NASA Student Launch

Centennial Challenge MAV Project

2015-2016 PDR

November 6, 2015

River City Rocketry, JB Seed School of Engineering, 132 Eastern Parkway, Louisville, KY 40292

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Section 1. General Information

1) School Information/Project Title

School Name: University of Louisville
Organization: *River City Rocketry*
Location: J.B. Speed School of Engineering
132 Eastern Parkway
Louisville, KY 40292
Project Title: Project Free the Bird

2) Team Officials

Advisor Name: Dr. Yongsheng Lian
Contact Information: y0lian05@louisville.edu **or** (502) 852-0804

Dr. Lian serves as a faculty at the Department of Mechanical Engineering at the University of Louisville. He worked at the Ohio Aerospace Institute as a Senior Researcher from 2003 to 2005 and as a Research Scientist at the Aerospace Engineering Department of the University of Michigan from 2005 to 2008. He joined the University of Louisville in 2008. He has 17 years of experience in computational fluid dynamics. He developed algorithms to study fluid/structure interaction, laminar-to-turbulent flow transition, low Reynolds number aerodynamics, and its application to micro air vehicle, two-phase flow, and design optimization.

Team Captain/Safety Officer Name: Emily Robison
Contact Information: emrobi07@louisville.edu **or** (502) 758-0487

Emily is currently a graduate mechanical engineering student at the University of Louisville's J.B. Speed School of Engineering. This is Emily's fourth year with the team and will be returning as captain after leading the team to a second place finish last year. After helping the team take home the safety award during the 2013-2014 and 2014-2015 seasons, she will be returning as safety officer. She has spent four semesters on co-op working on various programs with Raytheon Missile Systems. Through this experience, she gained valuable knowledge in design, testing, assembly processes, and safety. Emily hopes to pursue a career in the aerospace industry after graduation.

Team Captain Name: Kevin Compton
Contact Information: kckev101@gmail.com **or** (847) 977-9471

Kevin is currently a junior mechanical engineering student at the University of Louisville's J.B. Speed School of Engineering. This is Kevin's third season competing in NASA's student launch project and first year as co-captain of River City Rocketry. After contributing to his team's first place victory in the maxi-mav division, Kevin has been busy obtaining a position at UPS's structural engineering airgroup division. Throughout the years of competition Kevin has acquired important knowledge in design, fabrication, manufactural integration, and problem solving. With these skills he hopes to end up in the field of aerospace after graduation.

3) Tripoli Rocketry Association Mentor

Name: Darryl Hankes
Certification: Level 3 Tripoli Rocketry Association
Contact Information: nocturnalknightrocketry@yahoo.com **or** (270) 823-4225

Darryl Hankes engaged himself in rocketry in February of 2003. In 2004, he joined Tripoli Indiana and where he received his Level 1 TRA certification. In 2006 at Southern Thunder, Hankes received his Level 2 TRA certification. A year later, in 2007, Hankes successfully attempted his Level 3 TRA Certification at Mid-West Power. Over the years, Hankes has flown an R10,000 twice in a team project along with countless M-R projects with clusters, staging, and air starts. He is the former prefect for the Tripoli Rocketry Association, Bluegrass Rocket Society (TRA #130), which provides launch support during test launches. Hankes has mentored the team through all seasons that River City Rocketry has participated in NASA's student launch competitions. The team is pleased to see his return for this year's competition.

4) Team Members and Organization

The University of Louisville's team this year will consist of approximately 25 students coming from a variety of backgrounds. In order to support the technical efforts on the project, the team consists of students from the mechanical engineering, electrical and computer engineering, and computer engineering and computer science departments (CECS). Additionally, the team has recruited other STEM disciplines from across the university in order to support the team, specifically with the intent of enhancing our educational outreach.

The project has been broken up into the following technical leads:

- *Launch Vehicle* – responsible for the simulation, design, and construction of the launch vehicle. A key responsibility is to ensure the desired altitude is achieved by closely monitoring the mass properties of the vehicle throughout the season.
- *Recovery* – responsible for the analysis, design, testing, and manufacturing of all competition parachutes for the team.
- *Mechanical AGSE* – responsible for the mechanical design, analysis, testing, and manufacturing of all mechanical AGSE systems.
- *Electrical/CECS* – responsible for the electrical design, prototyping, and manufacturing of all electrical AGSE systems. Additionally, oversees any extra electrical or CECS projects that enhance the overall product.
- *Integration* – responsible for ensuring that all systems successfully integrate without interference, communication issues, etc. Also responsible for the design and manufacturing of test prototypes to verify successful electrical and mechanical system integration.

Each of the team leads were selected based on their past team experience, technical abilities, interest, and leadership qualities. We are confident that the leadership selected has the technical know-how, dedication and experience to lead the team to design a successful and innovative system.

The other leadership roles are website lead, outreach lead, and safety officer, which have also been selected based on experience. These are all former members that have filled these exact, or similar roles in the past and have the skills required to successfully execute the required tasks.

5) PDR Summary

Vehicle

Using OpenRocket to model the flight characteristics of the launch vehicle, the vehicle parameters were established. These characteristics are defined below in Table 1.

Property	Defined characteristic
Diameter (in)	6-4
Length (in)	108
Empty mass (lb)	23.94
Loaded mass (lb)	29.84
Motor selection	CTI 3147-L935-IM-P

Table 1: Launch vehicle parameters.

The diameter of the launch vehicle was chosen to be 6 inches to allow adequate room for all payloads and recovery hardware. In order to reduce weight, a 6 inch to 4 inch transition will reduce the aft diameter of the launch vehicle. Total length of the launch vehicle shall be 108. This length was determined as providing adequate space for all recovery systems, payload containment, and mission electronics. Width size and length defined, the weight of the launch vehicle was determined to be 23.94 lbs. In order to safely launch the vehicle and provide a margin of error for mass assumptions of various components, a CTI 3147-L935-IM-P solid Ammonium Perchlorate motor was chose. Exact details for size, weight, and motor selection are outlined further in Section 5.

Recovery

A unique recovery system has been developed this year. When apogee is reached the nose cone and lower section of the rocket will separate via black powder charge. Once separation has been completed a single polyconical parachute will be deployed and oriented with a centerline reefing system to simulate a drogue parachute. At 800 feet, a micro servo will rotate enabling the de-reefing process that allows the parachute to open into a main state. Once the main state is reached the launch vehicle will descend the remaining altitude at the terminal velocity of 12.71 ft/sec.

AGSE

The AGSE has been designed to complete all tasks within a 5 minute time window. The payload will be captured and inserted into the rocket using a telescopic arm. The payload capture device will utilize mechanical locking mechanisms to prevent motor stalling. The vehicle will be actuated by a ball screw configuration with a 3 rail guide tower launch platform. Finally the igniter installation device will utilize two belts to install the igniter. The igniter will be spooled prior to launch and the belts will straighten the igniter as it is inserted.

6) Flysheet

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

Institution	University of Louisville	Milestone	PDR

Vehicle Properties	
Total Length (in)	108
Diameter (in)	6.12
Gross Lift Off Weight (lb)	20.84
Airframe Material	Carbon Fiber
Fin Material	Fiberglass
Drag	Drag coefficient: 0.34

Motor Properties	
Motor Manufacturer(s)	Cesaroni
Motor Designation(s)	L935-IM
Max/Average Thrust (lb)	356.5/209.9
Total Impulse (lbf-sec)	707.4
Mass (before, after burn)	5.6, 1.8
Liftoff Thrust (lb)	148.4

Stability Analysis	
Center of Pressure (in from nose)	79.36
Center of Gravity (in from nose)	62.18
Static Stability Margin	2.81
Thrust-to-Weight Ratio	12.06
Rail Size (in)/ Length (in)	96
Rail Exit Velocity (ft/s)	60.9

Ascent Analysis		
Maximum Velocity (ft/s)	640	
Maximum Mach Number	0.58	
Maximum Acceleration (ft/s^2)	345	
Target Apogee (1st Stage if Multiple Stages)	5287	
Stable Velocity (ft/s)	50	
Distance to Stable Velocity (ft)	7.9	

Recovery System Properties – Reefed Parachute				
Manufacturer/Model	Polyconical - custom made			
Size	677 ft^2			
Altitude at Deployment (ft)	Apogee			
Velocity at Deployment (ft/s)	0			
Terminal Velocity (ft/s)	126			
Recovery Harness Material	9/16" tubular nylon			
Harness Size/Thickness (in)	9/16"			
Recovery Harness Length (ft)	27			
Harness/Airframe Interfaces	1/4 inch U-bolt and quick link connected to a swivel and qiucklink.			
Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4

Recovery System Properties – Fully deployed Parachute				
Manufacturer/Model	Polyconical - custom made			
Size	677 ft^2			
Altitude at Deployment (ft)	800			
Velocity at Deployment (ft/s)	126			
Terminal Velocity (ft/s)	12.71			
Recovery Harness Material	9/16" tubular nylon			
Harness Size/Thickness (in)	9/16"			
Recovery Harness Length (ft)	27			
Harness/Airframe Interfaces	1/4 inch U-bolt and quick link			
Kinetic Energy of Each Section (ft-lbs)	Section 1 (Nosecone)	Section 2 (Propulsion Bay)	Section 3	Section 4
	12.29	47.71		

Recovery Electronics	
Altimeter(s)/Timer(s) (Make/Model)	PerfectFlite StratoLogger (x3) Arduino Mini (x1)
Redundancy Plan	Nosecone avionics bay will utilize a Stratologger for a primary and redudundant altimeter. Reefing system shall utilize an arduino with barometric pressure sensor as primary altimeter, redundant Stratologger shall be used

Recovery Electronics	
Rocket Locators (Make/Model)	Garmin Astro DC 40 (x1)
Transmitting Frequencies	Garmin Astro DC 40 - 151880 MHz
Black Powder Mass Upper Airframe Chute (grams)	4

Pad Stay Time (Launch Configuration)	1 hour

Black Powder Lower Airframe Chute (grams)	N/A

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

Institution	University of Louisville

Milestone	PDR

Autonomous Ground Support Equipment (AGSE)	
Capture Mechanism	Overview
	A threadless screw will move down the height of the ground station where two gripper arms will grab the payload. From there, they will raise to system height, the rod rotates 90 degrees and then inserts the paylaod into the vehicle.
Container Mechanism	Overview
	The payload will be inserted into two clips, located inside the payload bay. The clips mechanically retain the capsule. The door to the payload bay will actuate via servo, sealing the payload from the environment.
Launch Rail Mechanism	Overview
	The rail will not be locked in place, instead, a screw mechanism will guide the tower to the proper position. A motor will monitor and provide necessary torque to keep the platform at the 5 degree of vertical postion as stated from the statement of work. The motor will monitor and provide required torque to maintain position.
Igniter Installation Mechanism	Overview
	The igniter will be augmented with dowel rods and aluminum tape for shielding. Four wheels will extrude the igniter wire until it is in the proper placement in the vehicle. A magnetic field sensor will detect a magnetic flag on the wire to ensure proper placement.
CG Location of Launch Pad (in inches) When Rail is Horizontal (Use Base of Rail as the Reference Point)	
Moment Analysis	Vehicle horizontal: 22 inches (relative to ground) Vehicle in launch position: 26 inches (relative to ground)

Payload	
Payload 1	Overview
	The AGSE will autonomously retrieve a payload utilizing a telescopic that will incorpate an acme screw and worm gearboxes to lock into specific positions. The launch vehicle will be secured to the AGSE using a guide tower launch platform. The guide tower will consist of three sheetmetal rails that will guide the rocket to a safe exit velocity. The vehicle will be actuated by a ball screw. The ingiter will be installed using a belt driven ingiter installation device. The igniter will be spooled prior to start of the autonmous sequence and will be straightned as it is inserted.
Payload 2	Overview

Test Plans, Status, and Results	
Ejection Charge Tests	All ejection charges will be tested on the ground prior to flight to ensure that black powder charges are all properly sized.

Sub-scale Test Flights	
Full-scale Test Flights	

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

Institution	University of Louisville	**Milestone**	PDR

Additional Comments
Unconventional parachute deployment with Parachute reefing occuring at 800 ft.

7) Changes since Proposal

Vehicle

The primary change that has been made to the vehicle is that the airframe will be made out of carbon fiber instead of fiberglass. Originally, fiberglass was chosen due to the lower cost and ease of accessibility. However, due to a recent grant, the team is able to purchase the necessary equipment to manufacture carbon fiber tubes. As a result of this, the change was made to help reduce the weight of the rocket.

Recovery

The primary change that has been made to the recovery system is that a reefing ring, which is discussed further in Section 6, will be implemented. It was identified that the original method of reefing the parachute would not hold the parachute closed tight enough. To combat this, the new system is being incorporated. The methodology behind this system can be found in the recovery section of the document.

AGSE

The primary change that has been made to the AGSE is with regards to the launch platform. It was determined that by using structural tubing, the required factor of safety could not be achieved. In order to improve the factor of safety while maintaining a lightweight structure with minimal deflection, the launch platform was redesigned using sheet metal. Analysis supporting this change is detailed in the AGSE section of the document. Another benefit to this change is that it will be easier to manufacture, reducing the turnaround time.

Project Plan

The project plan is very much in line with where it was a proposal. The main change to the plan is that the budget has been able to be expanded due to an unexpected, and extremely generous grant. This grant provided extra support to purchase materials needed to manufacture carbon fiber parts, which in turn alters the project path for the vehicle design team. However, the schedule and budget are both in good standings.

Section 2. Facilities and Equipment

1) Facilities/Equipment

Engineering Garage

Engineering Garage is a facility used for the support of student design and research projects. Research prototypes, experimental test fixtures, and student design prototypes are fabricated in the facility. This facility is available 24 hours a day. Major equipment items include:

- Jet 13" × 40" lathe
- Jet drill press
- Tormach CNC 3-axis mill
- Tomach CNC lathe
- 4’ x 8’ SHOPBOT
- Air compressor
- Jet 3-axis manual mill
- LaserSystems 3’ x 5’ laser
- Media blaster
- Jet Horizontal band saw
- Jet 55 ton shop press
- 5000 lb. hoist
- Bench grinder
- Jet vertical band saw
- Hand tools
- SawStop table saw
- Power hand tools
- Hand tools

Figure 1: Engineering garage major equipment.

Included in the Engineering Garage the University has provided River City Rocketry with a storage and work space. This part of the Engineering Garage is open 24 hours and consists of numerous hand and power tools.

Figure 2: River City Rocketry cage.

FirstBuild

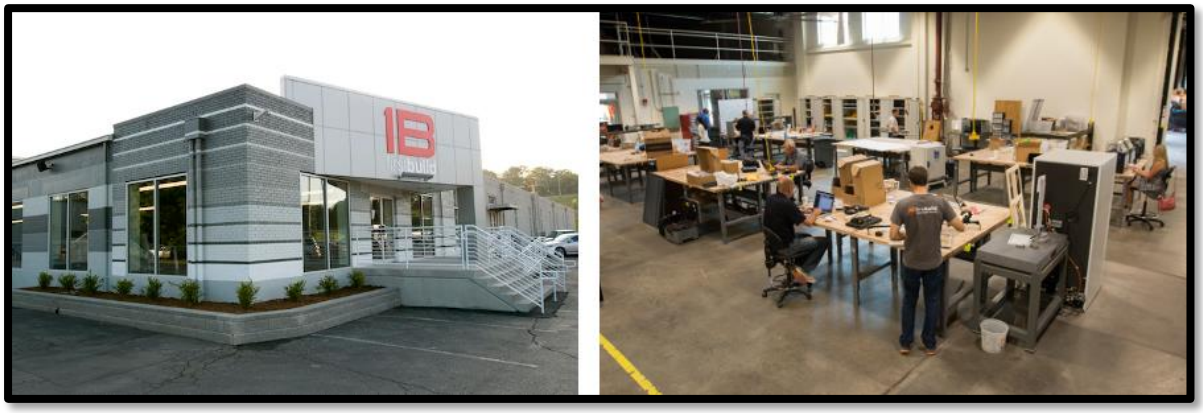

Figure 3: Part of FirstBuild's open workspace shown here (right).

Formed by GE Appliances, Local Motors, and the University of Louisville, FirstBuild, a microfactory, is a place for builders, makers and hackers to come together to bring their ideas to life. Having ties with the University, FirstBuild is excited to engage the team members in professional manufacturing practices and allowing them to use their equipment to build any necessary components. One past team member is currently employed there and will be the point of access to the machine shop for the team. Major equipment items include:

- 3-axis Haas CNC Mill
- OMAX Abrasive Waterjet
- Media Blaster
- Horizontal Band Saw
- Vertical Band Saw
- Haas CNC Lathe
- Sheet Metal Brakes
- Various Hand Tools
- 24”x48” Universal Laser Cutter
- 50 Ton Press

- 2 Metal Lathes
- Miter Saw
- Drill Press
- Surface Grinders
- 4 MakerBot 3D Printers
- Various Hand Tools
- Drills
- Soldering Equipment
- Air Compressor
- Objet 3D Printer

Samtec, Inc. Machine Shop:

As a team sponsor last year, Samtec Inc. has agreed to allow the team to use their extensive machine shop resources. One team member is currently employed there and will have 24 hour access to these facilities. A full staff of professional machinists is also available for advice, help, and advanced machining that is unable to be performed by students. Major equipment items include:

- 6 Bridge Port Mills
- Vertical Band Saw
- 2 Metal Lathes
- Miter Saw
- Drill Press
- 4 Surface Grinders
- Horizontal Band Saw
- 50 Ton Press
- Various Hand Tools
- Drills
- Soldering Equipment
- Air Compressor

Figure 4: From left to right: Bridgeport mill, surface grinder, and a metal lathe.

LVL1

LVL1 (pronounced “level one”) is a hackerspace. This is an open community lab and workshop located in Louisville, Kentucky that is democratically operated by its membership. LVL1 is accessible to the public at large as long as an official member is present at the space. Members can access LVL1 24 hours a day using a building key. The team will maintain a membership at LVL1 throughout the build phase of the season. This allows the team unlimited access to LVL1 any time. Major equipment items include:

- CNC Table
- Table Saw
- 40W CO_2 Laser Cutter
- MakerBot 3D Extruder Printer
- Pneumatic Tool System
- Router
- Chop Saw
- Wood Lathe
- Welder
- Soldering Irons
- Anti-Static Mat
- Miter Saw

Rapid Prototyping Facility

The Rapid Prototyping Facility is used in support of our sponsoring industrial consortium and student design projects. The facility creates prototypes and moldings from nylon, glass-filled nylon, polycarbonate, and varying metals using scanning lasers in a material layering process. Access is only granted to official university personnel upon request.

Lutz Micro/Nano Technology Center

The Lutz Micro/Nano Technology Center (MNTC) is composed of three core facilities:

- State-of-the-art class 100/1000 cleanroom for prototyping miniature devices and systems divided into 7 dedicated bays with advanced micro/nano fabrication equipment.
- MEMS Modeling and TCAD Lab for the design, layout, and simulation of micro/nano devices.
- Micro/Nano Post-Processing Lab for packaging and testing of completed components

All three micro/nanotechnology core facilities are utilized for both research and instructional purposes. They provide a state-of-the-art environment for the fundamental and current fabrication techniques used to manufacture integrated circuits (ICs), discrete microelectronic devises, MEMS devices such as sensors and actuators, and various electro-optic devices. Access is only granted to official university personnel upon request.

Supporting Airfields

The surrounding NAR and TRA chapters have given permission to River City Rocketry team to utilize their airfields which are all located within 1.5 hours from the university. The local chapters also have monthly launches at their fields with FAA clearance to fly at or above Level 2 altitudes.

2) Computer Software

Dahlem Supercomputer Laboratory

This laboratory was provided by the Vogt Engineering Center to support the research and instructional missions of the Speed Scientific School. The main feature of this facility is Adelie, a supercomputer available to all Speed School engineering students. Adelie is a 64 bit Linux cluster parallel system based on the Opteron processor. The system currently consists of 28 nodes with a total of 94 processor cores, 192 Gigabytes of memory, 2.2 Terabytes of disk storage, and 329 Gigaflops of aggregate processor speed.

Another part of the facility is the Access Grid Node, which is an internet-based system for world-wide video conferencing developed by Argonne National Laboratories. The

laboratory also hosts 30 computers with similar software as that is used in the Kurz Laboratory, accommodation for individual laptops, and printing equipment.

Students are able to access this laboratory from 8am-5pm on weekdays or by request.

Speed School Software Bundle

Any enrolled engineering students have access to an external website where they may download several software packages for personal use. The software available for students includes:

- Microsoft Office 2013 Suite
- Maple
- Matlab
- Minitab
- Mathcad
- SolidWorks with Simulation and Flow Simulation
- MS Project and MS Visio
- Microsoft Visual Studio
- NI Circuit Design Suite
- LabVIEW
- ANSYS 16 with Workbench 2.0
- Engineering Equations Solver

Web Conferencing Capabilities

Conference and lecture rooms are open to students, upon reservation, for conference calls, and/or presentations. Each room comes equipped with a desktop computer with internet access, a conference telephone with speaker phone, and a projector or large screen TV. A webcam can be obtained from an engineering department or borrowed from the team's advisor. Software to run WebEx can easily be installed on any computer without special permissions.

3) Website Compliance

The team website is www.rivercityrocketry.org. While the primary functionality of the website required by the competition is to host team documents, the team understands the value of an engaging and informative website. The following are additional features of the website:

- Keep public up to date on the project with project updates.
- Inform educators of available educational outreach programs.
- Bank of articles, pictures, and videos from the team.
- Link to social media outlets.
- Team member pictures and bios.
- History of team documentation.

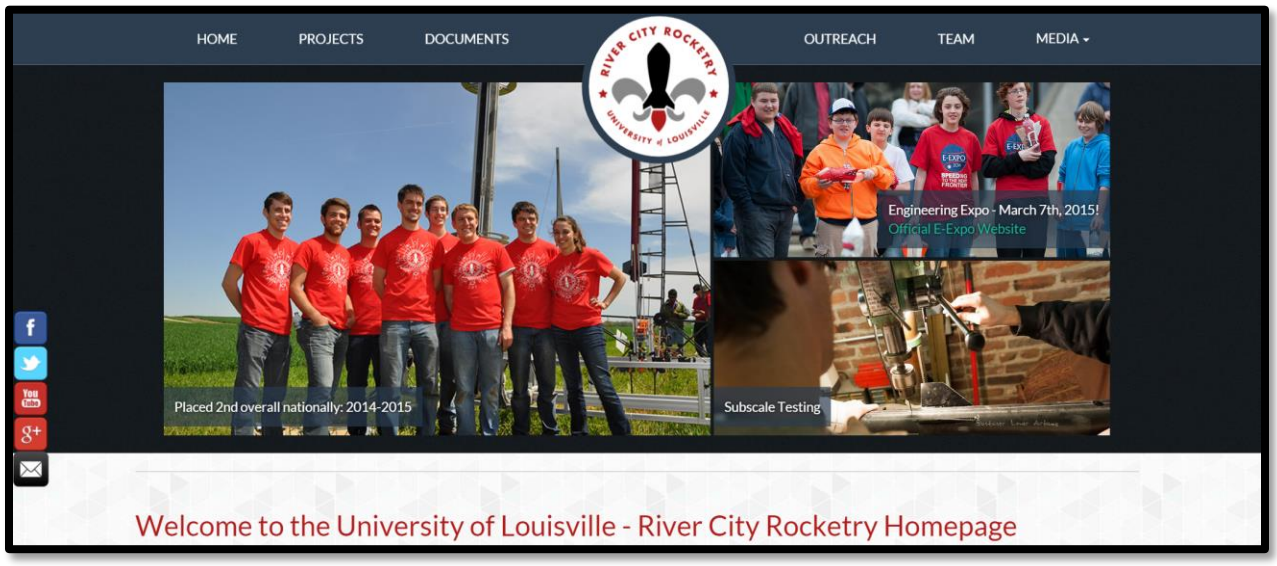

Figure 5: RiverCityRocketry.org home page.

The backend coding of the website will be completed using PHP with MySQL as a backend. The front end will just encompass the basic HTML/CSS/JQuery model. The hosting of the website will be done on University of Louisville - JB Speed School of Engineering servers that we gained access to from the computer science department.

