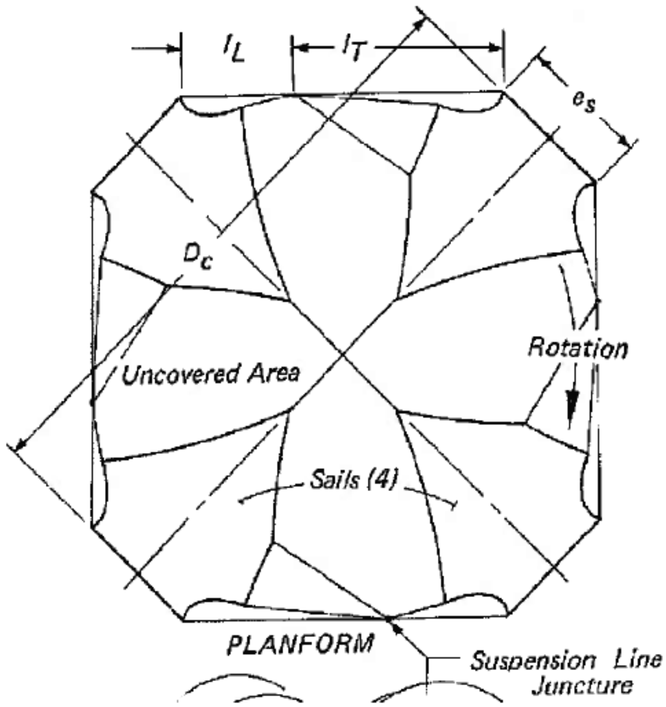


Figure 20: Vortex ring gore layout.

The dimension D_c was calculated using the following relationship:

$$\mathrm{D_c} = \sqrt{4.59 D_o} \quad (22)$$

The dimensions I_T and I_L were optimized using the following relationship.

$$\frac{I_T - I_L}{D_C} = 0.125 \quad (23)$$

The dimension e_s was calculated using

$$e_s = D_C - \sqrt{2}\,[I_L + I_T] \quad (24)$$

The inflated profile of the vortex ring parachute is shown in Figure 21.

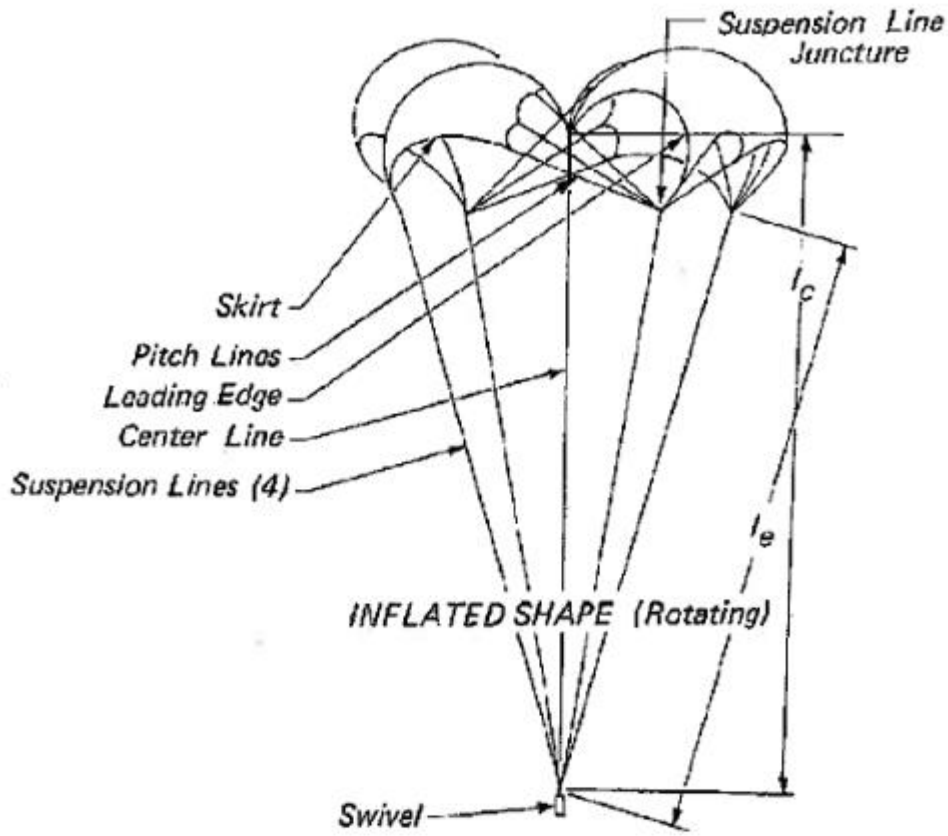


Figure 21: Inflated vortex ring parachute schematic.

The length of the suspension lines was optimized using the following ratio:

$$\frac{I_e}{D_c} = 1.0 \tag{25}$$

The length of the centerline was optimized using the following ratio:

$$\frac{I_c}{D_c} = 0.94\ to\ 1.05 \tag{26}$$

The dimensions calculated for the vortex ring parachute are shown in Table 11.

Dimension	Length [ft]
D_C	4.5
l_C	4.5
l_E	4.5
l_T	1.5
l_L	0.9
e_S	1.0

Table 11: Calculated dimensions for vortex ring parachute.

The shroud lines and the lines used to tether together the panels are designed based off the schematic shown in Figure 22. All lengths are functions of the nominal diameter of the parachute.

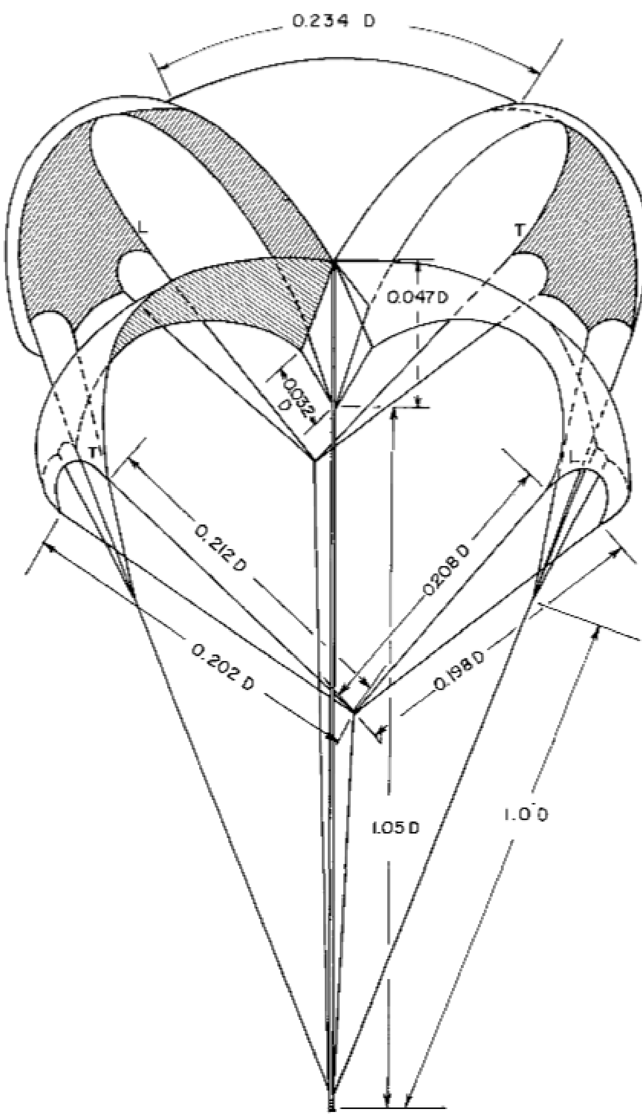


Figure 22: Vortex ring schematic for lines that tether the panels together.

The two cruciform parachutes will be constructed using the schematic shown in Figure 23.

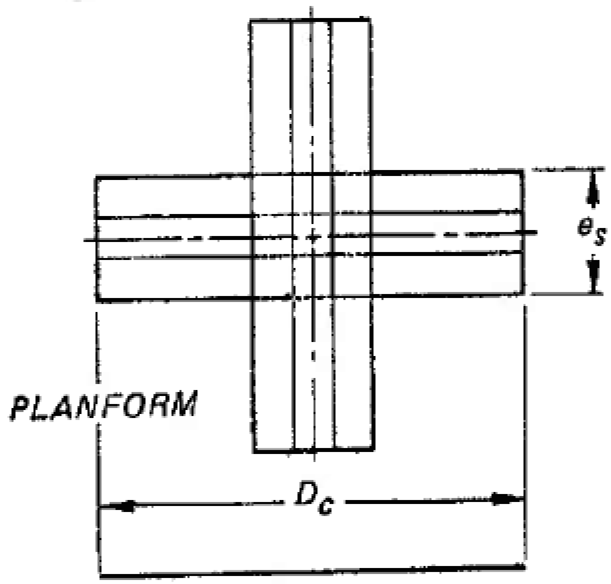


Figure 23: Cruciform construction schematic.

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

$$\frac{e_s}{D_c} = 0.263 \; to \; 0.333 \qquad (27)$$

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

$$D_o = 2D_c e_s - e_s^2 \qquad (28)$$

The inflated profile of the cruciform parachute is shown in Figure 24.

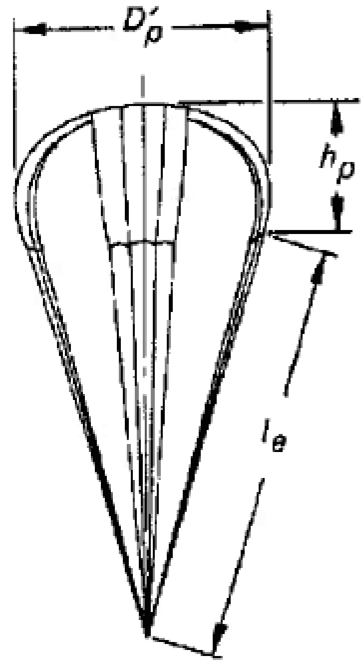


Figure 24: Inflated cruciform parachute schematic.

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

$$\frac{I_e}{D_o} = 1\ to\ 2 \qquad (29)$$

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 12.

Section of rocket	e_s (ft)	D_c (ft)	l_e (ft)
Lower airframe	1.5	5.1	17.3
Cache capsule	1.0	3.3	11.1

Table 12: 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.

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.

The suspension lines will be made of 1/8 inch nylon para-cord with 400 lb tensile strength. 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.

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.

Testing

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 prevent tangling during deployment.

Since the team has not had any experience with this geometry of parachute, a subscale version will be constructed. The subscale parachute with undergo ground testing to verify the C_D and to ensure successful deployment. The parachute will also be tested in flight on our subscale rocket to further verify the design.

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 can 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 and the separation of the lower airframe events, Perfect Flite Stratologgers, pictured in Figure 25, will be used. These will be used to trigger black powder ejection charges.

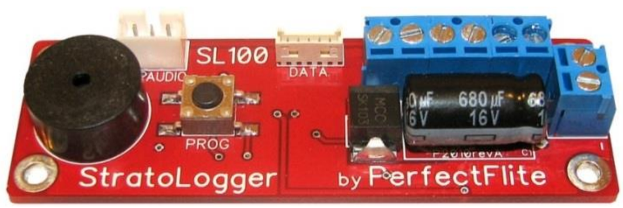


Figure 25: PerfectFlite Stratologger

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 to house the altimeters as shown in Figure 26.

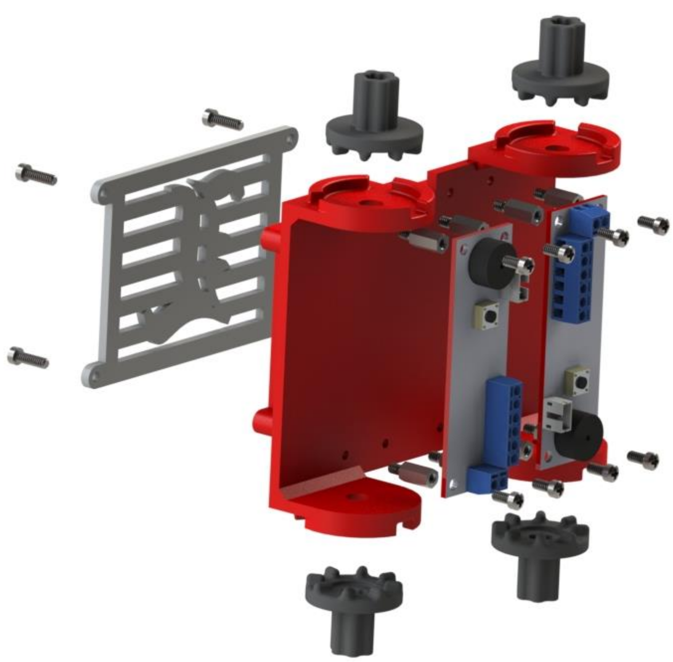


Figure 26: Altimeter sled.

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 27.

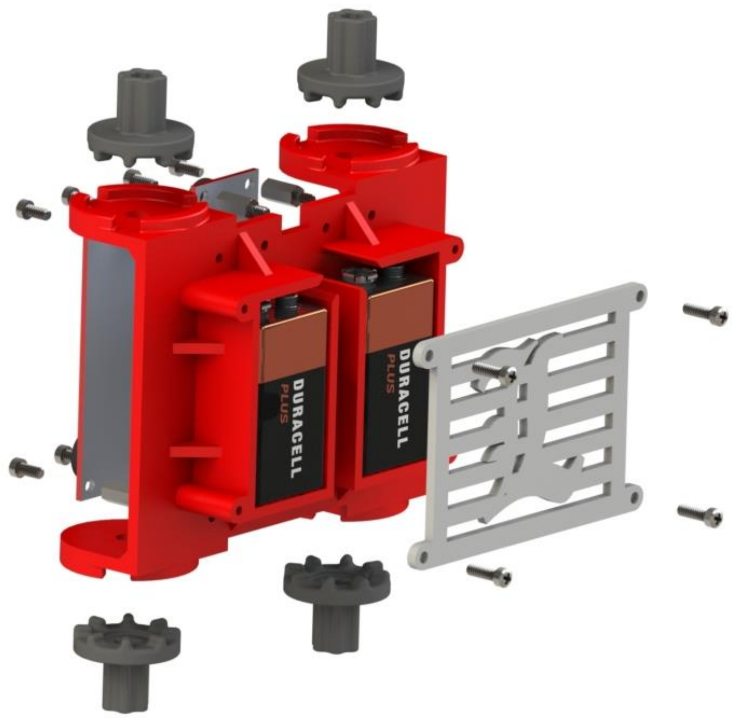


Figure 27: Battery clips view of altimeter sled.

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 28, 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 28: Rubber dampener.

The altimeter sleds will be mounted on ¼ inch threaded rods between two sets of bulk plates as shown in Figure 29.

Figure 29: Altimeter sled full assembly.

Each altimeter will be locked into the on position through use of a Featherweight screw switch, shown in Figure 30. 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.

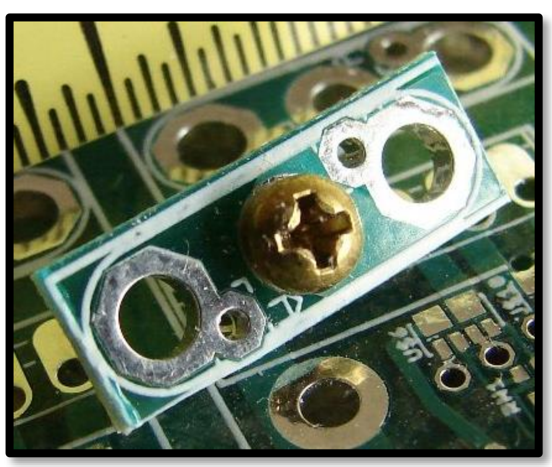


Figure 30: Featherweight Screw Switch.

To satisfy the GPS requirement, both of the avionics bays will use a Garmin Astro DC 40. 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.

Since the cache capsule is a self-contained unit, all required avionics will be located in a specified compartment within the capsule. Due to the size constraints, the avionics setup will be different. The capsule will have redundant altimeters located in the electrical bay to initiate the capsules ejection from the upper airframe. One altimeter will be a TeleMetrum v2.0, pictured in Figure 31. The TeleMetrum is a recording, dual-deploy altimeter with an integrated GPS and telemetry link. The GPS feature on the TeleMetrum satisfies the requirement for the payload container to contain a GPS locator.

Figure 31: TeleMetrum v2.0 Altimeter.

Since it is unnecessary to have a redundant GPS locator, the secondary altimeter will be a Stratologger. This selection was made because the Stratologger provides the same dual-deploy altimeter functionalities as a TeleMetrum for half the cost.

Deployment Mechanisms

With the detachment of the lower airframe, the section of the upper airframe that houses the cache capsule will be exposed. The cache capsule will be mounted to a bulkplate using a non-explosive actuator release such as the one pictured in Figure 32.

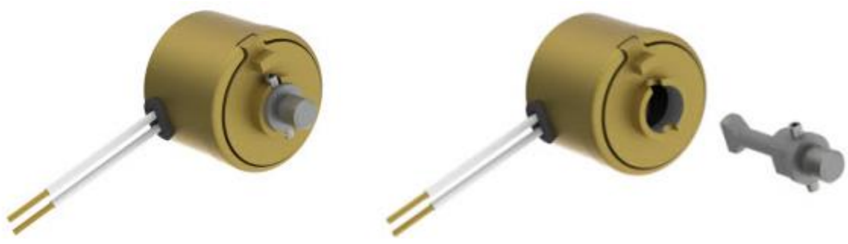


Figure 32: Non-explosive actuator release.

The actuator will release at 1,000 ft, deploying the cache capsule which is recovered under a small parachute. The actuator operates without generating any external fragmentation or debris, making this a safe system to operate near the parachute for the cache capsule.

Challenges

The primary recovery challenges are shown in Table 13.

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 13: 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 60 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 33, 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: 38.3 lbs
- Stability Margin: 1.99 caliber (From tip: CG – 87.35 in, CP – 99.61 in)

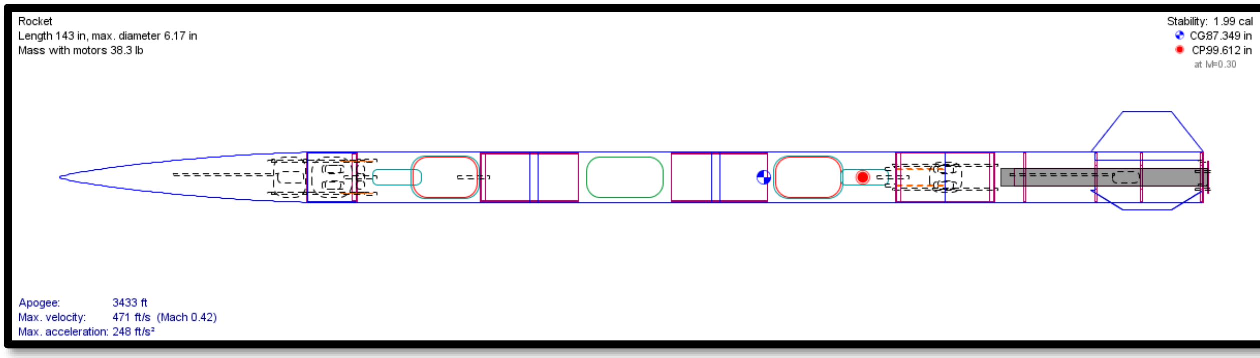


Figure 33: OpenRocket schematic of the full scale launch vehicle.

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 14 lists the various weights of each section of the launch vehicle.

Section of Launch Vehicle	Length ofSection (in)	Mass (lbs)
Nose Cone	30.85	5.335
Main Recovery Bay	27.5	5.905
Cache Containment Bay	21.5	7.83
Secondary Recovery Bay	28	4.977
Propulsion Bay	32	8.466
Witness Rings	2	0.201
Motor	N/A	5.604
	Total Mass	**38.318**

Table 14: 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 34.

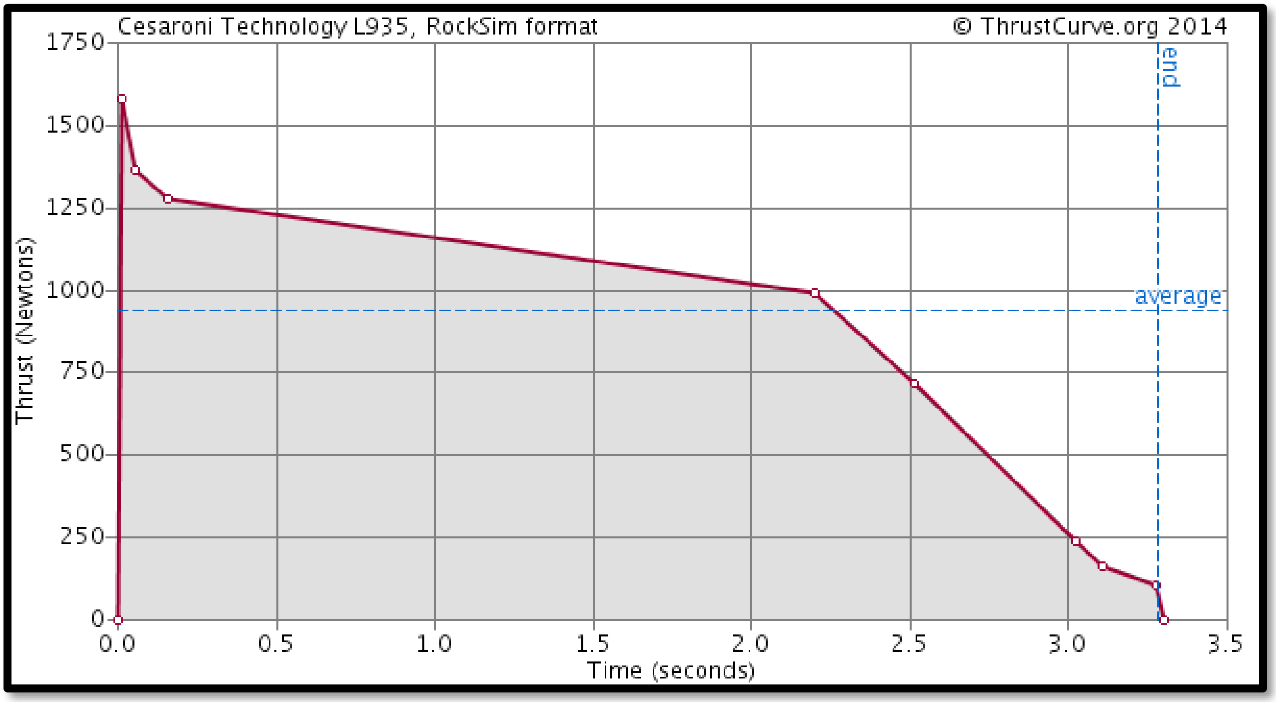


Figure 34: Thrust curve of the CTI 3147-L935-IM-P motor.

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

Thrust-to-Weight Ratio	5.48
Rail Exit Velocity	66.2 ft/s
Projected Altitude	3,422 ft
Maximum Acceleration	248 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 15: Justification for motor selection.

The following plots shown in Figure 35 through Figure 38 display various simulation results indicating the proper motor selection, CG and CP locations.

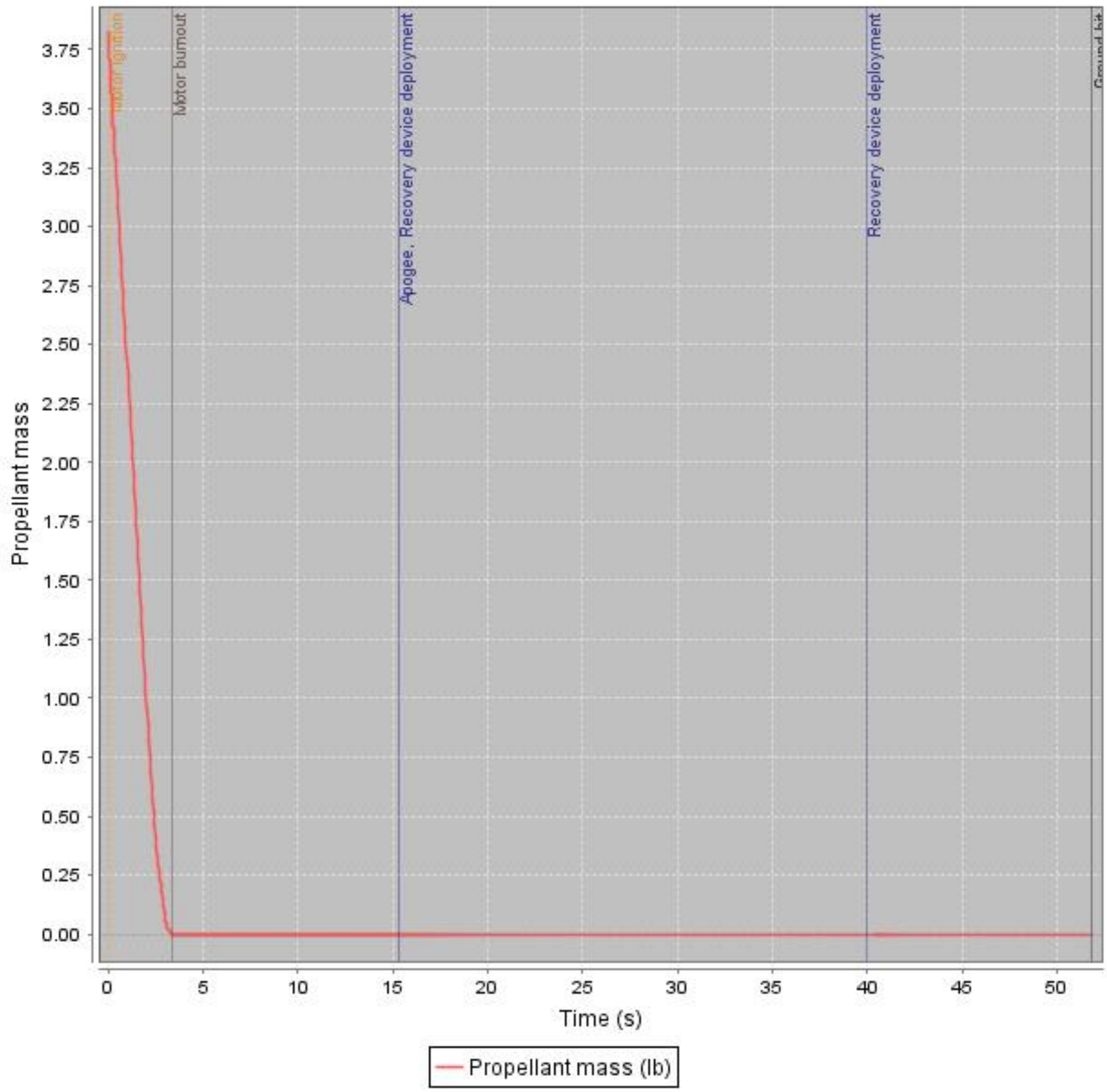


Figure 35: A plot of mass propellant versus time.

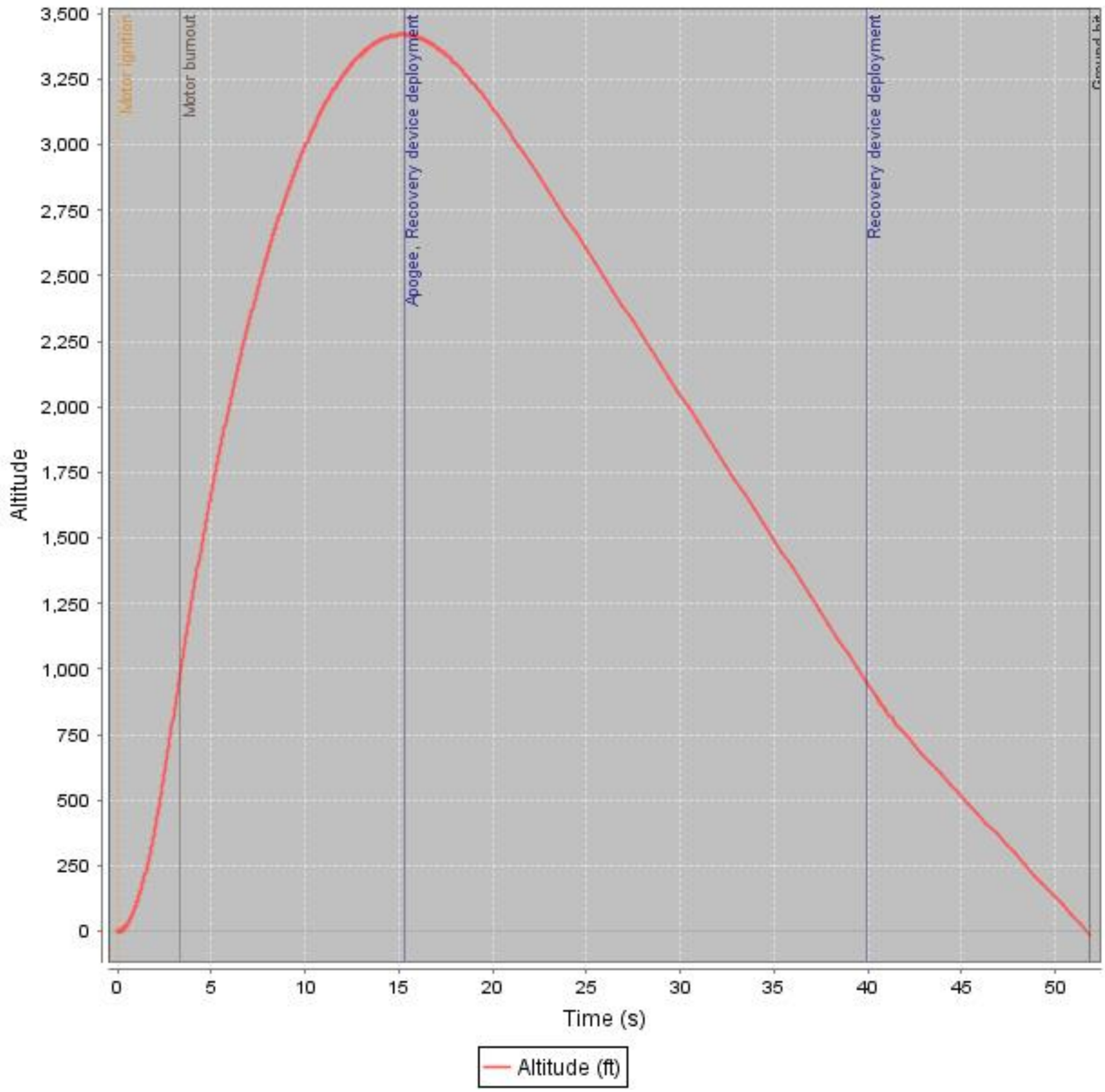


Figure 36: A plot of altitude versus time.

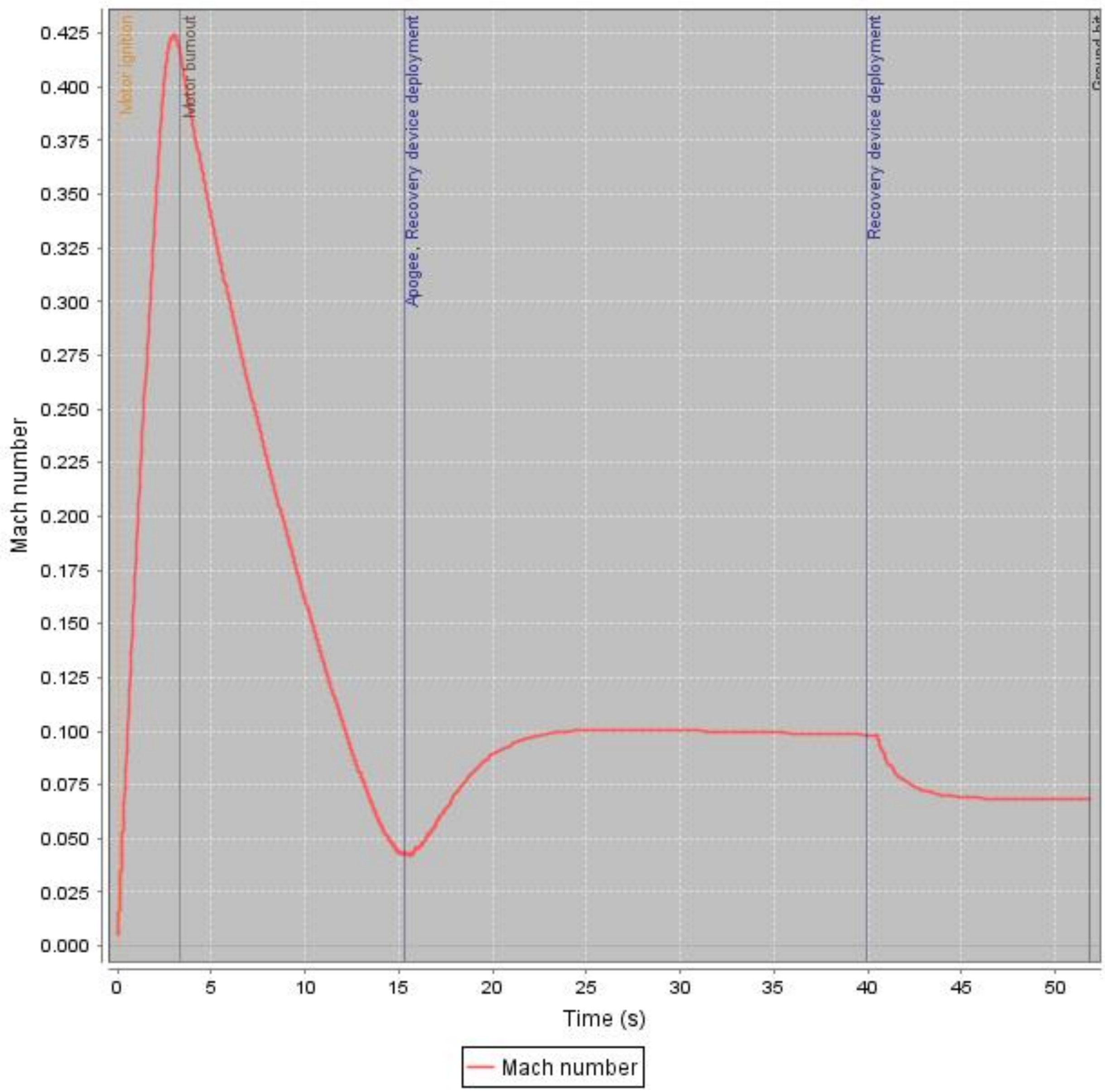


Figure 37: A plot of Mach number versus time.