Section 3. Safety

4) Safety Plan

Safety Officer Responsibilities

Emily is the safety officer for the River City Rocketry team during the 2015-2016 season. She is responsible for ensuring the overall safety of the team, students and public throughout all team activities, as well as assuring compliance with all laws and regulations. The following are the Safety Officer's specific responsibilities:

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

Emily has written a team safety manual that each team member is required to review and sign indicating compliance. The document includes hazards, proper safety plans and procedures, PPE requirements, MSDS sheets, FAA laws, and NAR and TRA regulations. The manual will be revised throughout the year as a need arises. Emily is responsible for making sure that each team member has read and acknowledged the safety manual

and will continue to enforce all statements in the safety manual. The manual can be found on the team website so that it is easily accessible for all team members at all times.

Hazard Analysis

Risk Assessment Matrix

By methodically examining each human interaction, environment, rocket system and component, hazards have been identified and will continue to be brought to the team's attention. Each hazard has been assigned a risk level through the use of a risk assessment matrix, found in Table 4 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 2.

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 2: 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 (PPE) 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 3.

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 3: 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 4. 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-High	5-Moderate
Likely-(2)	3-High	4-High	5-Moderate	6-Moderate
Moderate-(3)	4-High	5-Moderate	6-Moderate	7-Low
Unlikely-(4)	5-Moderate	6-Moderate	7-Low	8-Low
Improbable-(5)	6-Moderate	7-Low	8-Low	9-Low

Table 4: 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 in the hazard matrices located in the appendix.

Some risks are currently unacceptably high. This is because all risks have been identified and addressed through preliminary concept design work and 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, verifying the safety of 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 are risks present from working with machinery, tools, and chemicals in the lab.

Launch Pad Functionality Risk Assessment
The hazards outlined are risks linked to the launch pad functionalities of the AGSE. Due to the high importance of a stable launch tower, the system will be rigorously tested prior to any launches.

Vehicle Actuation Device Risk Assessment
The hazards outlined in this section will discuss the risks associated with the vehicle actuation device. Risks will be considered for when the system is both non-operational and operational.

Igniter Installation Risk Assessment
The hazards outlined in this section will discuss the risks associated with the autonomous igniter installation process. This is of particular concern since the team does not want to risk a premature ignition of the motor.

Ground Station Risk Assessment
The hazards outlined 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 Capture Device Risk Assessment
The hazards outlined in this section will discuss the risks associated with the payload capture device. The payload capture device interfaces with multiple systems, making it prone to hazards.

Main Controller Risk Assessment
The hazards outlined in this section will discuss the risks associated with the main controller for the AGSE. The main controller is responsible for all electrical systems on board the AGSE so any hazards to this device are critical.

Master Controls Risk Assessment
The hazards outlined in this section will discuss the risks associated with the master controls for the AGSE. This is critical as failures in any system will result in a failed mission or could yield severe personnel hazards.

Stability and Propulsion Risk Assessment
The hazards outlined 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 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.

Vehicle Assembly Risk Assessment
The hazards outlined are risks that could potentially be encountered throughout the assembly phase and during launch preparation.

Environmental Hazards to Rocket Risk Assessment
The hazards outlined 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 are risks that construction, testing or launching of the rocket can pose to the environment.

Launch Procedures
The safety officer is responsible for writing, maintaining, and ensuring the use of up to date launch procedures. These are critical to ensure the safety of personnel, spectators, equipment and the environment. Checklists are to be used for any test launch.

The checklists are broken up into checklists for each subsystem for pre-launch day as well as launch day. This allows the team to keep organized and prepares the team for a quick and efficient launch prep on launch day. Each subsystem checklist must be 100%

complete and be signed by a representative of that subsystem. Checklists are then collected by the safety officer and the overall final assembly checklist can be started. After completion of the final assembly, all sub-team leads, captains and the safety officer must approve the rocket as being a go for launch. The “at the launch pad” checklist is then completed and personnel are assigned tasks of tracking each section of the rocket during recovery.

Each checklist thoroughly written in order to set the team up for a safe and successful launch. Each subsystem checklist includes the following features to ensure that assemblers are prepared, safe, and recognize all existing hazards:

- Required equipment list
- Required hardware
- Required PPE
- ⚠**CAUTION** – label to identify where PPE must be used.
- ⚠WARNING - label to signify importance of procedure by clearly identifying a potential failure and the result if not completed correctly.
- ⚠ DANGER - label to signal the use of explosives and indicates specific steps that should be taken to ensure safety.

5) 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	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

not allow smoking, open flames, nor heat sources within 25 feet of these motors.	safety in the team lab manual that the entire team is responsible for understanding.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	All launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any safety issues.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its batter and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The team will comply with this rule and any additional precautions that the Range Safety Officer makes on launch day.
6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants 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.	The teams AGSE will function as the launch pad for the rocket. The AGSE will be rigorously tested for stability before a launch will be allowed. The length of the tower will be designed to ensure that in

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.	any allowable wind condition, the rocket will be able to attain a rail exit velocity that will ensure a stable flight. The AGSE will have a blast deflector integrated into the design. The team will be familiar with and comply with the minimum distance table at all launches.
8. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.
9. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams and a maximum expected altitude of less than 610 meters (2000 feet).	All team launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any rocketry safety issues.
10. **Launcher Location.** My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the	The team will comply with this rule and any determination the Range safety Officer makes on launch day.

appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	
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 5: NAR safety code compliance.

6) 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
- 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. In order to prevent an accident, a thorough safety checklist will be created and will be reviewed on launch day. 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 she determines anything to be unsafe or at a high risk level.

7) Local/State/Federal Law Compliance

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

8) 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.

9) Safety Compliance Agreement

The University of Louisville River City Rocketry team understands and will abide by the following safety regulations declared by NASA. The following rules will be included in the team safety contract that all team members are required to sign in order to participate in any builds or launches with the team.

1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.
2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.
3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

Section 4. Integration

Integration is a crucial aspect of the project. Without taking into consideration how integration plays a roll between each of the sub-subsystems, the project is bound to not work together. The team addressed this risk at the beginning of the project. This kept everyone on the same page from the beginning and prevents having to backtrack and redesign at the last minute to make sure that the systems work together.

In order to successfully design and build a system that integrates properly, a set of project requirements were defined by the team leads. This included AGSE electrical and mechanical, vehicle, recovery and integration team lead's input. The following guidelines were set at the beginning of the design process:

AGSE:

- Weight limit: 125 lb
- 2in dimension tolerance to be added to all dimension requirements set by NASA.
- Time to complete autonomous tasks: 5 minutes
- Rail length: 10 ft

Vehicle

- 3 fins
- 6 inch airframe transitioned to the 4 inch airframe
- Fin diameter: 17 inch max
- Can contain 75mm motor
- Rocket Length: 11 ft.

As different integration issues come up, the project requirements will be added to and modified. However, requirements that have been set cannot be changed without the consensus of all sub-team lead's agreement on the change. This ensures that all team members are on the same page with regards to potential integration issues. This has been and will continue to be the team's mitigation plan for integration issues.

Integration concerns that are contained within sub-systems will be maintained by their respective subsystem. Until the issue relates to another sub-system, will it be mitigated via the group of team leads. The integration concerns that are independent to each sub-system are discussed in their respective sections.

Section 5. Technical Design: Vehicle

1) Design and Verification of Launch Vehicle

Design Overview

The primary focus for the launch vehicle is efficiency of the design. The strict adherence to efficiency will allow the team to revamp and innovate previously used designs while still posing challenges to both design and fabrication. Because of the refurbishing of previous designs, the team can focus on making previous designs more efficient as well as pushing the team to use the highest quality and precision in all components of the launch vehicle.

Figure 6 shows the basic layout of all launch vehicle subsections: nose cone bay, recovery bay, payload bay, transition, and propulsion bay.

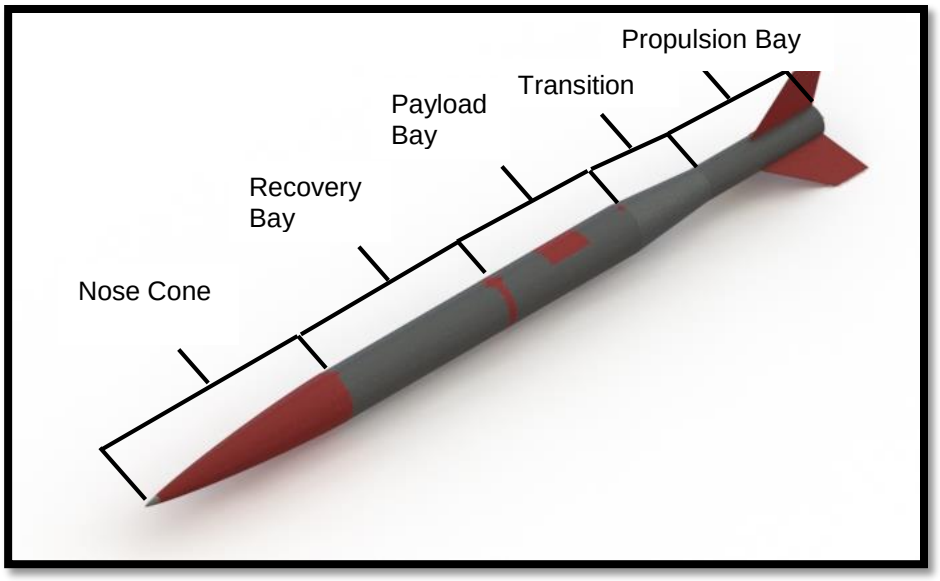

Figure 6: Full scale launch vehicle.

The launch vehicle will be constructed primarily of carbon fiber airframe, featuring a removable fin system, utilizing all internal space with maximum efficiency, and having a single reefing recovery system. Flight success for the launch vehicle is defined using the following requirements:

1. Rail exit velocity of the rocket shall exceed 55 ft/s.
2. The launch vehicle shall attain an apogee of 5,280 ft with zero anomalies.
3. All recovery events shall occur at the programmed altitudes.
4. All vehicle sections shall land under mandated kinetic energy requirements.

With the above points accomplished, the flight and recovery of the launch vehicle will be deemed a success.

Applicable formulas

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

$$m_a = m_r + m_e - \frac{m_p}{2} \quad (1)$$

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

$$k = \frac{1}{2}\rho C_D A \quad (2)$$

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

$$q_1 = \sqrt{\frac{T - m_a g}{k}} \quad (3)$$

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

$$x_1 = \frac{2kq_1}{m_a} \quad (4)$$

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

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

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

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

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

$$m_c = m_r + m_e - m_p \quad (7)$$

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:

$$q_c = \sqrt{\frac{T - m_c g}{k}} \quad (8)$$

$$x_c = \frac{2kq_c}{m_c} \quad (9)$$

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

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

The coasting distance can then be computed using

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

The peak altitude is then determined using

$$PA = y_1 + y_c \quad (12)$$

The center of gravity location is calculated using

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

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

$$X = \frac{(C_N)_N X_N + (C_T)_T X_T + (C_N)_F X_F}{(C_N)_N + (C_N)_T + (C_N)_F} \quad (14)$$

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

$$X_N = \frac{2}{3} L_N \quad (15)$$

where L_N is the nose cone length. C_{NT} in equation 14 is the center of pressure of the Conical Transition, calculated using

$$(C_N)_T = 2\left[\left(\frac{d_R}{d}\right)^2 - \left(\frac{d_F}{d}\right)^2\right] \quad (16)$$

where d_R is the rear diameter of the transition, d_F is the fore diameter of the transition, and *d* is the diameter at the base of the nosecone. X_T in equation 14 is calculated using

$$X_T = X_P + \frac{L_T}{3}\left[1 + \frac{1 - \frac{d_F}{d_R}}{1 - \left(\frac{d_F}{d_R}\right)}\right] \quad (17)$$

where X_P represents the distance from the tip of the nosecone to the fore of the transition, and L_T is the length of the transition. C_{NF} in equation 14 is the fin center of pressure coefficient calculated using

$$(C_N)_F = \left[1 + \frac{R}{S+R}\right]\left[\frac{4N\left(\frac{S}{d}\right)^2}{1+\sqrt{1+\left(\frac{2L_f}{C_R+C_T}\right)^2}}\right] \quad (18)$$

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

$$X_F = X_B + \frac{X_R(C_R+2C_T)}{3(C_R+C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{(C_R C_T)}{(C_R+C_T)}\right] \quad (19)$$

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).

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 payload within its airframe. The payload will be located directly above a conical transition. This transition to a lower diameter airframe will facilitate efficiency of the rocket. The reduction in diameter will reduce the weight housed in the lower section of the rocket, thus raising the center of gravity of rocket and increasing stability.

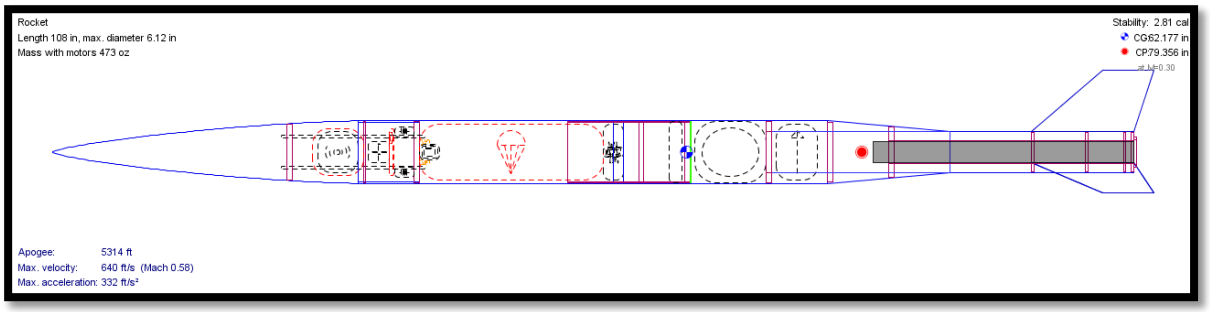

Figure 7: OpenRocket simulation of 2015-2016 launch vehicle.

Figure 7 shows the launch configuration of the launch vehicle. The vehicle is designed such that the payload system and adjustable ballast will be located directly above the airframe transition at the center of gravity. The figure also shows a single recovery bay. This recovery configuration was chosen in order to reduce the uncertain masses of the rocket. The recovery schematic will be discussed in Section 6.

For stability, the rocket will use three swept clipped delta fins. The swept clipped delta fins were chosen due to the known efficiency of their shape. Further analysis will be performed to verify efficiency and flow characteristics of the fin shape. The tip and root chord lengths are 5 inches and 10 inches respectively, providing a stability margin of 2.8

with the motor installed. Although four fins typically provides better aerodynamic qualities than three fins, the chosen configuration will be used to provide larger clearance for insertion of the payload into the launch vehicle.

Airframe

The launch vehicle airframe will be constructed from 6 inch diameter filament wound carbon fiber. Using a 4-axis X-winder composite winder, 6k carbon fiber tow will be wound to obtain a maximum wall thickness of 0.06 inches. As a result of the airframe being custom wound, the structural properties are unknown. Therefore, the airframe shall be tested prior to use in the launch vehicle to determine the characteristics of the composite and verify the integrity of the chosen wall thickness.

Nose Cone Design

The Von Karman Nosecone, seen in Figure 8 was chosen due to its performance and efficiency at subsonic speeds.

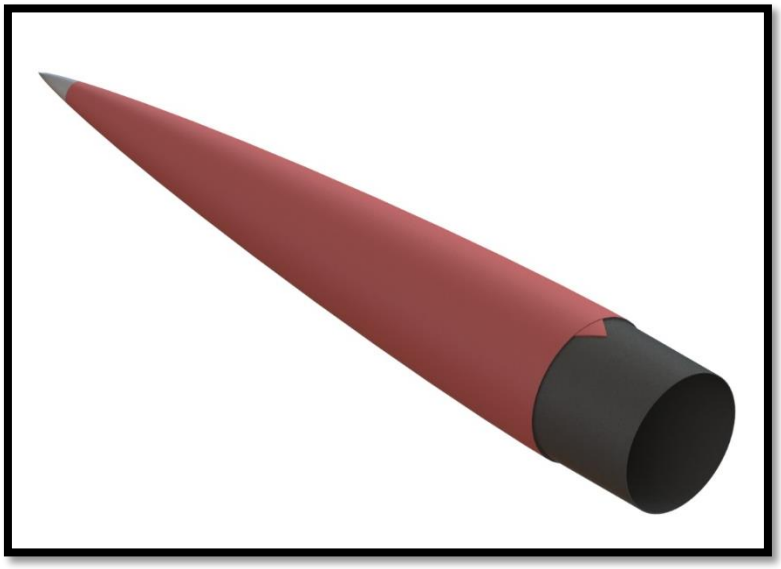

Figure 8: Von Karman nosecone.

The internal dimensions of the Von Karman nosecone allows for the containment of an avionics bay, thus allowing an efficient use of space. Fiberglass was chosen for the nose cone material to avoid signal attenuation of the GPS tracking device installed in the launch vehicle.

The launch vehicle will be constructed by strictly adhering to proven manufacturing processes. All separating sections of the launch vehicle shall be joined to their respective coupler with 4-40 nylon shear pins. Similarly, sections which will not be separating through the course of the flight will be joined with 6-32 UNC BHSCS. Different threads have been selected for the separating and non-separating sections in order to prevent accidental installation of metal screws into separating joints and vice versa.

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 6.

Glenmarc's G5000 Epoxy	
Tensile strength	7,6000 psi
Compression strength	14,800 psi
Shore "D" Hardness	85
Elongation at break %	6.30%

Table 6: G500 epoxy material properties.

Ballast System Design

Prior to manufacturing, the team must rely solely on the OpenRocket simulation and hand calculations to estimate projected altitude and flight characteristics of the launch vehicle. Experience tells that the true weights of components may vary from their originally predicted, calculated, and researched values. The change in weight has the possibility of changing the overall weight of the launch vehicle. In order to achieve the target altitude, an overall mass of 415 oz. was selected. Current predictions for the weight of the launch vehicle prior to ballast are 394 oz., allowing for a growth of 21 oz. in the overall weight of the launch vehicle. In the absence of this additional manufacturing weight, a weighted ballast system has been designed to increase the weight of the launch vehicle to the desired 415 oz.

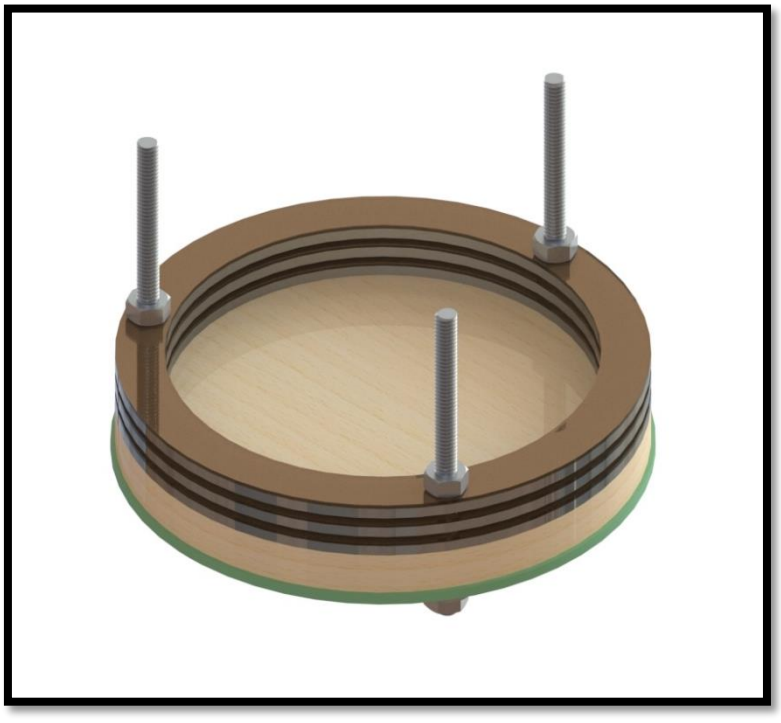

Figure 9: Rendered image of the payload bay ballast system.

The primary design goal of the ballast system is to ensure the launch vehicle has an exact weight and center of gravity to reach the target altitude. Secondary to weight, the design is such that it will not interfere with any other section, namely that of the payload bay. The ring design of the masses allows for smaller incremental weight increases while still providing space for the addition of a camera array manufacturing allows.

The ballast system consists of three components:

1. AISI 1018 low carbon steel weighted rings
2. Silicone rubber ballast spacers/dampeners
3. ¼”-20 UNC-3A threaded rod

Figure 10 shows the detailed drawing for the weighted rings to be used in the ballast system.

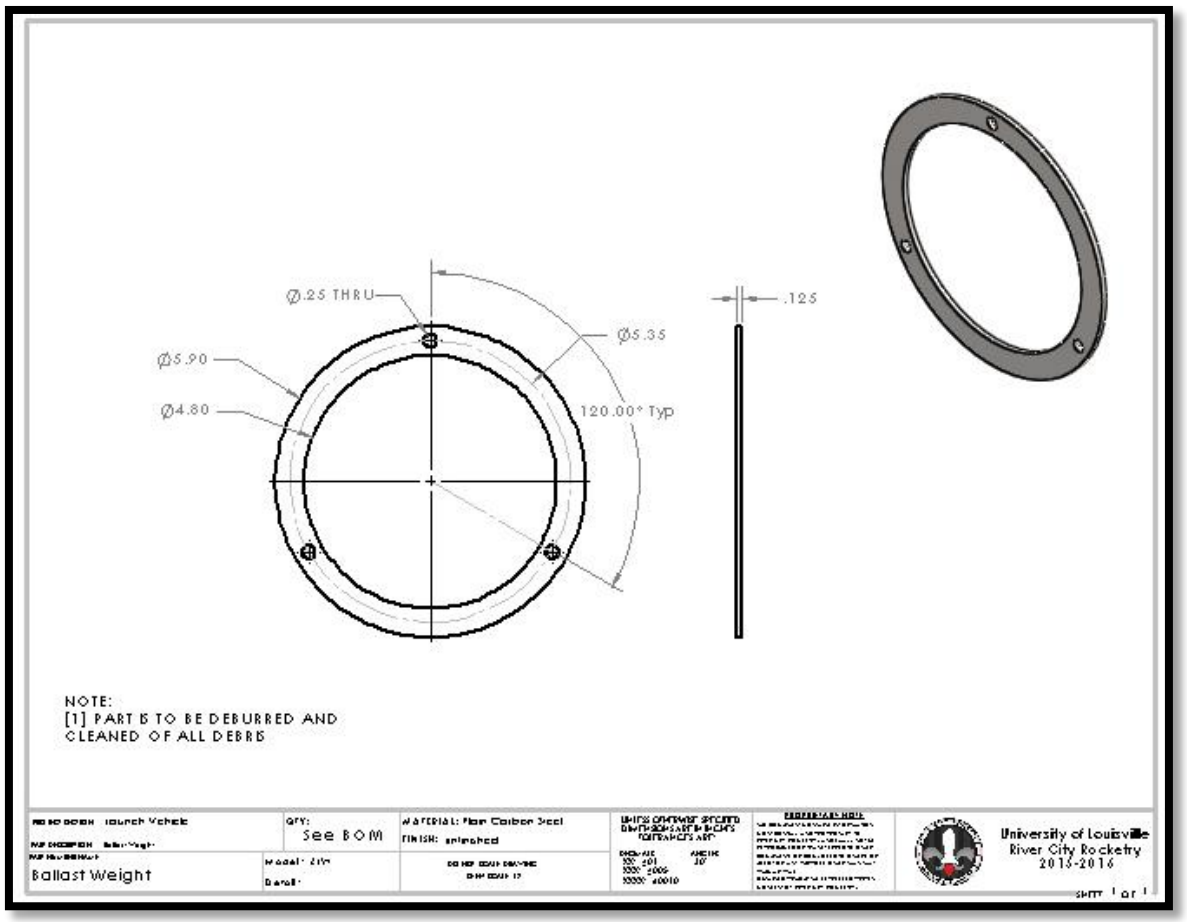

Figure 10: Detailed drawing of ballast weighted ring.

Figure 11 shows the detailed drawing of silicone rubber ballast spacer and dampener.

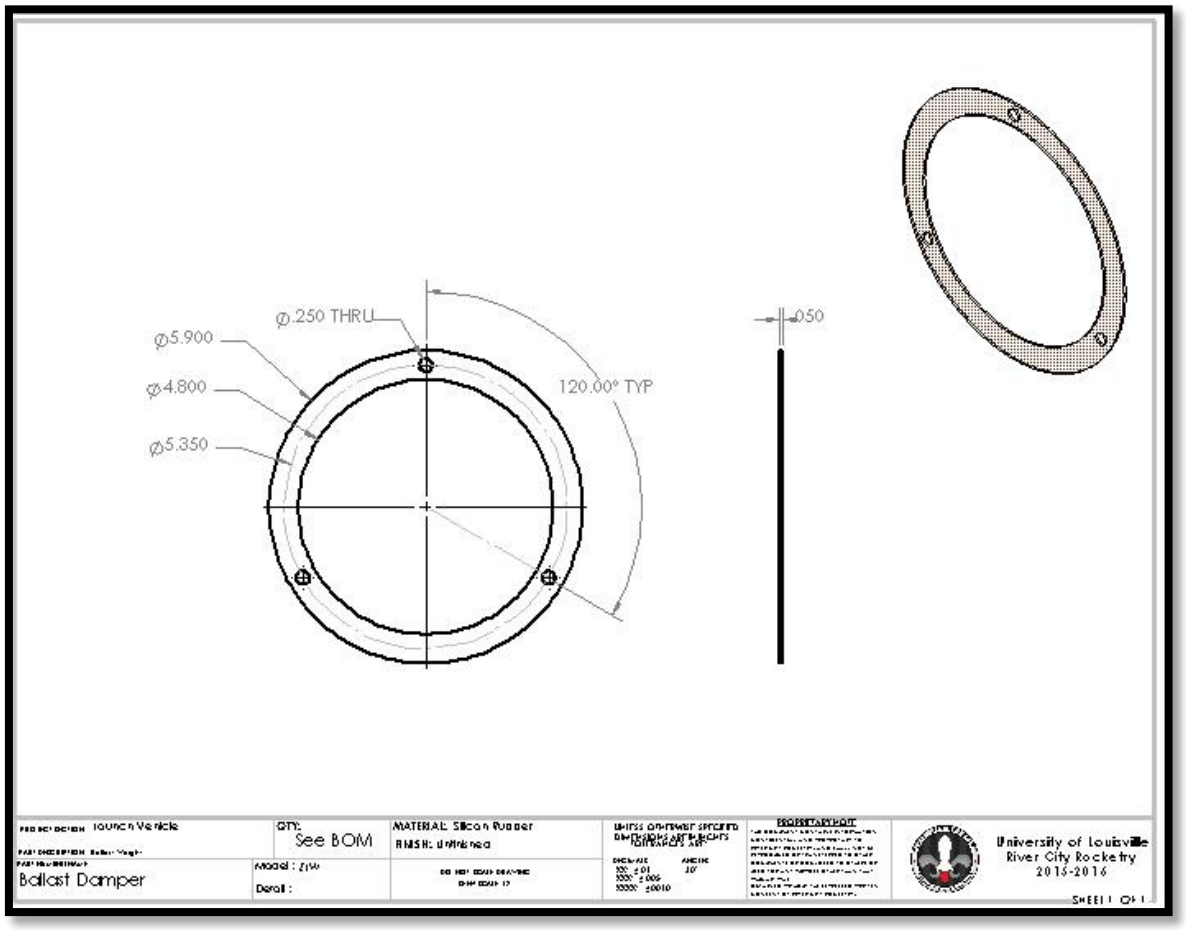

Figure 11: Detailed drawing of ballast spacer/dampener.

The inclusion of the ballast spacer/damper was to reduce any and all vibrations that could occur during powered ascent of the launch vehicle. The spacer also acts to reduce any gaps present from non-coplanarity of the steel rings. The material thickness for the steel was chosen to allow slight adjustments in weight of the rocket to achieve the target 405 oz. Table lists the adjustable masses of the 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/dampener	Silicone rubber	0.045 lbs/in^3	0.019 lbs

Table 7: Ballast component properties.

Following construction of the launch vehicle, all components weights shall be measured to determine the exact weight of the rocket. The ballast weights and spacers can then be added in such a manner as to achieve the required 405 oz.

Propulsion Bay Design

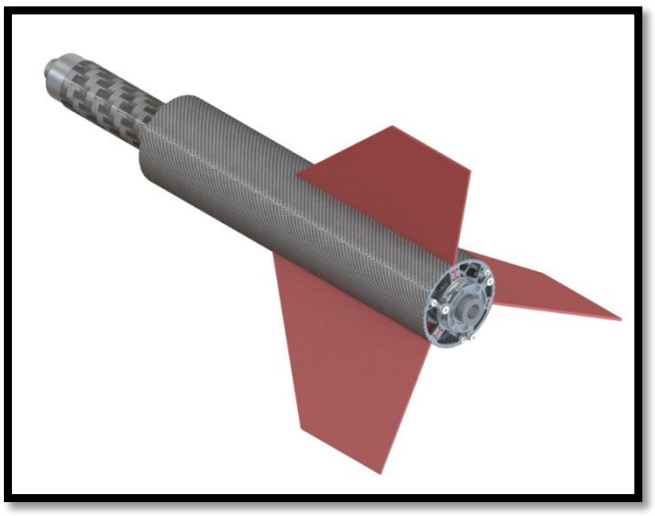

Figure 12: Propulsion bay assembly.

Two primary goals will be completed by the propulsion bay:

1. Serve as the attachment point for the removable fin system.
2. House the motor and motor casing to propel the launch vehicle.

Airframe

The propulsion bay airframe will be constructed from 4 inch diameter filament wound carbon fiber tubing. The fin slots will be precision cut using a 4-axis Haas CNC mill. Due to the compressive nature of filament found tubing, an insert jig will be designed to hold the original round shape of the tubing while the fin slots are being machined.

Motor Tube

The motor tube will be constructed from 2.13 inch diameter filament wound carbon fiber tubing. The motor tube will be cut to a length of 24 inches, allowing for 1.75 inches of motor overhang.

Removable Fin System

In order to reduce weight and remove epoxy joints, a precision fin mounting system has been designed for the launch vehicle. This system will eliminate the possibility of damaging fins or epoxy joints during transportation of the launch vehicle, which could result in an inability to launch. Additional fins will be readily available at launch, allowing for any damaged fin to immediately be replaced prior to the launch of the vehicle.

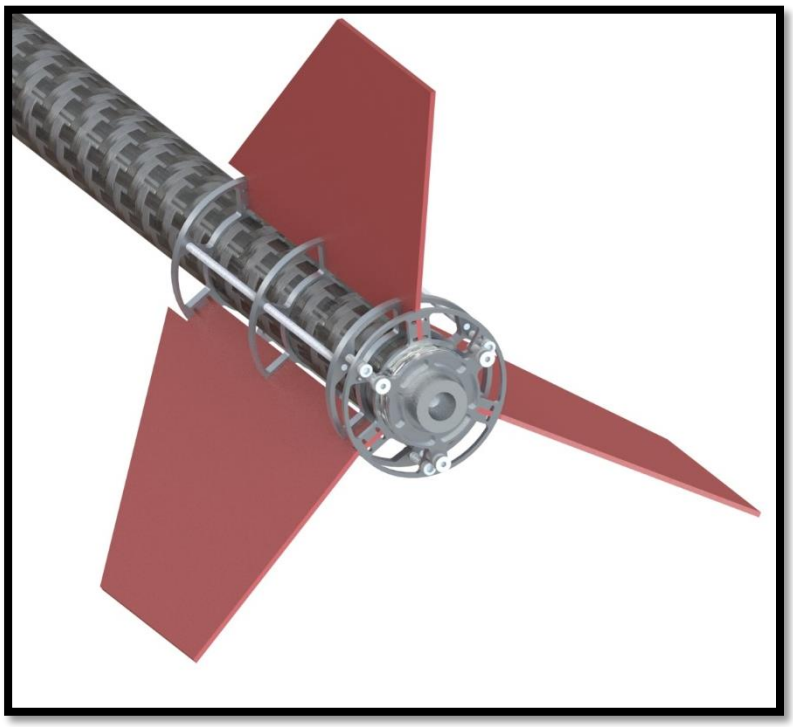

Figure 13: Removable fin system assembly (airframe removed for clarity).

Figure 13 shows an assembled rendering of the removable fin system as it will appear in the propulsion bay prior to launch. The assembly consists of three centering rings, a rear fin retainer, and a motor casing retainer. The centering rings will be the only components epoxied to the motor mount tube and airframe. Proper alignment of the centering rings is paramount to the success of the removable fin system. To ensure proper alignment, three #10-24 UNC-2A 6061 Aluminum threaded rods will connect the centering rings. These threaded rods will also act to transfer thrust from the motor to the mid and fore centering rings during powered ascent.

The fin retainer will mount to the aft centering ring via three #10-24 UNC-2A socket head cap screws 1 inch in length. With the motor installed in the casing and motor tube, the motor retainer will mount to the fin retainer via three #10-32 UNF-3A shoulder screws ¾ inch in length. All fasteners in the system will be made from 18-8 stainless steel. An exploded propulsion bay assembly is shown below in Figure 14.

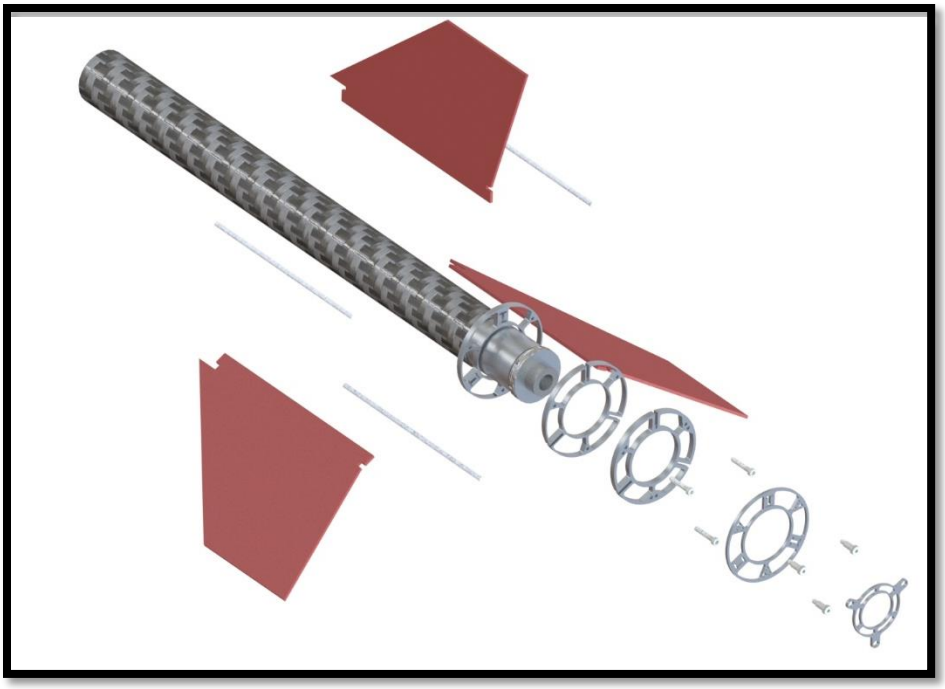

Figure 14: Exploded view of propulsion bay assembly.

The three centering rings are designed to house the fins. The mid and aft centering rings are designed for a pressed fitment of the fin. The fore centering ring is designed for the fin tab to slide into the ring, thus locking the fin in place, preventing the fin from being removed vertically as well as preventing fin waggle. The fin retainer is designed with a receptacle similar to that of the fore centering ring to hold the fin tight, while still allowing for removal of the fins when the threaded fasteners are removed.

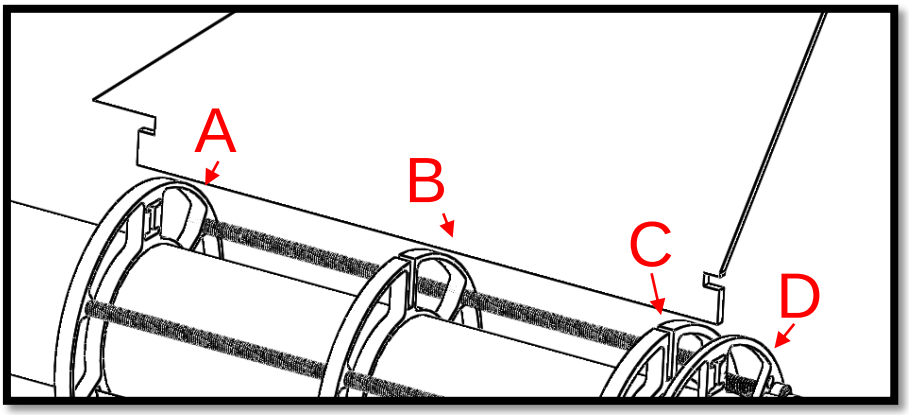

Figure 15: Highlight of four contact points of removable fin system.

Each fin will have four points of contact to the propulsion assembly:

A. Fore centering ring
B. Mid centering ring
C. Aft centering ring
D. Fin retainer

During installation, the fin is fit through the airframe into the mid and aft centering ring at point B and point C. Once the fin tab has bottomed on the centering ring, the fin will be pressed forward into the fore centering ring at point A. The fin retainer is then assembled unto the rear fin tab and attached via the threaded fasteners. Once installed, the threaded fastener will hold the fin retainer rigidly in place, thus fully containing the fins for launch.

Centering Ring Design

The centering rings are to be machined from 6061-T6 aluminum. The design of each centering ring is such that the initial machining will be performed by an OMAX abrasive waterjet. Once cut, each centering ring will be subjected to a secondary tapping process for threaded fasteners. Each centering ring is designed to have an interference fit between each fin and the centering ring slot, creating a single, ridged body. To reduce overall weight of the centering rings, each ring was subject to a design study and optimization. Figure 16, below, shows a rendering of the fore centering ring.

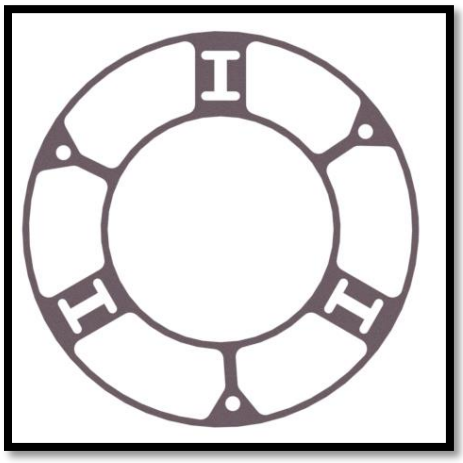

Figure 16: Front view of fore centering ring.

The fore centering ring has through slots for the insertion of the fins. Each slot is spaced 120^{o} radially, to equally space the launch vehicle fins. A detailed drawing of the fore centering ring is show in Figure 17.

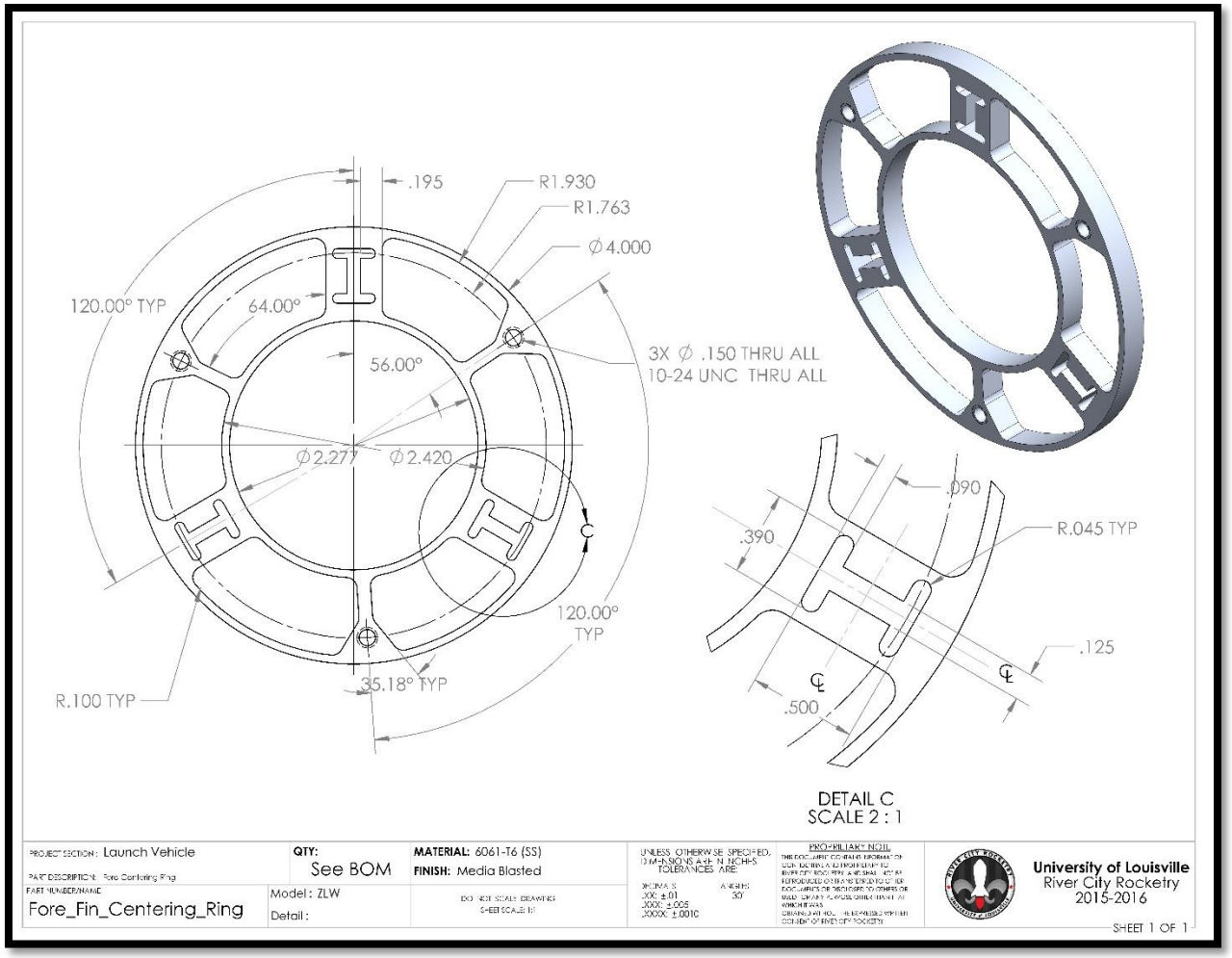

Figure 17: Detailed drawing of fore centering ring.

The centering ring has a 6 set of equally spaced weight reduction slots. While reducing weight, material removal also effected the strength of the section. To combat this issue, Finite Element Analyses (FEA) were performed for each centering ring as shown in Table 8. The percent of motor force carried by each load was determined based off of the loading distribution through the propulsion bay assembly.

Component	Load applied	% of motor force
Fore centering ring	567 N	33%
Mid centering ring	567 N	33%
Aft centering ring	1701 N	100%

Table 8: FEA parameters.

With the parameters outlined above, the fins were optimized to have an isolated factor of safety of 2.0. A sample displacement plot generated from the FEA static model is shown below in Figure 18.

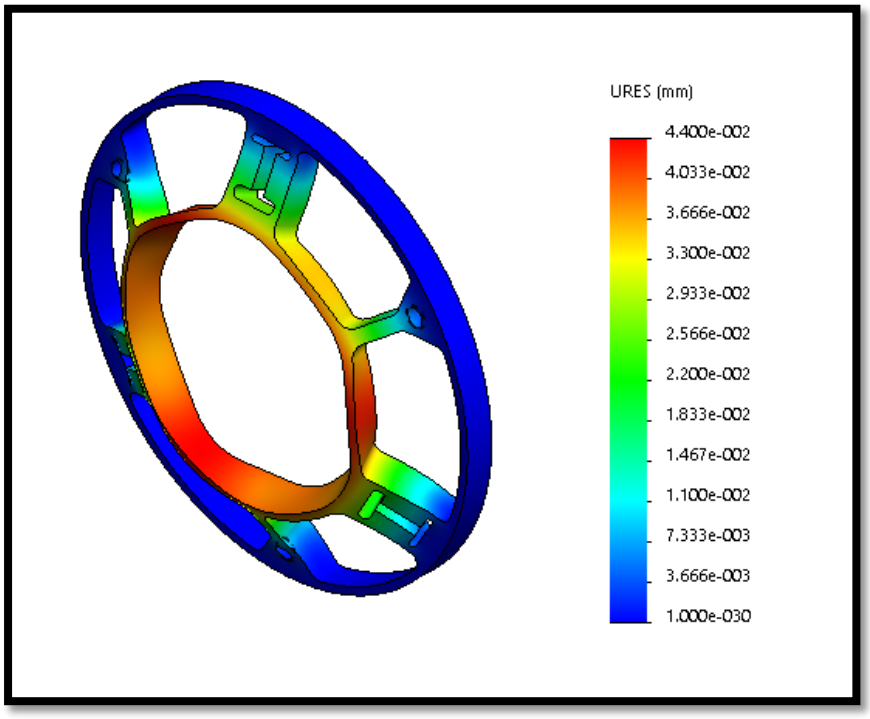

Figure 18: Finite element analysis displacement plot.

The design optimization yielded the following parameters for each centering ring as shown in Table 9.

	Maximum stress (MPa)	Maximum displacement (mm)	Minimum factor of safety
Fore centering ring	103.5	0.044	2.65
Mid centering ring	101.1	0.056	2.85
Aft centering ring	112.1	0.074	2.45

Table 9: Finite element analysis results.

Based upon the results of the FEA optimization, the team is confident in the structural design of the removable fin assembly. As outlined in the launch vehicle airframe section above, the material properties of the overall assembly are unknown. The structural integrity of the propulsion bay will be tested prior to the first full scale test of the launch vehicle.

Motor Retention

To properly secure the motor casing to the propulsion bay, a custom motor retainer has been designed. Since drogue recovery will not be facilitated by motor ejection, the motor retainer will be subjected to the following loads:

1. Supporting the weight of the launch vehicle while waiting for launch
2. Support the weight of the motor casing with motor installed
3. Withstand impact force of parachute deployment

Figure 19 shows a detailed drawing of the motor retainer.

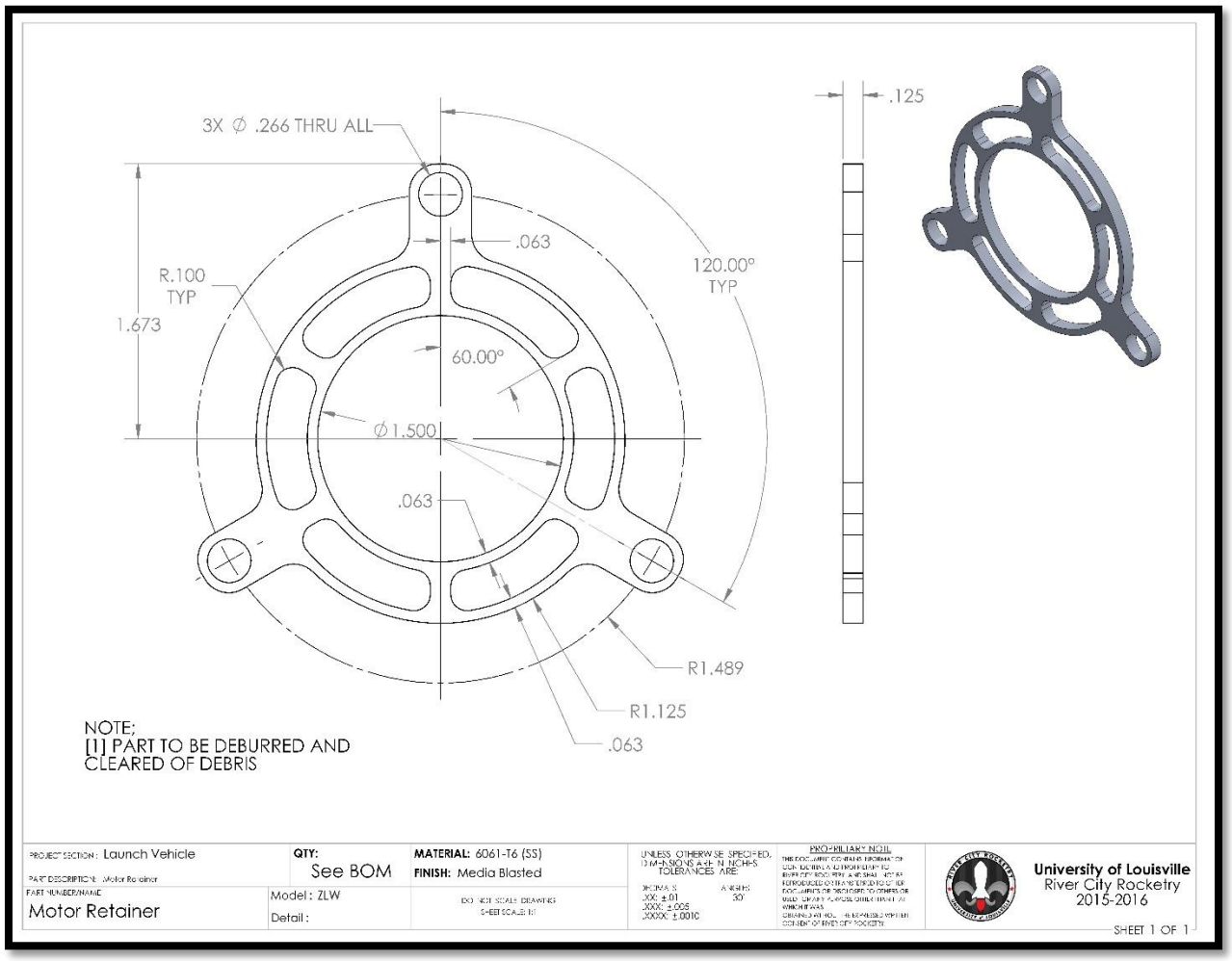

Figure 19: Detailed drawing of motor retainer.