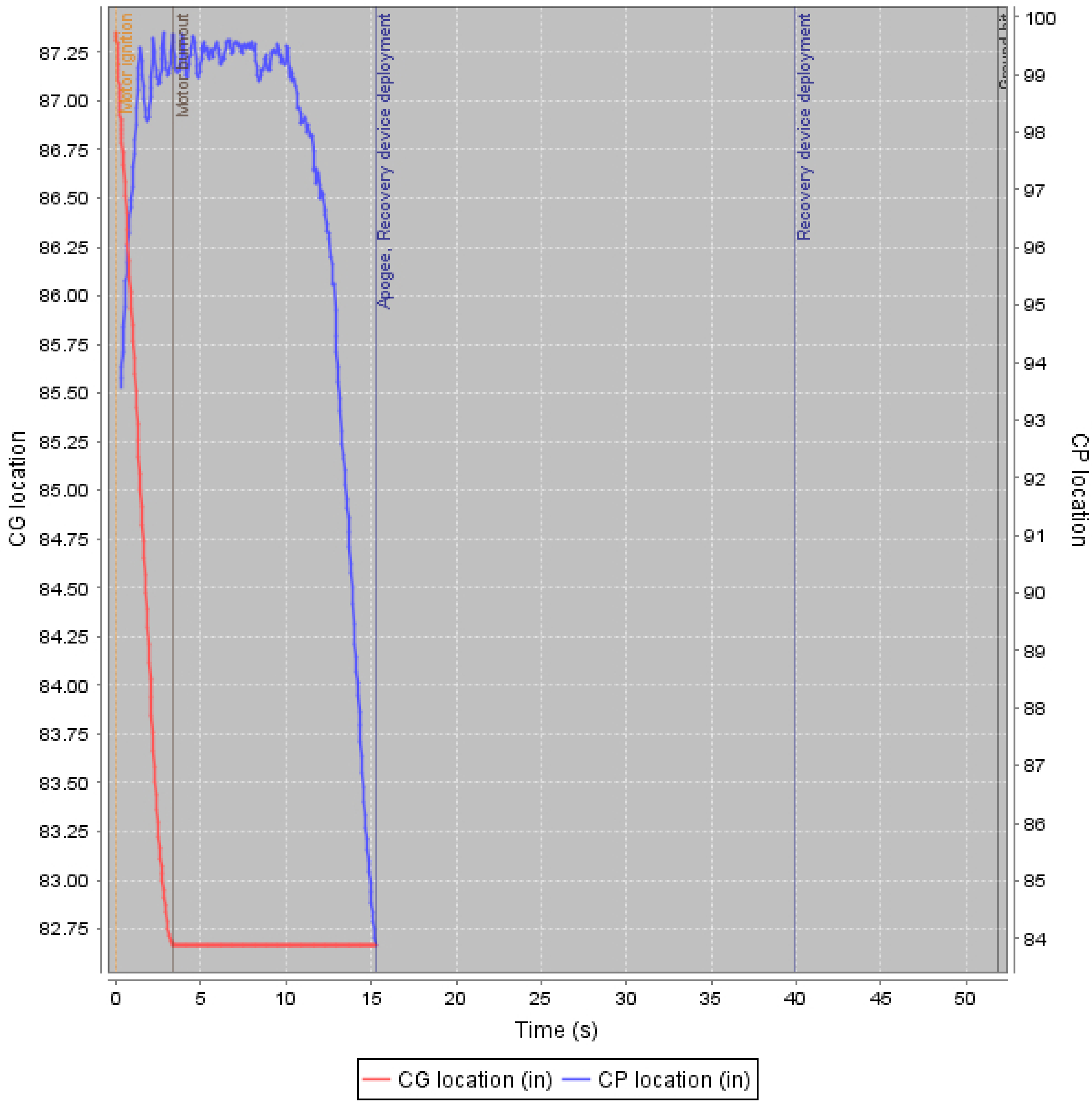


Figure 38: A plot of CG and CP locations versus time.

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 16, 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 16: 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 39 and Figure 40. The overall size of the capsule with the doors closed is 8.375" x 5.25" x 2.7".

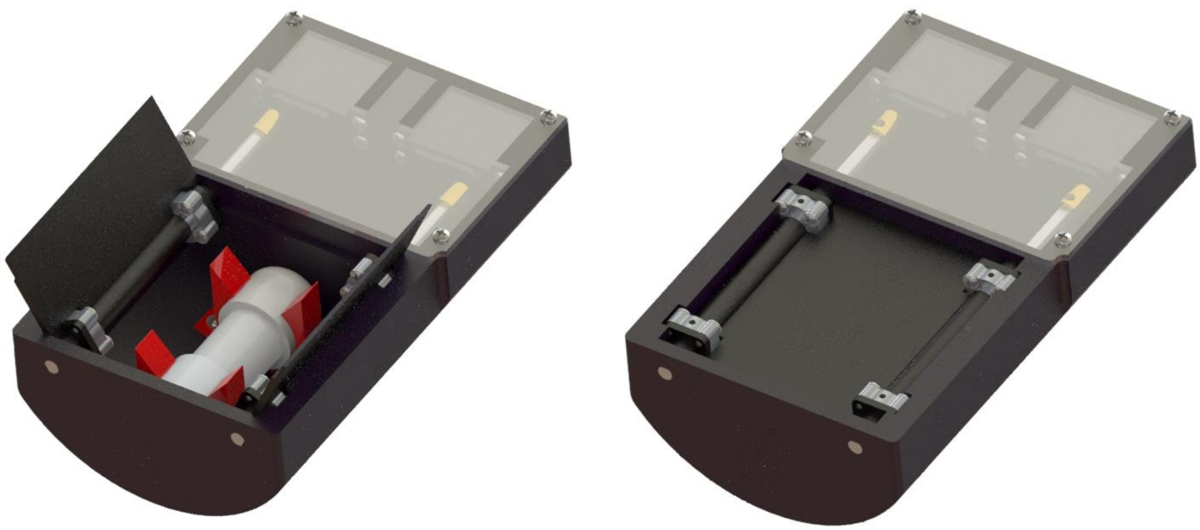


Figure 39. Payload capsule with open (left) and closed (right) doors.

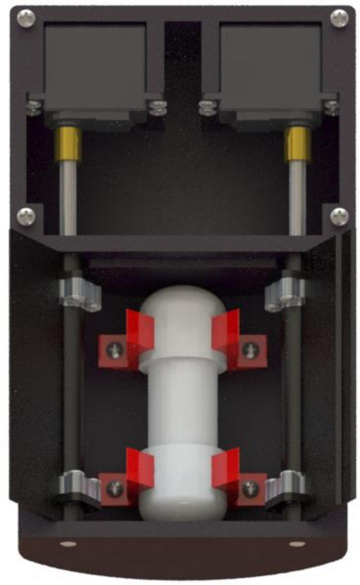


Figure 40. Top view of payload capsule.

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 41. 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 41: 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 42.

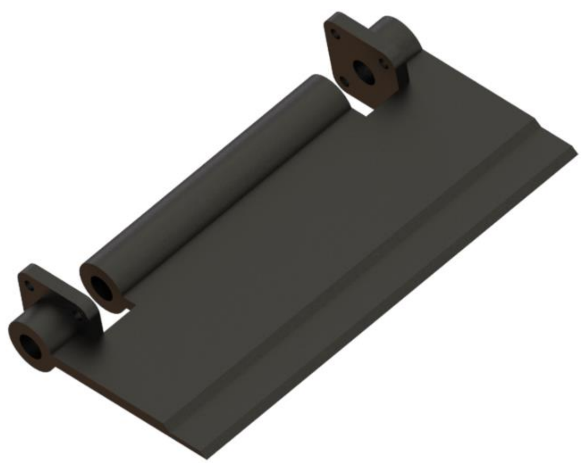


Figure 42. Capsule door.

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 17: 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 43 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 43: 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 44 shows the layout of the door and track assembly. The system is designed so that its rotational path is constrained by the two 3D printed titanium guides. By having the door rotate open instead of linearly, we are able to save space inside the launch vehicle.

Figure 44: 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 45. Polyethylene was the material of choice for the track wheels for having a static coefficient of friction of 0.175 between itself and the titanium track guides.

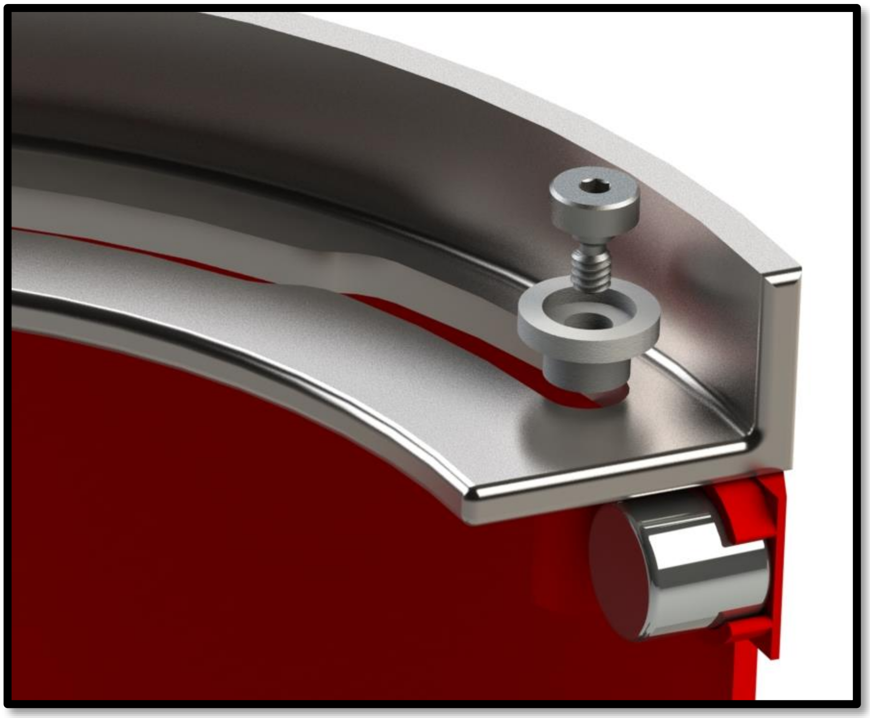


Figure 45: Exploded view of the track guide system.

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 45. There is a neodymium magnet at each corner of the door. When the door is closed, the magnets align with their respective ferrous target which is epoxied on the outside of the airframe. These ferrous targets can be seen on the outside of the cache containment bay in Figure 43.

With a gap of 0.2 inches, as seen in Figure 46, the team used online calculators found on the magnet's supplier's (K&J Magnetics, Inc.) website to get generalized pull force values between the neodymium magnets and their ferrous targets.

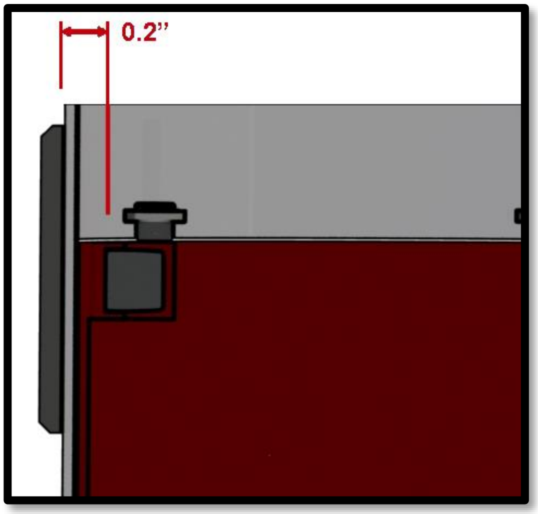


Figure 46: View of the gap between the neodymium magnet and ferrous target.

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 47.

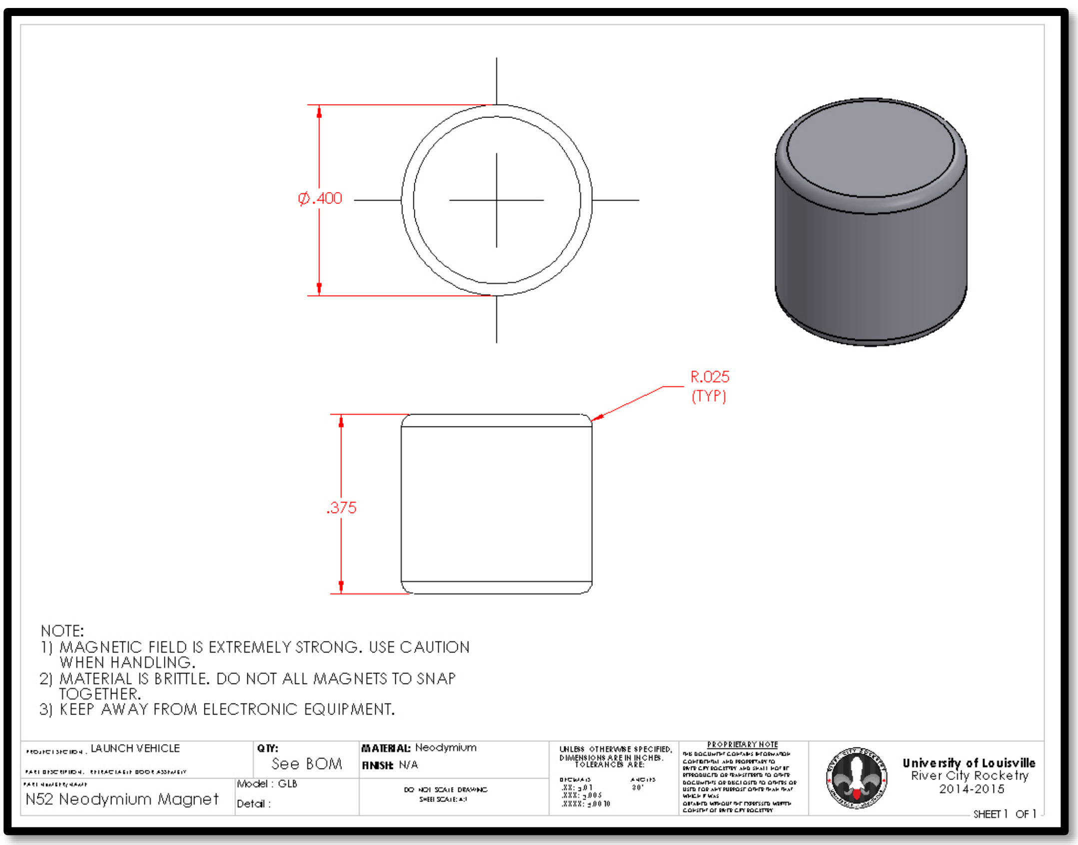


Figure 47: Detailed drawing of the N52 neodymium magnet.

With the geometry defined, the team extrapolated a pull force value of 0.59 lbs between the N52 neodymium magnet and its ferrous target. Figure 48, below, shows a plot of distance between magnet and target versus pull force.

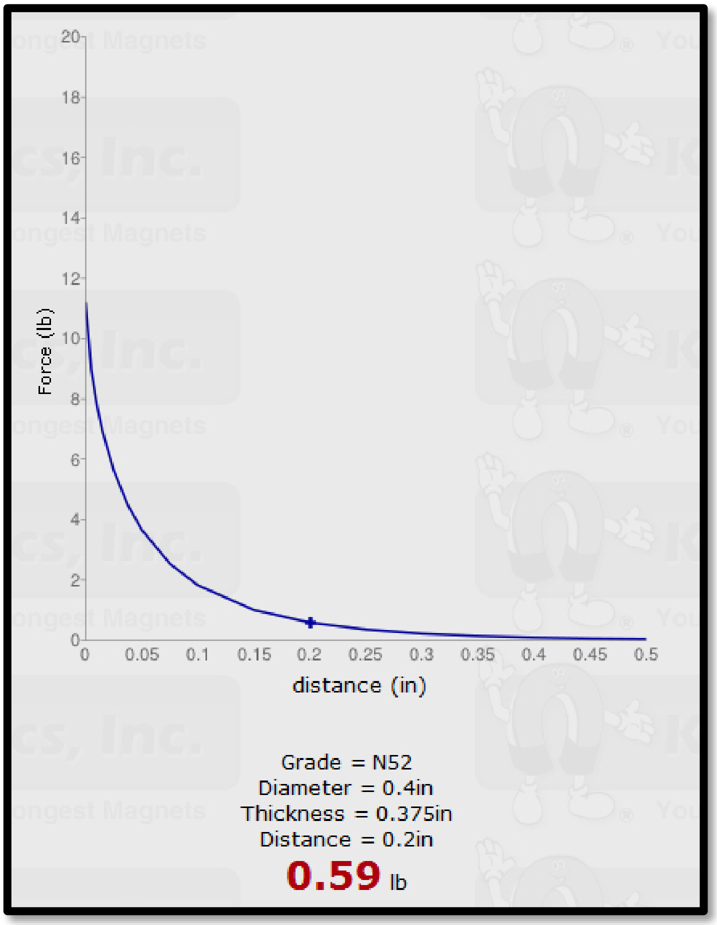


Figure 48: Graph of distance between magnet and ferrous target versus pull force.

Neodymium Magnet Grade	N52
Diameter (in)	0.4
Thickness (in)	0.375
Distance from Target (in)	0.2
Pull Force (lbs)	0.59
Number of Magnets/Target	4
Combined Pull Force on Door (lbs)	2.36

Table 18: Geometric and force values of the magnets.

The combined pull force on door from the neodymium magnets and their ferrous targets was deemed sufficient for the system's needs.

To ensure a proper seal, a channeled silicone gasket will be installed along the edges of the cutout in the airframe, as seen in Figure 43. When the door is closed, the magnets are attracted to the ferrous targets, and pulls the door tight against the silicone gasket. The team will do testing on the system to ensure the seal is sufficient.

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 49.

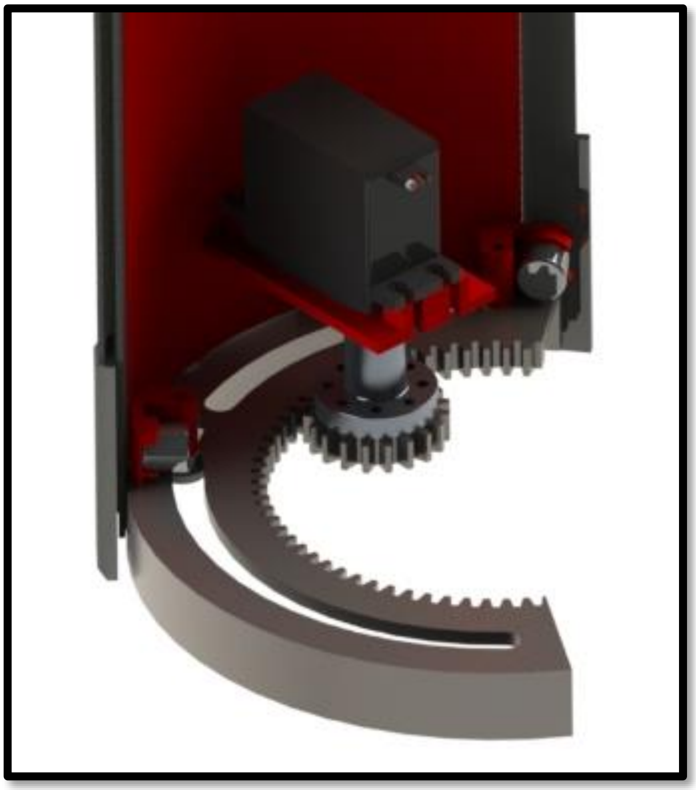


Figure 49: Close-up view of the control system for door actuation.

The design uses a circular rack and pinion gear system to drive the door. The pinion is attached to the servo motor by use of a hub. 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 lower guide, as seen below in Figure 50, has the rack for the gear system machined into it.

Figure 50: Bottom view of the lower guide with gear system rack.

The original design of the track guides used one single path that the track wheels were to run along. This designed was replaced by one where each track wheel runs in its own separate track. This eliminates the issue of the door making contact with the airframe during opening and closing.

Table 19 lists the various materials and their properties of the components that make up the retractable door assembly.

Material	Components	Characteristics
6061-T6 Aluminum	Door Guides Pinion Gear	Density: 0.098 lbs/in^3 Tensile Strength: 35,000 psi
Plain Carbon Steel	Ferrous Targets	Density: 0.284 lbs/in^3 Tensile Strength: 78,300 psi
Neodymium	Magnets	Density: 0.267 lbs/in^3 Tensile Strength: 10,667 psi
Silicone Rubber	Gasket	Density: 0.039 lbs/in^3 Tensile Strength: 348 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
Carbon Fiber	Airframe	Density: 0.050 lbs/in^3 Tensile Strength: 120,000 psi

Table 19: 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 20.

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 opened and closed.	On-board computer electronics will work hand in hand with ASGE systems to synchronize payload insertion and door actuation movements.
The door shall remain airtight when closed.	A custom silicone gasket will be designed and integrated into the door system to create an airtight seal around the edges of the door.
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 20. Solutions to various door design challenges.

5) 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

<u>Risk Assessment Matrix</u>

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 23, 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 21.

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 21: 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 22.

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 22: 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 23. 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 23: 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 55 are risks present from working with machinery, tools, and chemicals in the lab.

Launch Pad Functionality Risk Assessment

The hazards outlined in Table 56 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 57 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 58 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 59 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 60 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 61 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 62 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 63 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 64 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 65 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 66 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 67 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 68 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 69 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 be inhibited except when my rocket is in the launching position.	All launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any safety issues.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its batter and will wait 60 seconds after the	The team will comply with this rule and any additional precautions that the Range Safety Officer makes on launch day.

last launch attempt before allowing anyone to approach the rocket.	
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	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	
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 24: 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 25.

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 25: AGSE sub-stations.

Figure 51: Full loaded AGSE.

The overall system dimensions are shown in

Table **26**.

Overall Mass (lb_m)	Overall Width (in)	Overall Height (fully erected) (in)	Overall Height (closed) (in)	Overall Depth (in)
343.74	29.25		30.84	

Table 26: Overall system dimensions.

Changes since Proposal

Table **27** shows the changes since proposal for the overall system. Each sub-system changes will be shown in their system description.

Change	Justification of Change
Timeline has been changed.	Centennial challenge time update.
Auto leveling system and station raising system has been added.	Lower requirements for payload capture and containment system and allow for system to operate on variable ground.

Ground station has been re-done.	Changes to VES geometry and auto leveling system necessitated a change.
Weather station has been added.	Increase science value of system.

Table 27: 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 **52.**

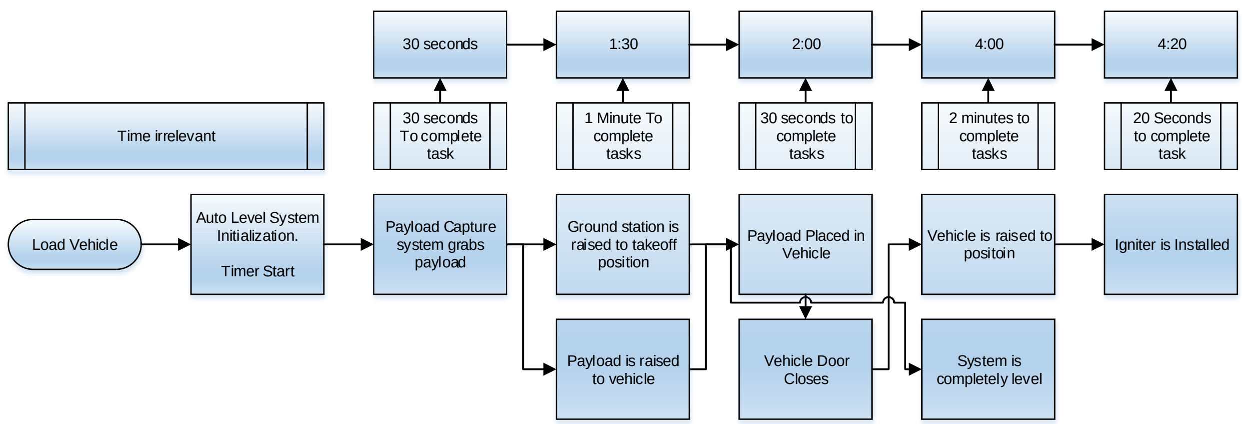


Figure 52: System timeline.

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 53 and Figure 54 respectively. The general dimensions of the payload arm are shown in Table 28.

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

Table 28: General dimensions of payload arm not including length of shafts.

Figure 53: Payload arm in vertical position.

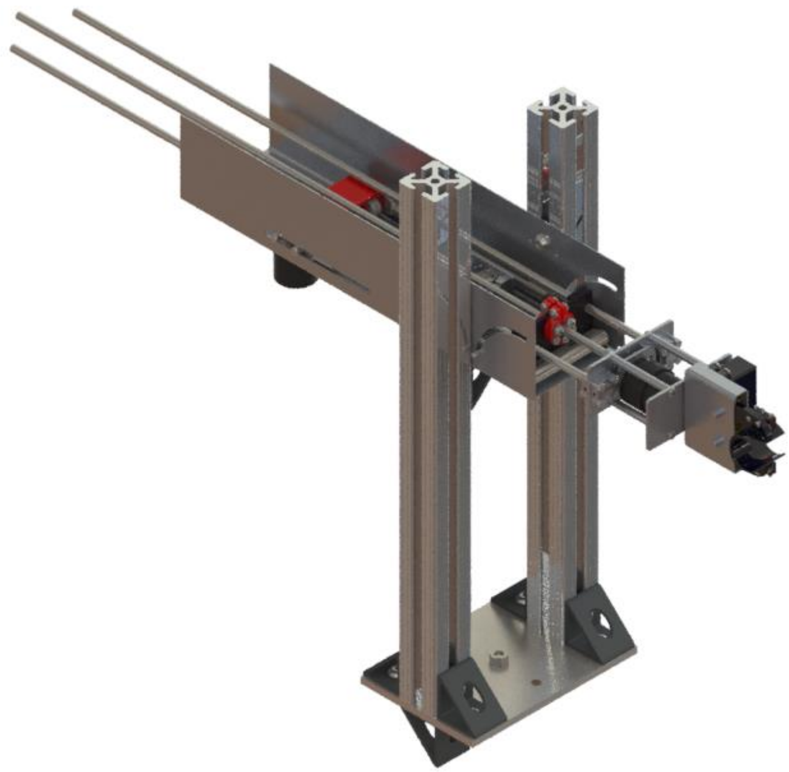


Figure 54: Payload arm in horizontal position.

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 55 shows the gripper assembly.

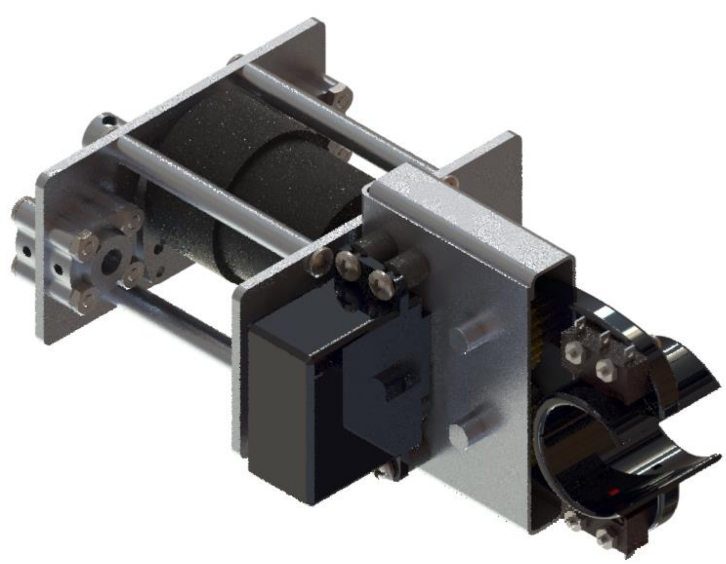


Figure 55: Gripper assembly.

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 56.

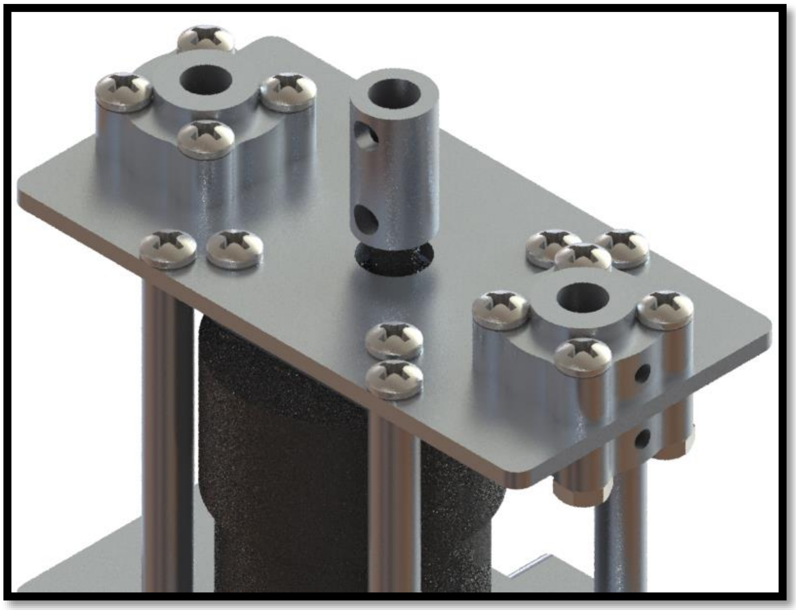


Figure 56: View of motor attachment plate.

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 57.

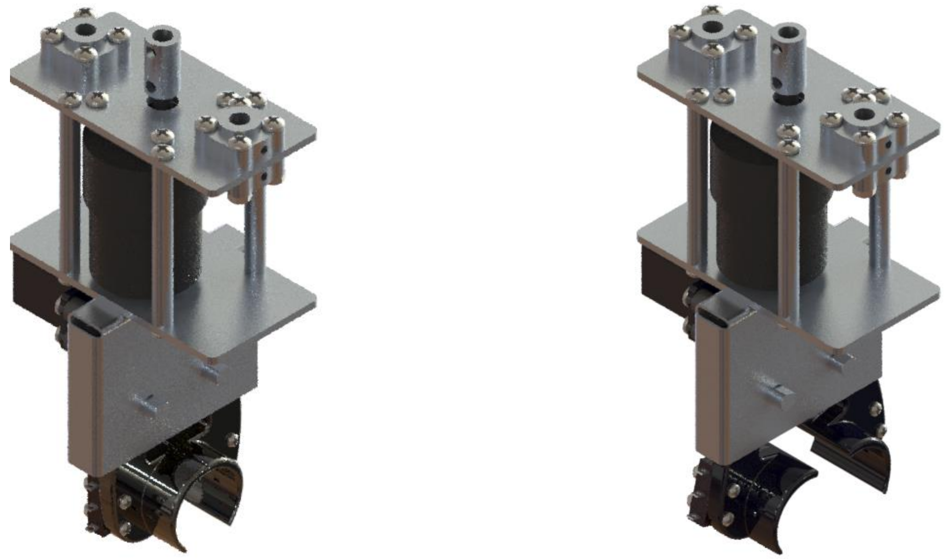


Figure 57: Gripper assembly with closed (left) and open (right) payload arms.

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 58.

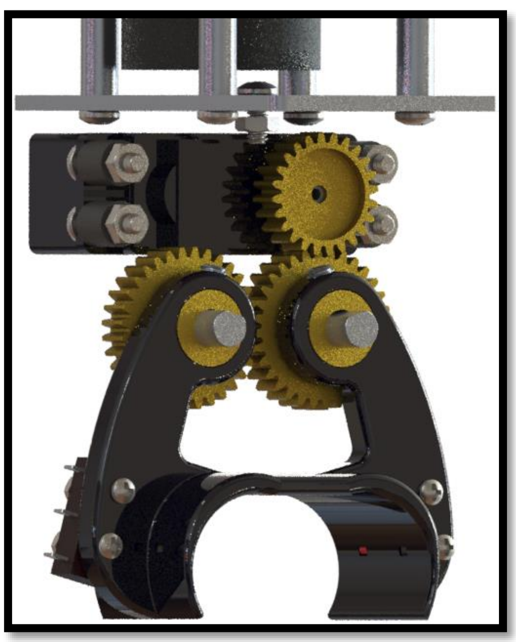


Figure 58: View of gears used to move payload arms.

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 29.

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 29: Gripper gear specifications.

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

$$c = \frac{d_1 + d_2}{2} \qquad (30)$$

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 30.

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 30: 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 58. 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 0.25 in 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 18 in to 48 in, 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 59: Threadless ball screw assembly.

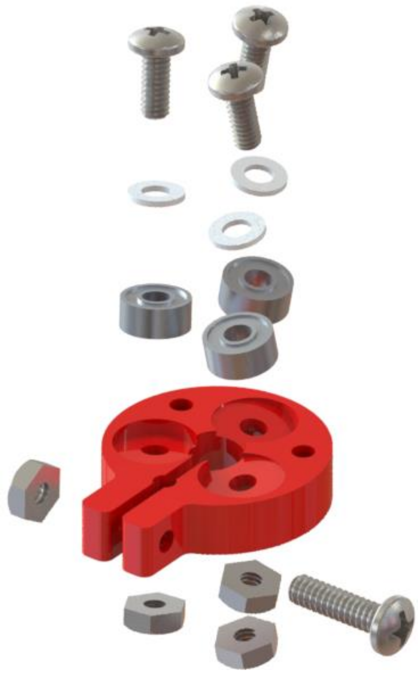


Figure 60: Exploded view of threadless ball nut.

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

$$P = \pi D \tan(\theta) \tag{31}$$

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 61.