Prior to motor installation, the launch vehicle fins and fin retainer must be installed. With the casing installed, the motor retainer will be attached to fin retainer via three #10-32 UNF-3A shoulder screws ¾ inch in length. The motor retainer will be machined from 6061-T6 aluminum, using an OMAX Abrasive Waterjet provide a tolerance of ±0.001 inches.

Fin Design

In order to reduce drag and better interface with the AGSE the launch vehicle will utilize 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 travel below supersonic speeds. The fins will be cut using an OMAX Abrasive Waterjet. This manufacturing method has been proven to be faster and more precise than traditional manufacturing methods. Figure 20 shows a detailed drawing of the launch vehicle fins.

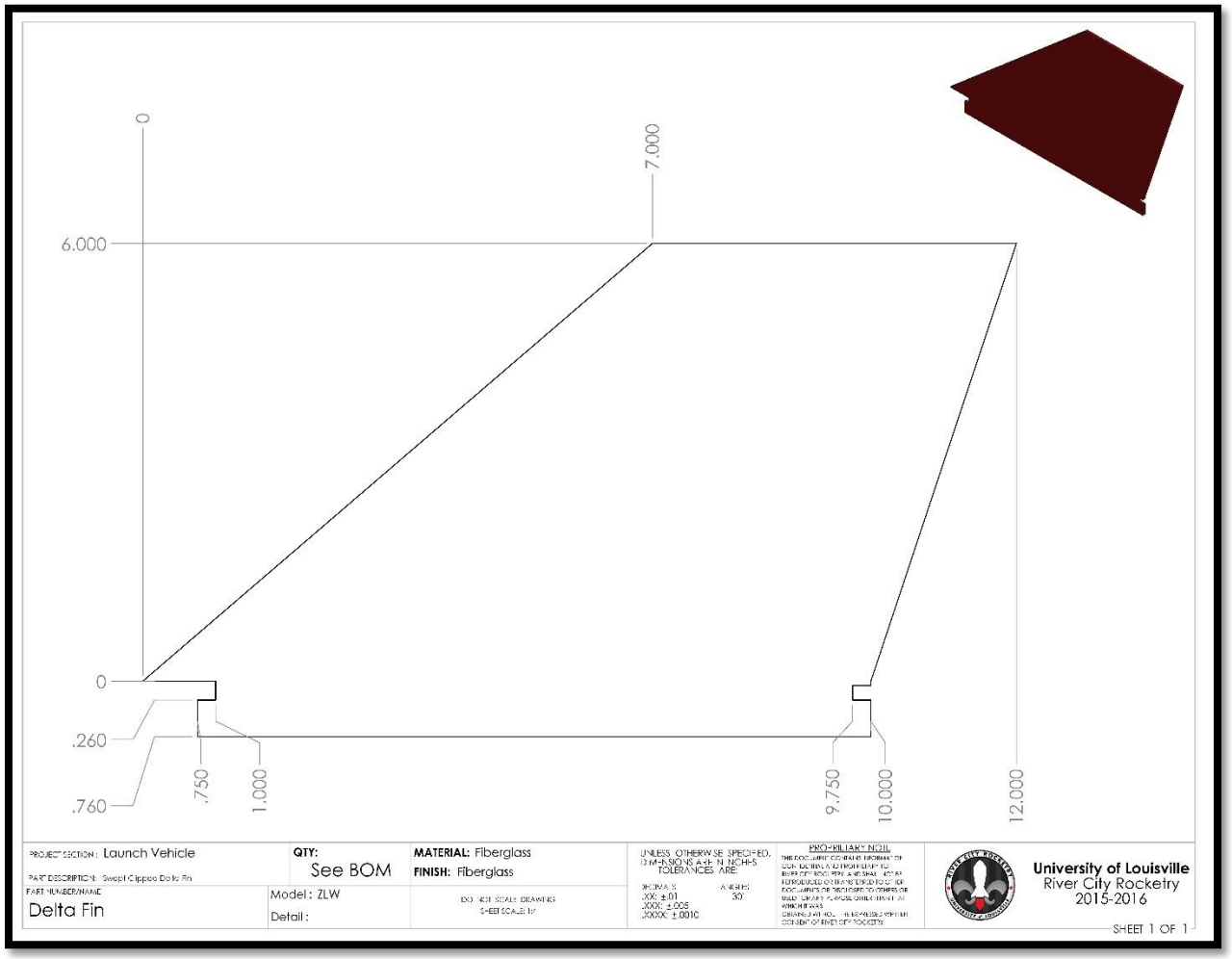

Figure 20: Detailed drawing of launch vehicle fins.

Table 10, below, shows a list of material and their properties to be used in the propulsion bay.

Material	Component	Characteristics
6061-T6 Aluminum	Centering ring Rear fin retainer Motor 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 mount tube	Density: 0.050 lbs./in^3 Tensile strength: 120,000 psi
18-8 Stainless Steel	Shoulder Screw Socket Head Cap Screw	Density: 0.290 lbs./in^3 Tensile Strength: 90,000 psi

Table 10: Component material of propulsion bay.

Subscale Testing

A subscale version of the launch vehicle will be constructed in order to test the flight characteristics and aerodynamic qualities of the vehicle. The subscale launch vehicle, shown below in Figure 21, is a one half scale model of the full size prototype.

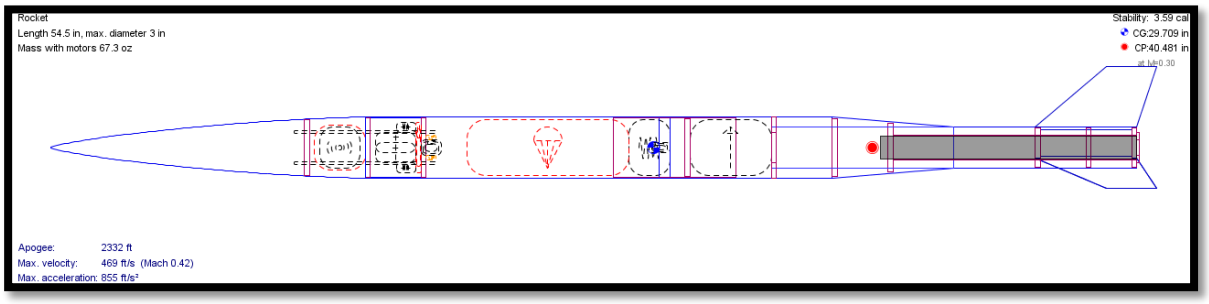

Figure 21: Subscale launch vehicle design.

The primary goal of the subscale test vehicle is to allow the team to test various designs which will be implemented into the full scale vehicle. The two primary designs to be tested are:

1. Structural integrity and aerodynamic properties of transition section
2. Custom reefing deployment parachute system and custom parachute design

To ensure a valid test of the above systems, achieving launch characteristics similar to that of the full scale launch scenario is paramount. Table 11 shows a comparison of the full scale to subscale flight characteristics.

Property	Full scale	Subscale
Diameter (in)	6	4
Length (in)	108	54.5
Empty mass (in)	383	56.9
Motor selection	CTI 3147-L935-IM-P	CTI 217-H170-BS
Stability caliber	2.81	3.71
Rail exit velocity (ft/s)	60.9	66
Maximum velocity (ft/s)	640	342
Maximum acceleration (ft/s^2)	345	342

Table 11: Comparison of full scale and subscale flight characteristics.

The team has designed the subscale launch vehicle to have a lower maximum velocity while maintaining a similar maximum acceleration and launch rail exit velocity. Due to the difference in flight time, no motor was suitable to provide similar velocity and acceleration characteristics to the full scale flight. For this reason, a lower velocity was deemed acceptable as the acceleration of the vehicle will provide greater stress to the launch vehicle.

2) Mission Performance Predictions

Performance Criteria

The following criterion must be met in order for the mission to be considered a success.

1) Rocket returns completely reusable without the need for repair.
2) An apogee of no more than 50 feet above 5,280 feet and no less than 5,180 feet is attained.
3) Horizontal drift of less than 1,000 feet is experienced with a wind speed less than or equal to 20 mph.
4) Vertical velocity does not exceed 0.65 mach.
5) Rail exit velocity is greater than 55 ft/s.
6) Kinetic energy of each separating section does not exceed 75 $ft\text{-}lb_f$.
7) The launch vehicle maintains a stability margin of no less than 2.5 during ascent

Overall Launch Vehicle Characteristics

In order to determine the overall flight characteristics of the launch vehicle, a model was created using OpenRocket. The following characteristics were obtained for the launch vehicle:

- Overall Length: 108.0 inches
- Maximum Body Diameter: 6.12 inches
- Overall Mass: 29.56 lbs
- Stability Margin: 2.81 caliber (From tip: CG - 62.18 inches, CP – 79.36 inches)

Figure 22, below, shows the design of the full scale launch vehicle.

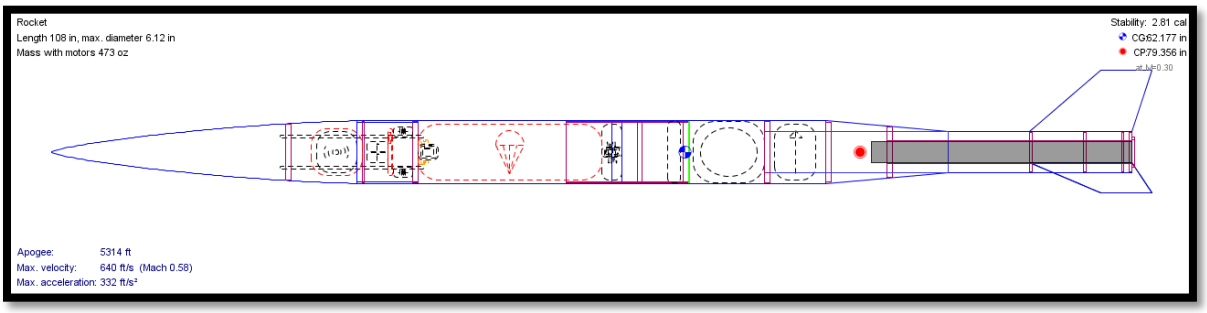

Figure 22: OpenRocket simulation of full scale launch vehicle design.

Critical Mass Components and Statement

Utilizing the software, OpenRocket, component masses from previous year, and estimations based upon component material densities, the mass of the launch vehicle was calculated. While not accounting for epoxy weight, the mass reflects maximum allowable mass of the rocket to achieve the target altitude. As stated in Ballast System Design section, the ballast masses will be adjusted to account for added epoxy weight during construction of the vehicle. Table 12, below, lists the weights of each section of the launch vehicle.

Section of launch vehicle	Length of section (in)	Mass (lbs)
Nose cone	30	6.40
Recovery bay	26	4.83
Payload bay	20	8.32
Transition	12	0.98
Propulsion bay	20	3.70
Motor	N/A	5.61
	Total mass	**29.84**

Table 12: Mass and length of critical launch vehicle sections.

The motor choice, defined in the following section, has been made with a maximum launch vehicle weight selected. The added weight will account for 17% growth in launch vehicle weight due to additional fasteners, epoxy joints, and miscalculated component masses. The team has deemed that 17% growth is an acceptable margin.

Motor Selection

The full scale launch vehicle will utilize a Cesaroni L935-IM solid Ammonium Perchlorate rocket motor. Based on the familiarity with motors from this supplier and with this particular motor, Cesaroni was the sole choice for motor selection. Cesaronin motors are known for their ease of use, reliability, and performance characteristics. A detailed thrust curve of the L935-IM's thrust versus time is shown below in .

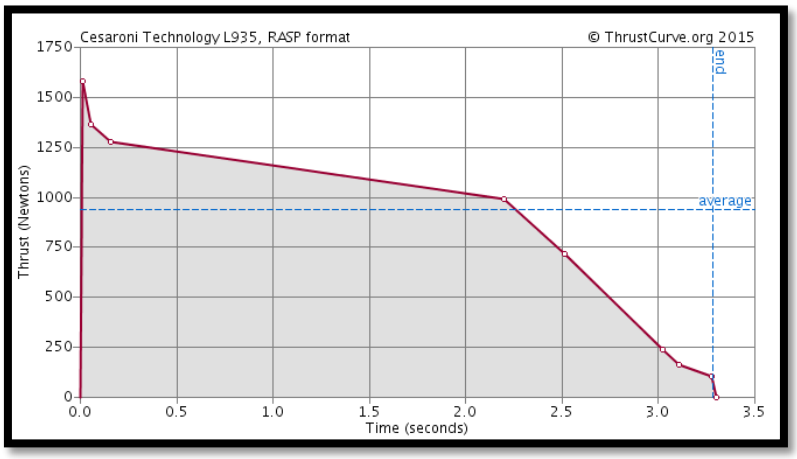

Figure 23: Thrust curve of CTI L935-IM.

The motor was chosen to allow the launch vehicle to reach a simulated apogee of 6088 feet without ballast. By installing ballast weight and induced manufacturing weight, the launch vehicle apogee can be dialed to exactly 5280 feet. Table 13 lists simulated vehicle information and motor details as a justification for the motor selection.

Thrust-to-weight ratio	12.06
Rail exit velocity	60.9 ft/s
Project altitude	5287 ft
Maximum acceleration	345 ft/s2
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 13: Simulated launch vehicle motor details.

The following plots shown in Figure 24 and Figure 25 display various simulation results, justifying proper motor selection and CG and CP location.

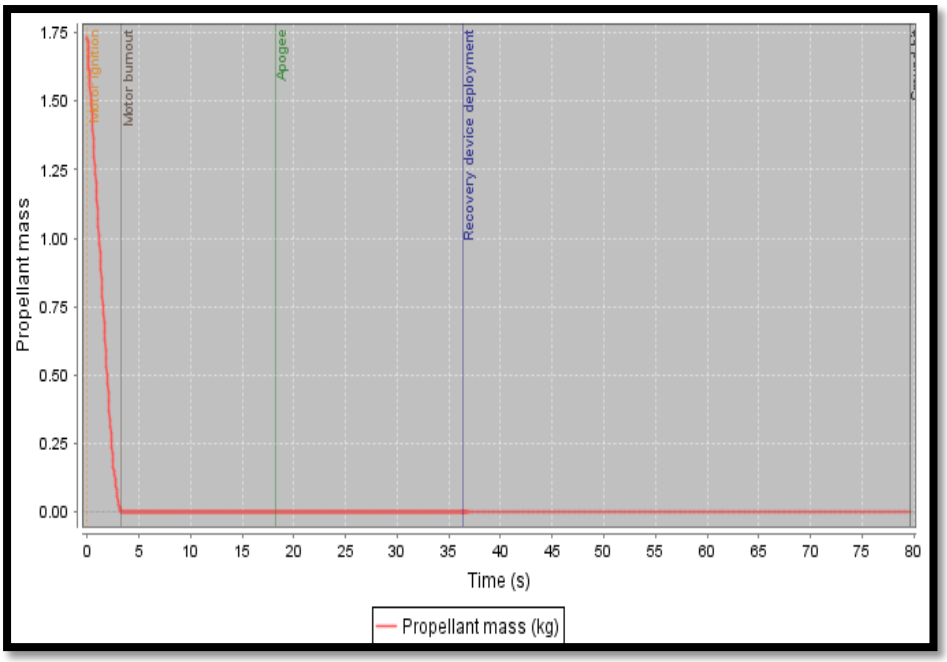

Figure 24: Propellant mass vs. flight time.

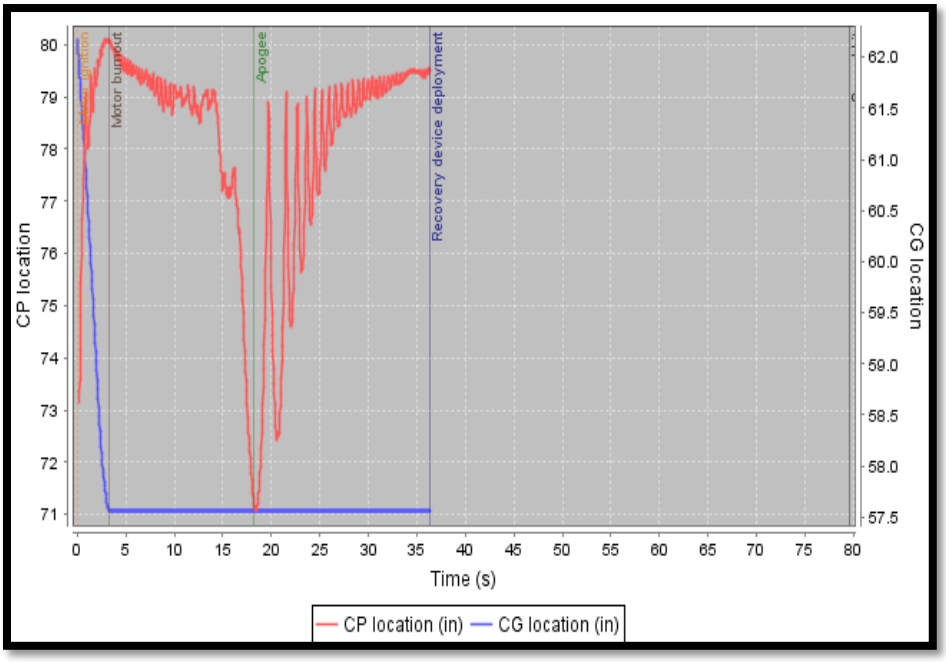

Figure 25: CP location and CG location vs flight time.

Figure 25 shows erratic behavior of the CP location following the launch vehicle reaching apogee altitude. This erratic behavior is due to the lack of ability to quantify a reefing system in OpenRocket and is therefore neglected.

There are inherent challenges to designing an efficient high powered launch vehicle. In order to ensure safety and vehicle performance, the team has focused, and will continue to focus on conquering various design challenges and finding innovative solutions to these challenges. Furthermore, the team shall verify that all designs stay within constraints laid out in the Statement of Work. Table 14, below, presents the details of various challenges and their related solutions.

Challenges	Solutions
The vehicle shall deliver the payload to, but not exceeding, an apogee altitude of 5,280 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.	The launch vehicle shall descend under a single recovery system, using a single Main and Drogue parachute configuration outlined in the Recovery section. The overall system shall have its own barometric altimeter. For complete redundancy, secondary backup altimeter shall be included as well.
The launch vehicle shall be designed to be recoverable and reusable.	The parachute will be designed to ensure the launch vehicle lands with a kinetic energy below the maximum kinetic energy laid out in the Statement of Work. Though appropriate material selection and manufacturing techniques, the rocket will be able to land at the maximum allowable kinetic energy without incurring any damage. 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.	The launch vehicle will be comprised of a single separation point, separating at the joint of the nosecone and recovery bay. These two sections will be tethered together during decent.
The launch vehicle shall be limited to a single stage.	Having a limited altitude of 5280' 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 use a Cesaroni L1030 six grain Xtra-Long Red Lightning 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 L1030 six grain Xtra-Long Red Lightning motor is 2,787.0 Newton-seconds.

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 14: Solutions to possible challenges set out in the Statement of Work.

3) Interfaces and Integration

Payload Containment

The Payload will be contained inside the launch vehicle using retaining clips mounted inside the Payload bay airframe. Figure 26 shows a preliminary design for the payload retaining clips.

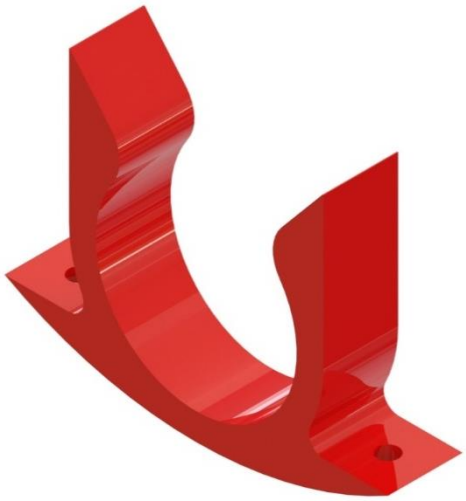

Figure 26: Payload retaining clips.

Two angled faces of the retaining clip serve as a guide for the payload capture device. Guidance allows payload to not be placed precisely in the center of the clips while still being retained securely in the launch vehicle. When a force is applied by the payload

capture device, the retaining clip will flex, allowing the payload to be retained. Once inserted, the clips will return to their original position, forming a press fit between payload and clip. Once inserted, the clip will maintain the position of the payload during the remaining AGSE activities and during all launch and recovery events.

Door System

Design

In order to keep all launch activities autonomous, a retractable door will be incorporated into the payload section of the launch vehicle. All activity will begin with the door in the open position. Upon depositing the payload into the payload bay via the payload capture device, the door will actuate to the closed position. A magnetic breakaway connection between a digital servo located in the payload bay and the AGSE central controller will facilitate the actuation of the door. Figure 27 shows a depiction of the payload bay with the door in the closed position.

Figure 27: Payload bay with door in closed position.

Two primary objectives were considered when designing the payload door assembly:

1. The door must be of an appropriate size to accept the payload and payload capture device without causing interference.
2. Once closed, the door is to have a proper seal along the payload airframe as to form a near seamless two piece structure.

The door is designed to be 3D printed using a Stratasys Fortus 400cc printer. The printer will allow for a precise creation of the designed door while allowing for and adjustable infill of material to adjust the strength characteristics needed to sustain a stable flight.

Track System

In order to save space within the launch vehicle and reduce overall length, a rotational door has been designed. Two 3D printed guide tracks will facilitate the closing of the door, ensuring a near seamless two part airframe. Figure 28 shows the layout of the Payload bay door inside the track system.

Figure 28: Payload door and track assembly.

4-40 UNC-2A threaded shoulder screws will attach to the payload bay door and travel along the rail guides. This can be seen in Figure 28 above.

Door Actuation

The rotary motion of the door will be controlled via a digital Hitec continuous rotation servo motor. The servo will be mount to the door as seen below in Figure 29.

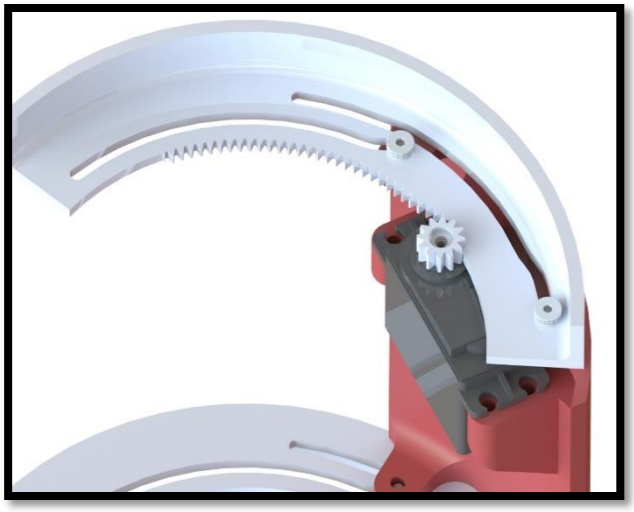

Figure 29: Payload bay rack and pinion mate.

The design will utilize a circular rack and pinion system to actuate the door. The pinion is attached via a hub attachment to the servo. As the door closes, the pinion rotates along with the door until the door is fully seated in the closed position. Both upper and lower guides shall have the same track geometry, allowing the door assembly to easily close. The geometry of the rail guides can be seen below in Figure 30.

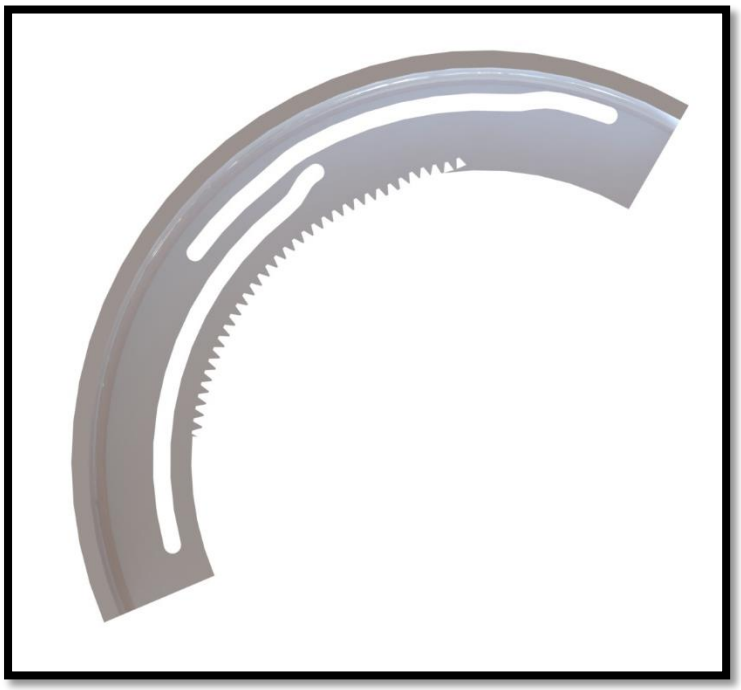

Figure 30: Rail guide track geometry.

In order to avoid contacting the airframe while actuating and in the open position, the track guides utilize a separate track for each shoulder screw. Additionally, the rack gear

geometry is similar to that of the track guides to ensure a constant contact between rack and pinion. This contact will be used to hold the door in the closed position during flight.

Challenges

To ensure the door system integrates with the rocket and functions as intended, certain solutions were sought for various design challenges, as seen in Table 15, below.

Challenges	Solutions
Design the door such that the payload and payload capture device will fit during payload insertion.	Proper dimensional analysis will be conducted to ensure no clearance issues are present throughout the design and revision of any payload containment and insertion systems.
The door shall be autonomously closed.	On-board computer electronics will work hand in hand with ASGE systems to synchronize payload insertion and door actuation movements.
The door shall remain sealed when closed.	The door will poses the same outer dimension as the airframe of the payload bay. Once the door reaches the closed position, a near seamless assembly will be created to avoid aerodynamic anomalies due to an open airframe.
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 open during flight.

Table 15. Solutions to various door design challenges.

Section 6. Technical Design: Recovery

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 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 unique power supply.
6. Each arming switch shall be capable of being locked in the ON position for launch.
7. Removable shear pins shall are utilized to contain 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.

Design

A reefing system is being implemented in the recovery scheme, which eliminates the need for a drogue parachute. This will be accomplished by using a centerline to reef the parachute. This prevents the parachute from fully opening, causing it to act like a drogue parachute. The reefed line will be severed at 800 feet, allowing the parachute to fully open to act like a main parachute.

Sizing

In order to ensure that the recovery meets all requirements of the competition, it is critical that the parachute is adequately sized. To determine the size of the parachute, the terminal velocity of the rocket was calculated using the following equation

$$V_t = \sqrt{\frac{2Eg_c}{m}} \qquad (1)$$

where E is the kinetic energy, g_c is the gravitational constant, and m is the mass of each section of the rocket. This was calculated using the maximum kinetic energy that was set

in the statement of work, which determined the minimum size of the parachute. The steady state velocity while under the parachute was calculated using

$$A = \frac{m^2 g}{\rho C_d E g_c} \quad (2)$$

The nominal diameter of the parachute was calculated using

$$D_o = \sqrt{\frac{4A}{\pi}} \quad (3)$$

where A is the diameter of the parachute. The calculations for the parachute sizing are shown in Figure 31 assuming worst case coefficient of drag.

C_D (worst case)	0.75
Mass (lbs)	23.89
Area(ft^2)	169.33
Diameter (ft)	14.68
Velocity (ft/sec)	12.71

Table 16: Parameters used to calculate parachute diameter.

Given the descent velocity of the system and the mass of each section, the kinetic energy was calculated. Several iterations of the calculations were run, altering the allowable kinetic energy in order to achieve a decent velocity that the launch vehicle can withstand. The calculations are shown in

Table 17.

Section	**Mass (lbs)**	**KE (ft-lb$_f$)**
Nose Cone	4.89	12.29
Booster (rest of rocket)	19.00	47.71

Table 17: Individual rocket section masses and kinetic energy calculations.

While the diameter of the parachute is larger than expected, this is due to conservative calculations. Uncertainty in values such as the coefficient of drag were taken to be worst case scenario. Subscale ground tests will be performed to determine the coefficient of drag, which is expected to increase. This will allow for the parachute size to be decreased.

Attachment Scheme

The reefing systems main component is called the reefing ring, which is shown in Figure 31. The reefing ring holds the parachute in a drogue state and severs the centerline to open the main parachute.

Figure 31: Reefing ring solid (left) and transparent isometric view.

The reefing ring has two slots which will each contain half of the shroud lines. The reefing ring will be held as far up the shroud lines as possible (i.e. closest to the parachute) via a reefed centerline. The location of the reefing ring controls how much the parachute can open, therefore controlling the drag.

To control the reefing system a cam deployment system will be utilized, as shown in Figure 32.

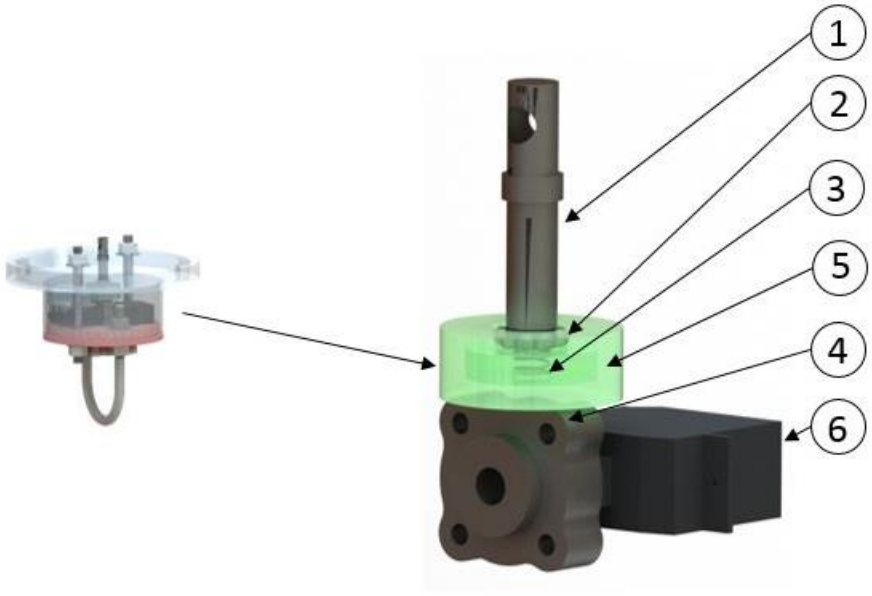

Figure 32: Cam deployment system.

The cam deployment system consists of the following parts list shown in

Table 18.

Item Number	Description	Quantity

1	Ejection Pin	1
2	3/32 ball bearings	9
3	0.187 inch by 0.125 inch compression spring	1
4	Ball bearing retainer	1
5	Servo hub	1
6	Micro servo 9g A0090	1

Table 18: Parts list for cam deployment system.

The cam deployment system holds the parachute in a reefed state until 800 feet. At 800 feet the micro servo will rotate 45 degrees pushing the ball bearing retainer upward, allowing the ball bearings to drop. This will release the ejection pin allowing the parachute to fully open. While the main parachute is opening, the force of the shroud lines will force the reefing ring to slide downward.

As a precaution a tender descender, as shown in Figure 33, will be located along the center reefing line, which connects the reefing ring to the top of the parachute. This will serve as the secondary mechanism to release the reefed line, ensuring that the parachute will fully open.

Figure 33: Tender descender.

The end of the shroud lines will connect to the top of the secondary reefing bay, shown below in Figure 34, which will contain a redundant reeling system.

Figure 34: Secondary reefing bay.

The secondary reefing bay will assist the reefing ring in sliding downward to ensure the parachute fully opens. The two groupings of shroud lines will be connected via two eye bolts. The reefing ring will be connected to the upper U-bolt, while the lower U-bolt is connected to the lower half of the rocket. Both which utilize 9/16 inch shock cord.

Recovery Flight Path

In order to recovery the payload safety, the rocket will separate into two sections. The sequence at which this occurs is shown in Figure 35.

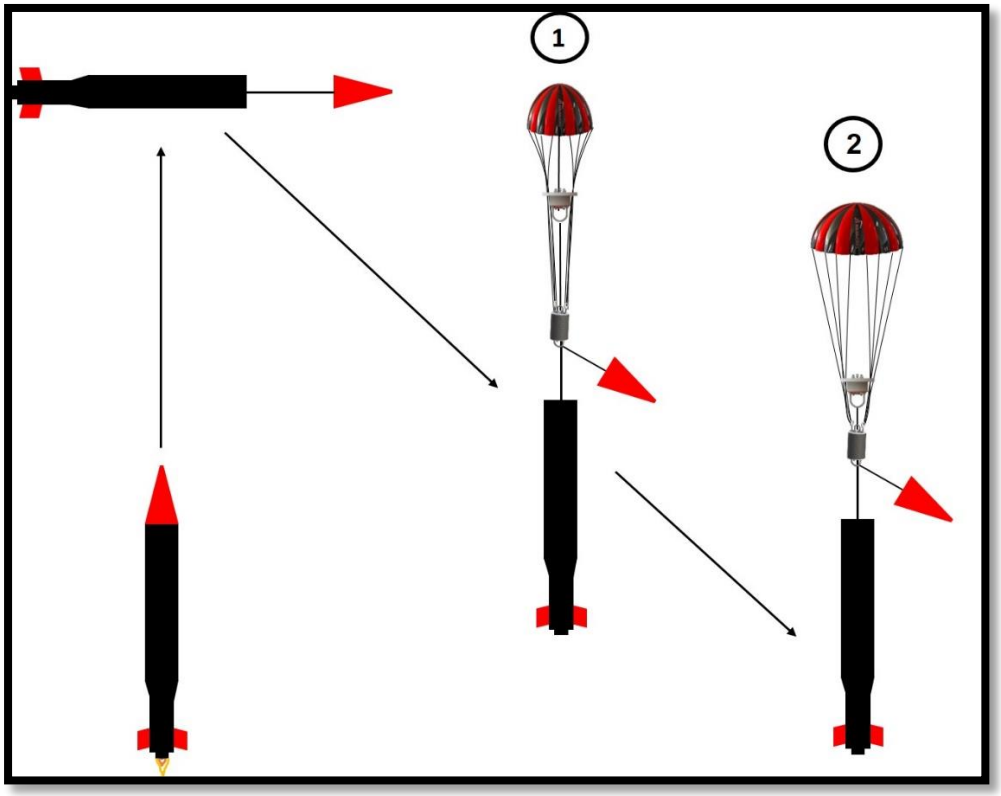

Figure 35: Recovery process.

A description of each event and altitude at which it occurs is listed below in Table 19.

Event	Altitude (ft.)	Description
1	5,280	Apogee. Upper stage of the rocket separates from propulsion bay. Reefed main parachute to act like a drogue.
2	800	The act of de-reefing allows main parachute to fully open.

Table 19: Recovery events and descriptions.

Since the main parachute also functions as the drogue, the need for duel deployment is eliminated. As a result of eliminating a bay in the rocket allocated for the drogue, the overall length of the rocket is reduced, leading to weight reduction opportunities in the AGSE.

Drift calculations have been performed to understand how far the rocket will drift given a range of wind speeds. The calculations were computed in increments of 5 mph, ranging from perfect conditions of 0 mph to the worst case scenario of 20mph. Shown in

Table 20 are the calculated drift values.

Wind speed	Drift (ft)
0	0
5	109.11
10	218.20
15	327.31
20	436.41

Table 20: Drift calculations.

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

A script was written to be able to easily calculate the drift for any possible wind speed. During launches, members are to run the script for drift calculations to ensure that the predicted drift radius is clear of any hazardous obstacles. Since the script may not be able to be run on a server immediately prior to launch, a graph has been derived from the calculated set points to allow for members to approximate the distance that the rocket will drift from the launch pad. This graph is shown in Figure 36.

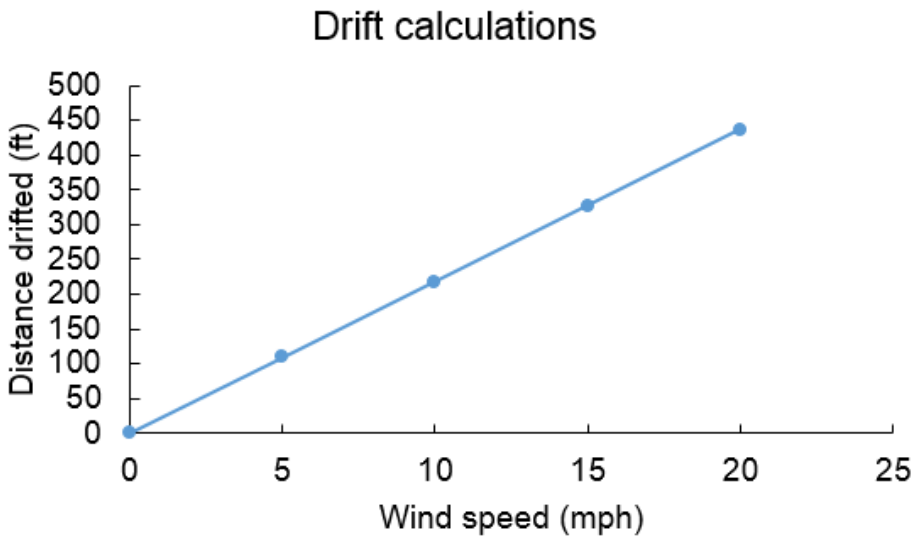

Figure 36: Distance rocket drifts from the pad for all wind speeds possibly encountered during a launch.

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

Geometry

The parachute system has potential risks that will be mitigated through extensive ground testing followed by a launch to validate testing results. The parachute criteria and risk mitigation is listed below in Table 21.

Parachute criteria	**Risk mitigated**
Low opening force.	The shock from separation of the nose cone and lower section of the rocket can cause entanglement, zippering of airframe or premature de-reefing.
Maximum stability	Ribboning and excess oscillation can result during reefing state.
Over loading	The weight of entire vehicle and resistive force from parachute could result in excess tension force on reefing ring.

Table 21: Parachute criteria and potential risks.

The risks of the recovery system are much more extensive than those listed here in the recovery section. Risks associated with recovery are analyzed in significant detail in the safety section in the hazard analysis.

Multiple parachute geometries were compared to select the optimal geometry for the recovery system based on the characteristics shown in Table 22.

Parachute geometry	C_D	C_x	Oscillation (degrees)
Flat	0.75-0.80	~1.7	±10 - ±40
Polyconical	0.75-0.92	~1.8	±10 - ±30
Triconical Polyconical	0.80-0.96	~1.8	±10 - ±20
Cross (Cruciform)	0.60-0.85	1.1-1.2	0 - ±3

Table 22: Parachute performance characteristics comparison.

The polyconical parachute was selected because of its low oscillation, relativity low coefficient of drag, as well as an average opening force. The polyconical is incorporated in three stages of trapazoids that make up one panel of the parachute and creates a center hole at the top of the parachute.

Due to the overall shape of the polyconical, it was decided that it would provide the most stability for a centerline reefing system. The configuration creates a center hole at the top of the parachute. Stitching paracord in a cross configuration allows for a loop ring to connect the center line down to the reefing ring enabling the reefing system.

The disadvantage of using flat parachute pattern is its reduced tensile strength that can cause the parachute to invert under the desired load that the parachute will experience throughout flight.

Layout

The polyconical parachute will be manufactured in accordance to the schematic shown below in Figure 37.

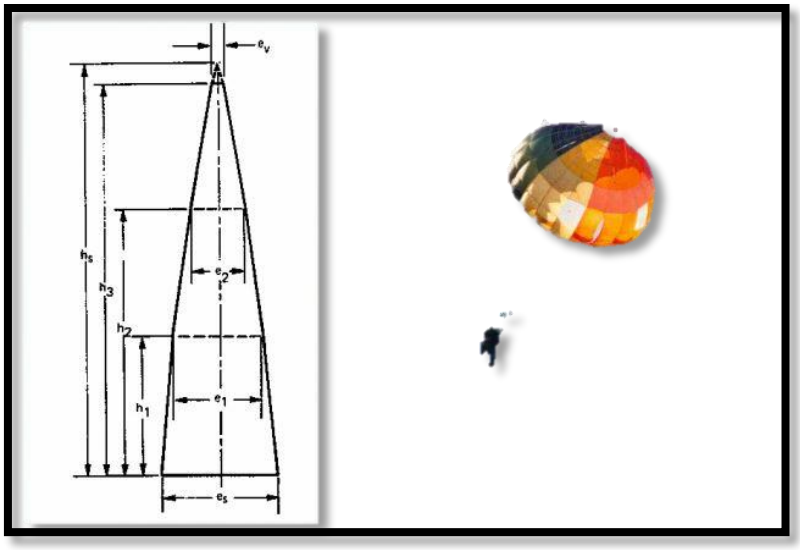

Figure 37: Polyconical schematic of one panel.

For ease of manufacturing the team has created a dimensionally driven layout shown below in Figure 38. The layout is scalable for ease of adjustment if testing results in the need of a larger or smaller parachute.

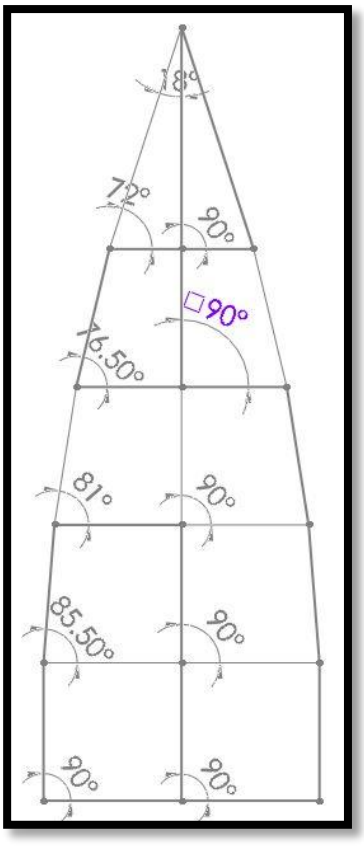

Figure 38: Polyconical scalable layout.

Since the team has little experience with center line reefing, an extensive amount of testing will be performed to determine the allotted tension force that the parachute can withstand before inversion occurs. This testing will help mitigate the potential risk.

Parachute Materials

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

The suspension lines will be made of 1/8 inch nylon para-cord with 400 lb tensile strength. The harness that connects the secondary reefing bay to the launch vehicle, the reefing ring to the secondary reefing bay, and the center reefing line will be made of 9/16 inch tubular nylon with a tensile strength of 500 lbs.

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

Bulkheads

The parachute will be tethered to both the nose cone and lower section of the rocket by attaching the harness to a bulkhead via a quick link. Figure 39 shows the nose cone bulkhead assembly which displays the location of the Perfectflight Stratologgers. The bulkhead and U-bolt in Figure 39 will be mirrored on the lower half of the rocket. These U-bolts will displace the overall force that the parachute exerts throughout flight.

Figure 39: Nose cone bulkhead assembly.

Each wooden bulkhead, or bulkplate, will be laser cut from ½" medium density plywood. When a bulkhead is closing off a section of airframe or coupler tubing, a 1/8" fiberglass bulkhead will be secured to the wooden bulkplate. The fiberglass bulkhead adds rigidity to the bulkhead assembly.

Precautions have to be met to ensure electronics are electrically shielded from each other throughout flight. This will alleviate the concern of programmed electronics failing due to interference from various electronic systems. Each bulkhead that is shielding electronics will have a layer of aluminum tape applied to its face.

Avionics

For the de-reefing system the electronics are placed inside the reefing ring. The central controller will be an Arduino mini as shown in Figure 40.

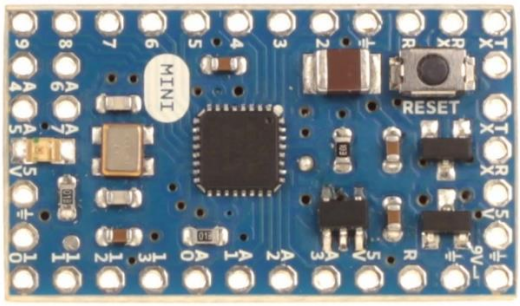

Figure 40: Arduino mini.

The Arduino mini will communicate with an adafruit BMPO85 barometric pressure sensor, shown in Figure 41, which will indicate when the launch vehicle has reached 800 feet.

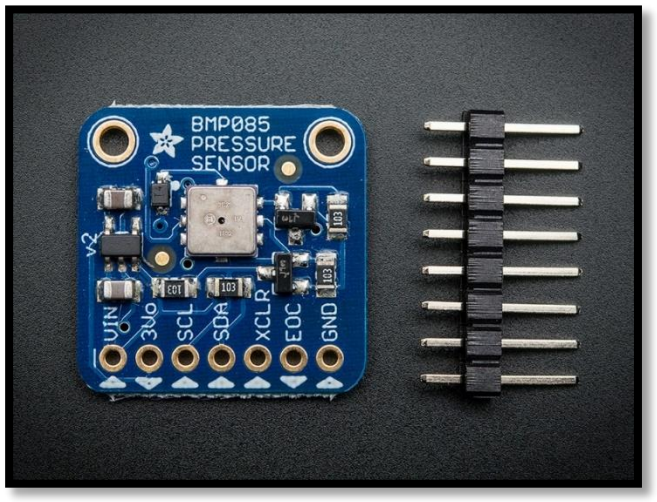

Figure 41: Adafruit BMPO85 barometric pressure sensor.

At this point a signal will be sent to the micro servo, shown in Figure 42, which will rotate 45 degrees releasing the ejection pin.

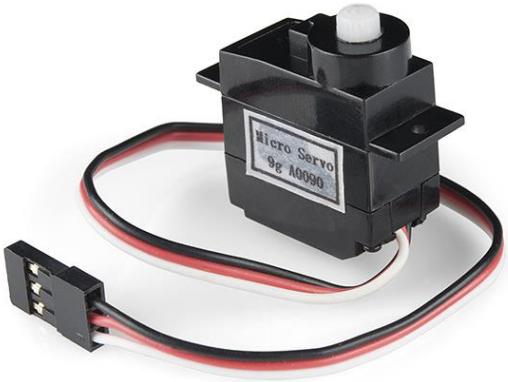

Figure 42: Micro servo 9g A0090.

For the deployment of the parachute and for the reefing system, electronics will be separated from all other systems. Due to the past success with the PerfectFlite Stratologger, shown in Figure 43, two units will be placed in the avionics bay. A set of PerfectFlite Stratologger's will be placed to ignite black powder charges.

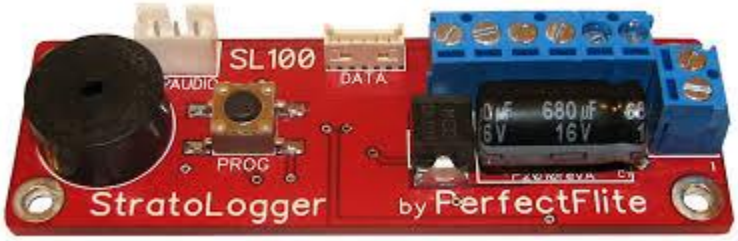

Figure 43: PerfectFlite Stratologger.