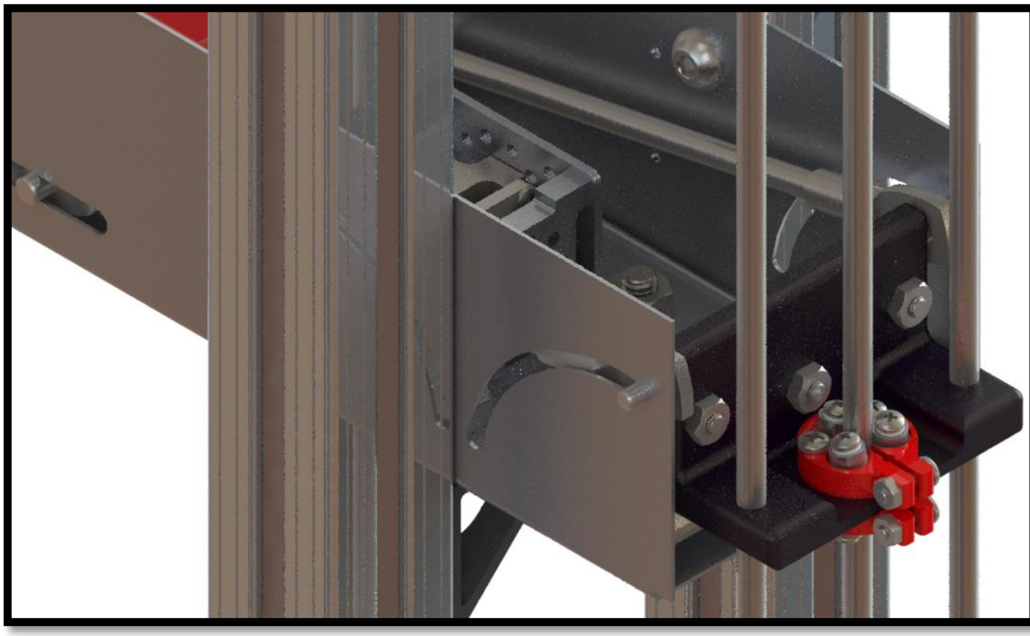


Figure 61: Threadless ball screw assembly mounted on u-shaped channel.

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 62. 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.

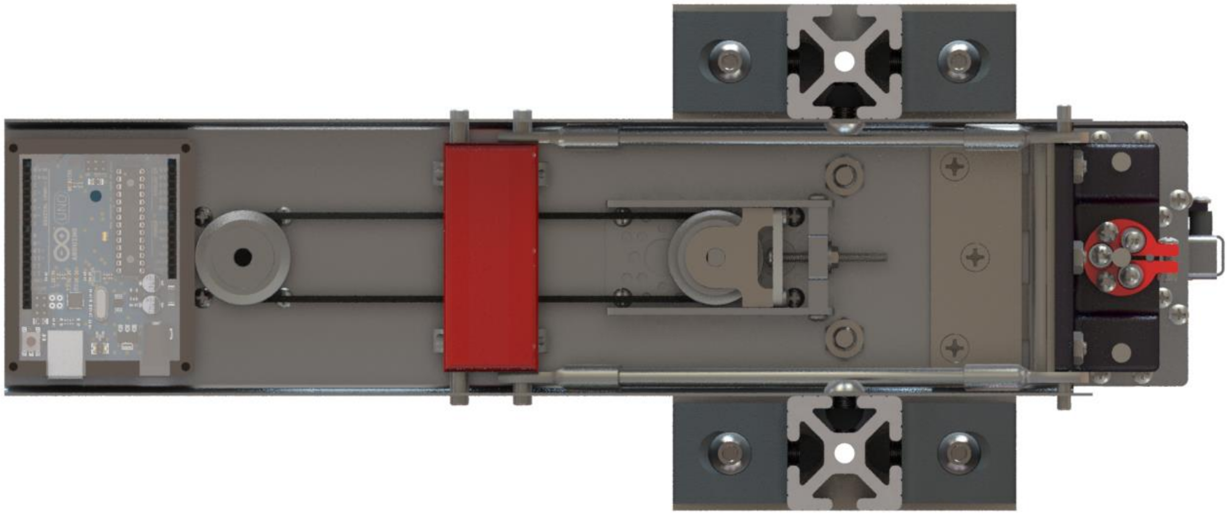


Figure 62: Top view of payload arm assembly.

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 63.

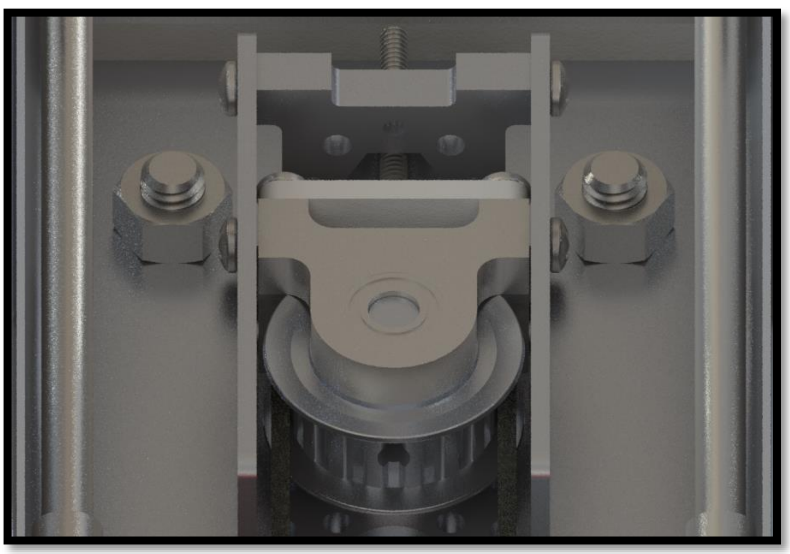


Figure 63: Belt tensioning pulley.

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 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 64 and Figure 65.

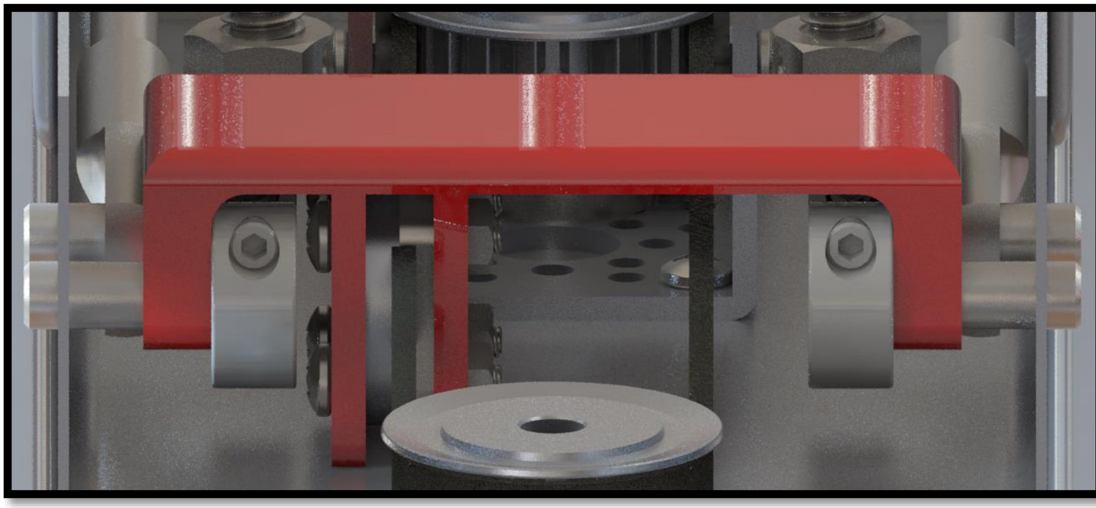


Figure 64: Slider mounted on timing belt.

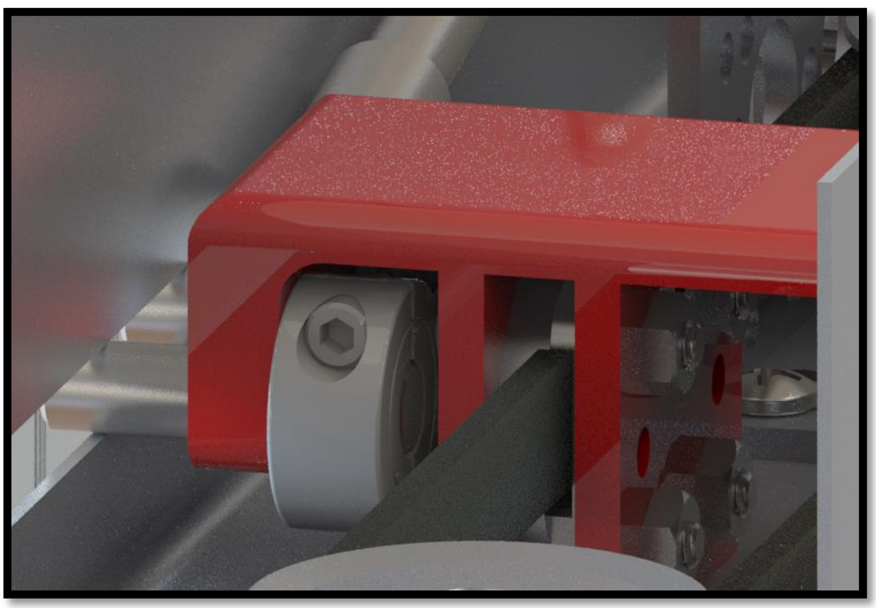


Figure 65: Another view of the slider.

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 66.

Figure 66: 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 67.

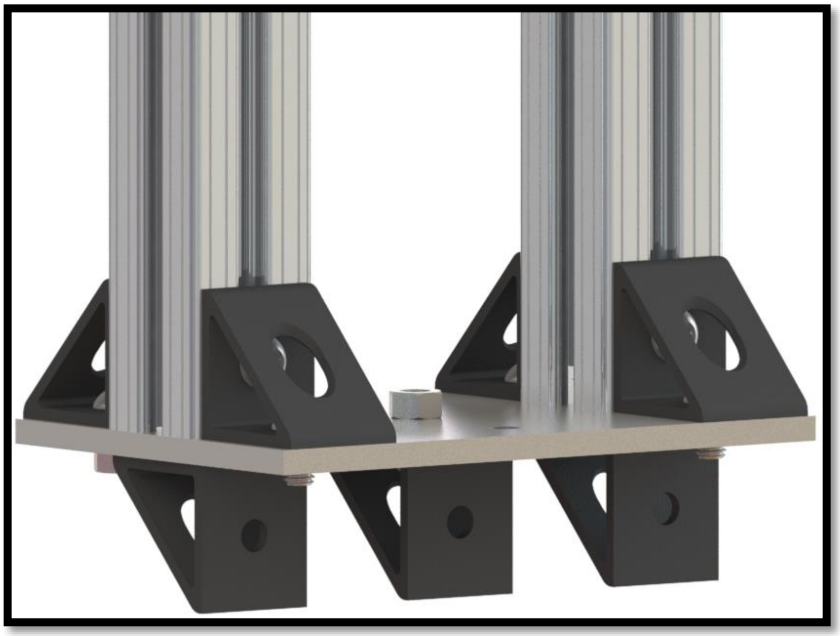


Figure 67: Payload arm mounting plate.

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 68 shows the constraints and loads that were applied to the shaft during the simulation.

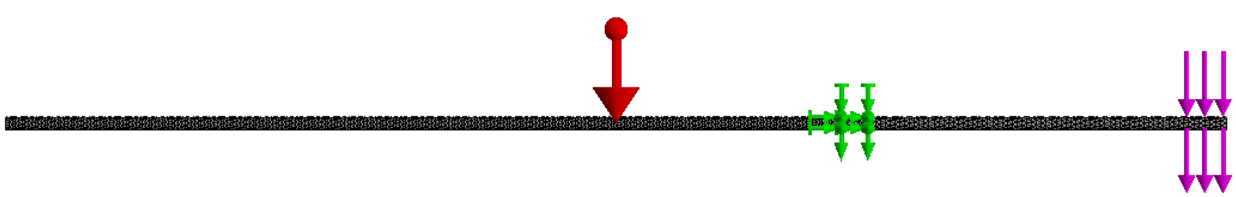


Figure 68: Constraints and loads on shaft.

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 68. The shaft was analyzed at its maximum extended length of 12in. In Figure 68 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 31.

Elastic Modulus (Pa)	210×10^9
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 31: 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 69 and

Figure 70 show the resulting plots from the simulation.

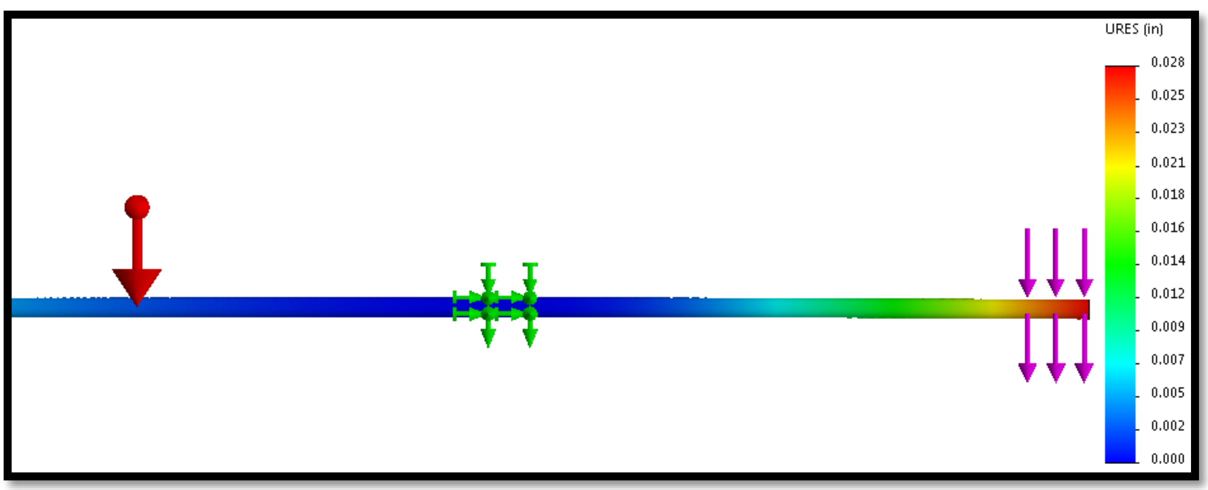


Figure 69: Vertical displacement plot.

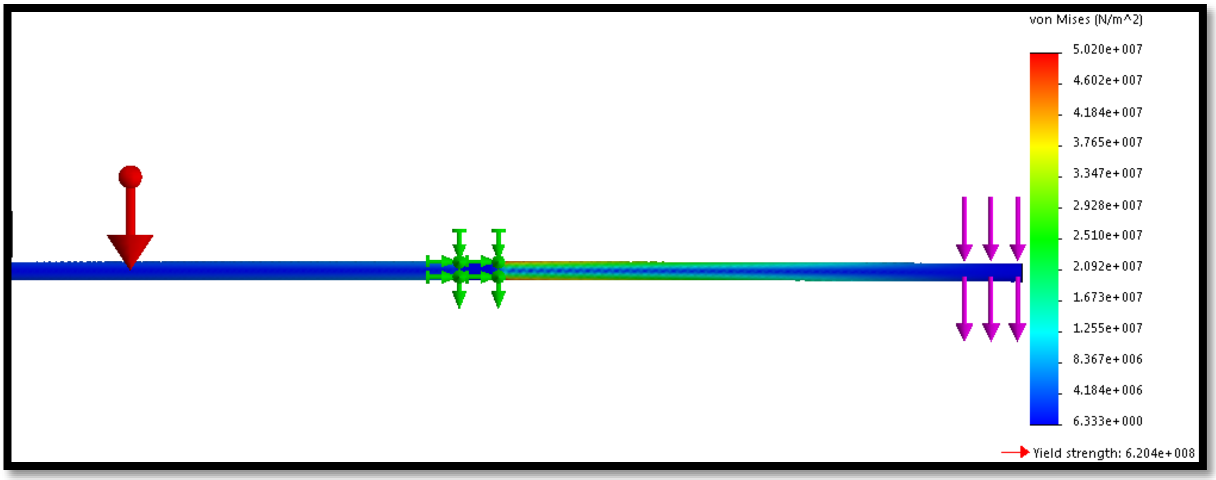


Figure 70: Von Mises stress plot.

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 32 were obtained.

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

Table 32: 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.

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 71.

Figure 71: 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 33 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 33: 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 34 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 ground and place it inside the rocket.	Each subsystem of the payload arm will be tested 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 34: Verification plan for payload arm.

3) Ground Station

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

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

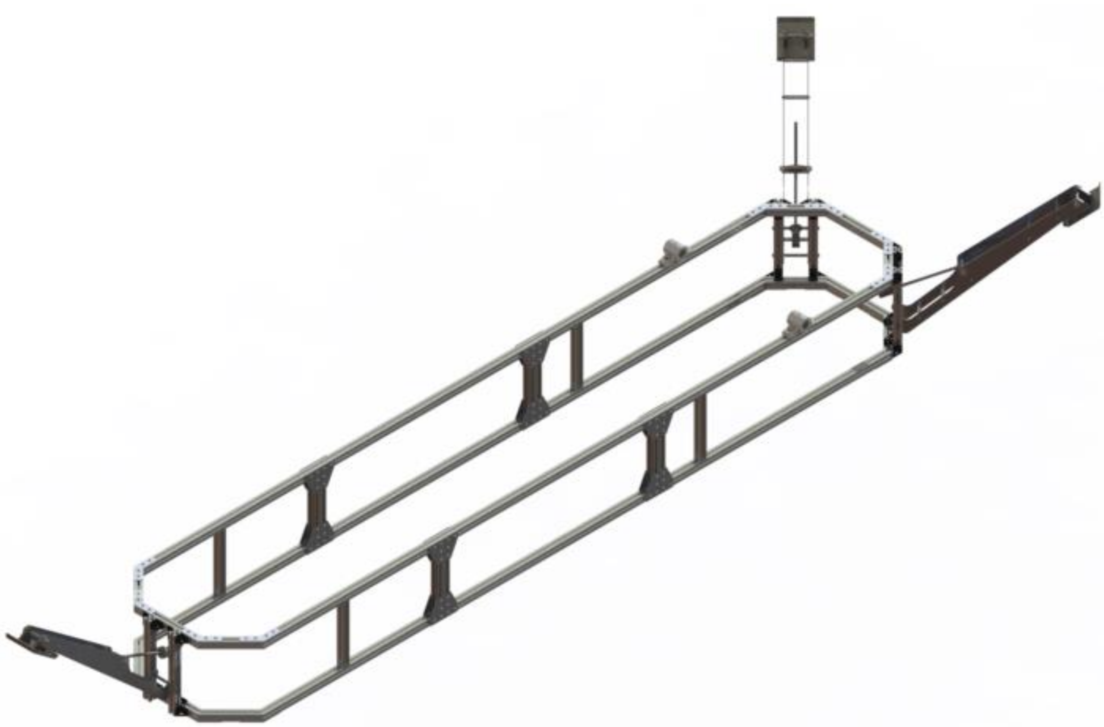


Figure 72: Ground station.

Table 35 shows the overall dimensions of the ground station.

Overall Length (in)	Overall Width (in)	Overall Height (in)	Overall Mass (lb_m)
156.257	29.250	15.750	159.46

Table 35: Overall system dimensions.

Changes since Proposal

The changes made to the ground station since proposal are shown in

Change	Justification for Change
The frame has been changed to include bearings for vehicle rotation.	Lower overall AGSE profile.
Three legs have been added to the station.	Allows the station to raise and lower itself for adaptation to terrain.
The structure has changed to break into sections.	Allow for transportation within team means.
The station sits on the ground initially.	Lower payload capture system requirements.
The station houses weather sensors.	Data logging of vehicle and station environment.
Sensor replaced with MPU-6050	Added gyroscope sensing to feedback control.

Table 36: Changes made since proposal.

Design

The design of the ground station consists of a framework and three outrigger stability and raising systems.

Station Frame

The frame consists of a bottom exterior rail, ten support rails, a top exterior rail, and two bearings. The bottom exterior rail consists of three identical straight rail t-slotted aluminum extrusions which are 48 inches long, six t-slotted extrusions that are angled at the ends to form the shape shown in Figure 73.

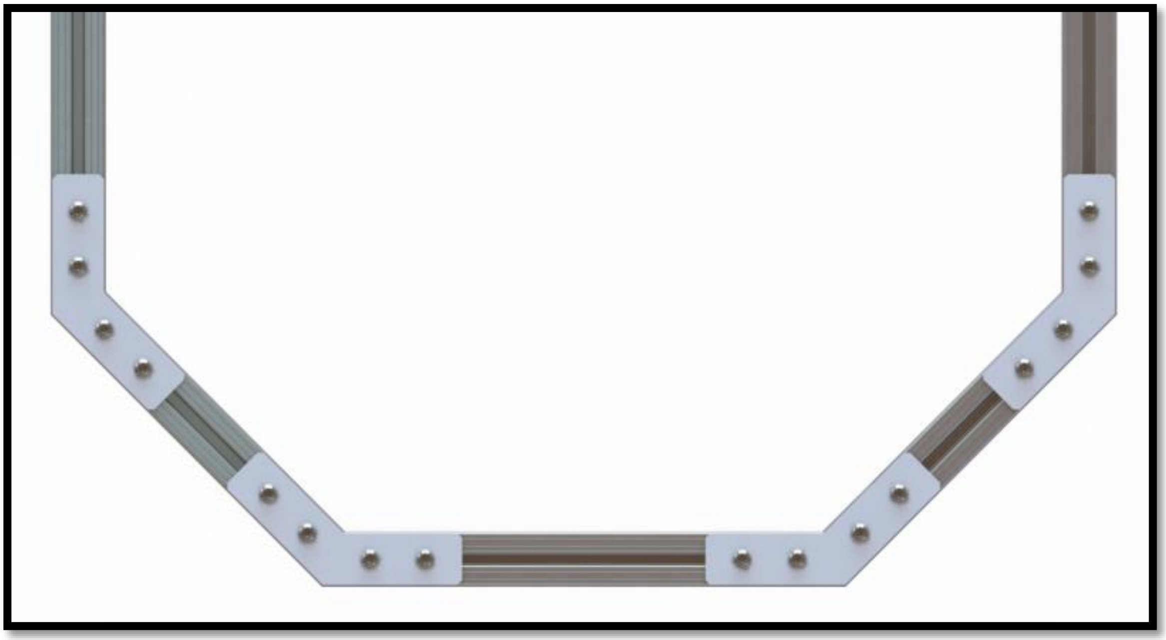


Figure 73: End profile.

The front and rear of the ground station are symmetric. The angled extrusions are connected using custom fasteners on the top and bottom of the rail, these fasteners will be waterjet out of 0.125 inch thick aluminum pieces. To reduce costs, these will be cut from the interior of the launch platforms stability rings mentioned in the Launch Platform section. To allow for transportation, the straight pieces of extrusion break along the pieces of 3 inch support beams shown in Figure 74.

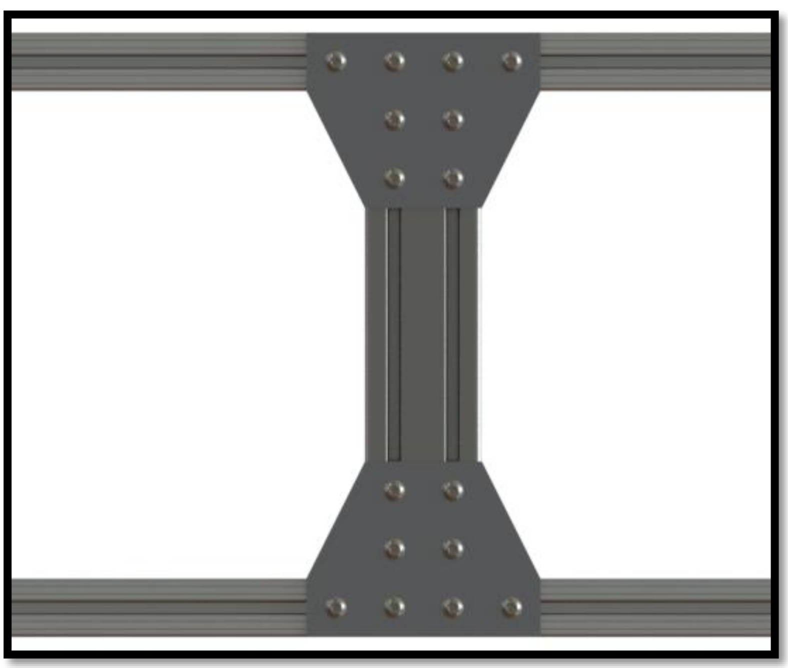


Figure 74: Support beams at station splits.

To integrate with the vehicle erection system, four more support rails are to connect the vehicle erection system to the ground station.

The bearings used are sleeve bearings with a shaft diameter of 1.5 inches and a max load of 565 lb_f which is within the total mass to be rotated. An example of the bearing is shown in Figure 75.

Figure 75: Vehicle rotational bearing.

Outriggers

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

The ground station will have a total of three outriggers. This will provide three adjustable points of contact between the AGSE and the ground. A three contact point system was selected because of its benefits in stability over a four point system. The outrigger assembly is shown in Figure 76.

Figure 76: Outrigger assembly.

The outriggers will consist of two parallel aluminum plates which will be waterjet out of 0.125” thick aluminum plates. These plates will be connected via five 5/8” aluminum spacers. These spacers will provide a 3.75” gap between the two plates. The outrigger will contact the ground though a custom foot pad. The foot pad is shown in Figure 77.

Figure 77: Outrigger foot pad.

The pad will be a weldment consisting of a 3/16” AISI 1020 cold rolled steel plate, with two vertical 1/2” mounting plates made from the same steel alloy. The weldment will attach via a ¾” steel rod that will be secured to the outriggers with socket head cap screws at either end.

The outriggers will be attached to the ground station via two of the vertical support rail extrusions as shown in Figure 78.

Figure 78: Outrigger ground station interface.

The outrigger will interface with the support rail via a support axle. The outrigger will be actuated by a ball screw configuration. The ball screw and associated motor will be mounted via a custom motor mount bar. This motor mount bar will also be attached to the vertical support rail extrusions and will allow for rotation of the motor and ball screw assembly. The ball screw nut will also be mounted to a custom rotational mount bar positioned between the outrigger plates.

Finite Element Analysis will be performed on the outrigger once an accurate estimate for the overall weight of AGSE is determined. This analysis will be used to select the appropriate motor, ball screw, geometries, and materials for the outriggers.

Controls

Overview

The purpose of the Automatic Platform Leveling System (APLS) is to control motors with MPU feedback to autonomously level the AGSE. A closed feedback system using an Arduino Uno microcontroller, a MPU-6050 Gyroscope, and three motors driven by an H-bridge circuit (to enable bi-directional rotation) will implemented. The APLS will remove human involvement from leveling the platform to test the feasibility of the design to be implemented on an interplanetary launch station.

Instead of using the ADXL345 Accelerometer, a MPU-6050 Gyroscope will be used. Both sensors are shown Figure 79. This Integrated Circuit will sense the degree of tilt on the launch station. After the angle is determined the MPU-6050 translates the internal analog data to serial I2C protocol. The outgoing I2C data is then received by the leveling system microcontroller. The MPU-6050 integrates an accelerometer and gyroscopic sensor on one die. This integration cross-references the gravitational acceleration (accelerometer) with angular movement (gyroscope). Using the integrated chip will allow the system to have more measurable resolution in the orientation of the platform. The MPU-6050 has on-board temperature sensors. The temperature sensing adds a data point to the science-value of the APLS system, allowing the system to compensate for changes in the immediate environment.

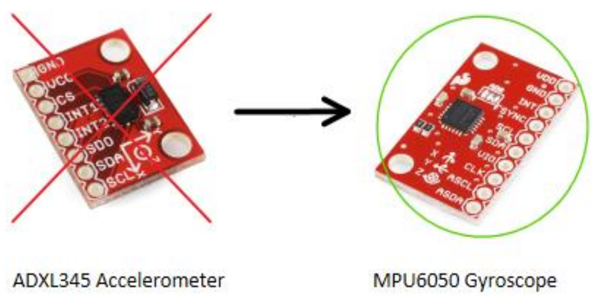


Figure 79: Accelerometer to gyroscope.

Testing and Development

The system is being prototyped on breadboards for a proof-of-concept. After the concept is proven, the landing station will be proven at a system level. The final integration of the controls will laid out onto a printed circuit board. The Processing Development Tool will be used to simulate the leveling status of the AGSE. A 3D model of the AGSE from SolidWorks will be used in combination with the Arduino and gyroscope to optimize the leveling algorithm and visualize the operation of the hardware.

Hardware Implementation

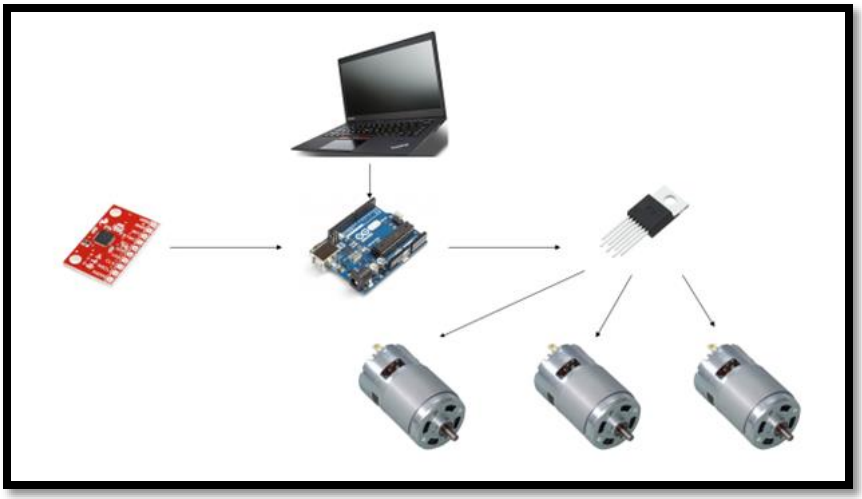


Figure 80 : General process overview.

Our Current prototype uses an Arduino Uno microcontroller, a MPU-6050 Gyroscope, and three motors to control the level of the AGSE, as shown in Figure 80.

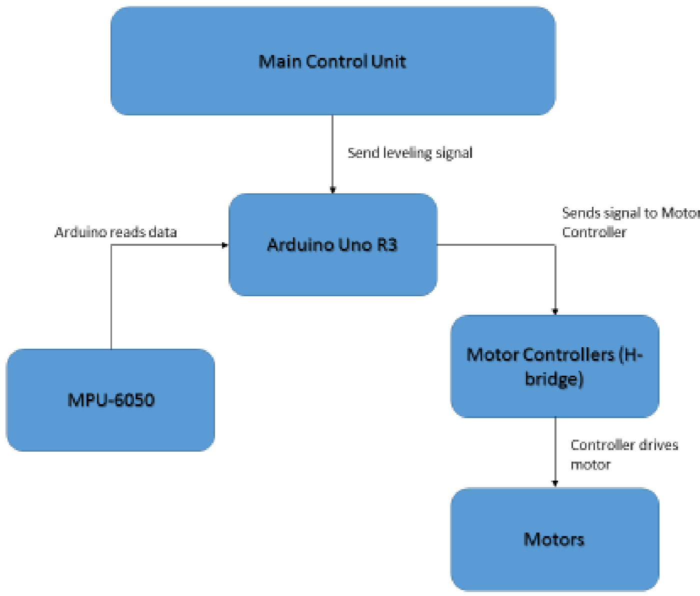


Figure 81: APLS Component overview.

A block diagram for the APLS structure is shown below in Figure 81. The motors used in the APLS will be controlled by an H-bridge circuit, shown in Figure 82, to enable bi-directional operation. The use of four transistors per motor will allow us to control the direction of current flow into the motor, allowing it to rotate both counterclockwise and clockwise. The motors must be able to drive power screws in both directions in order to ensure that we are able to both raise and lower our platform as needed.

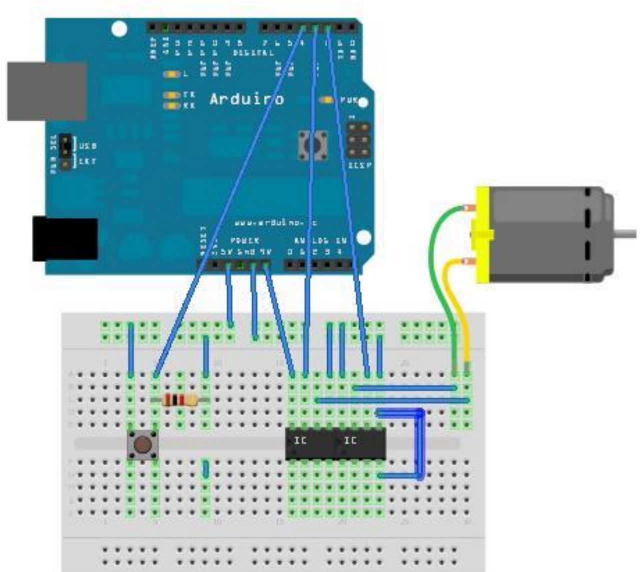


Figure 82 : H-Bridge with Arduino, breadboard implementation.

Processes and Software

The APLS will utilize a series of steps in order to level the AGSE. These steps are outlined in Figure 84. The Arduino Uno will be setup to receive position data from the gyroscope IC. Using the data from the accelerometer readings (Ax, Ay, Az), angle values for the platform can be found. The angle values for roll and pitch, shown in

Figure 83, are found using equation 1 and equation 2. The measurement for yaw, also shown in Figure 83, will not be needed for our system, but could be used for future expansion.

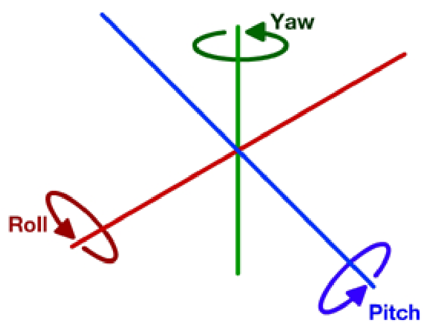


Figure 83: Roll, pitch, and yaw diagram.

$$\Phi\ (Roll) = \arctan\left(\frac{A_x}{\sqrt{A_y^2 + A_z^2}}\right) \tag{32}$$

$$\rho\ (Pitch) = \arctan\left(\frac{A_y}{\sqrt{A_x^2 + A_z^2}}\right) \quad (33)$$

The data will be compared to predefined positions using a lookup table. An action will occur based on the closest range of orientation defined in the program. The actuation is performed by the three motors connected to the system.

Each motor "group" will have control over specific changes in the orientation of the pad to correct the positioning of the gyroscope. The two motors positioned on a common side of the AGSE will change the roll of the structure. The single motor end of AGSE will change the pitch of the station. This process will continue until the position is matched to an acceptable range of angles.

In Figure 84, the step-by-step process for the APLS is described.