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. 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. Each StratoLogger will be powered by an individual Duracell 9V battery. Duracell batteries have been selected due to their reliability and the feature that their leads are internally soldered.

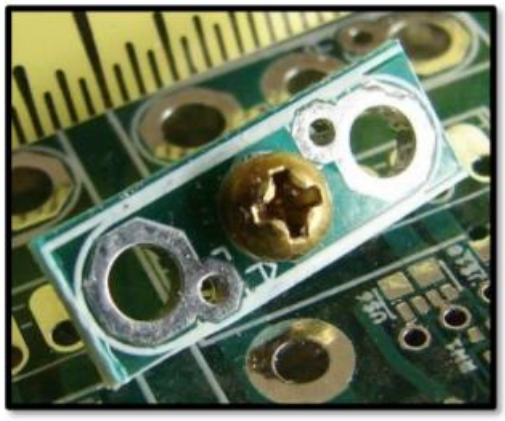

Figure 44: Featherweight screw switch.

Each altimeter will be locked into the on position through use of a Featherweight screw switch, shown above in Figure 44. The switches allow for easy arming of altimeters while the rocket is upright in the AGSE. Access holes will be drilled and marked to allow for arming.

The schematic for the wiring of the altimeters are shown in Figure 45.

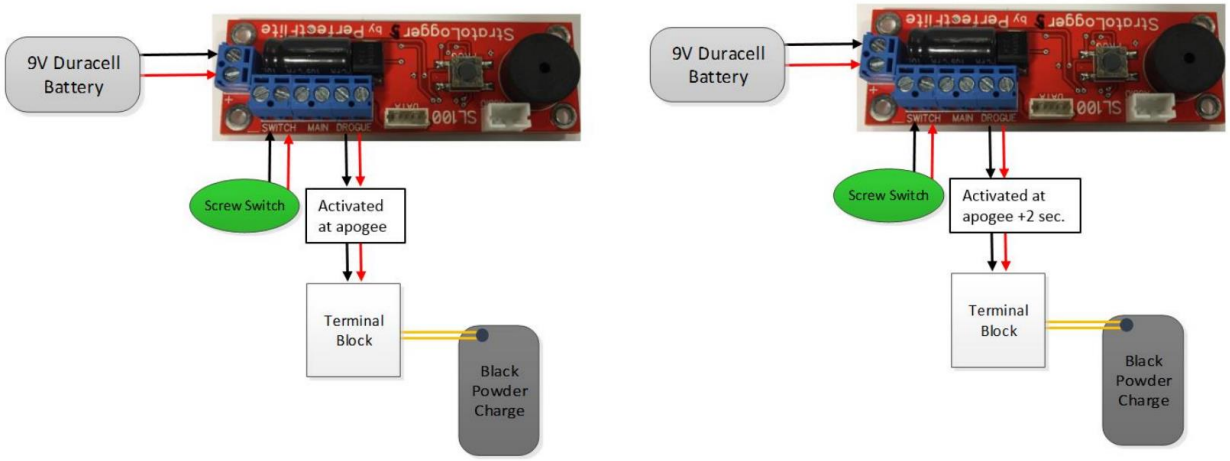

Figure 45: Main recovery electrical schematic.

To satisfy the GPS requirement, a Garmin Astro DC 40, operating at a frequency of 151,880 MHz and a wattage of 2W, will be positioned in the nose cone. The Garmin tracker will be mounted in the rocket on a custom 3D printed sled. The Garmin Astros have a range of 7 miles line of sight and approximately 2.5 miles in dense woods. Given the allowable drift requirements, the range is sufficient.

Challenges

Challenges	Solution
Avoiding parachute tangling during ejection	The parachute will be stowed in a deployment bag which will be custom made. Folding the shock cord accordion style while wrapped in blue painters tape allows for a clean unraveling of shock cord.
Custom made parachute, with reefed drag coefficient unknown, combining both drogue and main.	Testing will take place to validate coefficient of drag, and reliability of reefing system.

Table 23: Recovery challenges.

Section 7. Technical Design: AGSE

1) Autonomous Ground Support Equipment

Overview

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

1. Team must position launch vehicle horizontally on the AGSE.
2. Weight limit of 150 pounds.
3. Volume requirements including height of 12 feet, width of 10 feet, and length of 12 feet.
4. No use prohibited technologies, including:
    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
    d. Open circuit pneumatics
    e. Air breathing systems

In addition to the above requirements, the following control parameters must be met to for the AGSE to be considered a success:

1. Include a master switch to power on all autonomous procedures and subroutines.
2. Complete all proposed tasks within a 10 minute time limit.
3. Tasks will be completed autonomously in the following order:
    a. Capture and insert payload
    b. Actuate launch vehicle from the horizontal position to 5 degrees off of vertical
    c. Insert motor igniter into launch vehicle
4. Include a pause switch to halt all AGSE procedures and subroutines at the judge's discretion.
5. Upon deactivation of the pause switch, the AGSE must resume operations.
6. Include a safety light that indicates power is on and is amber in color.
7. The safety light must flash at 1 Hz when AGSE is on, and solid when AGSE is a paused state.
8. All system go light should be included to display when all systems have passed safety verification and the launch vehicle is ready to launch.

To achieve the above requirements, the AGSE has been divided into sub-systems described in Table 24.

Sub-system	Responsibility
Launch platform	Support and guide launch vehicle prior to and during launch.
Vehicle actuation	Raise vehicle from horizontal to launch position.
Payload capture	Capture and insert payload into launch vehicle.
Igniter installation	Insert igniter into launch vehicle after reaching launch position.
Sub-frame	Interface between each sub-system, house electronics, and provide a stable interface between the AGSE and the ground.

Table 24: AGSE sub-systems.

A rendering of the entire AGSE is shown in Figure 46.

Figure 46: AGSE in launch orientation.

The approximate overall AGSE dimensions are show in Table 25.

Mass (lb_m)	Width (in)	Horizontal orientation		Launch orientation	
		Height (in)	Length (in)	Height (in)	Length (in)
140	73.02	38.39	117.77	108.04	91.67

Table 25: Overall AGSE dimensions.

System Timeline

Per the SOW, the AGSE has 10 minutes to complete the proposed tasks. The system will be designed to complete these tasks within 5 minutes to account for additional attempts in the event of a system malfunction. The system timeline is shown in Figure 47.

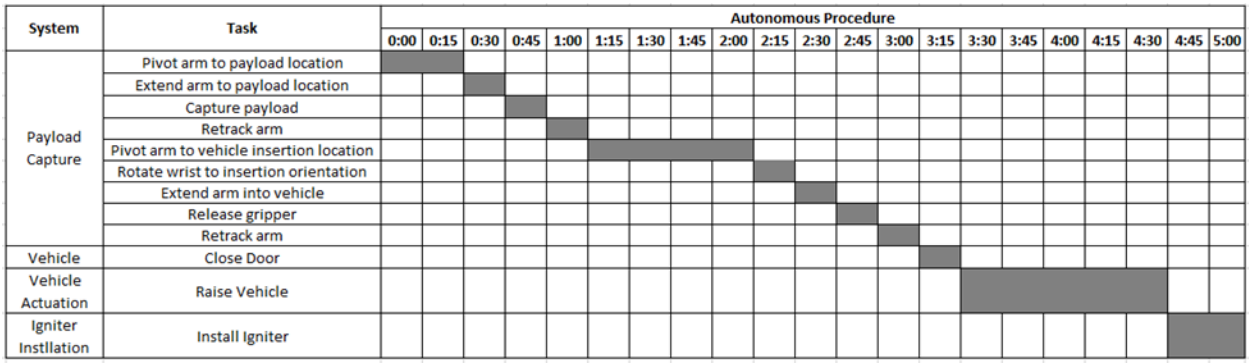

Figure 47: AGSE process timeline.

Analysis Guidelines

Throughout the design process of the AGSE a safety factor of 1.5 will be pursued for all components. However, designs under a factor of safety of 1.5 but over 1.0 will be considered at the team leadership's discretion. Currently, this exception has not been used for any analysis.

Geometry Optimization

The overall geometry of the vehicle actuation system, launch platform, and sub frame was optimized by analyzing the forces required to raise the launch vehicle. To analyze the forces, the geometry of the AGSE was defined analytically. Figure 48 defines dimensions of the AGSE.

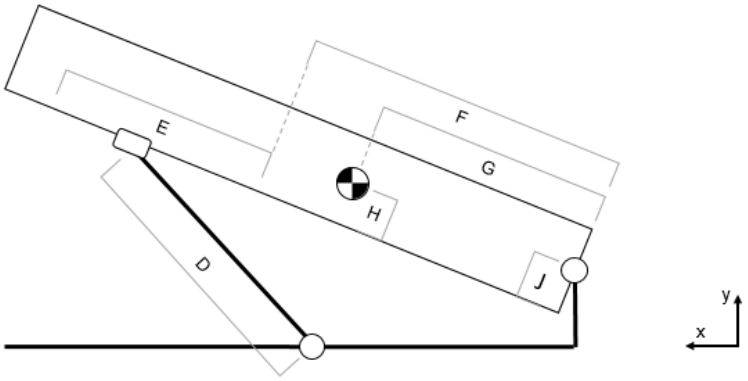

Figure 48: AGSE dimension definitions.

Figure 49 defines critical dimensions of the AGSE relative to the coordinate system.

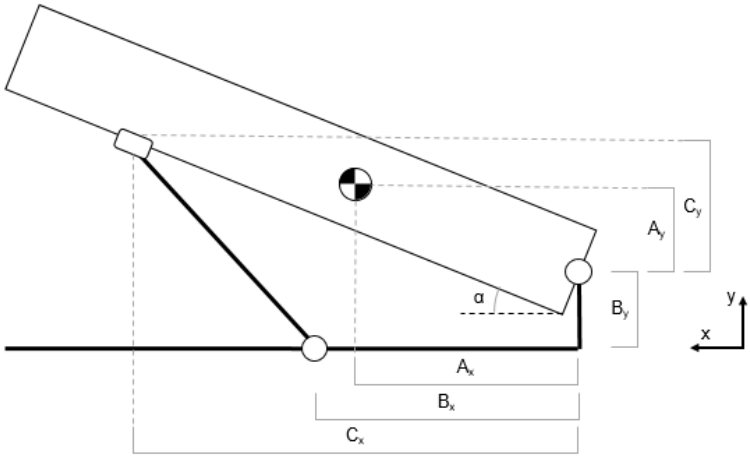

Figure 49: Critical AGSE dimensions relative to coordinate system.

Figure 50 defines the critical point forces applied to the AGSE.

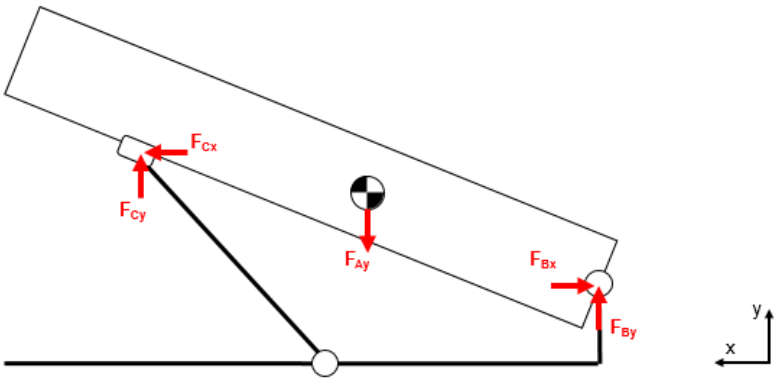

Figure 50: Critical point forces applied to the AGSE.

The following equations define the motion of the AGSE.

$$z=\sqrt{(B_x-J\sin(\alpha))^2+(B_y-J\cos(\alpha))^2} \quad (4)$$

$$\beta=\tan^{-1}\left(\frac{B_y-J\cos(\alpha)}{B_x-J\sin(\alpha)}\right) \quad (5)$$

$$h=\frac{D}{\sin(\beta+\alpha)} \quad (6)$$

$$\theta=\sin^{-1}\left(\frac{z}{h}\right) \quad (7)$$

$$\gamma=180-\beta-\theta-\alpha \quad (8)$$

$$Q=h*\sin(\gamma) \quad (9)$$

$$A_x=\cos\left(\tan^{-1}\left(\frac{H}{G}+\alpha\right)\sqrt{H^2+G^2}+T\cos(\alpha)\right) \quad (10)$$

$$A_y=\sin\left(\tan^{-1}\left(\frac{H}{G}+\alpha\right)\sqrt{H^2+G^2}-T\cos(\alpha)\right) \quad (11)$$

$$C_x=Q*\cos(\alpha)+J*\sin(\alpha) \quad (12)$$

$$C_y=Q*\sin(\alpha)-J*\sin(\alpha) \quad (13)$$

The following equations define the forces in the AGSE.

$$F_c=\frac{A_y F_{Ay}}{c_x \sin(\alpha+\theta)-\cos(\alpha+\theta)} \quad (14)$$

$$F_{Cx}=\cos(180-\gamma)\,F_c \quad (15)$$

$$F_{Cy} = \sin(180-\gamma)\, F_c \quad (16)$$

$$F_{Bx} = F_{Cx} \quad (17)$$

$$F_{By} = F_{Ay} - F_{Cy} \quad (18)$$

$$F_{Track} = F_C \cos(\theta) \quad (19)$$

$$F_{Screw} = F_C \cos(\theta) + \mu F_{Track} \quad (20)$$

where μ is the coefficient of friction between the track and the carriage wear pads.

The torque required to actuate the ball screw was found using

$$T = \frac{F_{Screw} L}{3e\pi} \quad (21)$$

where L is the length of the ball screw and e is the efficiency of the ball screw.

The parameters used to calculate the forces and torques internal to the AGSE are given in

Table 26 below.

F_{Ay}(lbs)	H (in)	G (in)	e	μ
100	7.40	50	90%	0.3

Table 26: Force calculation parameters.

The parameters F_{Ay}, H, and G are all estimates of the AGSE system, following a completed design these calculations will be re-run with parameters from the completed to verify the forces internal to the AGSE.

To optimize the geometry of the AGSE, a Matlab simulation was created. Parameters Bx, By, D, and J were varied by the specifications defined in

Table 27.

Parameter	Min (in)	Step size (in)	Max (in)
Bx	0	1	100
By	1	1	24
D	0	1	100

J	-6	1	29

Table 27: Geometry variation specifications.

The simulation verified each combination as a valid option using a set of conditional criteria. Valid options were defined as options that resulted in real solutions that would allow the launch platform to fully travel from the stowed position to the launch position.

The output of the simulation as a three dimensional scatter plot is illustrated below in Figure 51. This scatter plot compared the maximum force during the actuation of the launch platform versus total travel of the carriage versus the geometry parameter B_y.

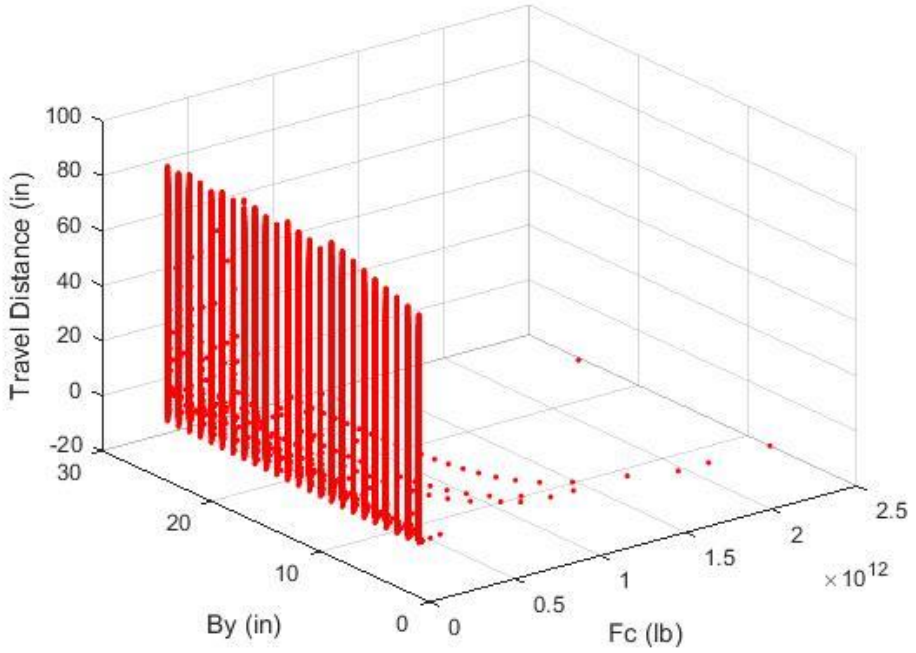

Figure 51: Simulation output plot.

The output of the simulation was loaded into an access database where additional filters were applied to the data resulting in the plot shown in Figure 52.

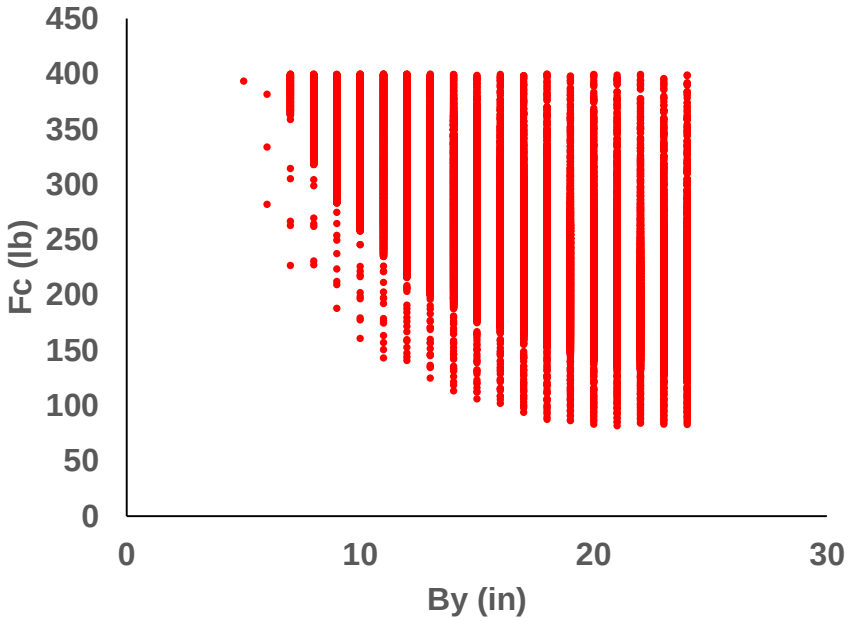

Figure 52: Maximum Fc force versus By distance.

By analyzing the data, a final configuration was chosen. The plot shown in Figure 52 shows that most By have multiple options of varying force. Therefore, a By was chosen that was easy to design to and a desired Fc was selected. Then these parameters were inputted into an Access database to analyze the dataset to find the remaining geometry parameters. A summary of this configuration is shown in

Table 28.

B_x (in)	B_y (in)	D (in)	J (in)
30	11	58	0

Table 28: Summary of optimized AGSE configuration.

The maximum forces and torques resulting from this configuration are shown in

Table 29.

F_c (lb)	F_{Bx} (lb)	F_{By} (lb)	F_{Cx} (lb)	F_{Cy} (lb)	F_{Track} (lb)	F_{Screw} (lb)	T (lb-in)
303.21	259.72	-56.48	259.72	156.48	57.51	297.71	11.14

Table 29: AGSE optimized configuration forces and torques.

2) Launch Platform

Overview

The launch platform must perform the following functions to be considered a success:

1. Guide the vehicle until it has reached a safe rail exit velocity.
2. Support full weight of launch vehicle in horizontal and launch orientations.
3. Stabilize vehicle during launch.
4. Maintain vehicle alignment during payload insertion.
5. Be reusable.

The overall approximate dimensions of the launch platform are show in Table 30.

Mass (lb_m)	Optimization opportunity (lb_m)	Width (in)	Height (in)	Length (in)
50	10.00	22.00	23.97	96.63

Table 30: Launch platform general dimensions.

A rendering of the launch tower assembly is shown in Figure 53.

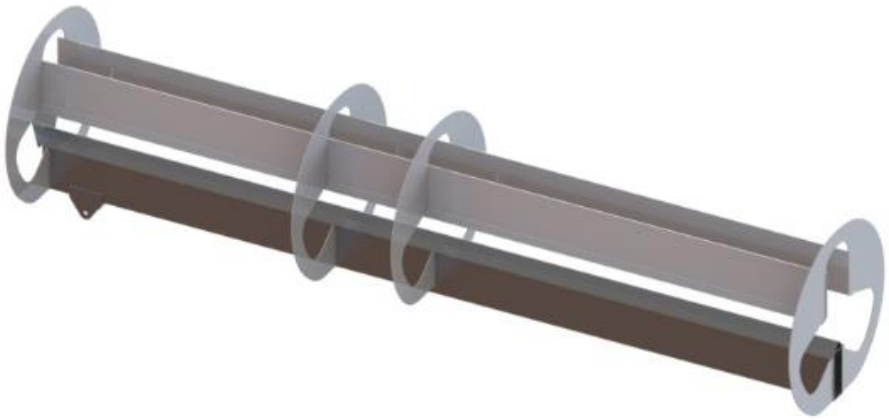

Figure 53: Launch tower assembly.

Changes since Proposal

The changes to the launch platform since the proposal are summarized in

Table 31.

Change	Justification
Rail length reduced to 96.5 inches from 120 inches.	The required rail exit velocity was reduced, providing an opportunity for weight savings.
Switch from structural tubing to sheet metal design.	Analysis showed increased deflection resistant with a reduction in overall weight by switching to a sheet metal design.

Base pivot changed to two pivot plates.	Change was necessary to provide adequate strength in joint.
Base pivot hole changed to hex.	Axle needed to move with launch platform to provide feedback to main controller.
Base plate material and thickness changed.	Base plate is no longer a critical structural component and is only holding the load of the rocket.
Track support tube integrated into launch platform lower rail weldment.	Provided increase structural integrity to the launch platform.

Table 31: Changes to the launch platform since proposal.

Design

The launch platform will consist of three rails connected in a guide tower configuration via four stability rings. A guide tower configuration was chosen for the launch platform because of its lower friction when compared to a traditional rail button configuration. The team has also had great success using a guide tower configuration for launch pads over the past several years.

Rails

The purpose of the rails is to guide the launch vehicle as it is gaining velocity. The upper two rails will be constructed by bending two pieces of 1/8" thick 6061-T6 aluminum sheet metal. The sheet metal will be cut on a CNC waterjet and bent on a CNC press break to an angle of 110 degree angle. Each rail will be a mirror image of the other and will be 96.5 inches long. The length was selected based on the minimum safe rail exit velocity of the launch vehicle. The rail configuration is shown in Figure 54.

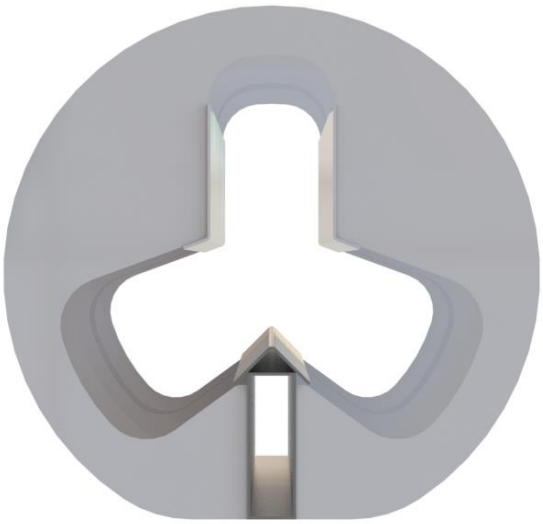

Figure 54: Launch rail configuration.

The configuration shown above in Figure 54 does limit the amount the rocket can rotate while exiting the launch pad. However, the team has previously utilized a guide tower with 4 rails which also reduces the amount the rocket can rotate when compared to a traditional 3 rail guide tower. Additionally, the launch vehicle's removable fin system has been tested and it was noted that the vehicle only rotated 3 times over the course of a 5000 foot flight. Therefore, the rotation of the launch vehicle over the 8 foot rail should be less than the 36 degree limit of this design. Based on this, it was determined the reduced opening was acceptable for the gains in strength of the tower.