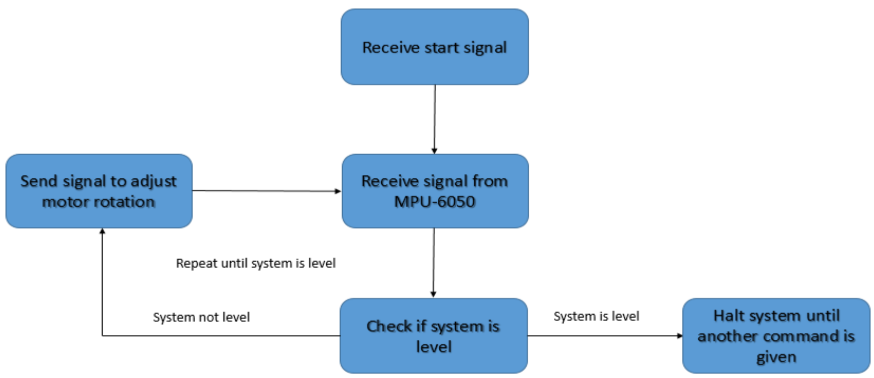


Figure 84 : APLS logic flow chart.

Once the payload has been sensed by the arm's tactile sensors, the master controller will send a start signal to the Arduino Uno to begin the leveling process. The MPU-6050 will begin sending data to the Arduino through the I2C bus. In response, the Arduino will send the appropriate orientation correcting signal to the DC motors. The actuation of the motors will adjust the platform.

The schematic for the MPU-6050 accelerometer is show below in Figure 85.

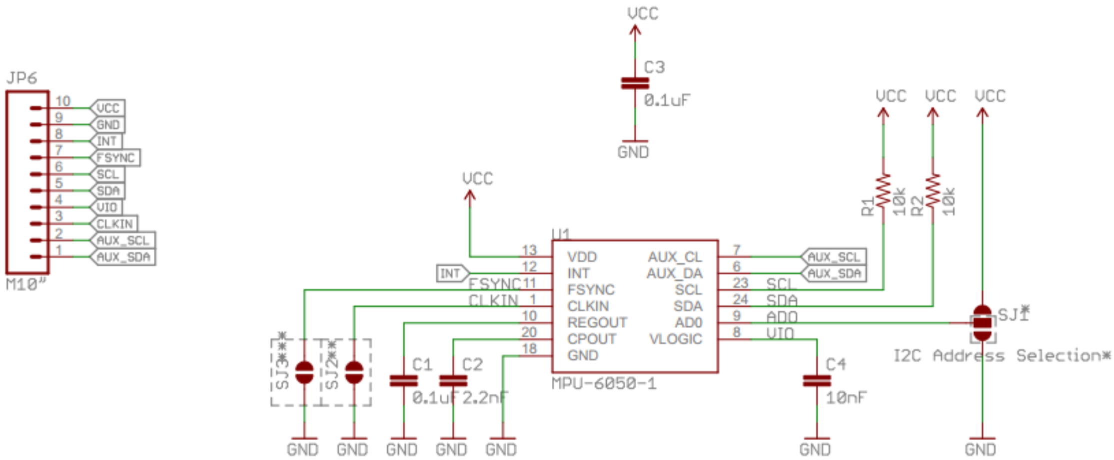


Figure 85 : MPU-6050 schematic.

4) Launch Platform

Overview

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

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

The overall dimensions of the launch platform are shown in Table 37.

Overall Height (in)	Tower Height (in)	Overall Width (in)	Overall Thickness (in)	Overall Mass (lb_m)
126.78	120.36	30.97	22.65	106.17

Table 37: Launch platform general dimensions.

Figure 86: Launch platform.

Changes since Proposal

The changes made to the launch platform since PDR are shown in Table 38.

Change	Justification for Change
The height has been changed from 120 inches to 120.36 inches.	Analysis was performed that determined the minimum height the vehicle needed to be guided.
The stability ring assemblies have added a new ring and the size of the rings has been made wider.	Adds stability to the guide rails and accounts for larger fins if necessary
The support rails were changed from 24 inch length to 18.375 inch length.	To lower the height requirement of the ground station. Less of the vehicle will rotate down thus less overall height is required.
The three bottom plates were changed from aluminum to steel	This changed the center of gravity position to lower the vehicle raising system requirements.
The placement of the stability rings has been defined.	Design to optimize the raising of the vehicle was performed and the spacing of the rings was a design variable.

Table 38: Changes made since proposal.

Design

The launch platform consists of three t-slotted aluminum extrusions which guide the vehicle with the aid of anti-friction tape until it has reached the minimum safe exit velocity. The gap between the guide rails and the vehicle is 0.112 inches after anti-friction tape.

Figure 87: Launch platform base.

The guide tower rests upon a base, shown in

Figure 87, 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 88, is where three 18.375 inch aluminum extrusions that stabilize the primary guide rails and is the base mounting plate for the ignition system.

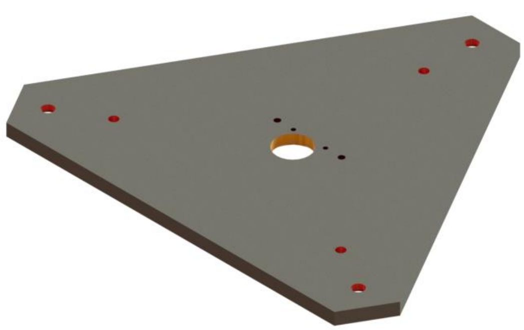


Figure 88: Platform bottom plate.

The middle plate, shown in Figure 89 , 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.

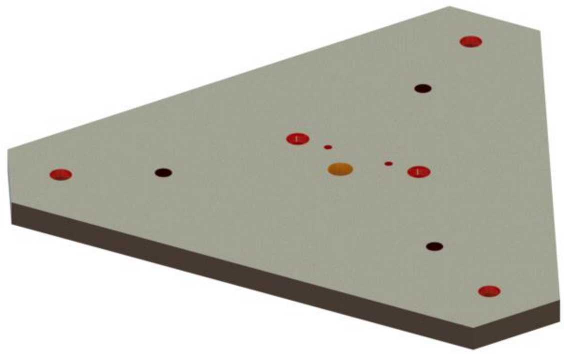


Figure 89: Middle base plate.

The uppermost plate, shown in Figure 90, is where the vehicle rests pre-flight. This is constrained by two sets of plates that connect and stabilize the support and guide rails.

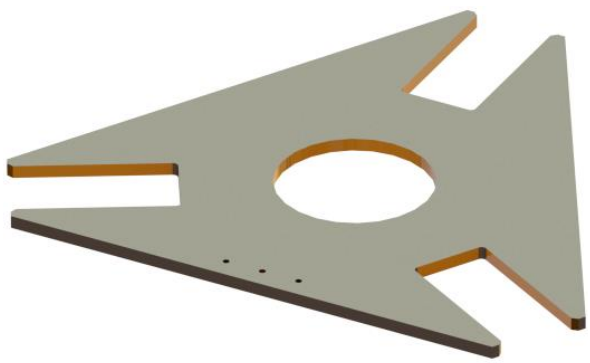


Figure 90: Uppermost base plate.

To ensure correct vehicle position during payload insertion, an alignment plate, shown in Figure 91, will hold one of the fins in the correct orientation and will only allow for translation along the axis of the launch platform.

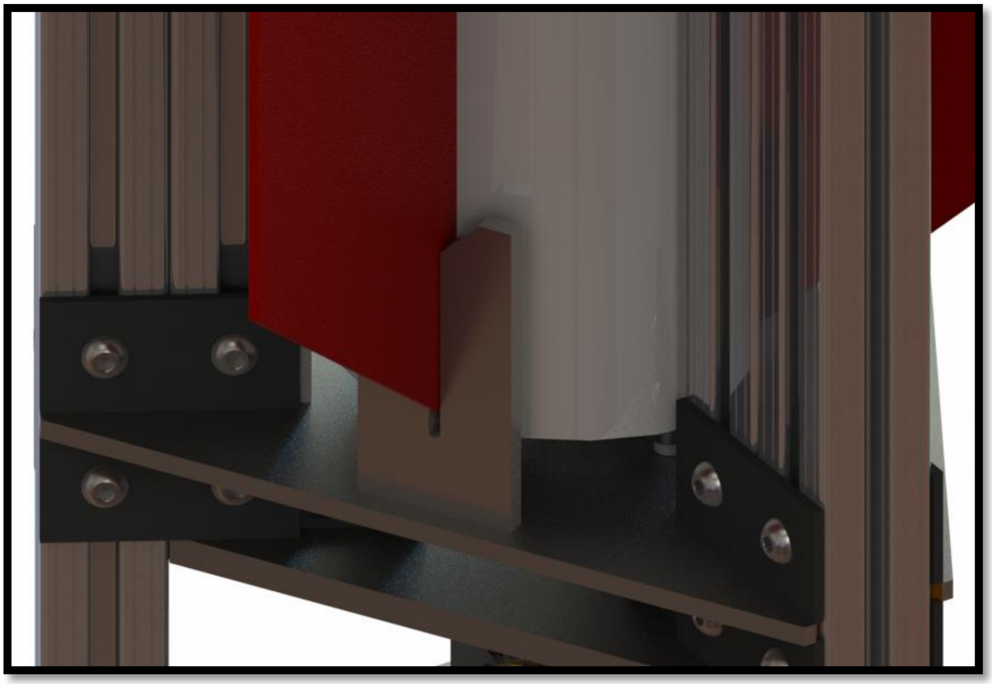


Figure 91: Vehicle alignment plate.

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 91. 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.

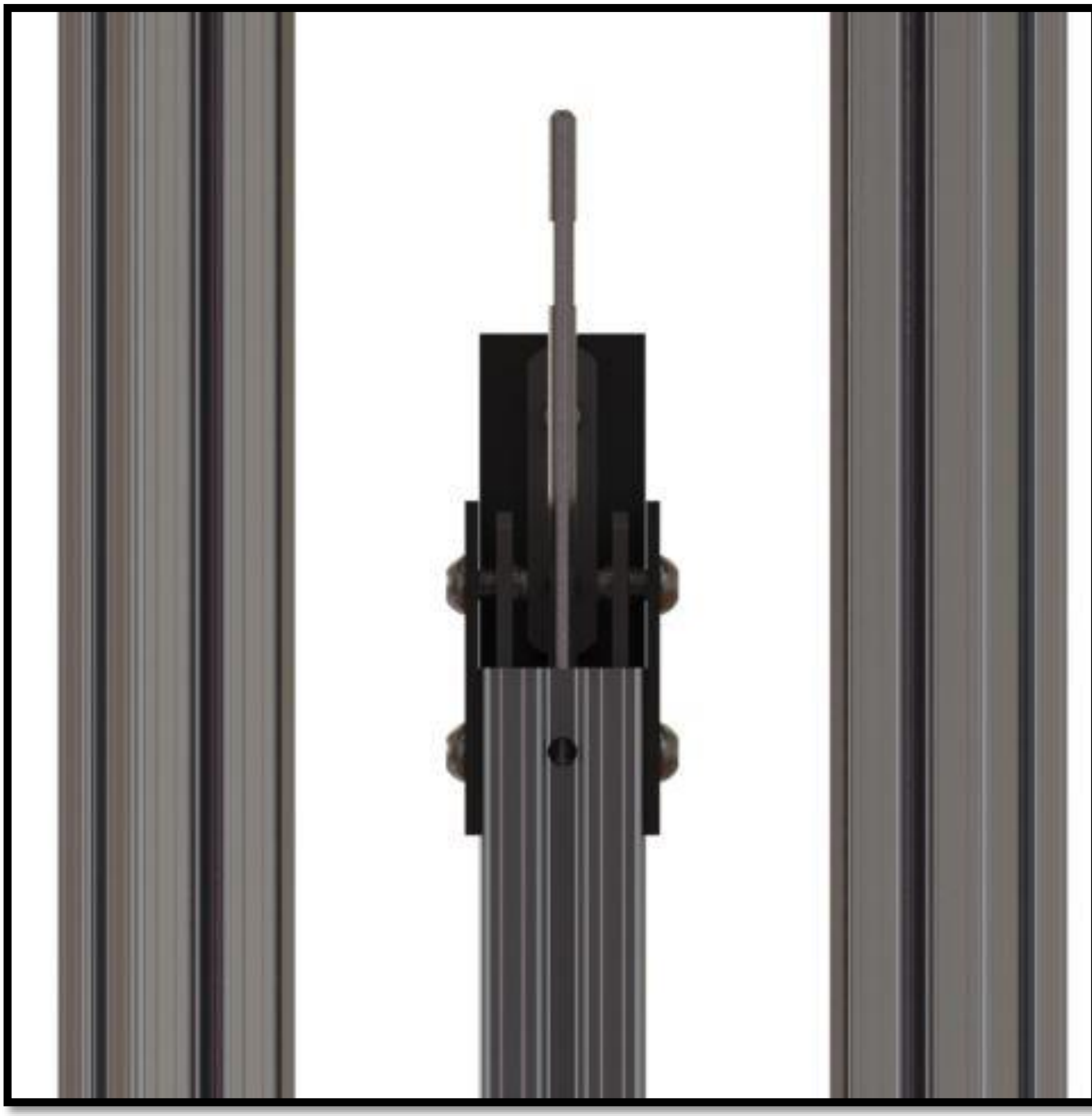


Figure 92: Tower connection joint.

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 93. These rings connect to three t-slotted aluminum extrusions which are 6.5 inches long.

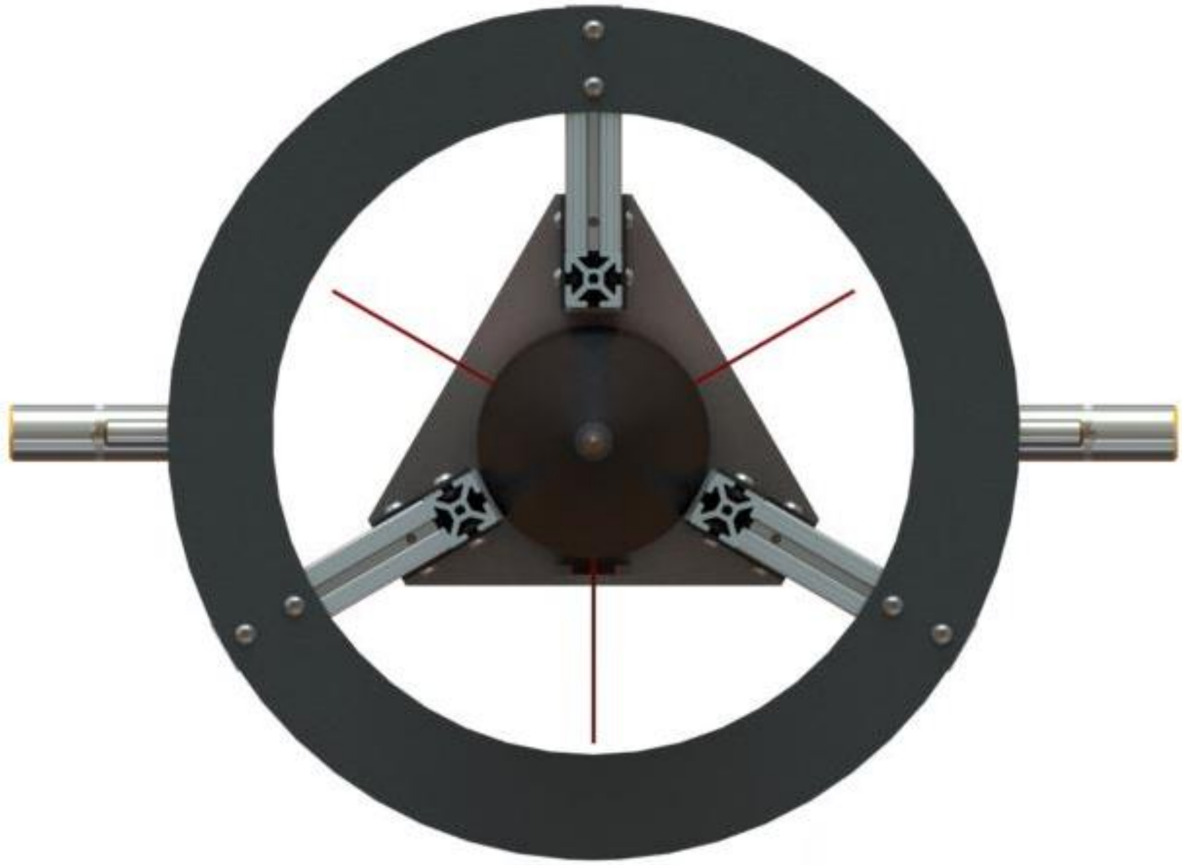


Figure 93: Worst case alignment.

The bottom most stability ring assembly, shown in Figure 94, 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 94: 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. Future shaft analysis will be performed to optimize the shaft diameter.

The secondary ring assembly, shown Figure 95, 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 95: V.E.S. connection ring.

The connecting shaft ends in a tapped hole to accommodate an X 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 96.

Figure 96: V.E.S. and platform connecting.

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

$$h = \int_0^{t_e} \mathrm{Vdt} \quad (34)$$

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 97.

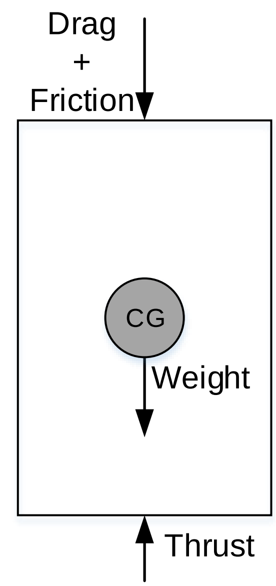


Figure 97: Vehicle takeoff F.B.D.

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

$$+\uparrow \sum F = ma \tag{35}$$

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

$$+\uparrow \sum F = T - mg - F_d - F_f \tag{36}$$

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

$$F_d = \frac{1}{2}\rho C_d A V^2 \tag{37}$$

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

$$m = m_w - b_r t \tag{38}$$

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 (36) through (38) can be combined to determine the acceleration of the vehicle and the resulting equation is shown below.

$$a_i = \frac{T_i - (m_w - b_r t)g - F_f - \frac{1}{2}\rho C_d A V_{i-1}^2}{m_w - b_r t} \tag{39}$$

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

$$k_1 = a_i(V_{i-1}) \tag{40}$$

$$k_2 = a_i\left(V_{i-1} + \frac{h}{2}k_1\right) \tag{41}$$

$$k_3 = a_i\left(V_{i-1} + \frac{h}{2}k_2\right) \tag{42}$$

$$k_4 = a_i\left(V_{i-1} + \frac{h}{2}k_3\right) \tag{43}$$

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

$$V_i = V_{i-1} + \frac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{44}$$

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 39 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 39: Trail 1 parameters.

Figure 98 shows the recorded flight data during the competition launch from the vehicles primary Raven altimeter.

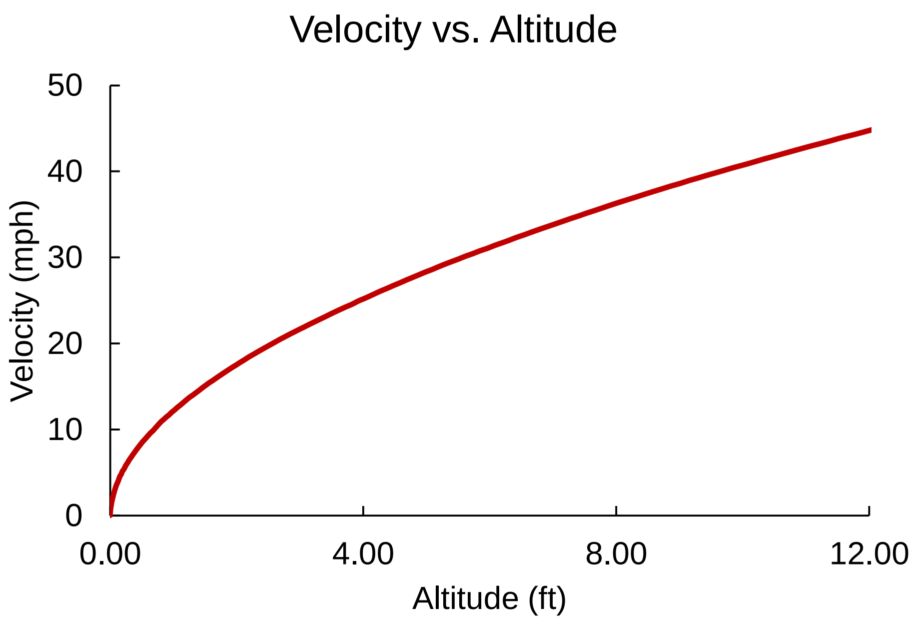


Figure 98: Velocity vs. altitude in tower.

The flight data was then compared vs. the predicted flight profile shown in Figure 99.

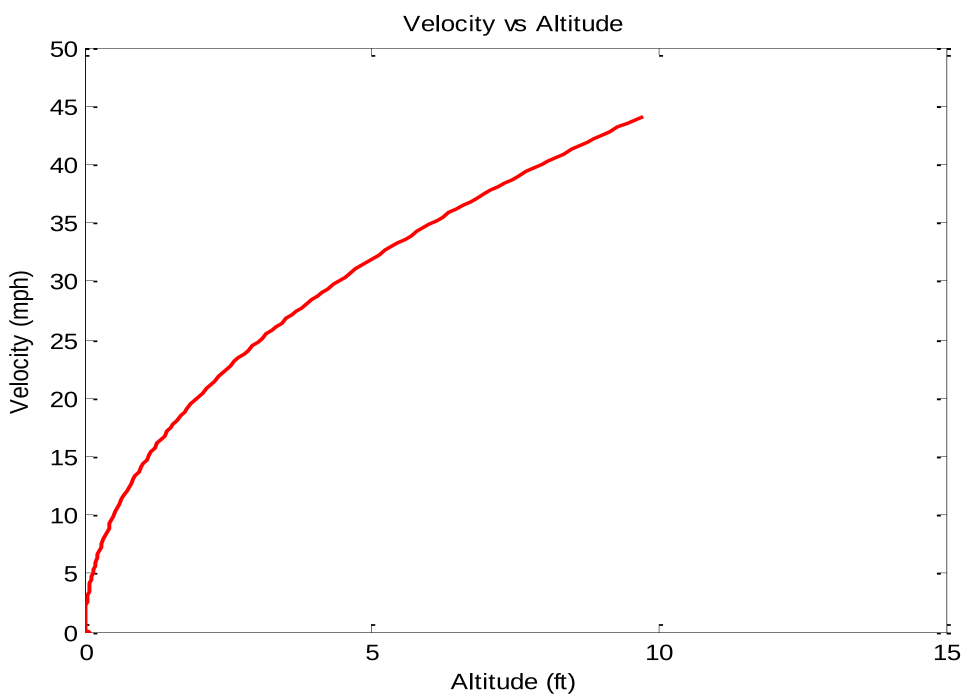


Figure 99: Predicted velocity vs. altitude in tower.

The exit velocities and percent error are shown in Table 40.

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

Table 40: 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

$$V_e = V_{e\,required} * (1 + P.E.) \tag{45}$$

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 41: Error adjusted exit velocity.

Figure 100 shows the predicted flight profile until rail exit.

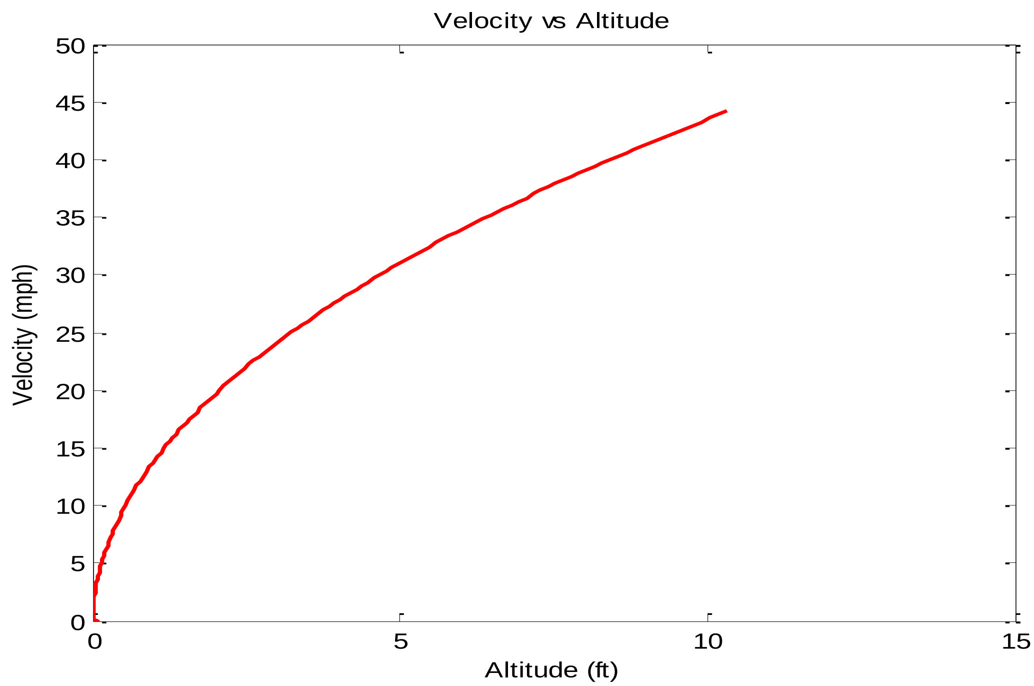


Figure 100: Predicted flight profile.

With the accounted velocity, the total height that the vehicle is to be guided is shown previously in Table 37.

Construction

The t-slotted aluminum extrusions will be cut at the station shown in Figure 101.

Figure 101: Milder saw cutting station.

From there, the pieces will be measured using a laser measuring system, and cut to length using a mill. Tolerances have been taken into account for the precision required at each station.

The stability rings will be cut using the waterjet cutter shown in Figure 102. In addition to the rings, all 2D fastening plates will be cut using the extra material from the center of the rings as they are all of the same material.

Figure 102: Waterjet cutter.

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, they will also have 3D printed deflector plates designed once all sensors are known.
Be transportable by passenger vehicle.	The platform breaks down into two separate sections along the guide rails for transportation.

Table 42: Launch platform design challenges.

5) Vehicle Erection System

Overview

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

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

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 103.

Figure 103: 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 104.

.

Figure 104: 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

$$y = \frac{Wx^2}{48EI}(3l - 4x) \tag{46}$$

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 43.

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

Table 43: 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 track was designed as a singular modular component to help with transportation to and from launches. Breaking down the vehicle erection system further would increase prep time on launch day and introduce failure points into the system.

The carriage will be actuated by a one inch ball screw. The ball 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 105.

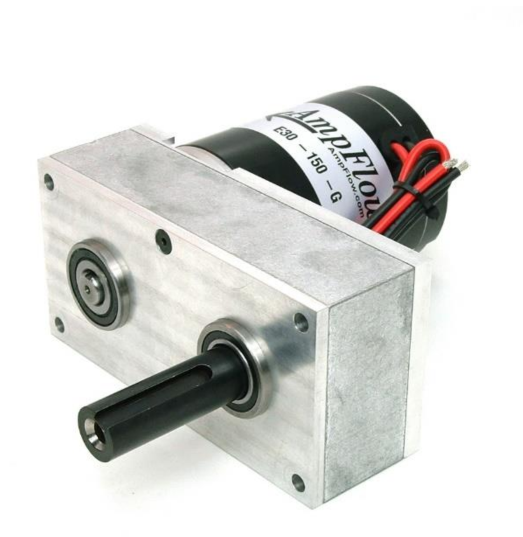


Figure 105: Ampflow brushed DC-E30-150-G gearmotor.

The carriage assembly is shown in Figure 106.

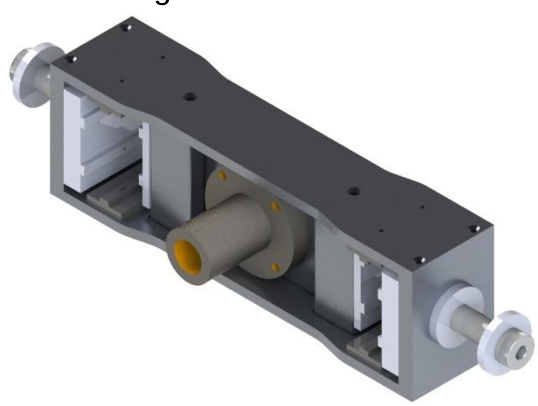


Figure 106: Vehicle erector carriage assembly.

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 107.

Figure 107: Carriage bottom plate.

A vertical mounting plate interfaces with the power screw and transfers the load from the screw to the carriage. 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 108.

Figure 108: 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 counter sunk 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 center carriage plate where the power screw nut would sit. A load of 100 lbs was applied to the shoulder bolt at a 45 degree angle. This load was applied through a simulated load bar as shown in Figure 109.

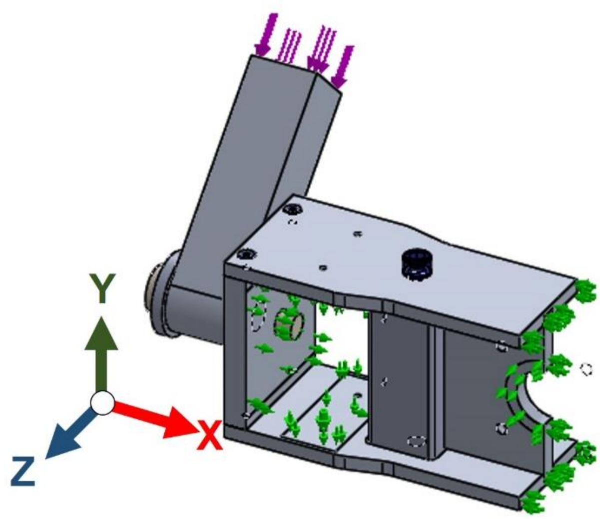


Figure 109: Carriage boundary conditions.

A stress distribution plot is shown in Figure 110.

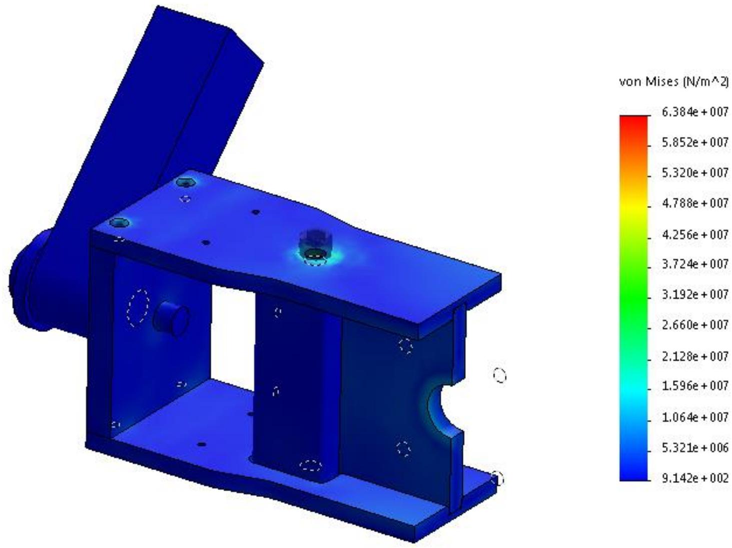


Figure 110: Carriage stress distribution.

The factor of safety distribution are shown in Figure 111.

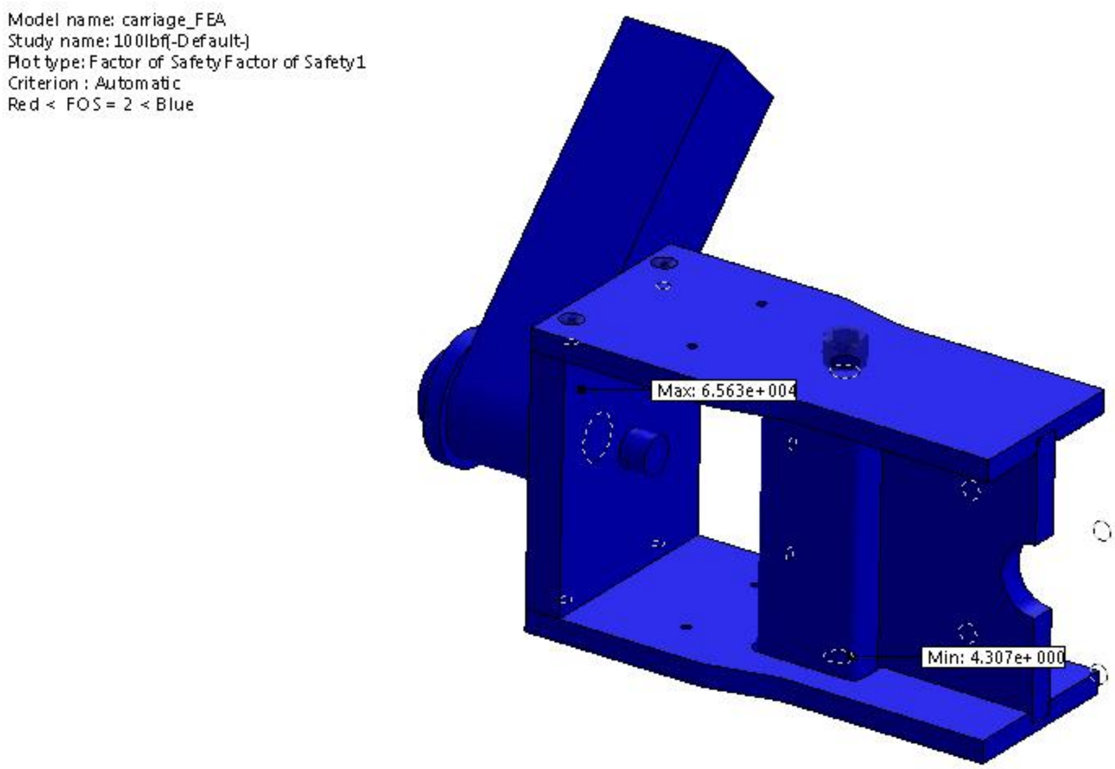


Figure 111: Carriage factor of safety distribution.

As shown in Figure 111 the minimum safety factor was 4.307. Further analysis will be completed in order to reduce weight and manufacturing costs for the carriage while still maintaining a minimum safety factor of 2.

The articulating arms will be made out of t-slotted aluminum extrusion. One articulating arm is shown in Figure 112.

Figure 112: 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.

Further analysis is planned for the articulating arms to better distribute the load between the articulating points on the launch platform and carriage. The current design introduces sharp critical points that could be mitigated with more analysis and design iteration.

Geometry Selection

The geometry of the vehicle raising system is shown in Figure 113

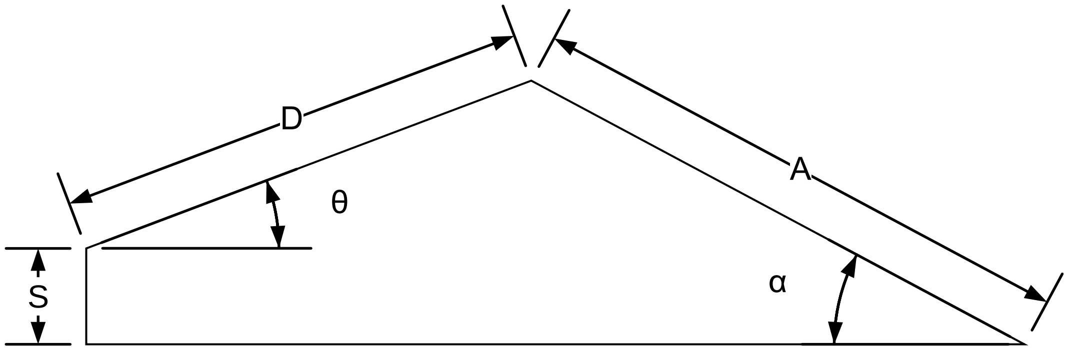


Figure 113: Vehicle erection system geometry.

where 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 114

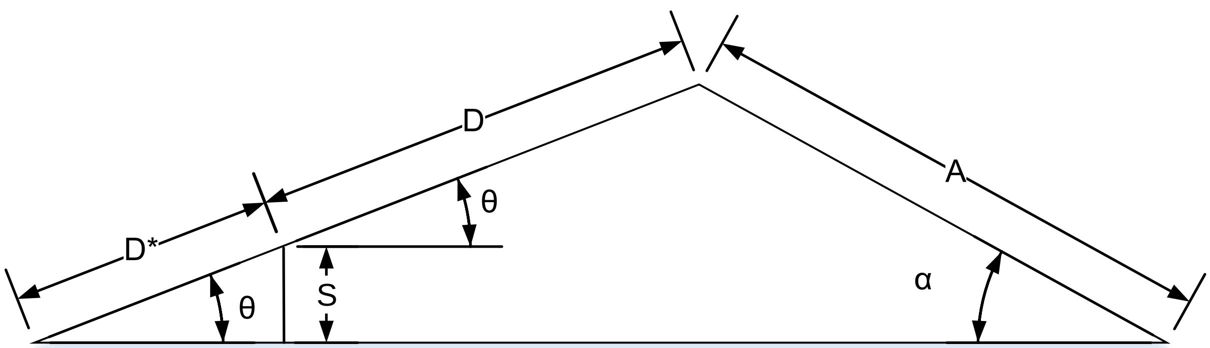


Figure 114: Extended geometry.

where 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 115

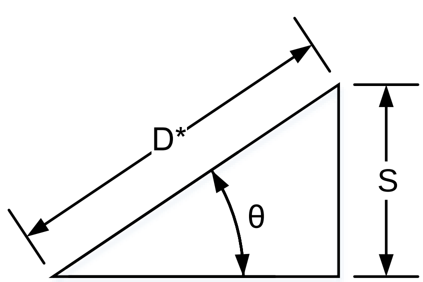


Figure 115: Extension triangle.

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

$$D^* = \frac{S}{\sin\theta}$$ 1. 47)

Using the law of sines, it can be shown that

$$\sin\alpha = \frac{\sin(\theta)\,(D + D^*)}{A} \tag{48}$$

By combining equations (47) and (48), the sin of α is calculated using

$$\sin\alpha = \frac{\sin\theta\left(D + \frac{S}{\sin\theta}\right)}{A} \tag{49}$$

The geometry of the system is different when θ equals zero. This initial state geometry is shown in Figure 116.

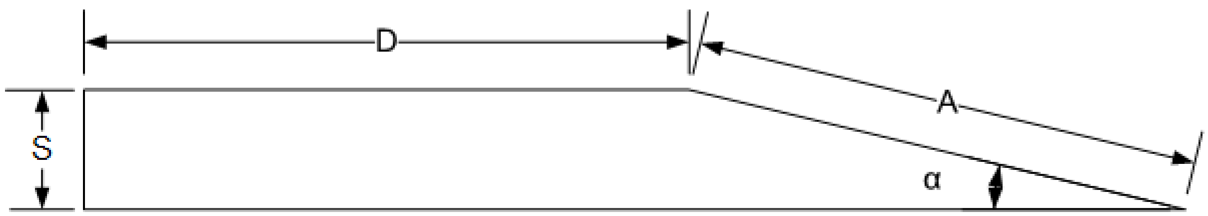


Figure 116: Stating geometry.

The triangle that consists of the raising arm and angle α is shown in Figure 117.

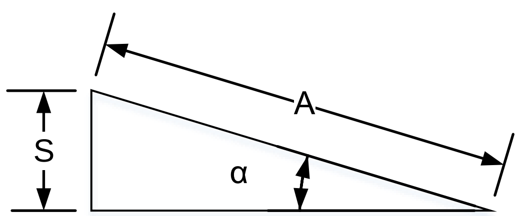


Figure 117: Initial state arm geometry.

From this geometry, the sin of α is determined using

$$\sin\alpha = \frac{S}{A} \tag{50}$$

By combining equations (49) and (50) α is determined using

$$\alpha = \begin{cases} \sin^{-1}\left(\frac{S}{A}\right), & \theta = 0 \\ \sin^{-1}\left(\frac{\sin\theta\left(D + \frac{S}{\sin\theta}\right)}{A}\right), & \theta > 0 \end{cases} \tag{51}$$

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. 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 44: 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

$$X_i = D + \sqrt{A^2 - S^2} \tag{52}$$

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

$$X_f = A\frac{sin(\pi - \theta - \alpha)}{\sin\theta} - \frac{S}{\tan\theta} \tag{53}$$

The total amount of carriage travel is then calculated using

$$Travel = X_i - X_f \tag{54}$$

The total geometry including forces is shown in

Figure **118**.

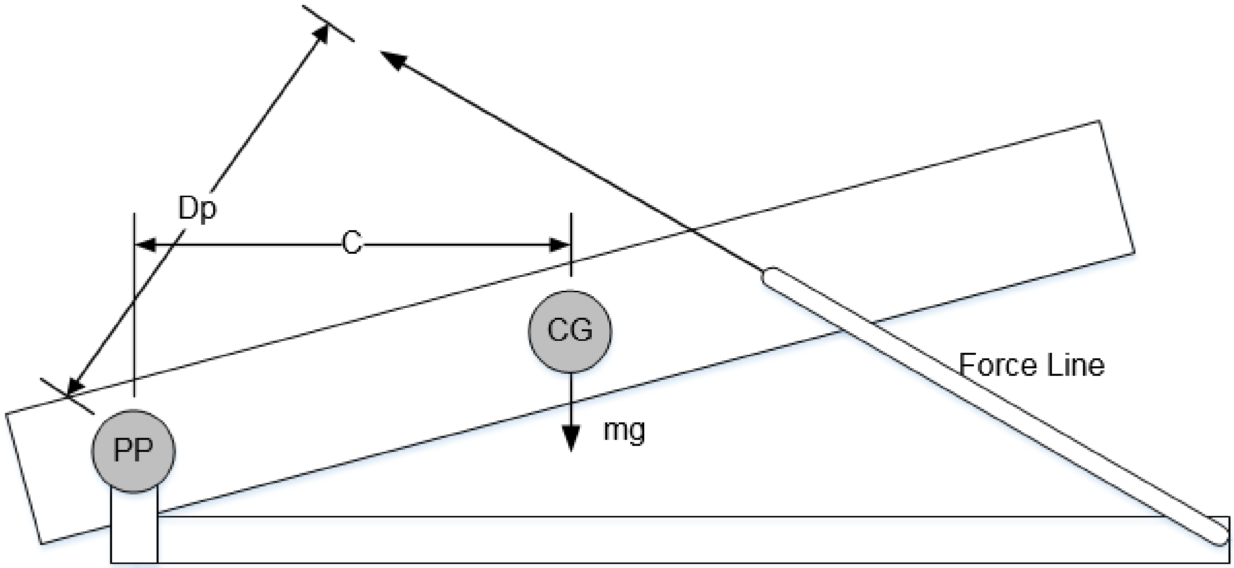


Figure 118: Total system description.

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

$$+\circlearrowleft \sum M_{PP} = F_a D_p - mgC \tag{55}$$

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 using

$$F_a = \frac{mgC}{D_p} \tag{56}$$

D_p is calculated using

$$D_p = \frac{S}{\sin\left(\frac{\pi}{2} - \alpha\right)} \tag{57}$$

The horizontal center of gravity distance is calculated using

$$C = C_0 \cos\theta \tag{58}$$

Combining equations (56) through (58), the raising force is determined using

$$F_a = \frac{mgC_o \cos\theta \sin\left(\frac{\pi}{2} - \alpha\right)}{S} \tag{59}$$

The initial opening force calculations were performed in addition to the carriage travel distance and plotted against each other in Figure 119. This is useful to see the different force, vs. travel relationships available to further determine the optimum solution.

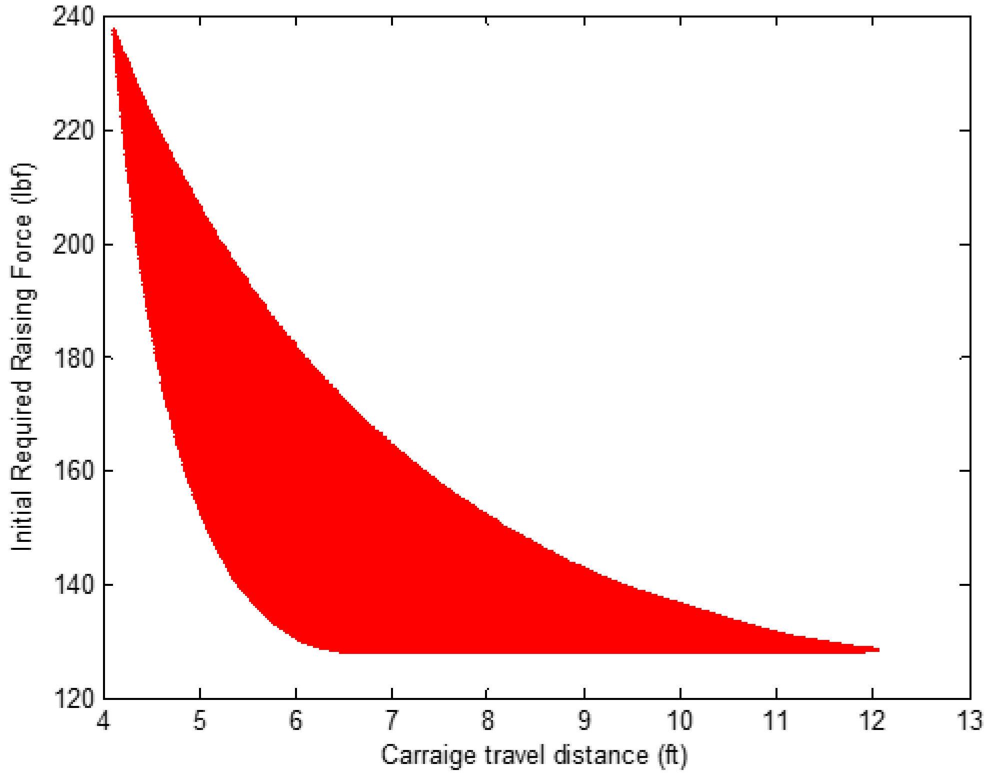


Figure 119: Initial raising force vs. carriage travel distance.

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 45: Optimized selections.

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

$$F_s = F_a \cos \alpha + F_f \quad (60)$$

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

$$F_f = \mu F_a \sin\alpha \tag{61}$$

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

$$T = \frac{F_s l}{2\pi v} \tag{62}$$

where l is the screw lead and v is the screw efficiency, typically 90% for ball screws. Table 46 shows the calculation parameters.

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

Table 46: Calculation parameters.

Figure 120 shows the required raising force vs. vehicle angle.

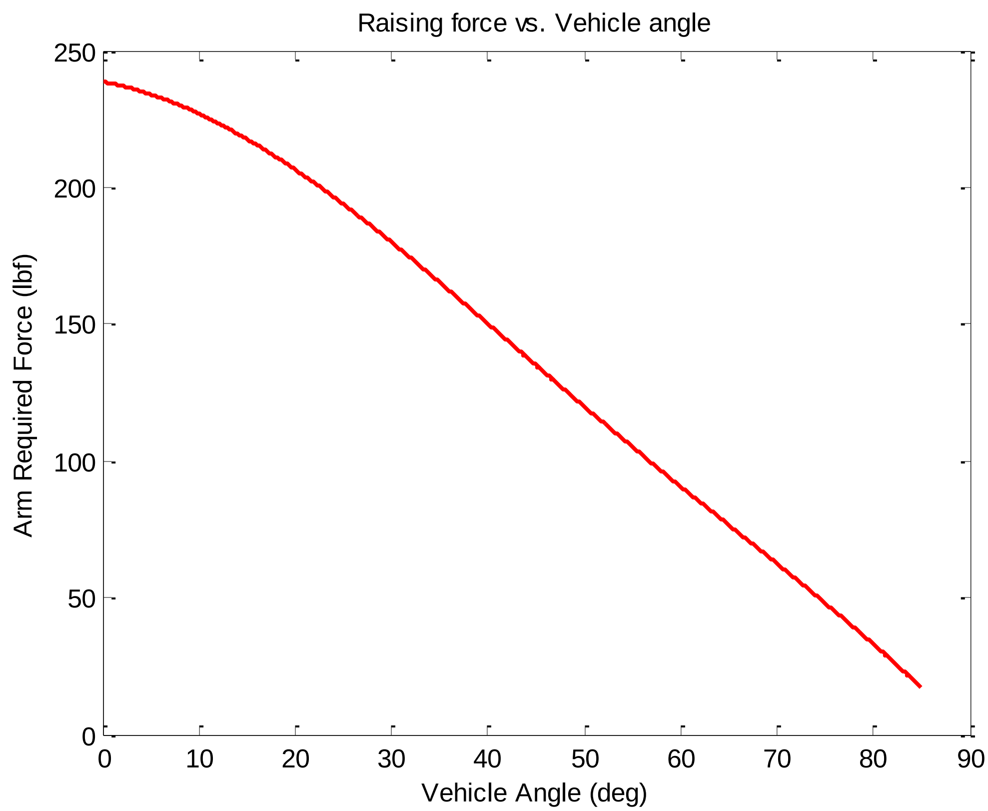


Figure 120: Raising force vs. vehicle angle.

Figure 121 shows the screw drive force vs the vehicle angle.

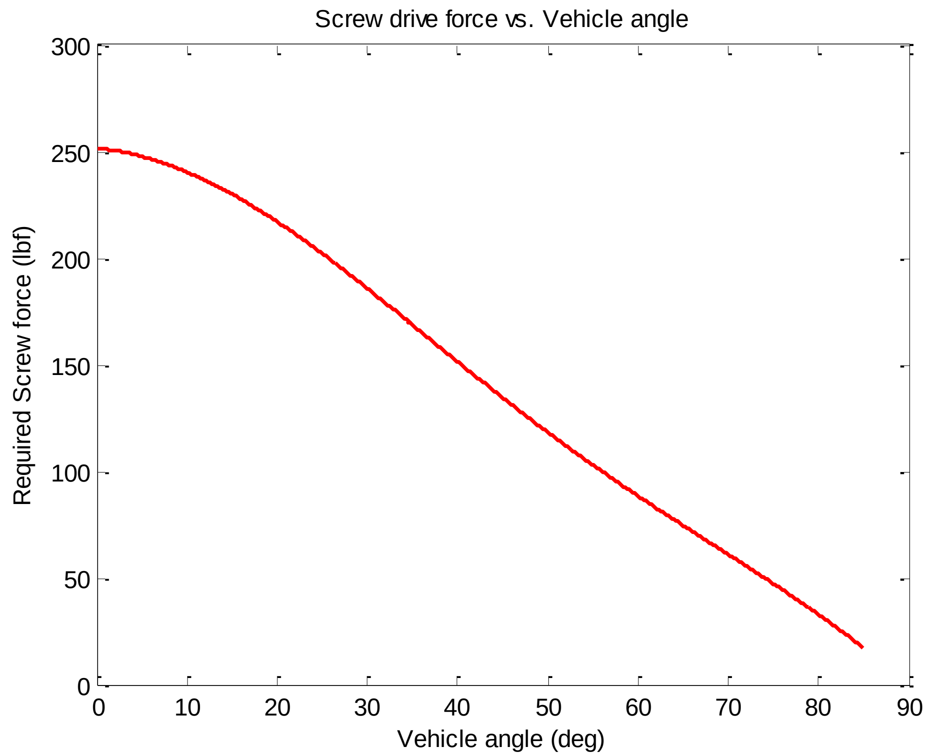


Figure 121: Screw drive force vs. vehicle angle.

Figure 122 shows the required motor torque vs. vehicle angle.

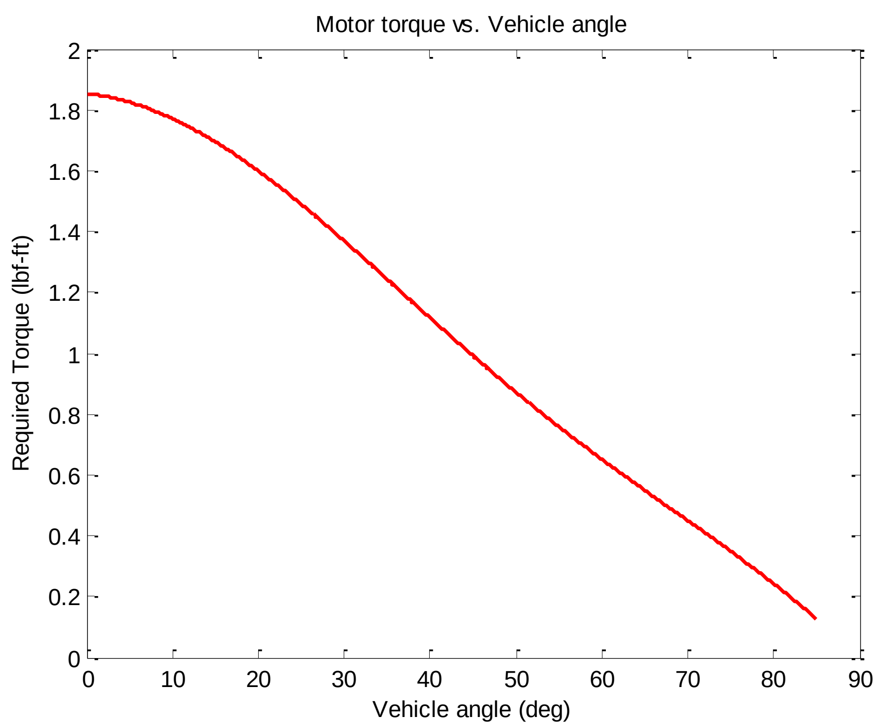


Figure 122: Required motor torque vs. vehicle angle.

Method of Testing

The vehicle track and carriage system will be tested separate from the rest of the vehicle erection system. The track and carriage will be tested with double the expected load to meet a required margin of safety. The carriage will be put through 20+ cycles to verify that the system will operate as expected when loaded. During testing the wear of the power screw, guide pads, deflections in the track, and other critical points will be documented to determine expected wear.

The articulating arms will be tested at the assembly phase to ensure they will handle the expected load. The arms will be installed on the completed AGSE and a simulated load double that of the expected load will be used to incorporate a factor of safety. Measurements will be taken to verify defections in the articulation arms are within allowable tolerance. This will be repeated over 20 cycles.

Changes from Proposal

The power screw configuration for the vehicle erector was changed to a single power screw to help mitigate jamming during the actuation of the carriage. Also the two motor design was changed to a single motor to reduce complexity and possible points of failure. With only one motor powering the screw, the transfer case was also removed.

The articulating arms and associated connection points shown in the proposal were presented as conceptual components. Further design worked moved the connection points to the neutral axis of the launch platform which optimizes the loading conditions in the connections. The articulating arms were upgraded to a t-slotted aluminum extrusion configuration to better handle the stresses involved with raising the launch platform.

The carriage vertical supports were changed from t-slotted aluminum extrusions to custom machined components. This was to increase the strength in the carriage after the initial FEA.

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 123.

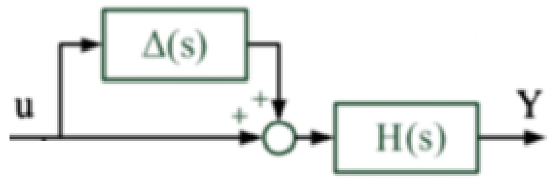


Figure 123: Process block diagram.

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 124.

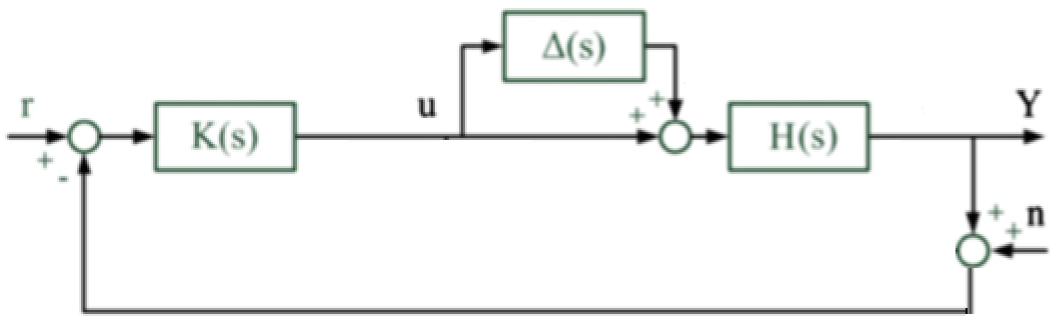


Figure 124: System block diagram.

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 125: 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

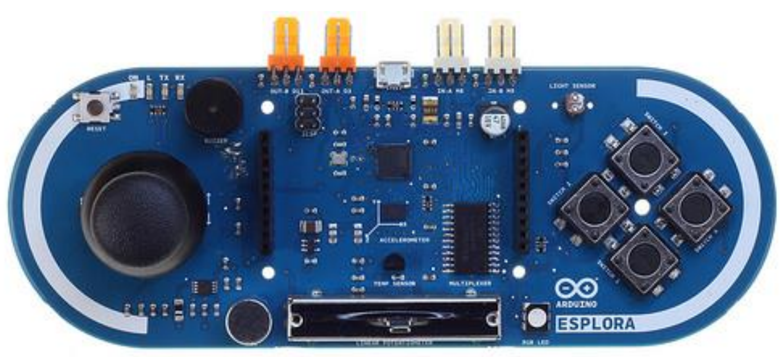


Figure 126: Arduino Esplora.

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 47: Various design challenges and solutions.

The design challenges will be listed in table form in addition to how we are going to overcome them.

Verification Plan

Requirement	Method of Completion	Method of Verification
Reduce carriage weight and manufacturing costs.	Revise design to reduce material in areas of low stress concentration.	Run FEA with minimum safety factor of 2
Vehicle Erector can handle load of erecting vehicle	Perform calculations based on optimized geometry and analyze individual components based on their loads.	Run FEA on individual components and test completed assembly with simulated load.
Deflection in track does not interfere with carriage travel.	Perform calculations for two times the expected load and design track based on results.	Test completed assembly with simulated load.
Articulating arms do not buckle under load	Perform calculations for buckling with two times the expected load.	Run FEA simulations on arms with a minimum safety factor of 2.

Table 48: Requirements and planning for system verifications.

6) Ignition Station

Overview

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

1. House the igniter without damage during 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 49: Ignition system overall dimensions.

Figure 127: Ignition station.

Changes since Proposal

The changes since proposal are shown in Table 50.

Change	Justification for change
The drive wheels have a groove added.	To prevent the igniter from moving outside of the system.
A spring tensioner system has been added.	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.
Enable switch added to igniter and ignition station.	Safety requirement in SOW to disable igniter until approved by launch safety officer.

Table 50: Ignition station changes since proposal.

Design

The design of the ignition station is similar to a cable extruder. Two wheel grip a dowel augmented igniter and push it up through the motor assembly. To keep the igniter in the correct position during operation, a cutout groove was added to the drive wheel. The wheel is shown in Figure 128.

Figure 128: Drive wheel.

These wheel are fastened to a gear by way of three 4-40 UNC 2A threads and will be coated in a temporary rubber ablative coating for added grip, and then a shaft collar is fastened to them via three 4-40 UNC 2A threads. The shaft collar fastens to the shaft by way of three 4-40 UNC 2A threads. This assembly is shown in Figure 129.

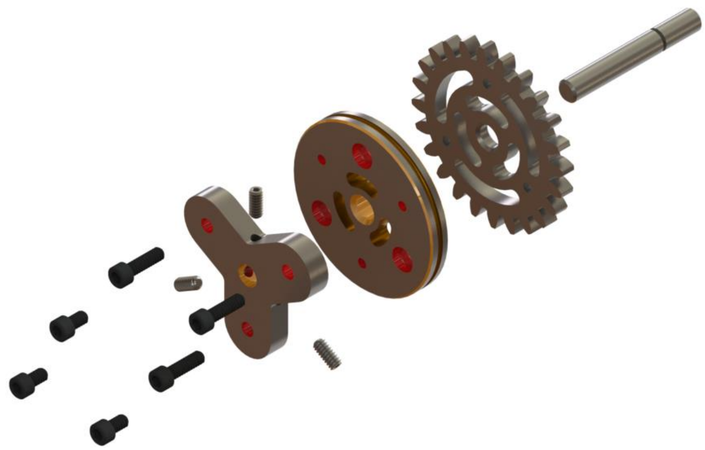


Figure 129: Drive wheel assembly.

The ignition system must also survive ignition without damage to electrical components; to accomplish this, two additional side plates will be used to act as additional blast deflectors. These are the two outside plates as seen in

Figure 127.

For ease of installation the two driven wheels are inside a slot of the main mounting plate. To keep constant tension throughout operation, a spring tensioner was designed and shown in Figure 130. This consists of a threaded rod with a cutout for the shaft, two removable nuts, this sits inside a brass sleeve bearing in one of the deflector plates, and a compression spring.

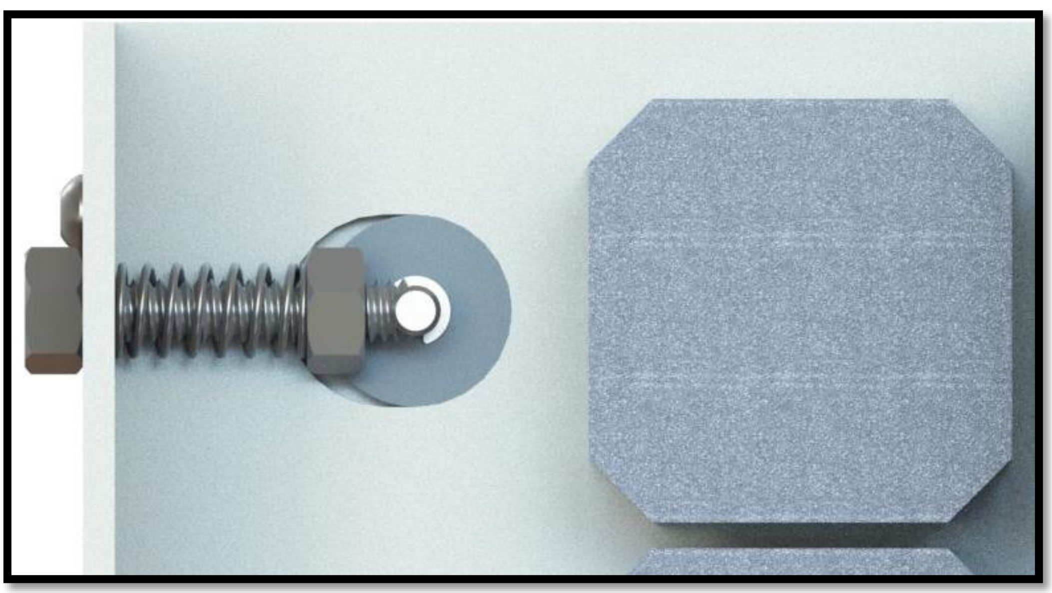


Figure 130: Spring tensioner.

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

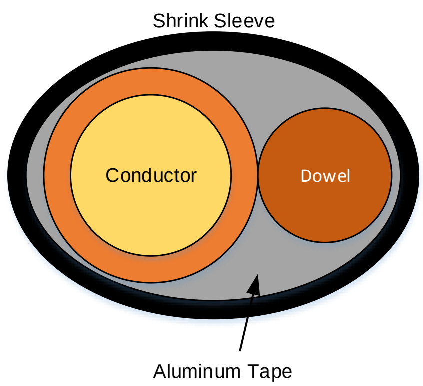


Figure 131: Augmented igniter.

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 132 shows the operational flow chart.

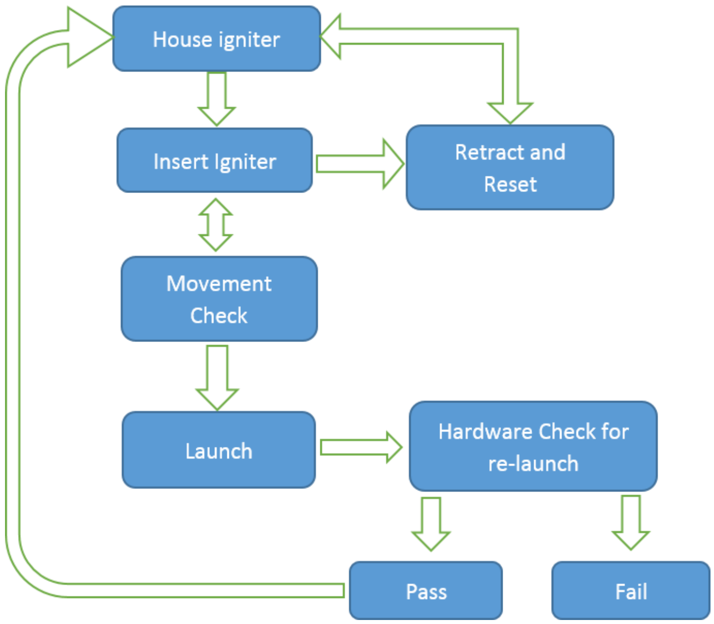


Figure 132: Operational flow chart.

One change in the system is the addition of the "enable ignition power" switch. 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 components used in controlling the ignitions station are the Arduino Uno microcontroller, a corresponding Adafruit motor shield, and two stepper motors. 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 133: 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 a AC-to-DC adapter or battery to get started.

Adafruit motor shield

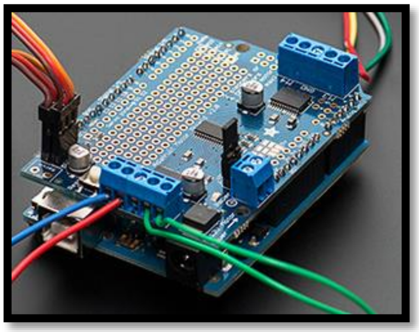


Figure 134: Corresponding motor shield.

The Adafruit motor shield contains the following connections and componenets: 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

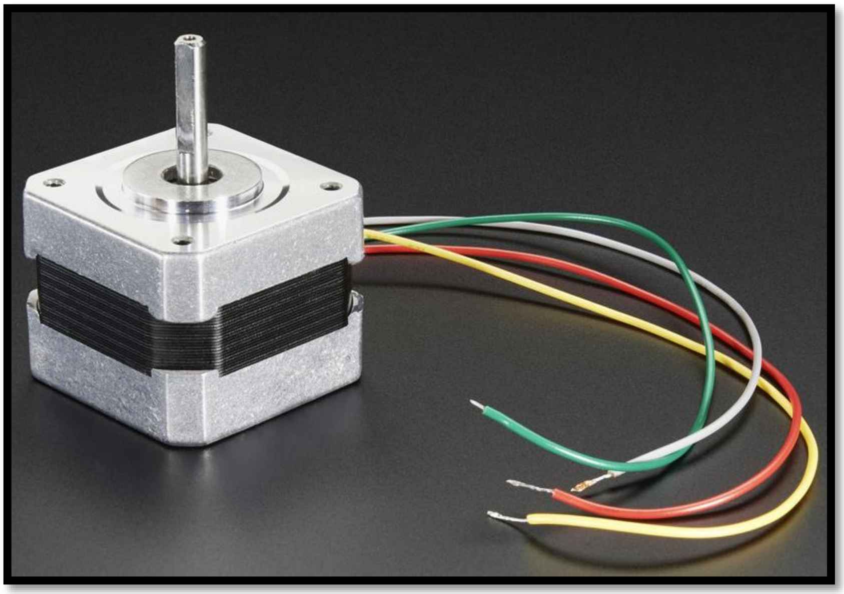


Figure 135: Stepper motor.

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. It is 12V rated voltage at 350mA max current.

The communications flowchart between the components is shown in Figure 136.

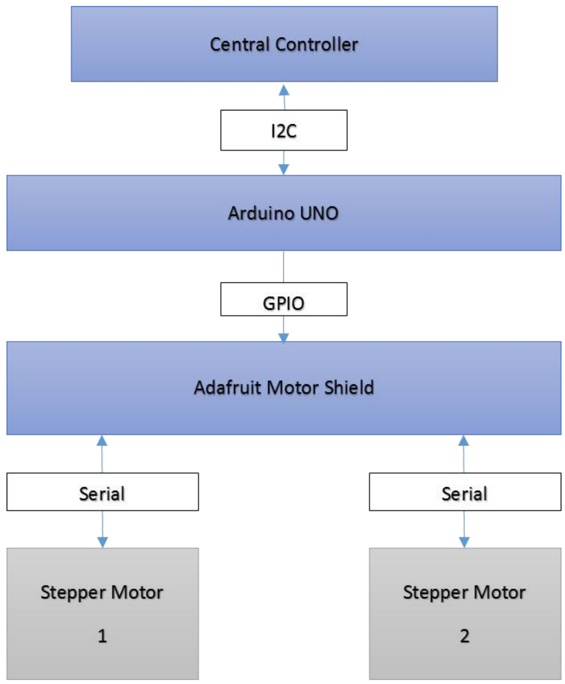


Figure 136: Component communications.