The lower rail is shown in Figure 55.

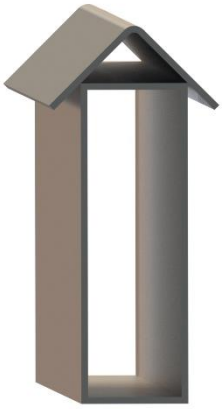

Figure 55: Launch platform lower rail.

The lower rail will be a weldment consisting of a 2"x6" 1/8" wall 6061-T5 aluminum rectangular structural tube and a bent sheet metal cap constructed from 1/8" thick 6061-T6 aluminum sheet metal. The sheet metal will be cut on a CNC waterjet and bent on a CNC press break. The sheet metal cap will be bent to a 90 degree angle and will be placed on top of the structural tube pointing downward. Both components will be 96.5 inches long and will be welded together along both sides of the cap for the full length of the rail.

Rings

A rendering of a launch platform ring is shown in Figure 56.

Figure 56: Launch platform ring.

Each ring will be used to stabilize the rails of the launch platform. The rings will be cut on a CNC waterjet from 1/8" thick 6061-T6 aluminum sheet metal. The rings will be 22 inches in diameter and will have an internal radius of 18 inches to allow for clearance with the launch vehicle. Each ring will be welded to the rails along each tangent edge.

Base

The purpose of the base of the launch platform is support the rocket once it has move from the horizontal orientation. The base also provides a rigid connection between the launch rails and provides a mounting point for the igniter installation device. The base is shown in Figure 57.

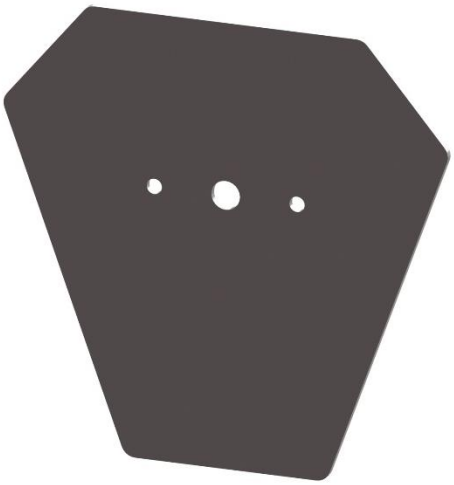

Figure 57: Launch platform base.

The base will be cut on a CNC waterjet from 6061-T6 aluminum sheet metal. The base will be welded to each of the rails along each tangent edge.

Base Pivot

Two pivot plates will be welded to the lower launch rail weldment. The pivot plates are shown in Figure 58.

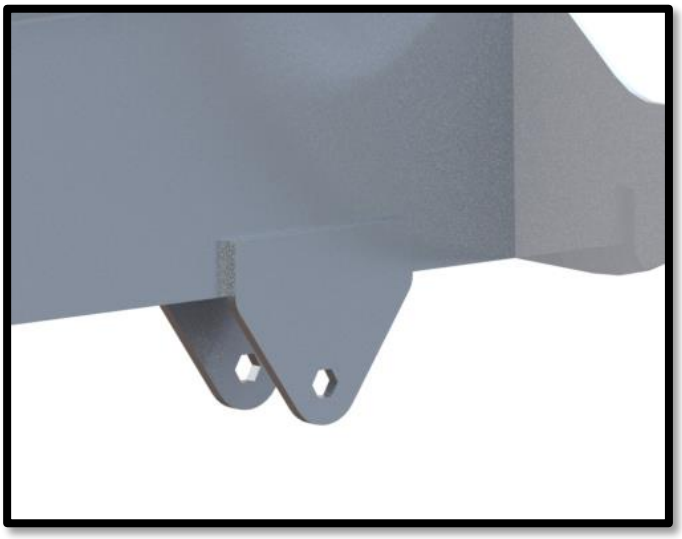

Figure 58: Launch platform base pivot point.

The pivot plates will be cut on a CNC waterjet from a ¼" thick 6061-T6 aluminum plate. A ½" hex hole will be broached into the plates. The hex hole will be used to attach the pivot plates to the pivot axle. The hex hole was chosen to fix the pivot axle orientation relative to the launch platform. The plates will be welded to the lower rail along each tangent edge. The base pivot plates on the launch platform will fit between the corresponding plates on the sub-frame.

The pivot axle is shown in Figure 59.

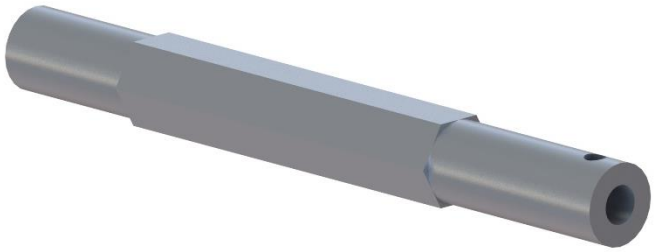

Figure 59: Base pivot axle.

The pivot axle will be used to connect the launch platform to the sub-frame. The axle will be machined using a manual lathe. Both ends of the axle will be threaded using a ½”-20 die. Two 1/2”-20 UNC 2B aluminum hex nuts will be used to secure the axle in place. Using the lathe, a center hole will be bored into one end of the axle. An 8-32 tapped hole will also be added perpendicular to the center hole using a manual mill and corresponding tap. The 8-32 tapped hole will receive an 8-32 UNC 3A stainless steel set screw which will secure the shaft of a potentiometer. The potentiometer will provide feedback to the main controller corresponding to the angle of the launch platform. The potentiometer interface is shown in Figure 60.

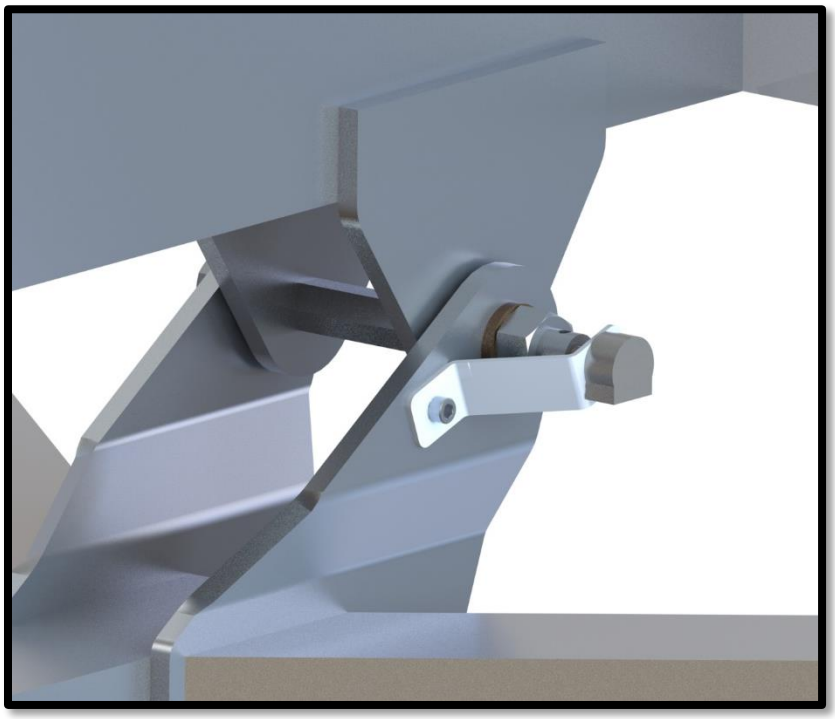

Figure 60: Base pivot potentiometer interface.

Analysis was performed to select the diameter of the pivot axle. Analysis included analyzing the maximum shear stress in the axle and determining the maximum deflection in the axle. The maximum shear stress in the axle was calculated using

$$\tau = \frac{2}{\pi r^3}\left(A\sqrt{\left(\frac{F_{By}}{2}\right)^2 + \left(\frac{F_{Bx}}{2}\right)^2}\right) \quad (22)$$

where A is the distance between the inner and outer plates on the axle, r is the radius of the axle, and r is the radius of the axle. The maximum deflection in the axle was calculated using

$$\delta = \frac{A\sqrt{\left(\frac{F_{By}}{2}\right)^2 + \left(\frac{F_{Bx}}{2}\right)^2}}{24EI}\left(3L^2 - 4A^2\right) \quad (23)$$

where E is the modulus of elasticity of the material, I is the moment of inertia for the axle, and L is the length of the axle.

The moment of inertia for the axle was calculated using

$$I = \frac{1}{4}\pi r^4 \quad (24)$$

The parameters shown in

Table 32 were used in the shaft design calculations.

A (in)	L (in)	E (ksi)	τ (psi)
0.375	3.00	10,000	30,000

Table 32: Base pivot axle calculation parameters.

The results from these calculations are summarized in

Table 33.

	Diameter (in)	Shear stress (PSI)	Maximum deflection (in)	Factor of safety
Minimum	0.23	20,000	0.0020	1.5
Design	0.5	2,000	0.0034	14.8

Table 33: Base pivot axle sizing calculations.

The final designed diameter was selected based on common shaft sizes above the minimum diameter and available tooling.

Geometry Selection

The final geometry and material selection of the launch tower was selected following analytical and simulation analysis. Analytical calculations were performed comparing the rail material used on the team's AGSE during the 2014-2015 NSL season to aluminum structural tubing. The results from these analytical calculations are summarized in Table 34.

Material	Moment of inertia (in^4)	Weight (lb_f)	Deflection (in)
1.5"x1.5" T-slotted aluminum extrusion	0.2542	13.43	2.22
2"x1" 1/8" Wall aluminum structural tubing	0.33171	8.04	1.74

Table 34: Material performance comparisons.

The deflection for each material was calculated using

$$\delta = \frac{PL^3}{3EI} \qquad (25)$$

where P is the load applied, L is the length of the beam, E is the modulus of elasticity, and I is the moment of inertia of the cross section.. Each calculation used a 10 foot length of material as a cantilever beam. The beam was loaded with a 10 pound load at one end and a fixed condition at the opposite end.

The moment of inertia for the t-slotted aluminum extrusion was found from supplier documentation. The structural tubing moment of inertia was calculated using

$$I = \frac{1}{12}\left[wh^3 - (w-2t)(h-2t)^3\right] \qquad (26)$$

where h is the height of the extrusion, w is the width of the extrusion, and t is the wall thickness of the tube.

Following the analytical analysis a finite element analysis (FEA) model was constructed of the structural tubing model, as shown in Figure 61.

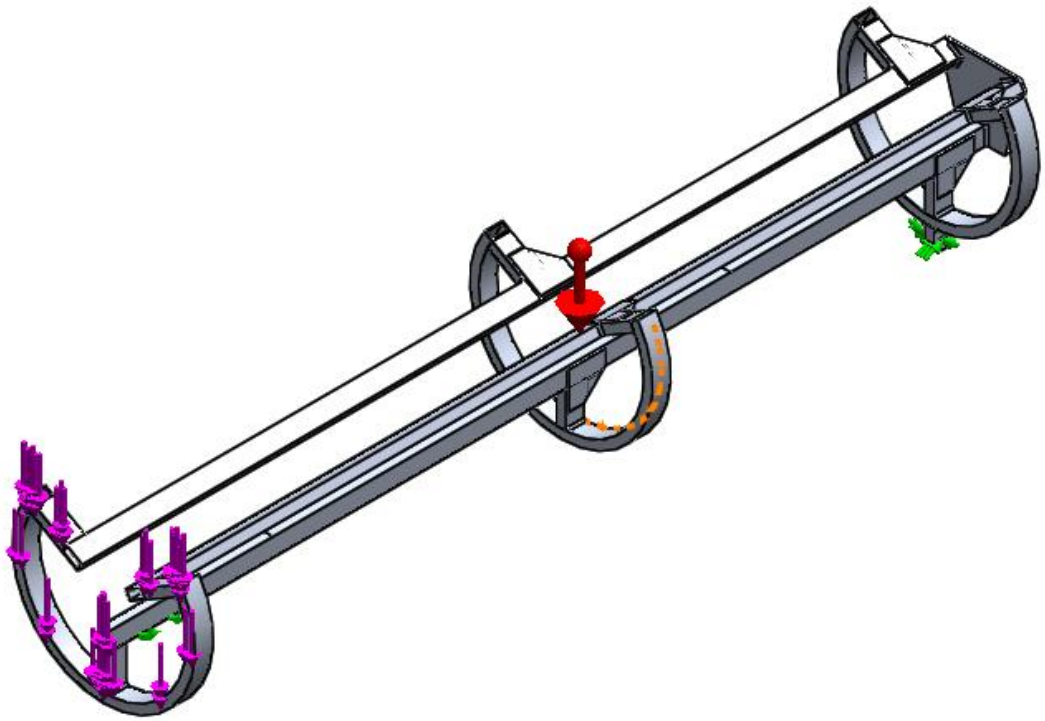

Figure 61: Structural tubing FEA model.

Fixed constraints were placed in two locations. At the rear of the launch platform a cylindrical fixed condition was placed in the axial and transverse direction on the face of the base pivot as shown in Figure 62.

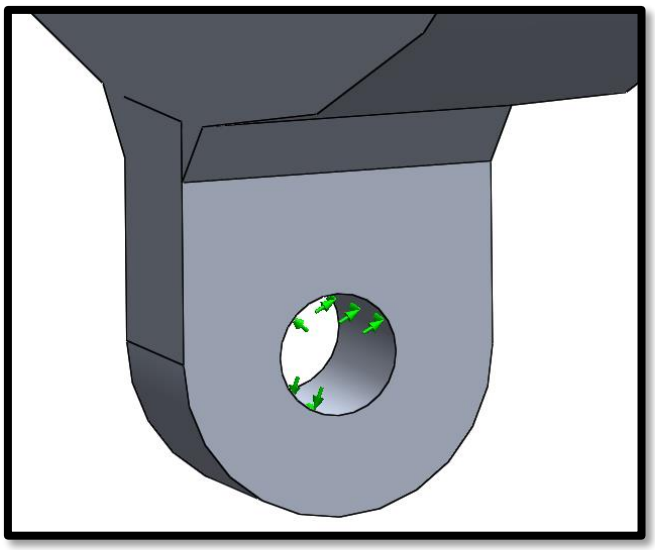

Figure 62: Base pivot fixed condition.

An additional fixed condition was placed at the front of the launch platform as shown in Figure 63.

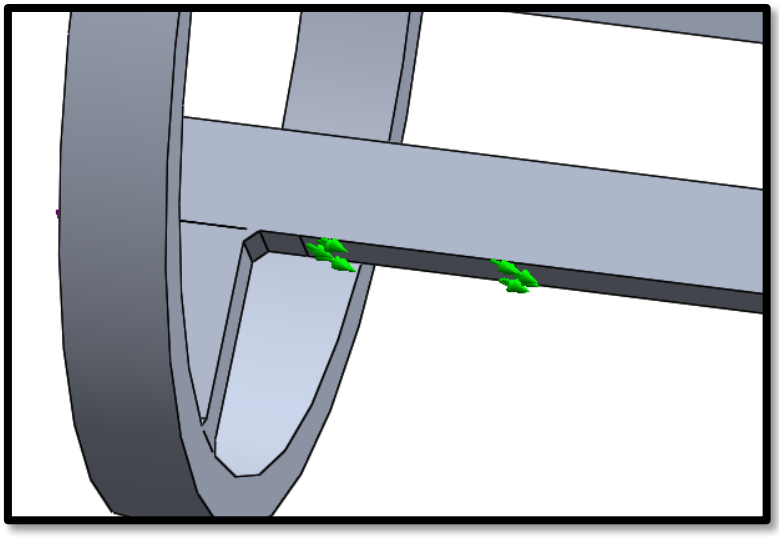

Figure 63: Actuation arm fixed condition.

This fixed condition was oriented at a 70 degree angle to the lower launch rail and was used to simulate the support reaction caused by the actuation arms.

A 40 pound load was added to the front face of the launch platform as shown in Figure 64.

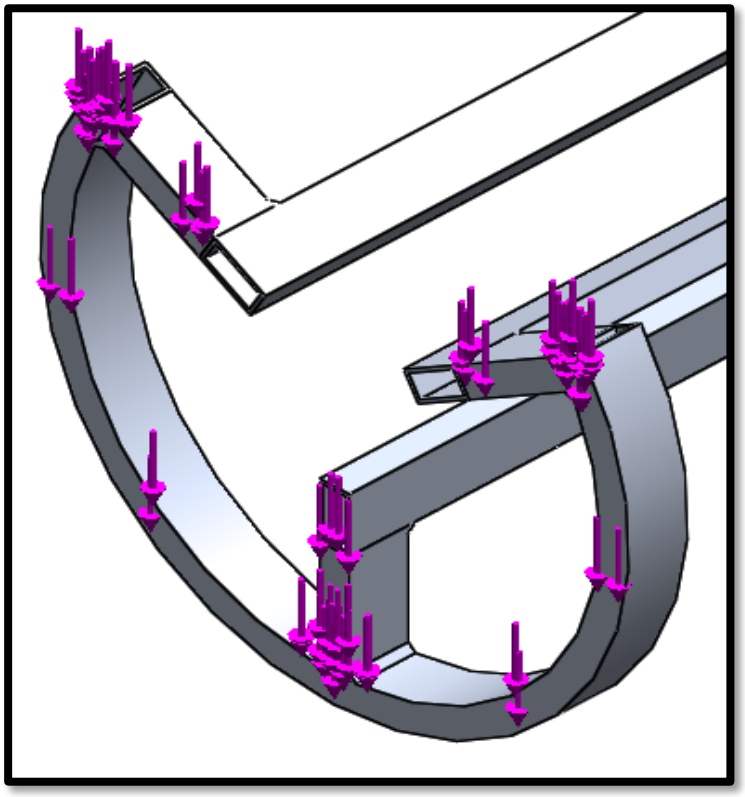

Figure 64: Simulation loading condition.

This load was a simplified loading to simulate the mass of the launch vehicle on the launch platform. Gravity was also applied to the entire model.

The FEA model was used to critique the design by analyzing the factor of safety and deflection plots. The simulation was run several times, varying material thickness, dimensions, and adding support structures until the weight reached an unsatisfactory level.

Following the weight increase, a sheet metal configuration was conceptualized and an FEA model was created. This model was loaded and fixed in the same configuration as the structural tubing model. Symmetry was used to simply the FEA model. The factor of safety plot from the sheet metal configuration is shown in Figure 65.

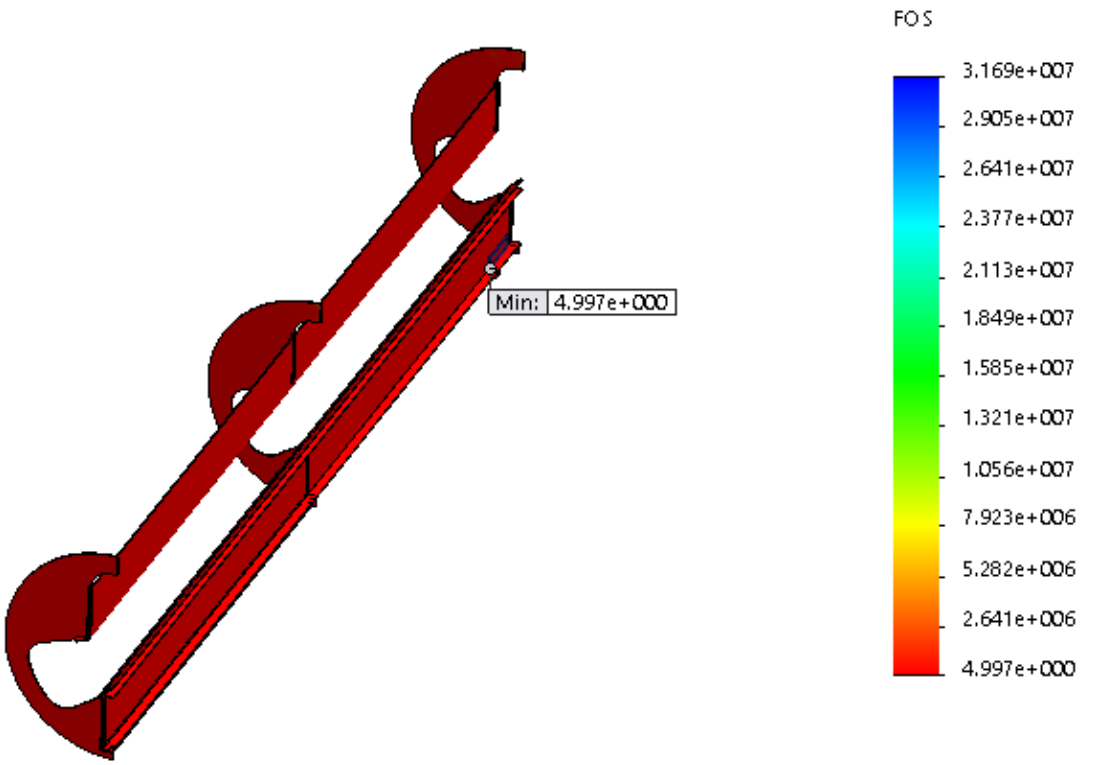

Figure 65: Sheet metal configuration factor of safety plot.

The deflection plot is shown in Figure 66.

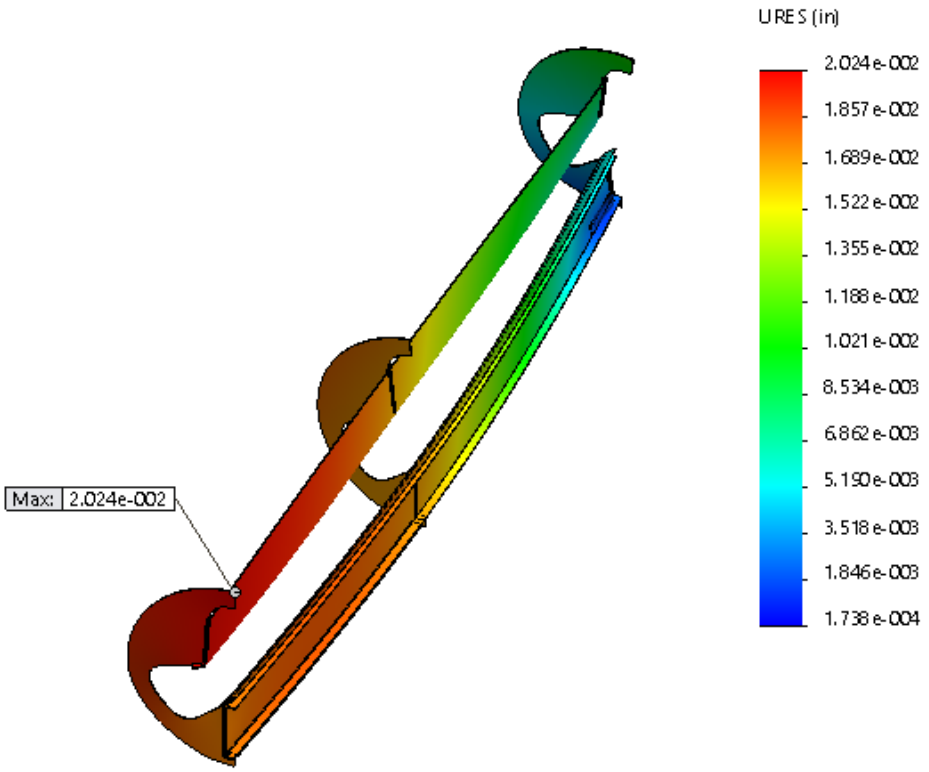

Figure 66: Sheet metal configuration deflection results.

A comparison of the max deflection, factor of safety, and weight of both configurations is shown in

Table 35.

Configuration	FOS	Max deflection (in)	Weight (lbs)
Sheet metal	5.00	0.020	52.84
Structural tubing	1.06	0.234	34.06

Table 35: Launch platform geometry simulation results.

Based on the increased factor of safety, reduced deflection, and reduction in manufacturing complexity the sheet metal configuration was chosen. Although this configuration has an increased weight, the reductions listed previously are worth the weight increase. Also the sheet metal configuration has several opportunity for material removal to reduce the overall weight of the configuration.

Based on the finding shown above in

Table 35, and the ease of manufacturing the sheet metal configuration was chosen. Further analysis will be completed to optimize the geometry of the launch rails, including

determining the optimal angle to bend the upper rails to and the optimal height of the upper rails.