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 two stepper motors to install the igniter into the motor.

The current hardware iteration of the design is shown in Figure 137.

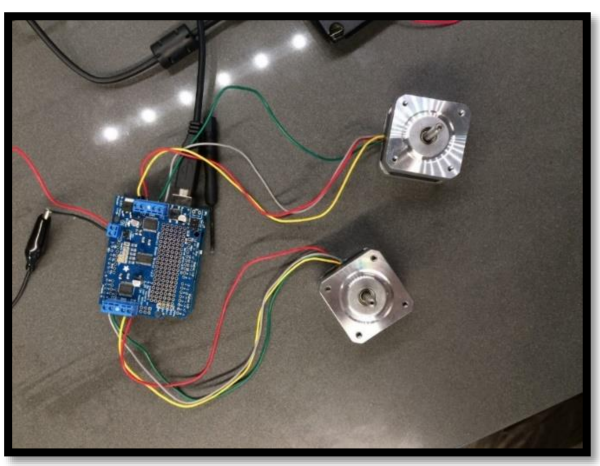


Figure 137: Design iteration.

Performance Characteristics

The circumference of the drive wheel is calculated using

$$C = 2\pi r \quad (63)$$

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

$$N = \frac{L}{C} \quad (64)$$

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

$$t = \frac{N}{\omega} \quad (65)$$

where ω is the rotational speed of the motor. Table 51 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 51: Performance evaluations.

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

$$N_s = \frac{L}{D} \quad (66)$$

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

$$D = F_c C \quad (67)$$

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

$$F_c = \frac{A_s}{360} \quad (68)$$

where A_s is the angle traveled per motor step. Table 52 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 52: Control values.

Future Plans and Testing

Continued testing of the electronics will determine the time needed for the task. A custom PCB will integrate the Arduino connections to the motor shield. The custom board will condense the design footprint, and increase robustness in the connection infrastructure. Having the fewest number of appropriate connections is desirable for an electronics system that is intended to represent a space faring setup with no future human interaction or correction.

7) System Controls and Integration

Overview

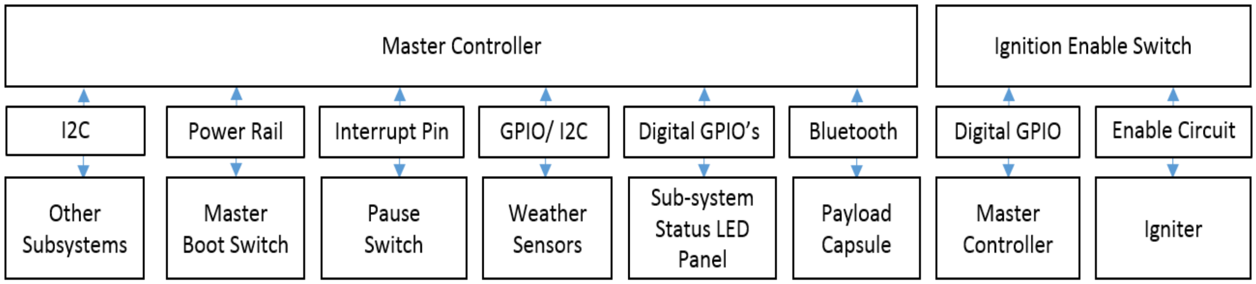


Figure 138: Housing electronics overview.

The electronics housed within the ground station, as well as their intended connections, are illustrated above in Figure 138. All MC system status monitoring is provided through the housing electronics via an indication/control panel that is accessible on the outside of the AGSE. This central control system provides a HMI (human machine interface) for the launch setup team and field safety officer. The station provides the integration for all other subsystems, communication, and process interrupt switches for the launch faculty.

The ground station includes an Arduino microcontroller acting as the MC device and initiates all subsequent processes including: station power, device boot sequence, manual halt procedures, and environmental data collection.

Changes since PDR

The system architecture has been modified to rely less on a central PC for critical functions. The current iteration of the system is a distributed architecture; it involves multiple microcontrollers communicating through an I2C communication bus setup in the configuration in Figure 139.

Communication Network

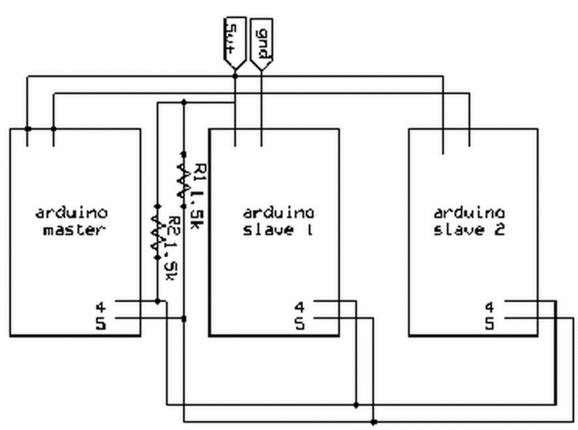


Figure 139: Arduino I2C network.

A PC was originally required for directing a computer-vision implementation. The computer vision system was needed to acquire the payload from an unknown location near the launch pad. The vision system was retired after communication regarding the MAXI MAV competition conveyed that the payload would be placed by the team. The retrieval process is now simplified by placing the payload in a predesigned location near the AGSE payload retrieval arm. There are real world applications that justify this change. Due to the increased capabilities of interplanetary based systems and rovers, the device that collected the sample should be capable of placing the payload in a predetermined and accessible area.

An additional change to the ground station are the weather data collection sensors (WDCS). The WDCS consists of the multiple, identical sensor clusters. Each board will read temperature, light, and air speed data from the immediate environment. A humidity sensor will be added to the cluster if one is found that does not require additional moisture added as the system ages. The data would add to the science value of the sensors, but would not endure the extreme conditions of the dry Martian environment.

Components

The ground station electronics consist of an Arduino Uno microcontroller, Status LED's, master toggle switches, WDCS, required wiring and voltage regulation boards for 9V and 12V supply lines.

The MC will be connected to the controllers of the VES, APLS, ignition station, payload retrieval arm through the serial network. Each system microcontroller will have a unique address by which it will receive activation commands from the MC over I2C.

The weather sensors will be connected through the MC's GPIO pins and I2C lines depending on the final sensors chosen.

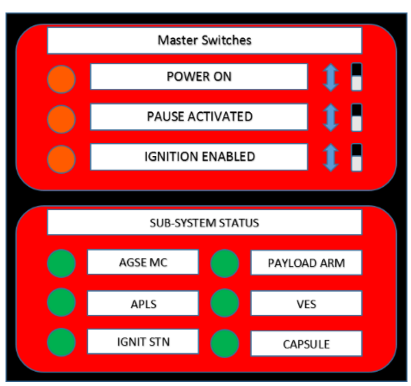


Figure 140: AGSE user interface.

As shown above in Figure 140, the launch staff will have access to an external user interface. The interface includes master boot, pause, and ignition toggle switches. 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.

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.

AGSE Power Distribution

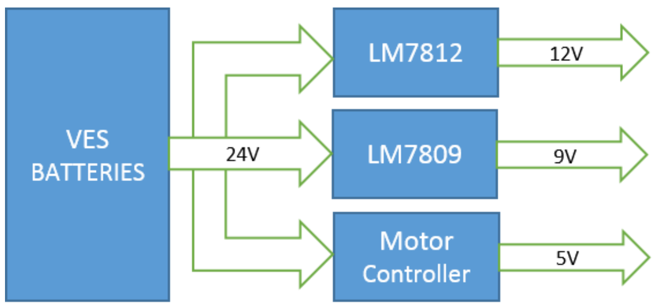


Figure 141: Regulated voltage lines.

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 141. 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 handle the supply needs of the system's Esplora microcontroller. All other microcontrollers in the AGSE use a regulated 9V line provided by the commercially available 7809 IC. The motors in the ignition station and payload retrieval arm use a 12V supply. The 12V line is regulated down through the LM7812 IC to attenuate uneven battery power; the IC also removes the noise that could cause anomalies in the performance of electrical systems.

Wire harnesses will be created to transfer the power required by each system, and organize connections for each subsystem. The wire will be sized accordingly for the needs of the cable's load. The power routing will be heavily isolated from the signal lines in the ground station. Operation of motors and other heavy electronics can cause interference on sensitive lines, and components. The wire harness will be routed into the stations frame to minimize risk of physical damage.

Communications with Vehicle

Overview

It was determined that the vehicle and AGSE should be in communication pre – launch. This was determined due the needed interaction between the payload capture system, part of the AGSE, and the payload containment system, part of the vehicle. If the vehicle tried to complete its task before the completion of the other system, then there existed the possibility that the system would fail. To accomplish this task, wireless communication was chosen because physical interaction could interfere with AGSE operations and structurally weaken the vehicle.

The system will consist of two Bluetooth classic (BT 2.1) radios. It will connect the Central Control PC to the vehicle wirelessly, allowing both systems to communicate. The communication will transmit the following: appropriate time to close the payload bay doors, launch data up to 1000m, and remote transmission for AGSE troubleshooting. A USB receiver circuit will be created to allow a BT 2.1 radio to interface with the PC easily. A separate PCB will be created to allow an identical radio to be mounted inside of the rocket itself. The radio to be used for this application is the WT41 Long Range Bluetooth Module from BlueGiga.

From BlueGiga's website: "The WT41 is a fully integrated *Bluetooth* 2.1 + EDR, class 1 module combining antenna, *Bluetooth* radio, and an on-board iWRAP *Bluetooth* stack. The WT41 provides a superior 110dB link budget and more than 1000-meter line-of-sight connectivity for *Bluetooth* applications where extreme radio performance or reliability is required. It also constitutes an ideal solution for developers that want to quickly integrate extremely high performing *Bluetooth* wireless technology into their design without investing several months in *Bluetooth* radio and stack development.

The WT41 uses Bluegiga's iWRAP *Bluetooth* stack, which is an embedded *Bluetooth* stack implementing 13 different *Bluetooth* profiles and Apple iAP connectivity."

Schematic

The WT41 Pinout is shown in

Figure 142 along with the pin descriptions in Table 53.

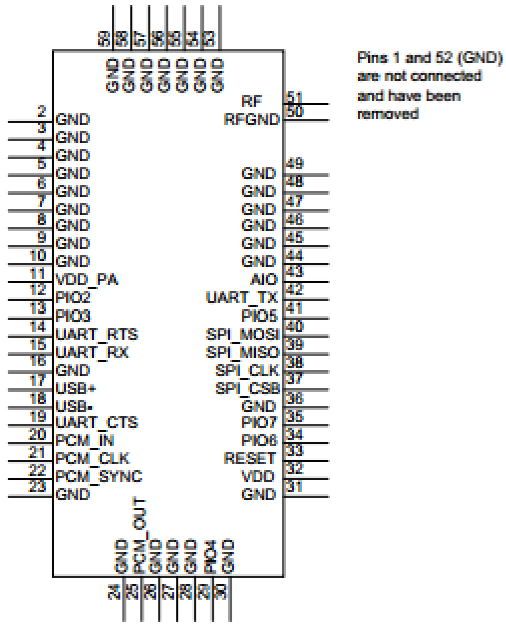


Figure 142. WT41 pin out.

	PIN NUMBER	PAD TYPE	DESCRIPTION
NC	1, 52	Not connected	Pins 1 and 52 (GND) have been removed from the module.
RESET	33	Input, weak internal pull-up	Active low reset. Keep low for >5 ms to cause a reset
GND	2-10, 16, 23,24,26-28, 30, 31,36,44-49, 53-59	GND	GND
RF	51	RF output	RF output for WT41-N. For WT41-A and WT41-E this pin is not connected
RFGND	50	GND	RF ground. Connected to GND internally to the module.
VDD_PA	11	Supply voltage	Supply voltage for the RF power amplifier and the low noise amplifier of the module
VDD	32	Supply voltage	Supply voltage for BC4 and the flash memory

Table 53. Supply and RF terminal descriptions.

Future 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. This testing will qualify the wire harnessing, connectors, and regulators used in the ground station.

The I2C bus will be tested for correct operation and response to system status at each phase of launch set up. A test sequence of transmissions will be sent and scanned on the bus.

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 pause interrupt will be tested to immediately pause upon activation of the master pause switch. All electronics must pause to a recoverable state to resume process upon deactivation of the switch.

The igniter enable switch will be tested to enable ignition system upon activation. No part of the instillation procedure can start until the enable ignition switch is activated.

8) Statement of Work Verification

Table 54 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 halting all AGSE procedure and subroutines. This will allow the other teams at the pads to set up, and do the same.	A secondary toggle switch will be implemented on the AGSE to halt all operations for safety and setup. 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 54: AGSE SOW verification.

Section 5. Project Plan

1) Budget Plan

Full Scale Vehicle Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
6" FG Von Karman Nosecone	1	$122.55	$122.55
6" CF Airframe Tubing (4 feet in length)	4	$404.80	$1,619.20
6" CF Coupler Tubing (1 foot in length)	5	$109.25	$546.25
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	**$4,321.66**

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**

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**

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**

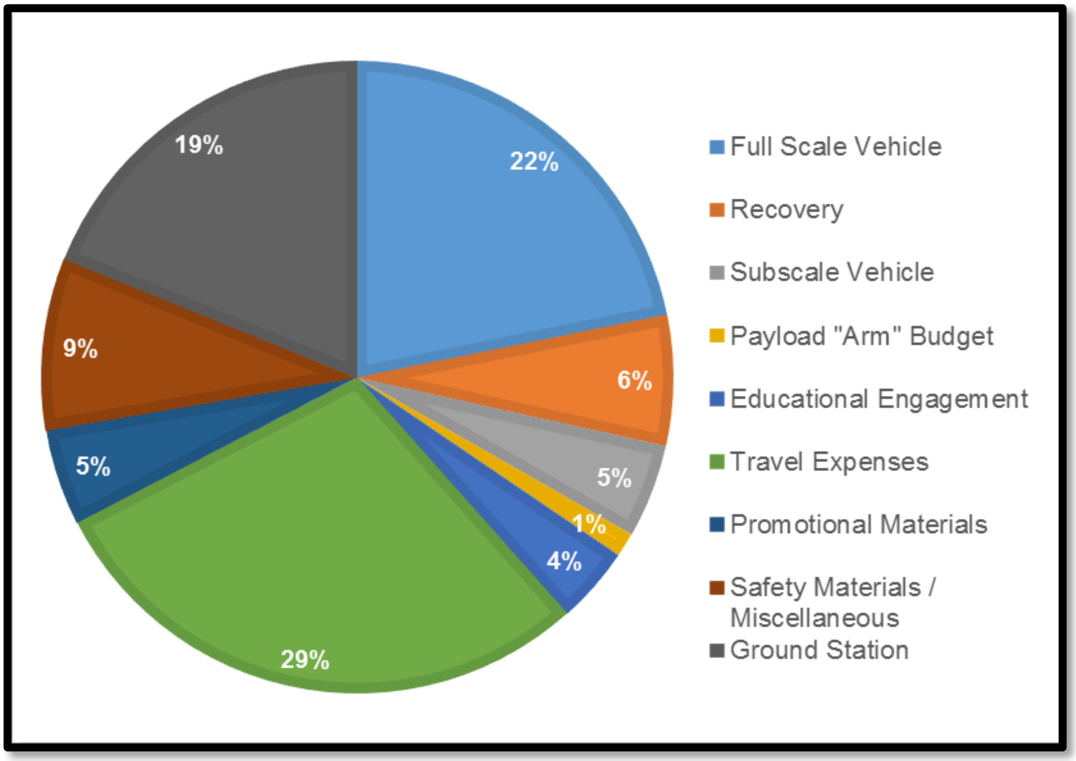
Travel Expenses Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Hotel (Competition in Huntsville, AL)	N/A	N/A	$4,000.00
Hotel (Testing at Thunderstruck in Ash Grove, IN)	N/A	N/A	$500.00
Gas (Competition in Huntsville, AL)	N/A	N/A	$1,000.00
Gas (For all out of tow n testing)	N/A	N/A	$250.00
		Overall Cost	**$5,750.00**

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**

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**

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 with 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 screws	1	$10.72	$10.72
1/8 inch Dowel Pins 0.5 inch long	1	$8.03	$8.03
#8-32 Button head screws (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 Powder	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

Overall Tentative Budget	
Budget	**Total Cost**
Full Scale Vehicle	$4,321.66
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	**$19,819.51**



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**	
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	
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	

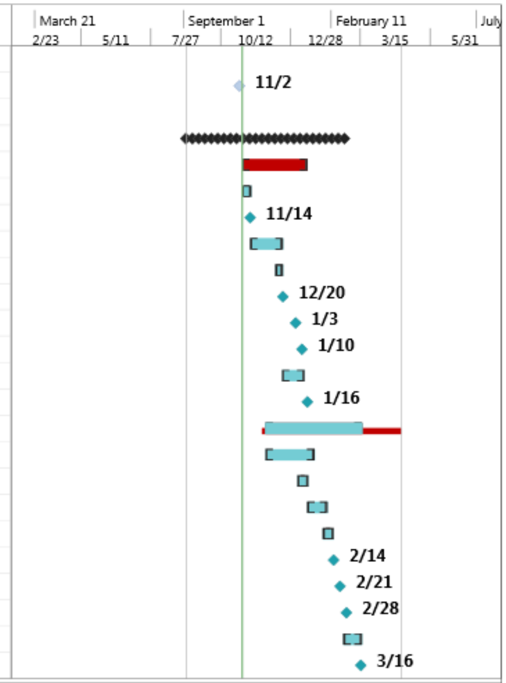


Figure 143: Overall timeline – part 1.

ID	Task Name	Duration	Start	Finish	Predecessors
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	

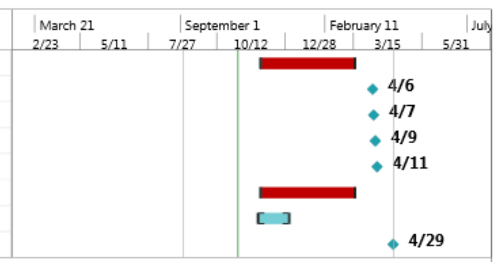


Figure 144: Overall timeline - part 2.

ID	Task Name	Duration	Start	Finish
1	**CDR**	**52 days**	**Wed 11/5/14**	**Thu 1/15/15**
2	Design subscale vortex ring	8 days	Wed 11/5/14	Fri 11/14/14
3	Size subscale parachute	4 days	Wed 11/5/14	Mon 11/10/1
4	Determine mounting hardware for subscale design	6 days	Wed 11/5/14	Wed 11/12/14
5	Part order for subscale	8 days	Wed 11/5/14	Fri 11/14/14
6	Construction-Parachute and deployment bag	26 days	Mon 11/10/14	Mon 12/15/14
7	Ground test vortex ring	26 days	Fri 11/14/14	Fri 12/19/14
8	Determine coefficient of drag	26 days	Fri 11/14/14	Fri 12/19/14
9	Subscale Launch	0 days	Sat 12/20/14	Sat 12/20/14

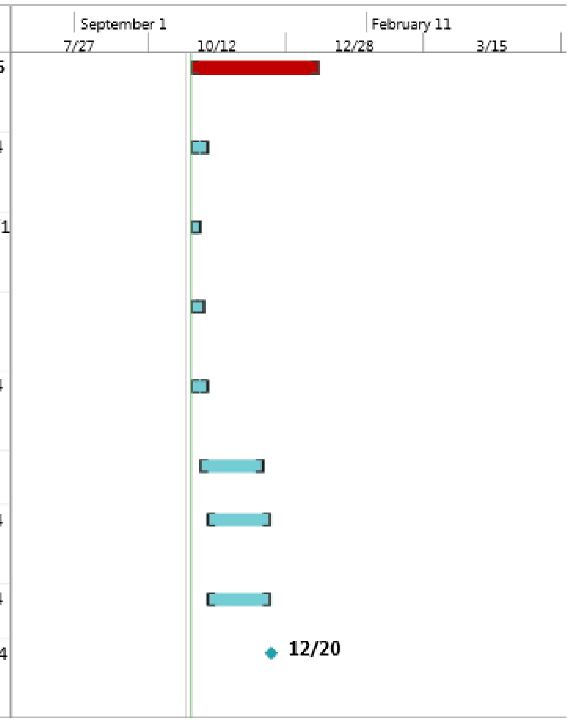


Figure 145: Recovery schedule - part 1.

ID	Task Name	Duration	Start	Finish
10	Test flight	0 days	Sat 1/3/15	Sat 1/3/15
11	Final Subscale Launch	0 days	Sat 1/10/15	Sat 1/10/15
12	Write CDR	17 days	Fri 12/19/14	Mon 1/12/15
13	CDR Due	0 days	Fri 1/16/15	Fri 1/16/15
14	**FRR**	**76 days**	**Mon 12/1/14**	**Mon 3/16/15**
15	Order full scale parts	40 days	Mon 12/1/14	Fri 1/23/15
16	Finalize full scale design	10 days	Mon 1/5/15	Fri 1/16/15
17	Construction of full scale vortex ring	16 days	Fri 1/16/15	Fri 2/6/15
18	Construction of full scale cruciform parachute	16 days	Fri 1/16/15	Fri 2/6/15

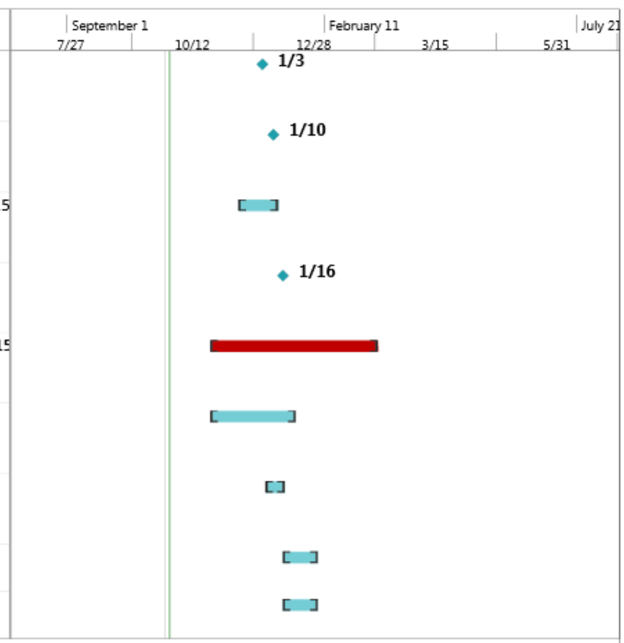


Figure 146: Recovery schedule - part 2.

ID	Task Name	Duration	Start	Finish
19	Ground testing - verrify predicted coefficient of drag for vortex ring	10 days	Mon 2/2/15	Fri 2/13/15
20	Full scale test flight	0 days	Sat 2/14/15	Sat 2/14/15
21	Write FRR	14 days	Wed 2/25/15	Mon 3/16/15
22	FRR Due	0 days	Mon 3/16/15	Mon 3/16/15

Figure 147: Recovery schedule - part 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	

Figure 148: Safety schedule - part 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	

Figure 149: Safety schedule - part 2.

AGSE Schedule.mpp

ID	Task Name	Duration	Start	Finish
1				
2	**Design Meeting**	**130 days**	**Tue 9/2/14**	**Tue 3/3/15**
30	Assign Tasks	3 days	Wed 9/3/14	Fri 9/5/14
31	**Concept Designs.**	**22 days**	**Sat 9/6/14**	**Mon 10/6/14**
32	ARM	22 days	Sat 9/6/14	Mon 10/6/14
33	Launch Platform	17 days	Sat 9/6/14	Sun 9/28/14
34	Vehicle Raising System	19 days	Sat 9/6/14	Wed 10/1/14
35	Ground Station	8 days	Thu 9/25/14	Mon 10/6/14
36	Ignition Station	9 days	Sat 9/6/14	Wed 9/17/14
37	**Design Evaluation**	**17 days**	**Thu 9/18/14**	**Fri 10/10/14**
38	ARM	3 days	Tue 10/7/14	Thu 10/9/14
39	Launch Platform	7 days	Mon 9/29/14	Tue 10/7/14
40	Vehicle Raising System	4 days	Thu 10/2/14	Tue 10/7/14
41	Ground Station	3 days	Wed 10/8/14	Fri 10/10/14
42	Ignition Station	5 days	Thu 9/18/14	Wed 9/24/14
43	Initial Material Order	0 days	Mon 11/10/1	Mon 11/10/1
44	**Design Updates**	**31 days**	**Wed 10/8/14**	**Wed 11/19/1**
45	ARM	24 days	Sat 10/11/14	Wed 11/12/1
46	Launch Platform	23 days	Wed 10/8/14	Fri 11/7/14
47	Vehicle Raising System	35 days	Wed 10/8/14	Tue 11/25/14
48	Ground Station	34 days	Sat 10/11/14	Wed 11/26/1
49	Ignition Station	10 days	Fri 10/24/14	Thu 11/6/14

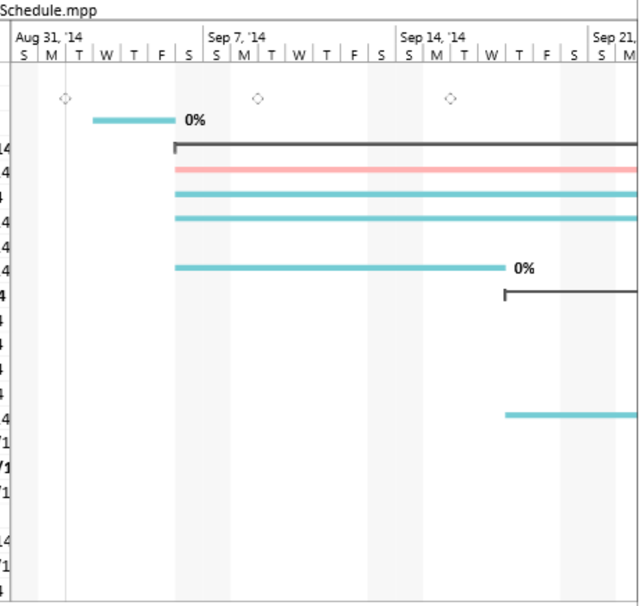


Figure 150: AGSE schedule.

4) <u>Educational Engagement</u>

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 151: Dhwani assisting student in preparing his rocket on the launch pad.

Curriculum

The team has developed a variety of programs that are to be incorporated in this year's outreach program. Included is a list of the different activities in which the team has participated in the past and will continue to do 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 152: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 153:Dhwani assisting in the launch of a paper rocket at E-Expo.

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 154: 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 155: Carlos helping a student prep her rocket for launch.

Figure 156: A middle school student launching her rocket.

One goal that the team has for this year is to expand our six week program. We want to bring a wider range of engineering disciplines to the students. This will be done by integrating programming, electronics, and robotics into our curriculum. This has not been fully developed, but we are in the process of working with a school to integrate the program. This school will be our trial run, to insure that the material is both challenging and engaging. Based on the feedback we get from this school, we plan to bring these new ideas to other schools.

Outreach Opportunities

Engineering Exposition (E-Expo)

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 157: 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.

Boy Scouts and Cub Scouts:

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.

Louisville Science Center Partnership:

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 158: 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.

Section 6. Appendix I – 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: 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:

1. ___________________________ *2.* ______________________________

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

Sustainer Propulsion Bay Assembly Checklist:

Required Equipment:

- *Gorilla Glue*
- *Grease*
- *Lower Sustainer Stand*
- *CTI3147-L935-IM-P 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 units (x2)*
- *GPS charger*

1. ___ 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*

1. ___ Check lower sustainer for contact with tracking device.
2. ___ Securely mount GPS to GPS sled in lower sustainer using 2 M3 screws and washers.
3. ___ Install lower sustainer door using socket cap screws.

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:

- *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)*

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. Use clamps as necessary to ensure a tight fold.
5. ___ 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.

6. ___Secure deployment flaps using shroud lines and fabric hair ties.

7. ___ 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.
8. ___ Attach swivel to recovery system.
9. ___ 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)*

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.

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:

- *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:

1. ____________________________ *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 lower sustainer and middle sustainer to sustainer avionics bay using socket cap screws.
2. ___ Check that the coupling does not allow for any flexing of the rocket between the sections. Should this occur, add layers of painters tape to the coupler tubing.
3. ___ Attach nose cone to upper sustainer using 4-40 socket cap screws.
4. ___ Tape motor igniter to the outside of the lower sustainer in a place easily seen by the field RSO.
5. ___ 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*

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 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.
6. ___ Before leaving launch pad area, double check for signs that all electronics are still operating correctly.
7. ___ Arm launch pad camera and begin recording.
8. ___ 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*

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 – Risk Assessment

Lab and Machine Shop Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Using power tools and hand tools such as blades, saws, drills, etc.	1. Improper training on power tools and other lab equipment.	1a. Mild to severe cuts or burns to personnel. 1b. Damage to rocket or components of the rocket. 1c. Damage to equipment	2	4	Low	1. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them. 1. Safety glasses must be worn at all times. 1. Sweep or vacuum up shavings to avoid cuts from debris.
Sanding or grinding materials.	1. Improper use of PPE. 2. Improper training on the use of a Dremel tool.	1a. Mild to severe rash. 1b. Irritated eyes, nose or throat with the potential to aggravate asthma. 2. Mild to severe cuts or burns from a Dremel tool and sanding wheel.	3	3	Low	1a. Long sleeves should be worn at all times when sanding or grinding materials. 1b. Proper PPE should be utilized such as safety glasses and dust masks with the appropriate filtration required. 2. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them.
Working with chemical components resulting in mild to severe chemical burns on skin or eyes, lung damage	1. Chemical splash. 2. Chemical fumes.	1. Mild to severe burns on skin or eyes. 2. Lung damage or asthma aggravation due to	2	4	Low	MSDS documents will be readily available at all times and will be thoroughly reviewed prior to working with any chemical. All chemical containers will be marked to identify appropriate precautions that need to be taken.

due to inhalation of toxic fumes, or chemical spills		inhalation of fumes,				1. Nitrile gloves shall be used when handling hazardous materials. 1. Personnel are familiar with locations of safety features such as an eye wash station. 1. Safety goggles are to be worn at all times when handling chemicals. 2. When working with chemicals producing fumes, appropriate precautions should be taken such as working in a well-ventilated area, wearing vapor masks, or working under a fume hood.
Damage to equipment while soldering	1. Soldering iron is too hot 2. Prolonged contact with heated iron	The equipment could become unusable. If parts of the payload circuit get damaged, they could become inoperable.	3	3	Low	1. The temperature on the soldering iron will be controlled and set to a level that will not damage components. 2. For temperature sensitive components sockets will be used to solder ICs to.
Dangerous fumes while soldering	1. Use of leaded solder can produce toxic fumes. 2. Leaving soldering iron too long on plastic could cause plastic to melt	Team members become sick due to inhalation of toxic fumes. Irritation could also occur.	3	3	Low	1. The team will use well ventilated areas while soldering. Fans will be used during soldering. 2. Team members will be informed of appropriate soldering techniques, avoiding contact of the soldering iron to plastic materials for extended periods of time.

	producing toxic fumes.					
Potential burns to team members while soldering	Team members do not pay attention while soldering	The team member could suffer minor to severe burns.	4	3	Low	Team members will be trained how to solder and will follow all safety protocols related to soldering.
Overcurrent from power source while testing	Failure to correctly regulate power to circuits during testing	Team members could suffer electrical shocks which could cause burns to heart arrhythmia	2	4	Low	The circuits will be analyzed before they are powered to insure they don't pull too much power. Power supplies will also be set to the correct levels.

Table 55: 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 3. Payload door jams 4. Anti-friction tape sticks to vehicle or is damaged	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 tower, allowing the rocket to freely move through the tower. Also, anti friction tape 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 raise. The friction tape 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. The launch tower also has a blast deflector to prevent brush fires.

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 plat 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	Analysis will be performed on the launch platform to ensure materials and geometries are adequate for the loads they will be experiencing. A minimum safety factor of 2 will be incorporated these critical components. Personnel will be required to maintain a minimum safe distance from the AGSE during operation.
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. A minimum factor of safety of 2 will be incorporated. 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 sieze.	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 inspected for debris 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.

Table 56: 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	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 will be analyzed and accounted for in the

	4. Nylon guides dislodge 5. Buildup of foreign objects and debris (FOD) on tracks and/or carriage.					design and tolerance of the carriage. 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 will be performed to determine the minimum bolt specifications based on the maximum loads the bolts will encounter and a factor of safety will be 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	Analysis will be performed to properly size the bearings to handle the anticipated loads with a minimum safety factor of 2.
Articulating arms buckle under load.	Material failure	Launch platform falls.	1	3	Moderate	Analysis will be performed to verify material selection and

						configuration of components to prevent failure.
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 will be 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 will be 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 will be performed to ensure the proper motor is 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 will be performed to ensure the correct motor is chosen to raise the vehicle within the time requirement.
Personal injury from AGSE	Personnel in close proximity	Personal injury	2	3	Moderate	Power will be disconnected from AGSE prior to working on the system or surrounding systems.

	while AGSE is in operation.					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. Electrical redundancy measures will also be implemented.
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 57: 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	2	3	Moderate	1,2. Sharp edges of the igniter installer should be filed down and de-burred.

		causing false signal to be sent, prematurely igniting the motor.				
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	2	2	Moderate	Personnel will be required to remain clear of AGSE during operation, and will maintain a minimum safe distance away.

		transporting the ignition installation system.				
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. Two sets of motors are in place to add redundancy.
Motor Failure	Short in stepper motor	Igniter installation fails.	1	3	Moderate	Two sets of motors are in place to add redundancy. 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.

Table 58: 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 will be performed to determine proper motor specifications.

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.
Improper outrigger pad orientation.	1.Uneven terrain 2.Object obstructs pad from contacting ground 3. Pad jams in outrigger	Unbalanced ground station, possible damage to surroundings/terrain	3	2	Moderate	Terrain will be inspected prior to placing ground station and the landing locations of the outrigger pads will be cleared of debris. Design of outrigger pads will avoid possibilities of jamming and orient pad so gravity assists in orientation.
Outrigger pad does not slide on terrain.	1.Obstruction in path of outrigger 2.Ground too soft 3. Coefficient of friction between pad and terrain too high	Ground station will not raise or will raise unevenly	1	2	High	Terrain will be inspected prior to placing ground station and obstructions will be cleared. Testing will be done to 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 4. Ground station footprint	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 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 will be performed to ensure the correct motors are chosen 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	Analysis will be performed on the materials used to construct the ground station to ensure that the deflection over the span is within acceptable tolerances.
Ground station collapses	Material failure	Vehicle may be damaged, personal injury to personnel, damage to sub systems.	1	3	Moderate	Analysis will be performed on the materials used to construct the ground station to ensure that the ground station will hold up to the anticipated loads with a minimum safety factor of 2.
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 59: ASGE – Ground station risk assessment.

Payload Retrieval Arm Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Control Failure	1. Code has incorrect set points 2. Feedback devices malfunction 3. Code does not execute properly 4. Actuators unresponsive.	Arm fails to retrieve and load payload.	1	3	Moderate	Tests will be performed to verify operation of arm system.
Payload arm unable to grip payload	1. Coefficient of friction between grips and payload is insufficient 2. Grips do not close to specific position 3. Gripping motor does not have enough torque	Arm fails to retrieve and load payload.	1	3	Moderate	Analysis will be completed to determine the proper materials for gripping the payload and motor size. Testing will be completed to verify grips close consistently on payload.
Failure to insert payload	1. Payload is dropped. 2. Payload is not aligned properly to enter rocket and/or retaining clips.	Payload is not loaded into rocket.	1	2	High	Testing will be completed to verify payload is gripped adequately and properly oriented when entering rocket.

Table 60: Payload retrieval arm risk assessment.

Main Controller Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Power failure	Non-functioning power supply	AGSE fails to operate.	1	4	Moderate	Analysis and testing will be completed to ensure that the power supply is dependable and adequately sized for the AGSE.
Communication failure	Break in line Short on Board	AGSE fails to operate.	1	4	Moderate	All wires will be guarded from mechanical hazards to protect wires from damage. Testing will be completed on all electrical systems to ensure wiring was completed properly.
Program execution failure	Non-functioning code	AGSE fails to operate.	1	3	Moderate	Testing will be completed to confirm code is running properly prior to launch.
System crash while running program	1. Loss of power 2. Break in communication line	AGSE fails to operate.	1	3	Moderate	Testing will be completed to ensure all components maintain communication and systems do not crash.
Improper sequencing of code	Improper code sequencing.	AGSE fails to operate.	1	4	Moderate	Testing will be completed to verify all systems are sequenced properly.

Table 61: 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 62: 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 switch and controller 3. Code error	Undesired launch sequence/ personal injury/ Disqualification	1	3	Moderate	Redundancies will be implemented to ensure the igniter safety system performs as expected.
I2C Communication Error.	1. Short on chip. 2. Heat Damage 3. Water Damage	AGSE systems fail to actuate, mission failure.	1	3	Moderate	Testing will be completed to ensure that the main controller performs as expected.
Power distribution failure.	1.System short 2. Break in line wires	AGSE systems fail to actuate, AGSE mission failure.	1	3	Moderate	Testing will be completed to ensure that the main controller performs as expected.
Failure to start/boot	1. Non responsive programming. 2. loss of power	AGSE systems fail to actuate, AGSE mission failure.	1	3	Moderate	Testing will be completed to ensure that the main controller performs as expected.

System sequencing error	1.Non responsive programming 2. Incorrect timing.	Damage to sub-systems	1	3	Moderati on	AGSE systems fail to actuate, AGSE mission failure.

Table 63: 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	1. Internal components supported by	1	5	Low	The bulkheads will be designed to withstand the force from takeoff

	bulkheads can support.	the bulkheads will no longer be secure. 2. Parachutes attached to bulkheads will be left ineffective.				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 excessively during flight.	1	5	Low	The removable fin design has been incorporated, ensuring that the fins are properly aligned. Due to the capability of machining the centering rings, all slots will be 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 64: 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 the rocket to be damaged.	2	5	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Simulations have been performed to validate the design. All custom made parachutes will be extensively ground tested to validate the design.
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	The rocket falls with a greater	2	5	Low	Through careful inspection prior to packing each parachute, this

	completely ineffective depending on the severity of the damage.	kinetic energy than designed for, causing components of the rocket to be damaged.				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 the rocket to be damaged.	2	5	Low	Parachutes will all be packed in their own, custom deployment bag that is made out of Nomex, a fire retardant material. With proper packing of the parachute and use of Nomex, this failure mode is unlikely.
Recovery system separates from the rocket.	1. Bulkhead becomes dislodged. 2. Parachute disconnects from the U-bolt.	1,2. Parachute completely separates from the component, causing the rocket to 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.

Table 65: 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. 2. Extremely cold weather	1,2. Ejection charges will not fire, preventing the rocket from splitting and the rover being deployed.	2	5	Low	Batteries will be checked for sufficient charge during launch day preparations. If the launch is delayed and the batteries have been left on, batteries should be rechecked for a sufficient charge to power the systems.

E-match fails	1. E-match become dislodged. 2. Faulty e-match.	1,2. Ejection charges will not fire, preventing the rocket from splitting and the rover being deployed.	1	5	Low	

Table 66: 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 personnel in the area and significant	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.

		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 67: 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.
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.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. Drift

		2. Irretrievable rocket components.				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	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

		powder charges, inducing critical events. 2. Rocket will not separate as easily.				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 for long periods of time.	Possibly weakening materials or adhesives.	4	4	Low	Rocket should not be exposed to sun for long periods of time. If the rocket must be worked on for long periods of time, shelter should be sought.

Table 68: 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 toxic fumes in the air.	Burning of ammonium perchlorate motors	Biodegradation	5	1	Low	Ammonium perchlorate will be burned in small quantities and infrequently. The amount of toxins released will cause minimal degradation.

Table 69: Hazards to environment risk assessment

Section 8. Appendix III – Technical Drawings

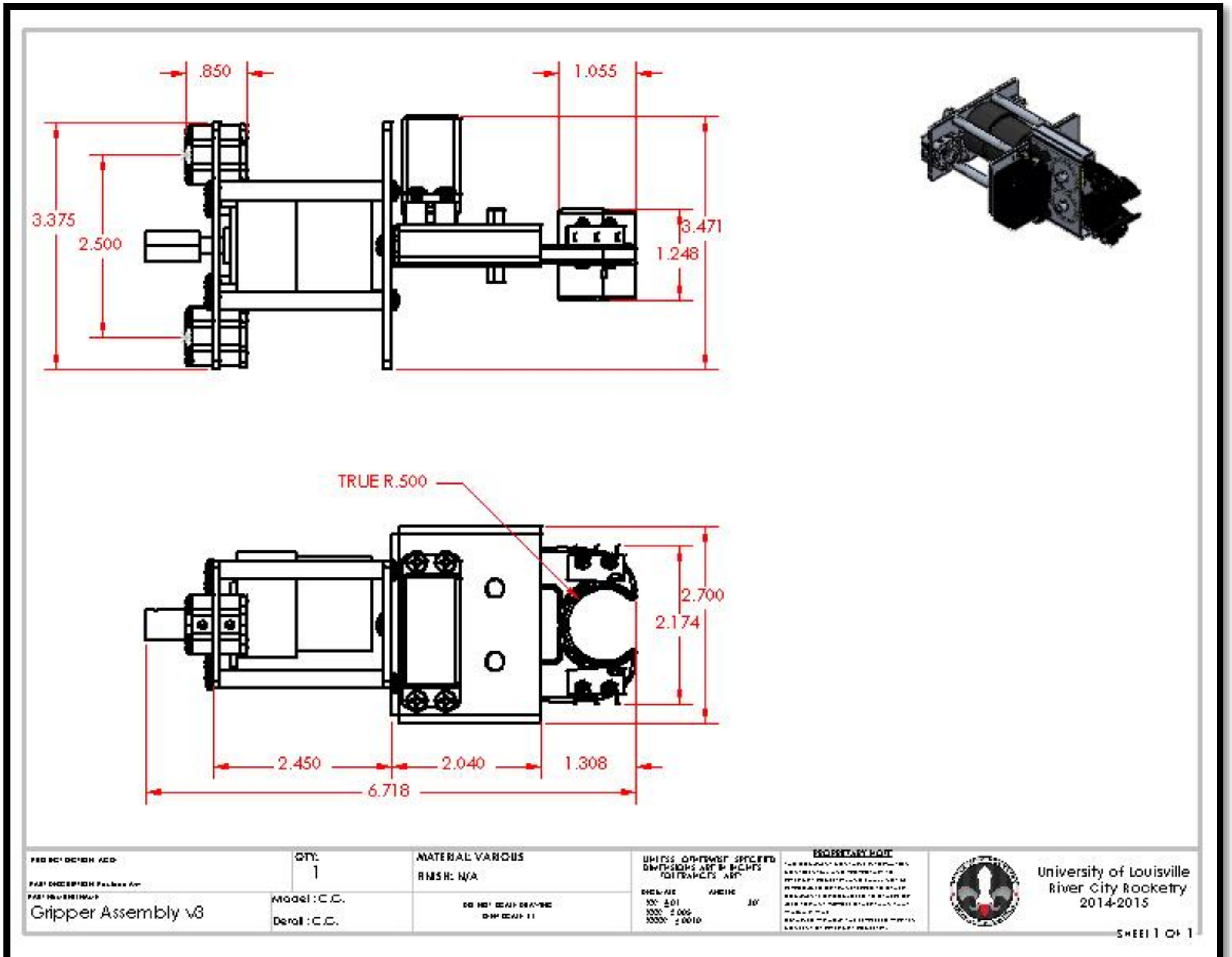


Figure 159: Gripper assembly.

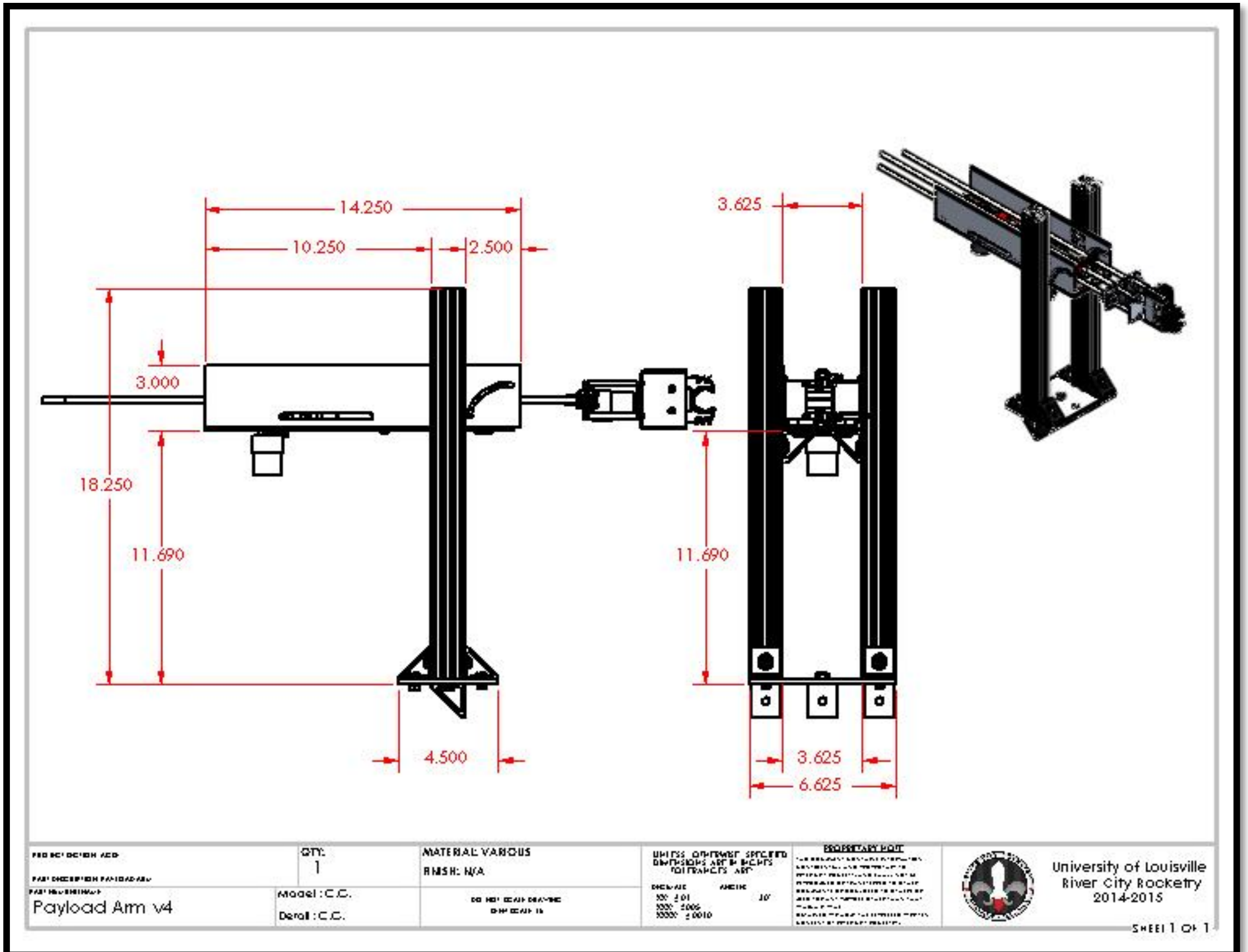


Figure 160: Payload arm.

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

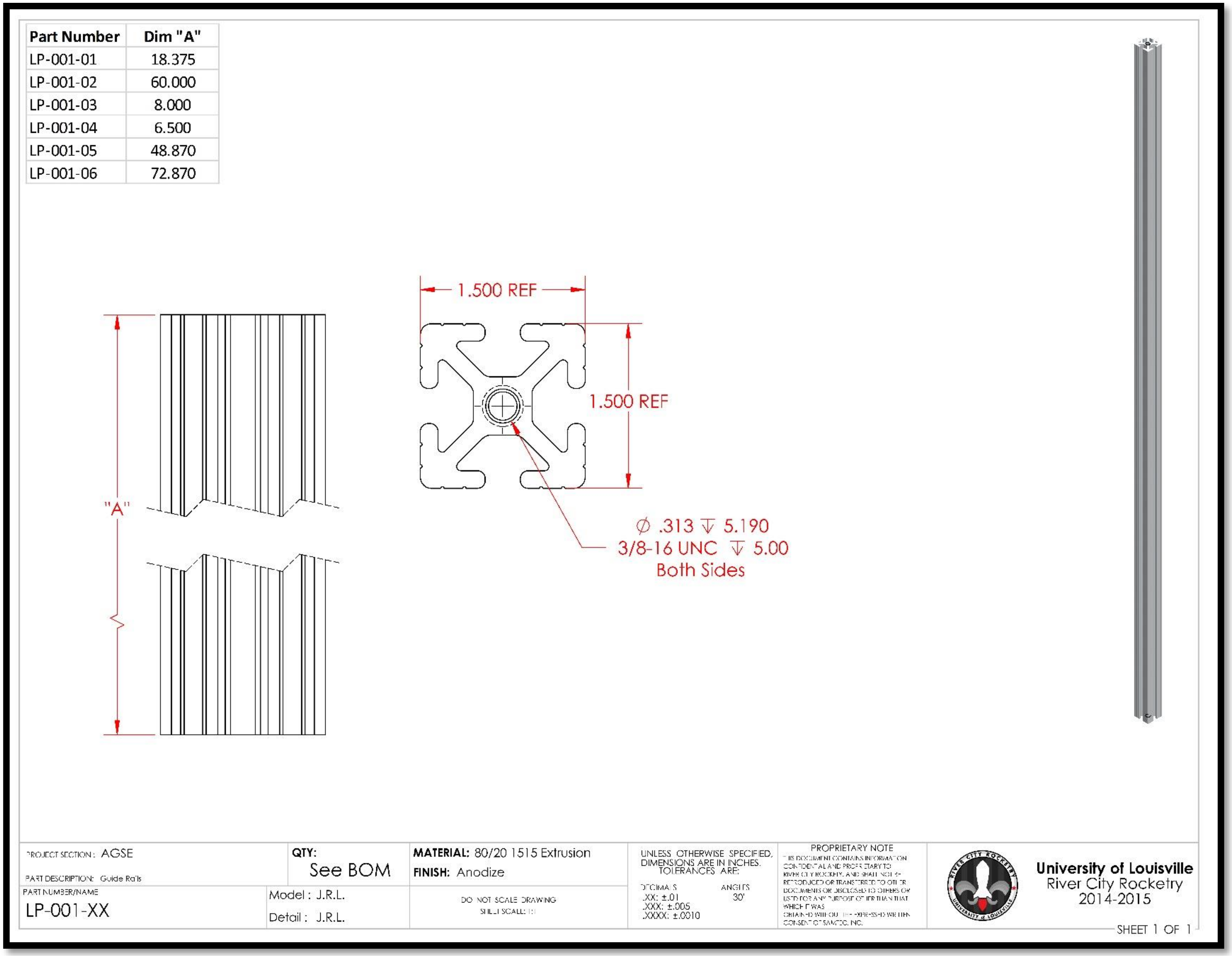


Figure 161: Launch platform rail drawing.

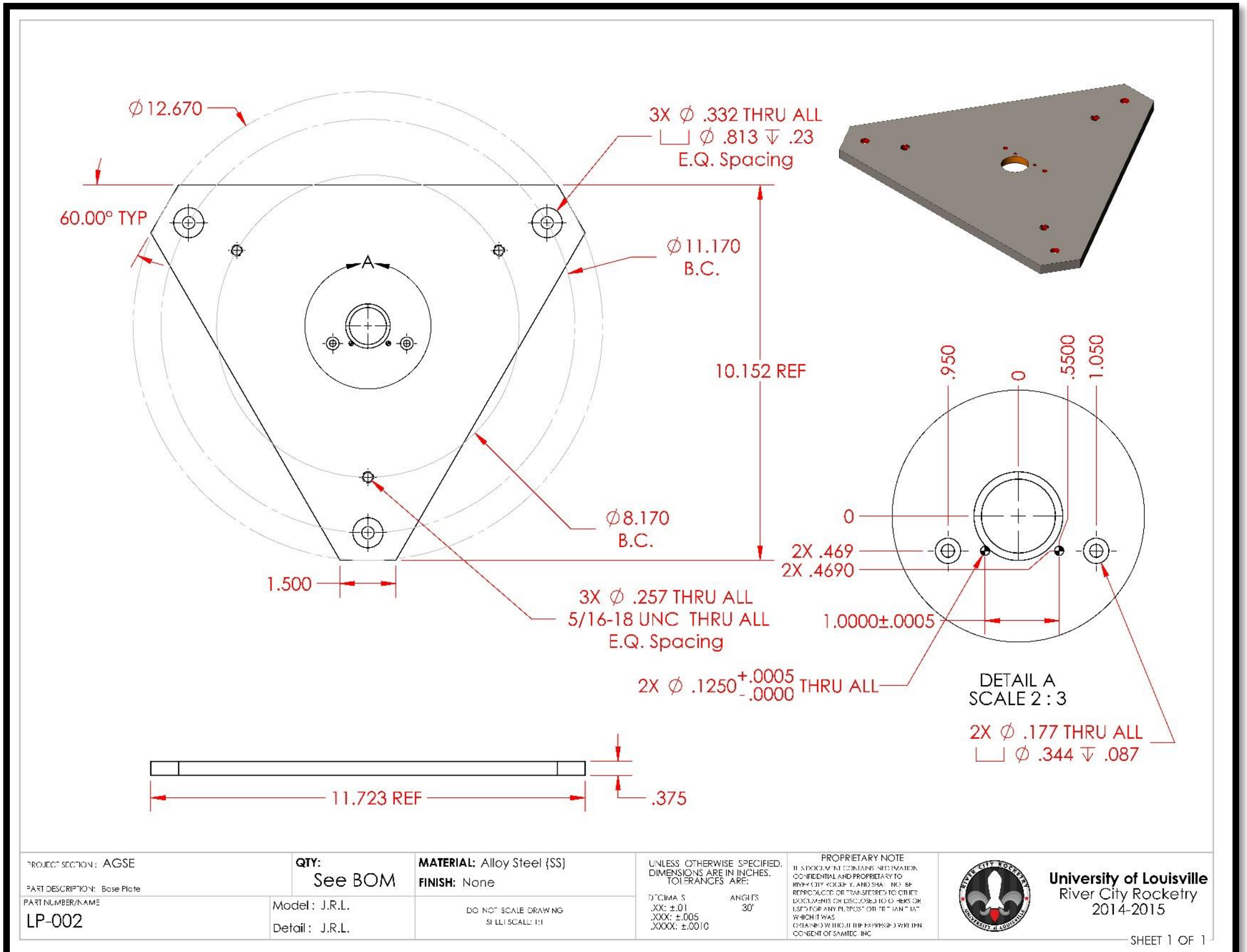


Figure 162: Bottom mounting plate.

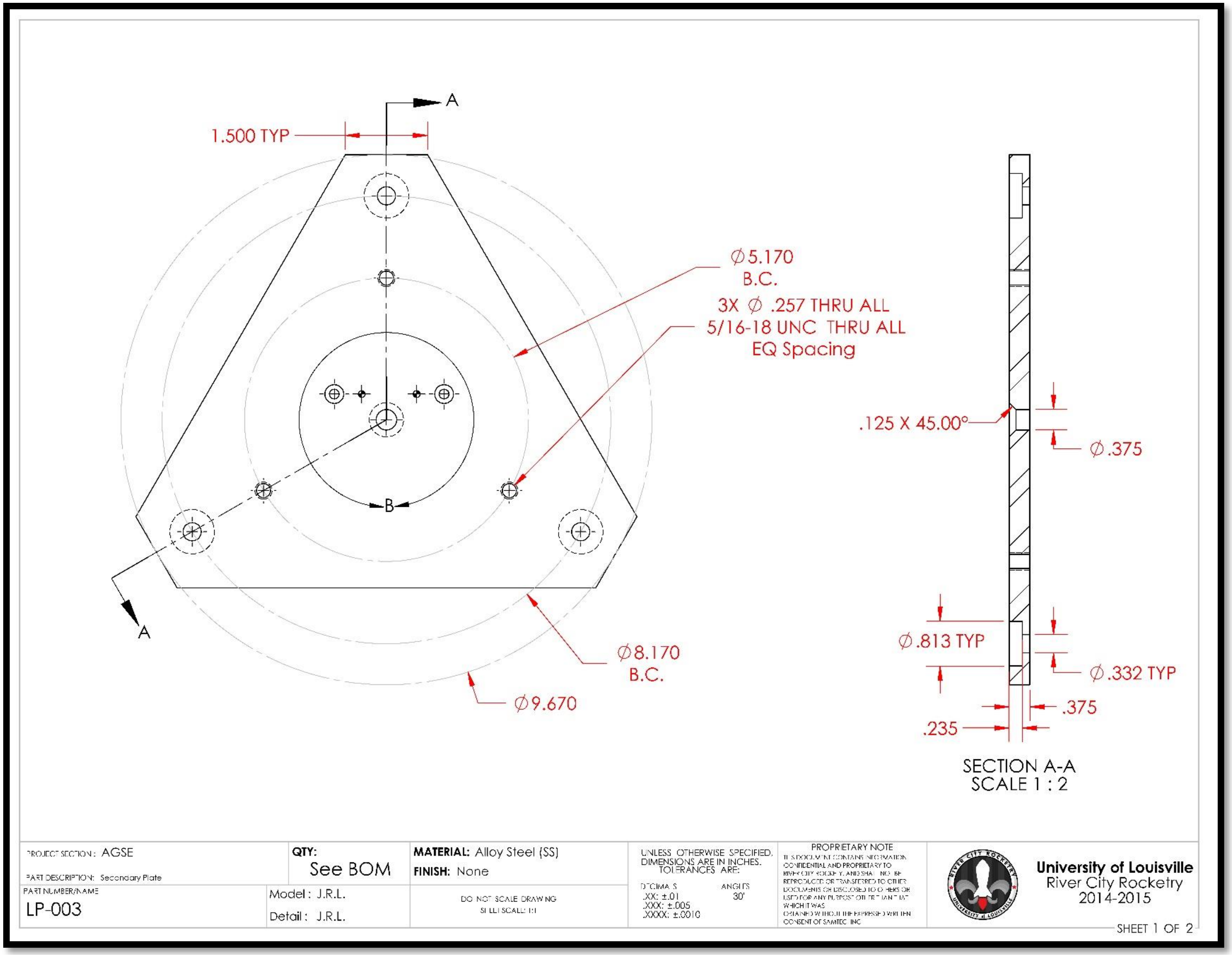


Figure 163: Middle mounting plate sheet 1.

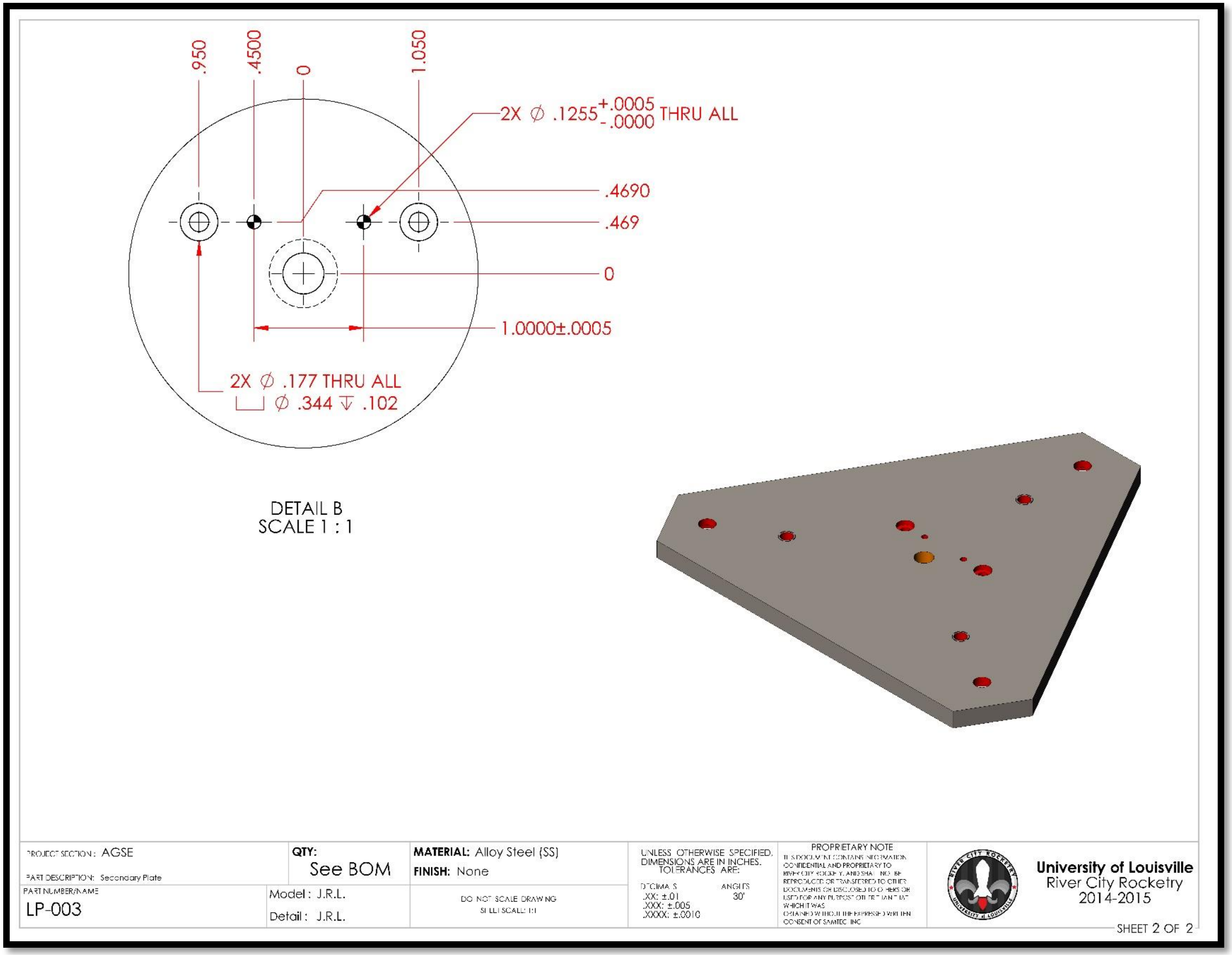


Figure 164: Middle mounting plate sheet 2.

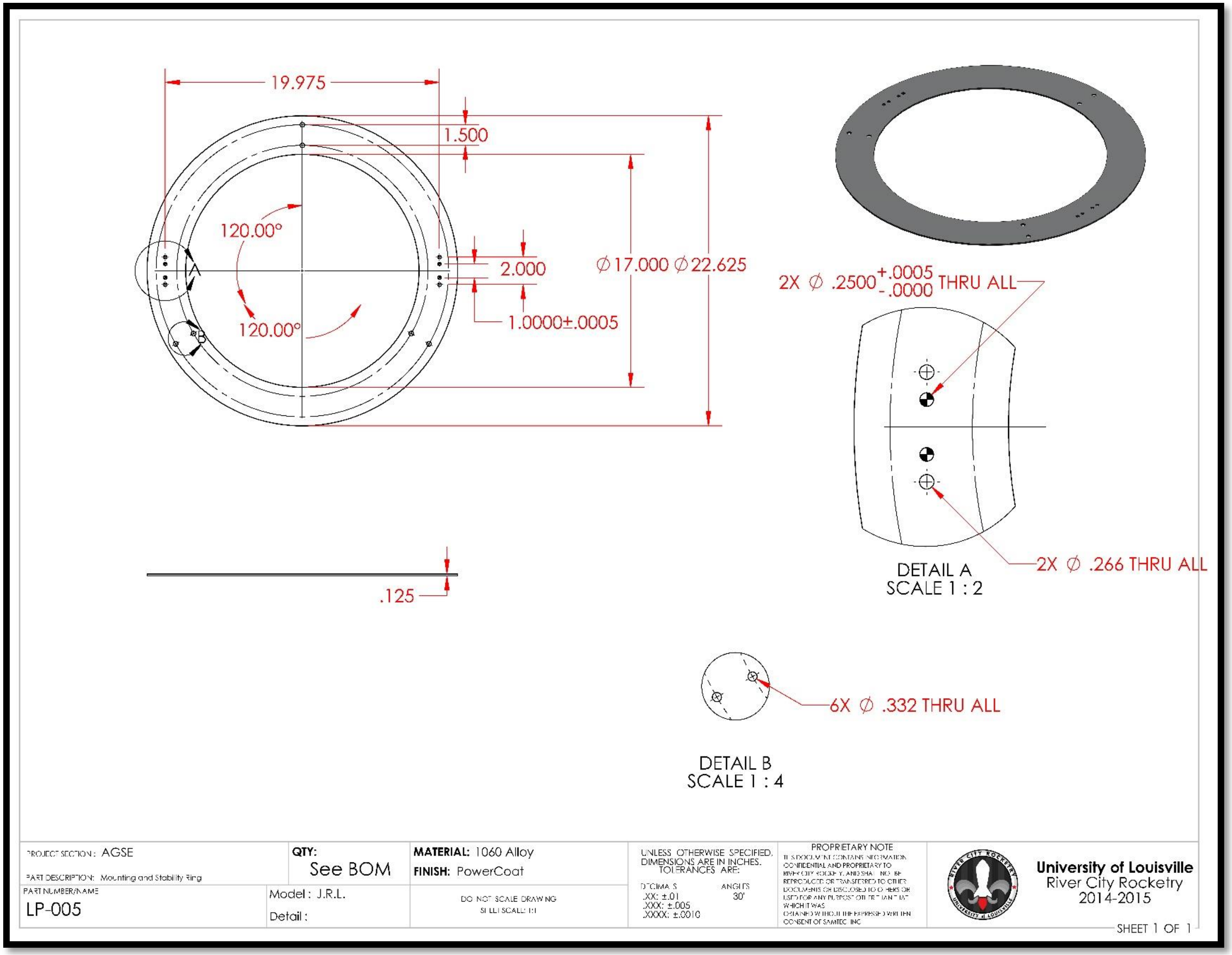


Figure 165: Stability ring.

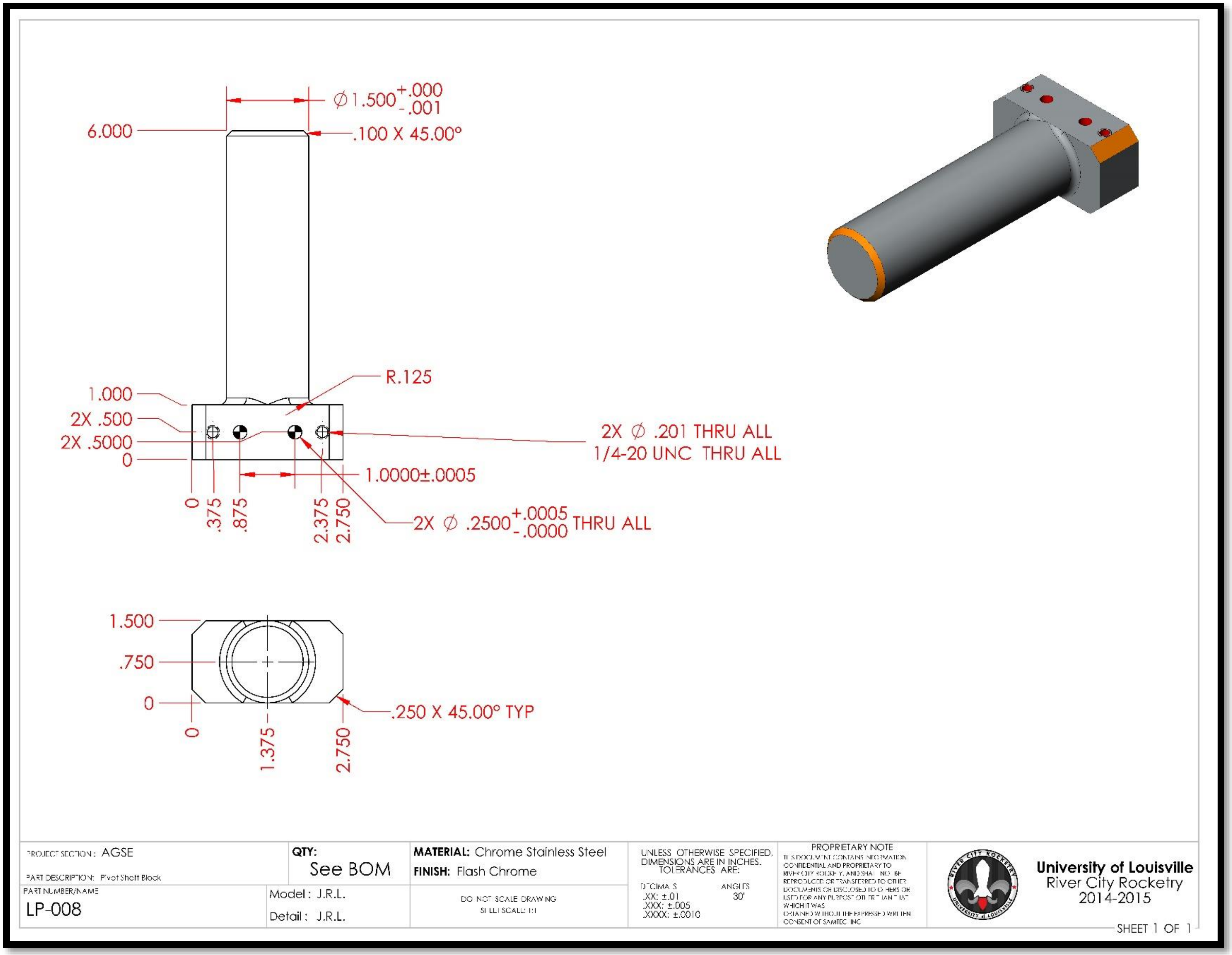


Figure 166: Shaft mount block.

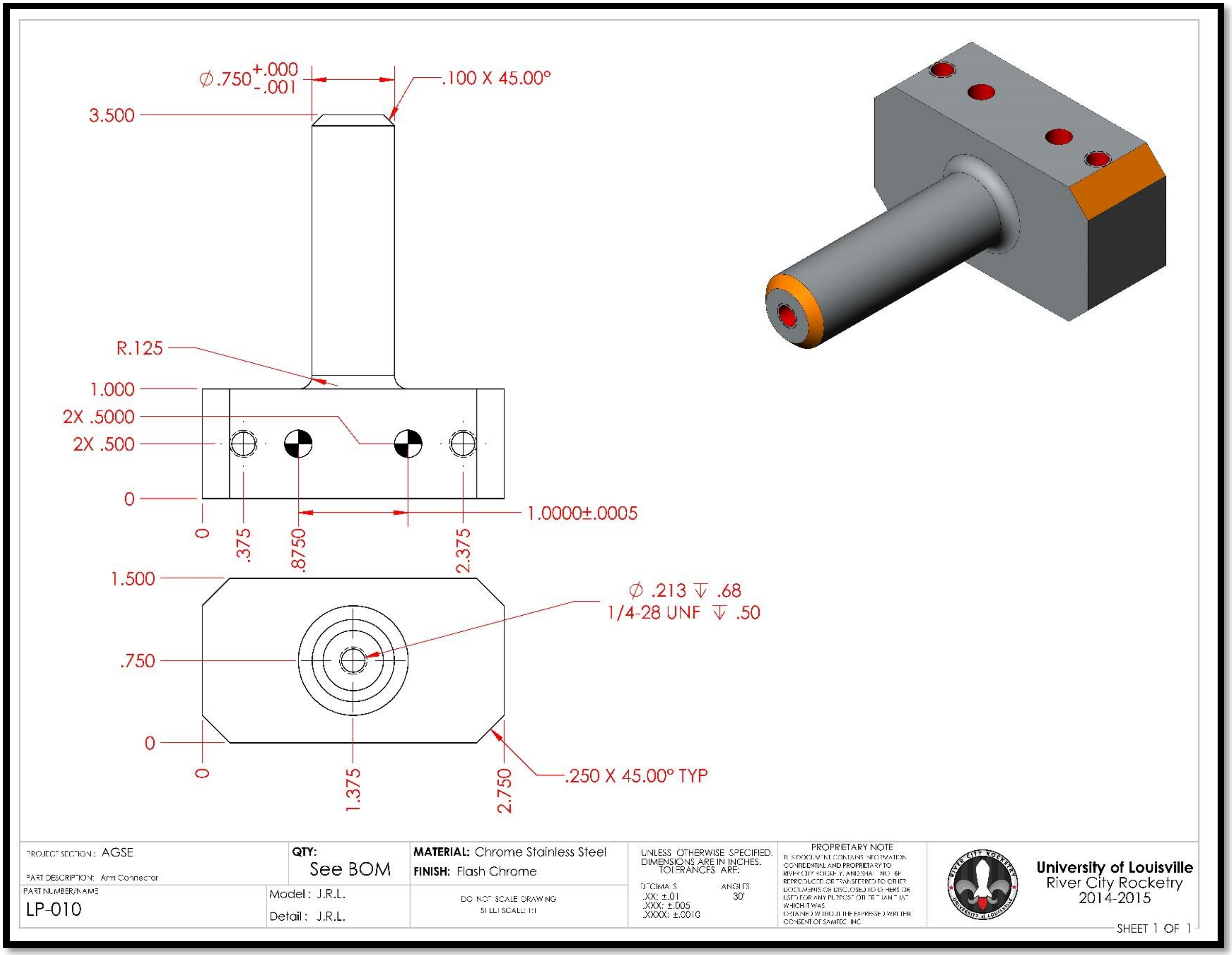


Figure 167: Arm mount block.

ITEM NO.	PART NUMBER	QTY.
1	IS-003	1
2	IS-005	1
3	94355A140	3
4	91251A105	3
5	91251A108	3
6	IS-017	1

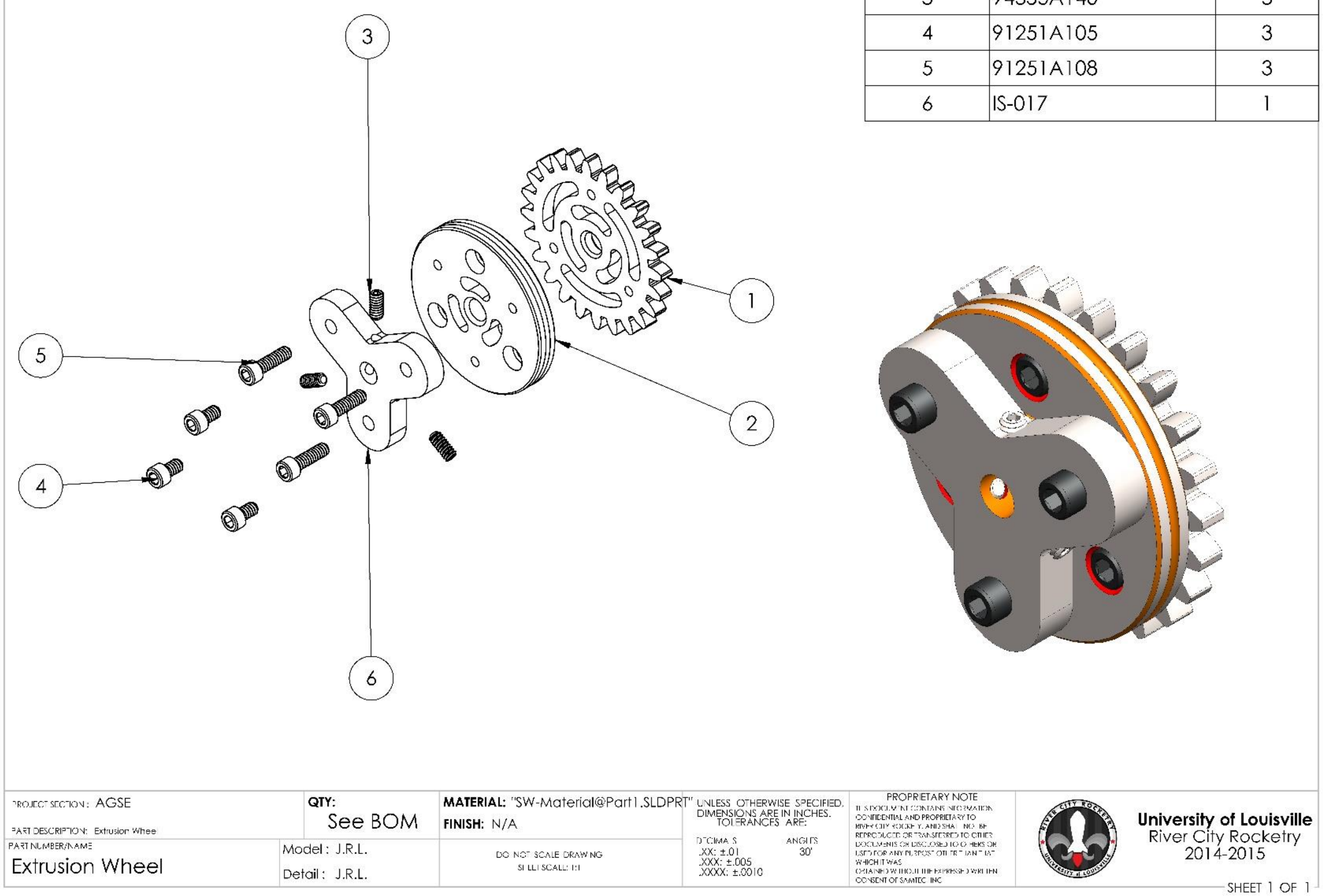
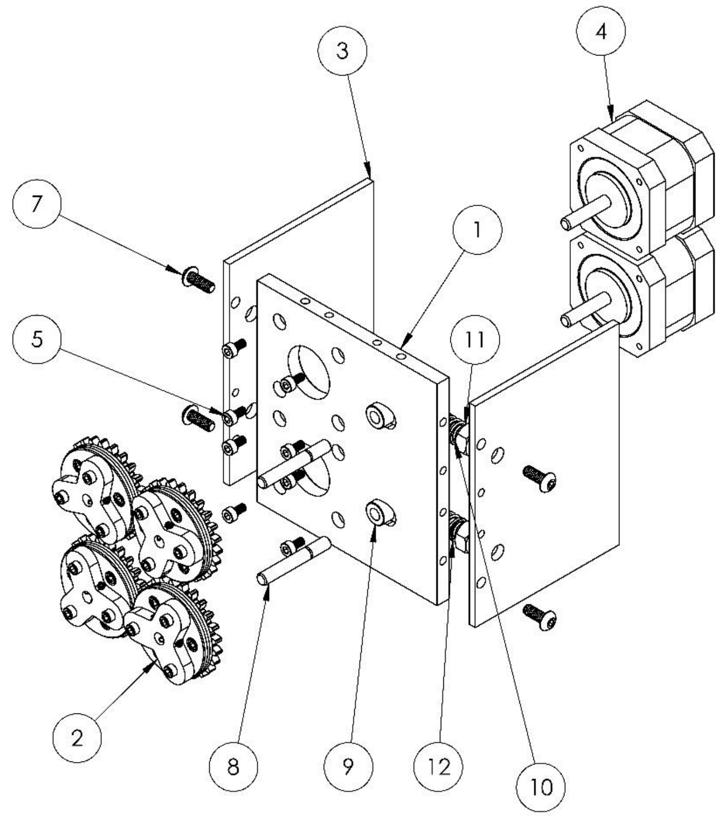
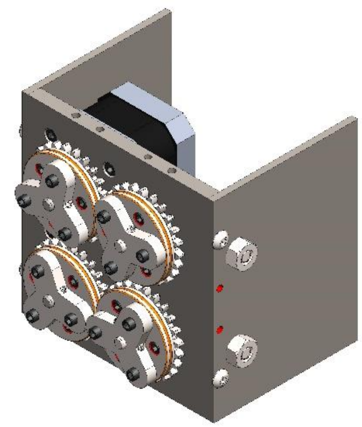


Figure 168: Extrusion wheel.



ITEM NO.	PART NUMBER	QTY.
1	IS-009	1
2	Extrusion Wheel	4
3	IS-014	2
4	Stepper motor - NEMA-17 size, 200 stepsrev 12V 350mA	2
5	91290A111	8
6	98317A211	2
7	92949A193	4
8	IS-015	2
9	Default	2
10	92185A516	2
11	HNUT 0.2500-20-D-S	4
12	9657K289	2



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
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 1

Figure 169: Ignition station.

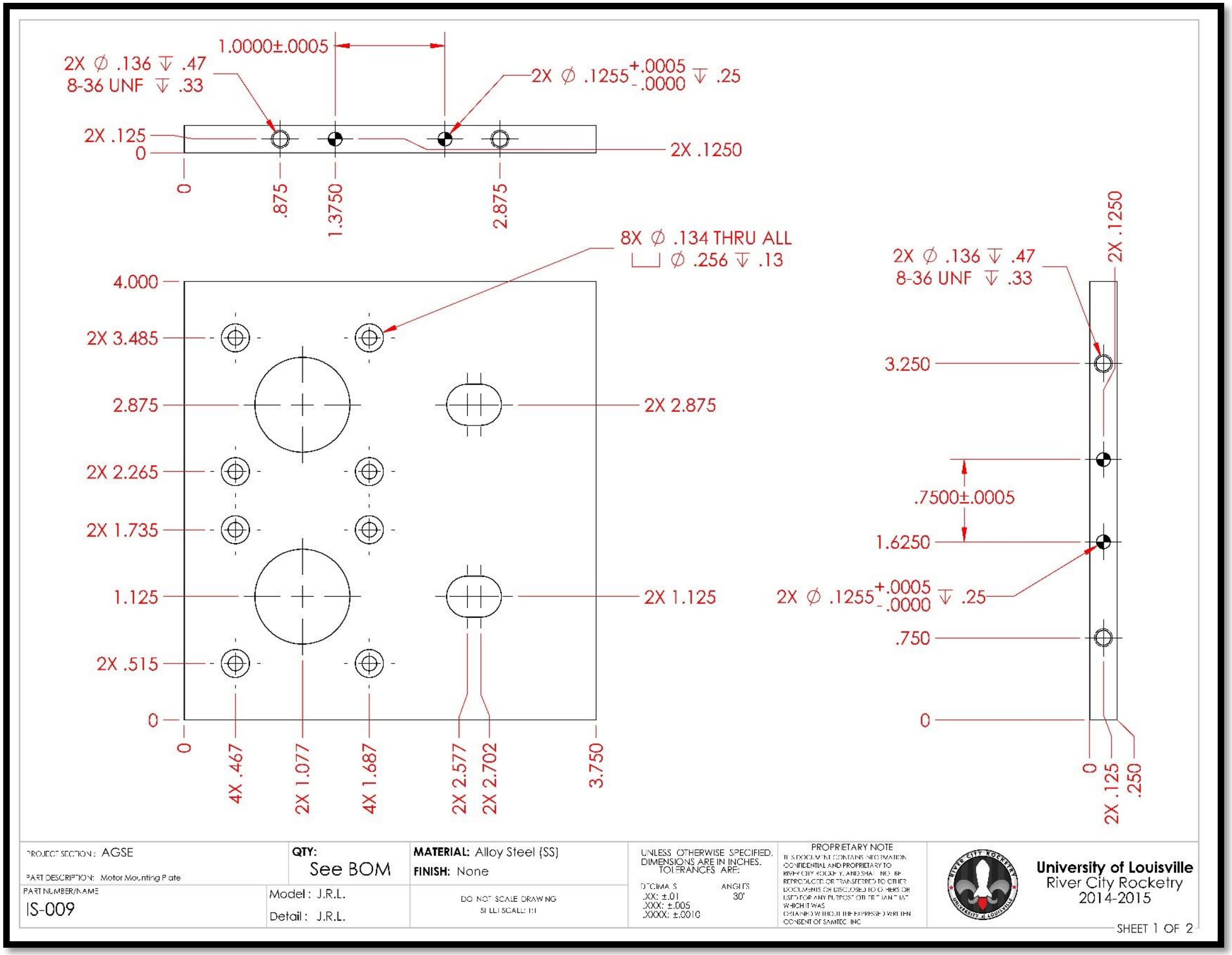


Figure 170: Mounting plate sheet 1.

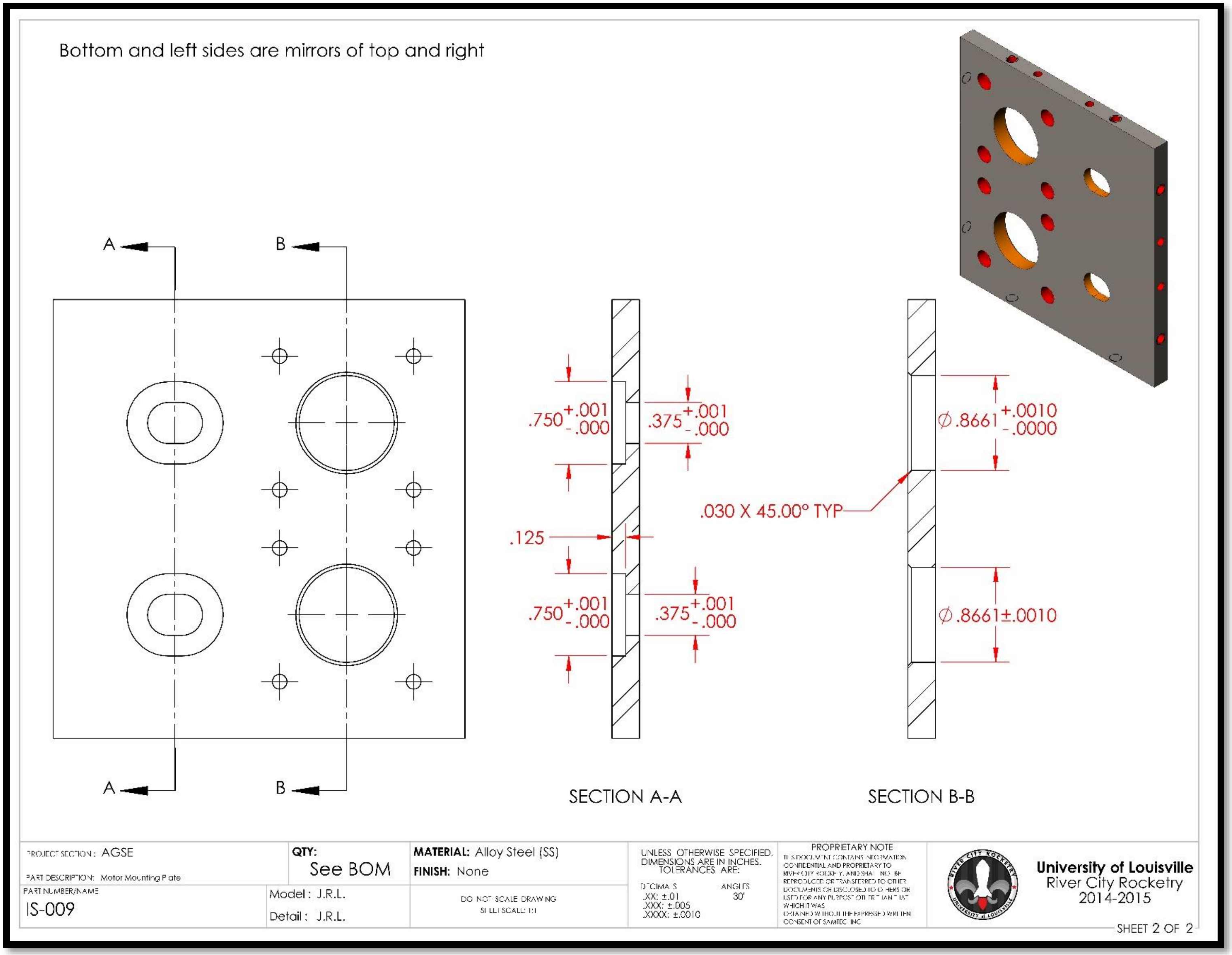


Figure 171: Mounting plate sheet 2.

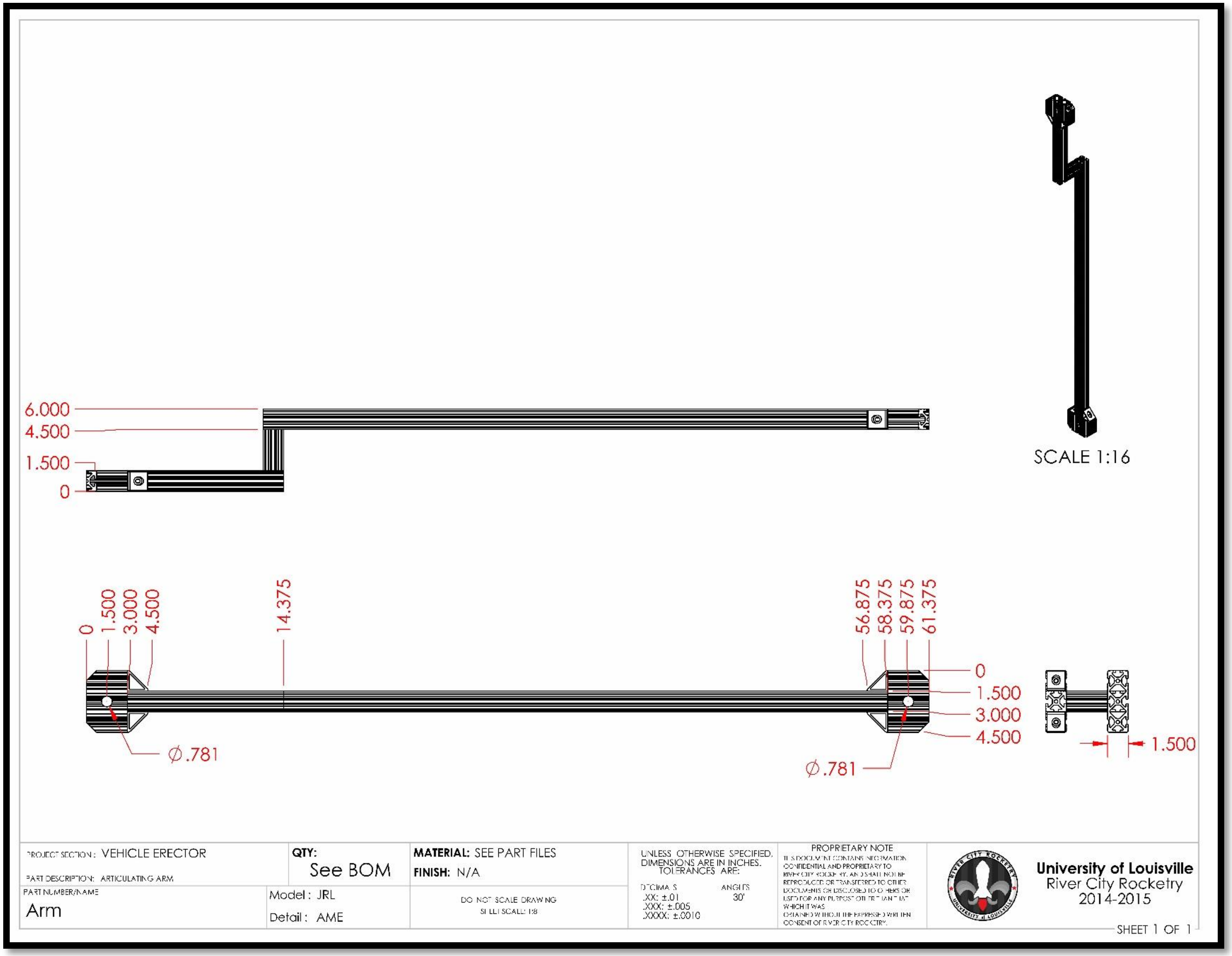


Figure 172: Articulating arm.

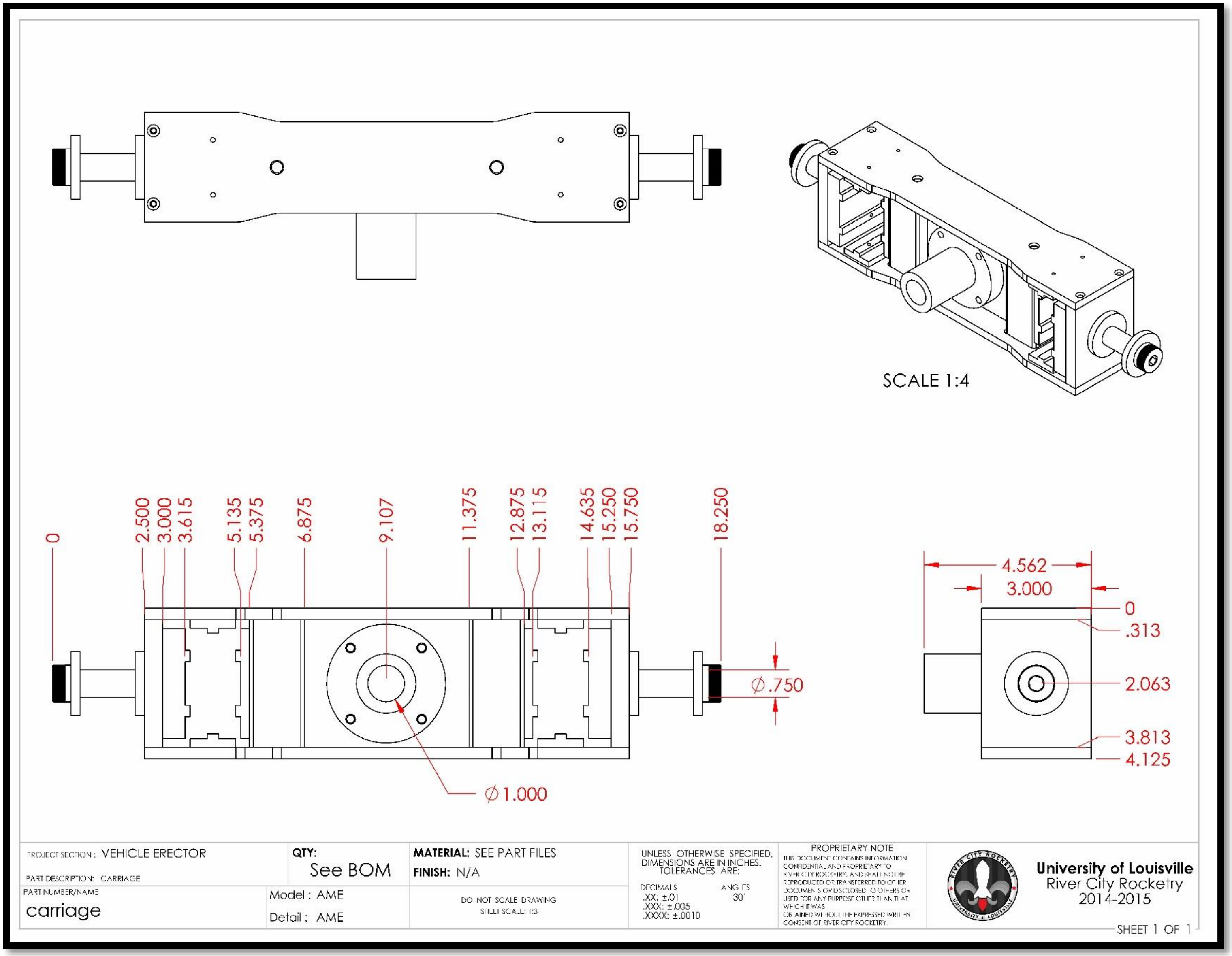


Figure 173: Carriage.

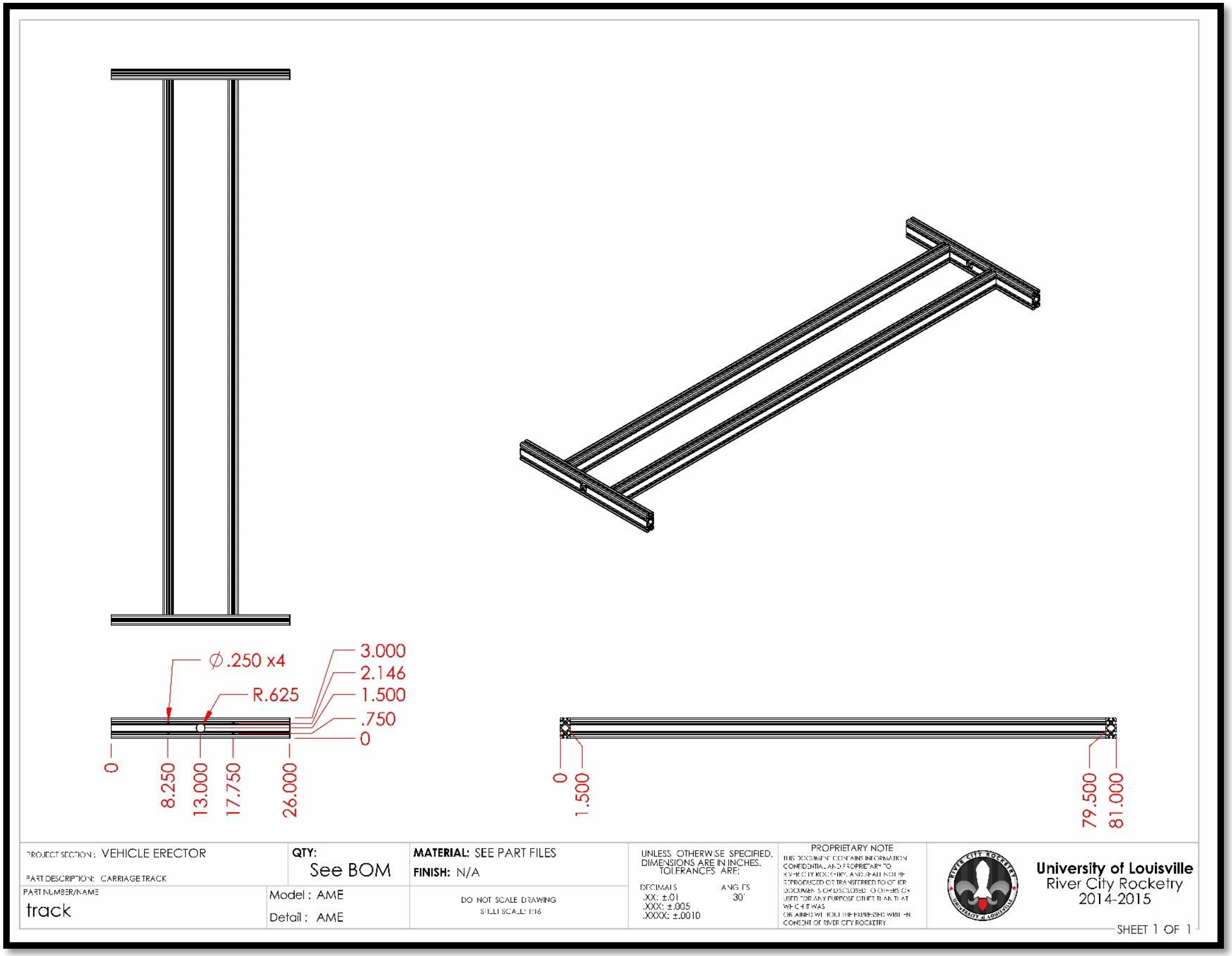


Figure 174: Vehicle erector track.

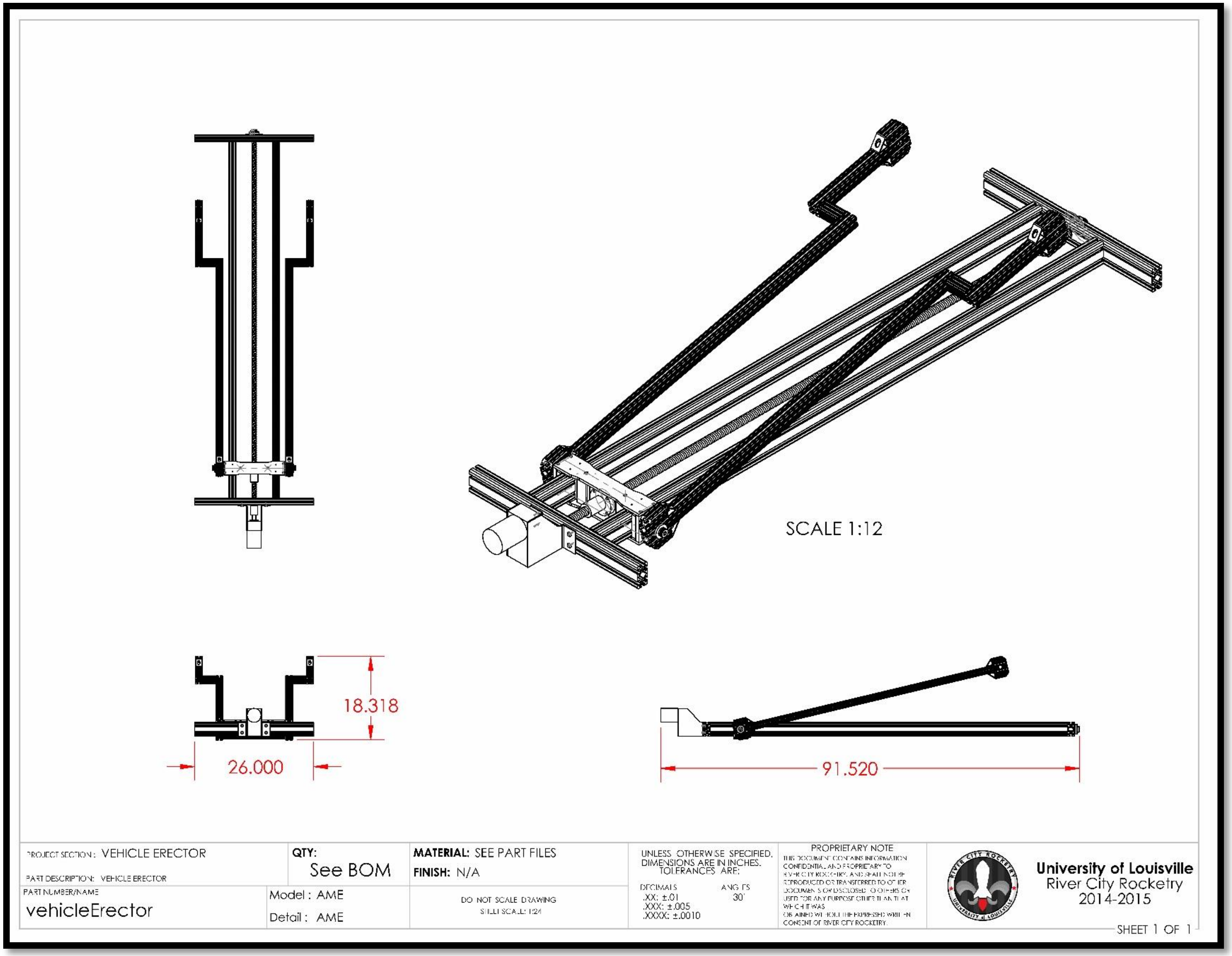


Figure 175: Vehicle erector.