Optimization Opportunities

The weight of a guide tower configuration is inherently heavy. Therefore, specific optimization analysis will be completed on components throughout the system to cut weight.

Material Removal

The rails are candidates for material removal. Structural analysis will need to be performed to determine the impact of removing material from these members. An example of a material removal pattern and associated finite element analysis is shown in Figure 67.

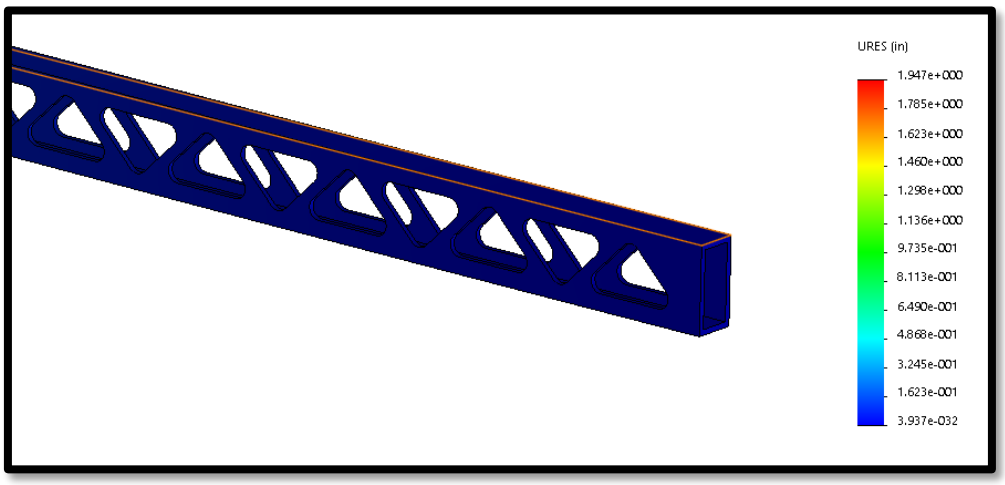

Figure 67: Launch rail material removal example pattern.

The example shown above uses an 1”x2” 1/8” wall 6061-T6 aluminum rectangular structural tube, but similar material removal could be performed on the sheet metal components of the launch platform. The pattern shown would result in a weight savings over a 10 foot length of 2.61 pounds. Optimization will be done to select the most weight efficient material removal pattern while maintaining the structural integrity of the member.

3) Vehicle Actuation

Overview

The vehicle actuation device must perform the following functions to be considered a success:

1. Actuate launch platform from horizontal to 5 degrees of vertical.
2. Hold vehicle steady during pre-launch procedures including raising of the launch vehicle, installation of igniter, and arming of recovery systems.

3. Upon power failure, system pause, reaching desired orientation, or other motion interruption the system shall maintain the launch vehicle orientation.
4. Stabilize launch vehicle during launch.
5. Be reusable.

The overall approximate dimensions of the vehicle actuation device are show in Table 30.

Mass (lb_m)	Optimization opportunity (lb_m)	Width (in)	Height (in)	Length (in)
28.69	3.00	8.00	5.125	63.43

Table 36: Vehicle actuation device general dimensions.

A rendering of the vehicle actuation device is shown in Figure 68.

Figure 68: Vehicle actuation device.

Changes since Proposal

The changes to the vehicle actuation device since the proposal are summarized in Table 37.

Change	Justification
Track bearing plates designed to weld to lower launch platform rail.	Bearing plates needed additional support.
Carriage redesigned to handle loads.	Previous design had no loading analysis.
Upper pivot point redesigned.	Articulating arms interfered with new carriage design.
Ball screw selected.	Analysis need to be performed to determine minimum screw diameter.
Motor changed	Previous motor was over powered and added too much weight.

Table 37: Changes to the vehicle actuation device since proposal.

Design

The vehicle actuation device will consist of a track and carriage system which will be mounted on the upper section of the launch platform. An actuation arm assembly will

connect the carriage to sub-frame at a stationary articulation point. Each component of the vehicle actuation device has been described in more detail below.

Track

A rendering of the track is shown in Figure 69.

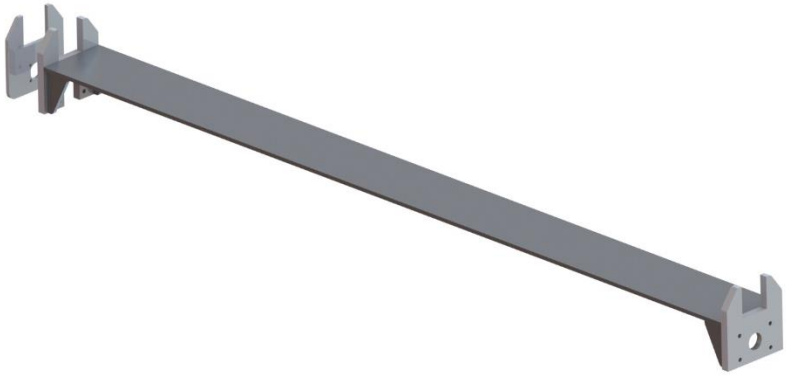

Figure 69: Vehicle actuation track.

The track will be constructed from a 4.5" x 55.5" ¼" 6061-T6 aluminum plate. This plate will be machined to length using a manual mill. The track will be centered on the lower rail of the launch platform and will be welded along both sides of the lower launch rail. The lower end of the track will include a removal bearing mount and a motor mount. The removable bearing mount is shown in Figure 70.

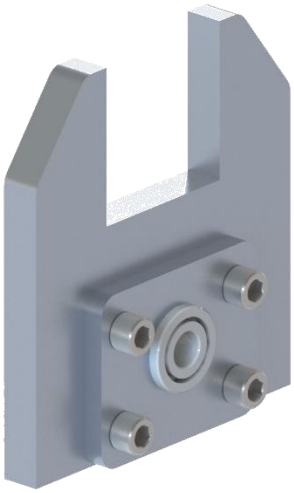

Figure 70: Removable bearing mount plate.

The removal bearing mount consists of two parts, a fixed mounting plate and removable bearing plate. The fixed mounting plate will cut on a CNC waterjet from a piece of ½" thick 6061-T6 aluminum plate and will be welded to the lower rail of the launch platform. The removable bearing plate will be cut on a CNC waterjet and will be post machined on a manual mill to prepare for a pressed fit bearing. The removable bearing plate will be

bolted to the fixed mounting plate using four 5/16”-18 UNC 3A ¾” long socket head cap screws.

Behind the removable bearing mount a motor mount plate will be welded to the lower rail of the launch platform. The motor mount plate is shown in Figure 71.

Figure 71: Motor mount plate with motor.

The motor mount plate will be cut on a CNC waterjet from a ¼” thick 6061-T6 aluminum plate. The motor will be attached to this plate using four M4 socket head cap screws.

The front end of the track will include a thrust bearing mounting plate. The thrust bearing mounting plate is shown in Figure 72.

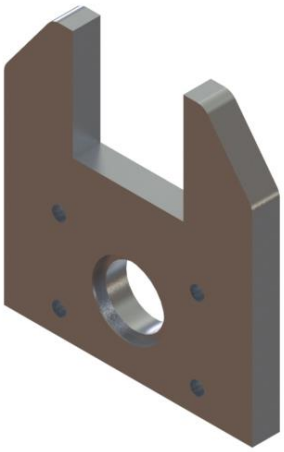

Figure 72: Thrust bearing mount.

The thrust bearing mounting plate will be cut on a CNC waterjet from ½" thick 6061-T6 aluminum plate and will be post machined using a manual mill to accept a press fit bearing. This bearing will also be counter sunk into the plate to allow for a thrust bearing to contact the mounting plate. The thrust bearing assembly will be further discussed in Vehicle Actuation. The track will also be equipped with two limit switches to provide a high and low limit feedback to the central processor to prevent jamming the carriage.

Carriage

A rendering of the carriage assembly is shown in Figure 73.

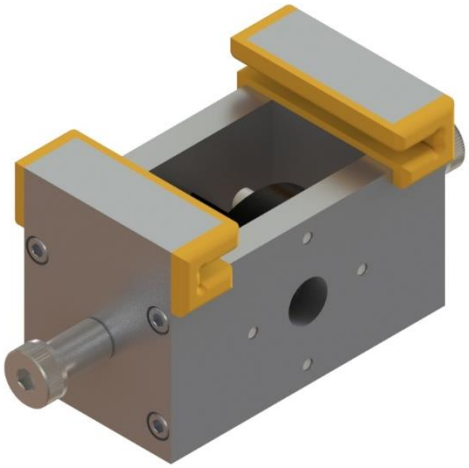

Figure 73: Carriage assembly.

The carriage will be consist of two track engagement plates, ball screw engagement plate, and a spacer. The track engagement plate will include a ½" slot that will hold the carriage onto the track and is shown in Figure 74.

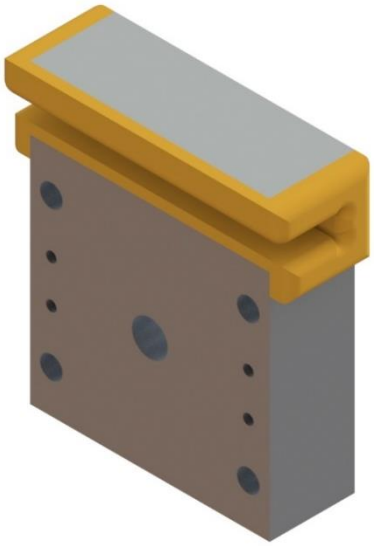

Figure 74: Carriage track engagement plate.

The slot will be wrapped in a 3D printed wear pads to reduce the friction between the carriage and the track.

The track engagement plate will include the mounting point for a 5/8” diameter 1” long stainless steel shoulder bolt with a ½”-13 UNC 3A thread that will attach the articulating arm to the carriage. The shoulder bolt was positioned at the neutral axis of the ball screw to avoid jamming of the carriage. Moving the shoulder bolt from the neutral axis of the ball screw would introduce loads that cause moments within the carriage assembly, leading to jamming. The plate will also include four counter sunk holes that will be used to fasten the spacer and ball screw engagement plate. To align the spacer and ball screw engagement plates, 1/8” dowel holes will be included. The track engagement plate will be cut on a CNC waterjet from 1” thick 6061-T6 aluminum bar stock and final machining will be completed on a manual mill. The final machining process will include cutting the slot, countersinking holes, and adding dowel holes.

The ball screw engagement plate is shown in Figure 75.

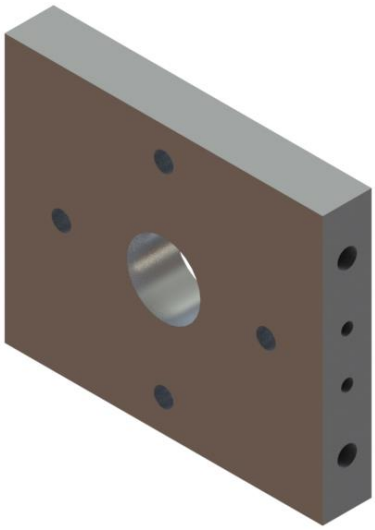

Figure 75: Ball screw engagement plate.

The ball screw engagement plate will be cut on a CNC waterjet from ½” thick 6061-T6 aluminum bar stock and final machining will be completed on a manual mill. The final machining process will include adding four ¼”-20 tapped holes for ¼”-20 1.25” long UNC 3A aluminum socket head cap screws to fasten the ball screw engagement plate to the track engagement plates. Four additional holes will be tapped on the front face of the part to fasten the ball screw nut to the carriage. Four ¼”-20 1” long UNC 3A aluminum socket head cap screws will be used to fasten the ball screw nut to the carriage.

The spacer is similar to the ball screw engagement plate, however it does not have the mounting holes for the ball screw nut. This component will also be cut on a CNC waterjet

from ½” thick 6061-T6 aluminum plate and final machining will be completed on a manual mill.

Further analysis will be completed to verify the carriage has been designed to a factor of safety of 1.5.

Actuation Arms

A rendering of the actuation arms is shown in Figure 76.

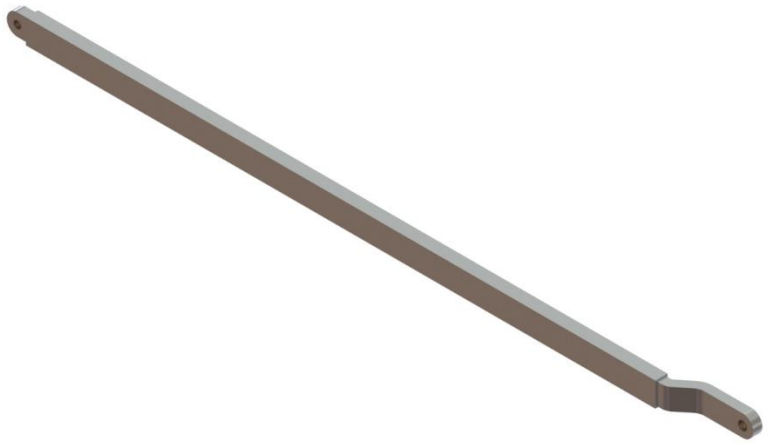

Figure 76: Actuation arms rendering.

The actuation arms will be constructed from two 1”x2” tube with 1/8” wall thickness 6061-T6 aluminum structural tubes. Each tube will be capped at both ends with a solid aluminum pivot point cut on a CNC water jet from ¾” 6061-T6 aluminum bar stock. The lower pivot point is shown in Figure 77.

Figure 77: Lower pivot point.

The lower pivot point will be inserted into the actuation arms to a depth of 1.1875” and welded to the arms along all tangent edges. The pivot includes a 0.625” hole that will receive a ½” shaft diameter ¾” long bronze bushing. The bronze bushing is used to reduce the friction in the actuation arms articulating points.

The upper pivot is shown in Figure 78.

Figure 78: Upper pivot point.

The upper pivot point will also be inserted into the actuation arms but to a depth of 0.625". The upper pivot point will require secondary machining to machine the pivot hole. The upper pivot will also receive the same bronze bushing as the lower pivot.

Further analysis will be completed to verify the actuation arms have been designed to a factor of safety of 1.5.

Ball Screw

The carriage will be actuated the length of the track using a 5/8" diameter 0.200 lead alloy steel ball screw. The ball screw will be anchored at each end using the track bearing mounts discussed earlier. Two ball bearings will be used to handle radial loads on the ball screw.

A thrust bearing assembly will also be used to handle the axial loads in the ball screw. The thrust bearing assembly will include the thrust bearing mounting plate discussed earlier, two trust bearings, a thrust coupler, and a thrust bearing retaining plate. The thrust coupler is shown in Figure 79.

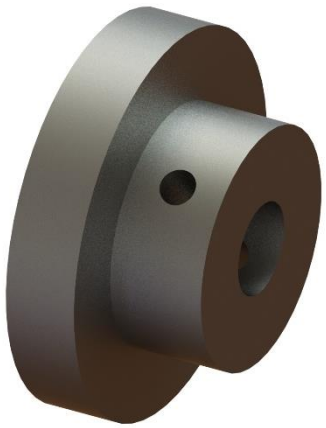

Figure 79: Thrust coupler.

The thrust coupler will be machined on a manual lathe from 2" AISI 4340 steel round stock. The coupler will be machined to receive two thrust bearings on each side of the coupler.

The thrust bearing will interface with the thrust bearing mounting plate and the thrust bearing retaining plate. The thrust bearing retaining plate will be fastened to the thrust bearing mounting plate using four 5/16"-18 UNC 3A 1.25" long socket head cap screws.

Motor

The vehicle actuation device will be powered using an AndyMark PG27 gearbox with AndyMark 9015 motor. The performance curve for the motor is shown in Figure 80. The overall reduction of the gearbox is 26.9:1 and will provide a stall torque of 3.55 ft-lbs.

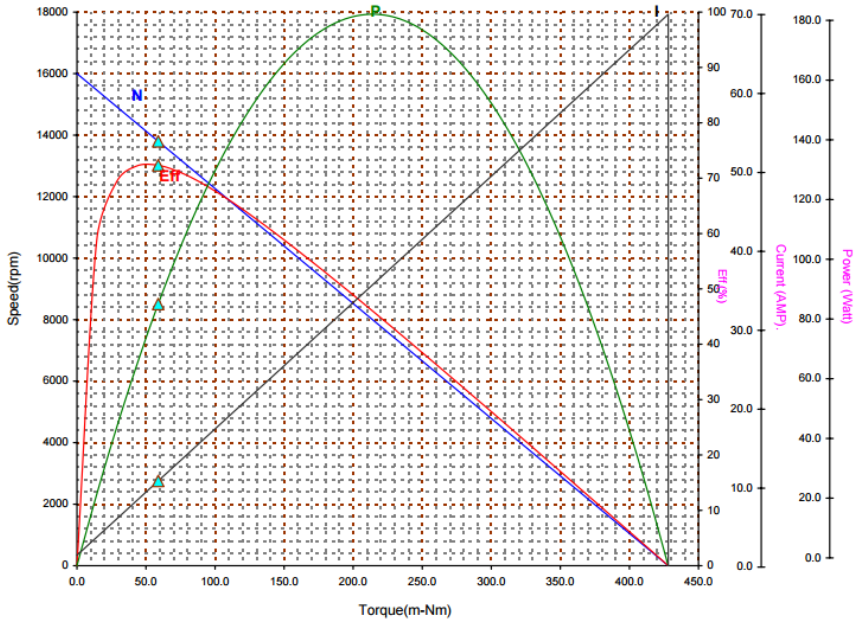

Figure 80: AndyMark 9015 motor performance curve.

Controls

Once activated, the VAS subsystem will enter a loop in which it alternates raising the vehicle and checking if the vehicle has been raised to 85 degrees off vertical. A visual representation of this sequencing is shown below in Figure 81.

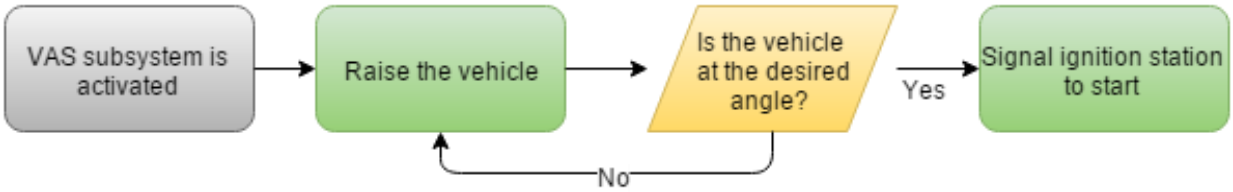

Figure 81: VAS flowchart.

Components

The VAS's electrical system will be composed of the following components:

SRX Talon motor driver

The Talon will be used on the VAS to drive the VAS motor. This motor driver will communicate with the MC via Serial and use its onboard PID control algorithms to actuate the vehicle to the desired angle using the PID closed feedback loop between the Talon and the potentiometer. Utilizing the PID algorithms provides a quicker and smoother actuation to the desired angle while also improving the accuracy of actuating to the correct angle. The motor driver has a maximum continuous current rating at 60A that exceeds the motor's maximum current draw for this application.

10K potentiometer with D-shaft
This component will be utilized in 3 applications on the AGSE. It will be used to measure angle on the payload arm's base pivot, measure angle on the wrist, and it will measure angle on the VAS. The variations in voltage that this component returns will be measured by the MC to determine angle.

Challenges

Table **38** shows the foreseen design challenges for the Vehicle Actuation System and their chosen solutions.

Challenge	Solution
Measure the Vehicle's angle with the launch base.	A potentiometer will be attached the base pivot to provide angle information to the MC.
Protect the Talon motor controller from a surge current from the motor.	A 100 amp fuse will be installed between the Talon and the motor.

Table 38: Design challenges and solutions for the VAS.

Verification Plan
To be considered successful, the Vehicle Actuation System must meet the requirements set forth in the statement of work. Table 2 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
Actuation of the launch platform from a horizontal to 5 degrees off the vertical (85 degrees).	The launch platform will designed to raise the vehicle from a horizontal position to 5 degrees off the vertical.	Each subsystem of the launch platform will be tested to ensure it can operate without any problems.
Each team will be given 10 minutes to autonomously capture, place, seal the payload within the rocket, raise the vehicle, and insert the igniter	The motor raising the vehicle 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 ensure it falls within its allotted time.
All AGSE system shall be fully autonomous.	The vehicle actuation system will be completely controlled by the MC.	The system must operate successfully without any team member intervening while testing.

Table 39: Verification plan for the VAS.

Changes since Proposal

Change	Justification for Change
Addition of a 100 Amp fuse.	Stall current of motor (133A) above that of the surge current of the motor driver (100A). Incorporate 100A fuse to protect motor driver.

Table 40: VAS electrical changes since proposal.

Future Testing

Test	Method	Pass
Determine the average current that each component will use and compare it to the max current that the corresponding component allows.	Use a digital ammeter to measure the current while applying a load equivalent to the expected load.	The current is less than or equal to 66 percent of the components max current.
Determine the accuracy of the potentiometer.	Run the VAS to a certain angle and compare the desired angle to a protractor measurement.	The potentiometer's angle measure is within ± .25 degrees of the actual angle measurement.

Table 41: VAS electrical future testing.

4) Payload Capture

Overview

The payload capture device must perform the following functions to be considered a success:

1. Retrieve payload from a location 12 inches away from the AGSE.
2. Install payload into launch vehicle.
3. Lock in position following loss of power.
4. Clear vehicle door before door is shut.
5. No gravity assistance for any function.
6. Be reusable.

The approximate overall dimensions of the payload capture device are shown in Table 42.

Mass (lb_m)	Optimization opportunity (lb_m)	Width (in)	Height (in)	Fully Extended Length (in)
7.37	0.40	4.00	3.41	40.82

Table 42. Payload capture device general dimensions.

A rendering of the payload capture device is shown in

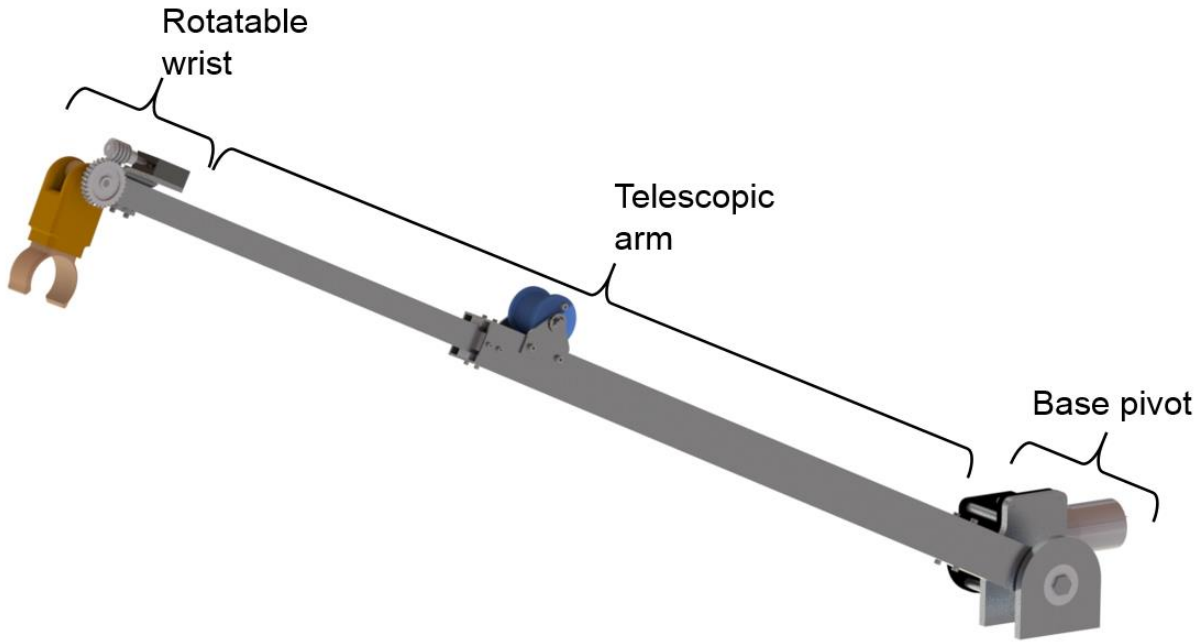

Figure 82.

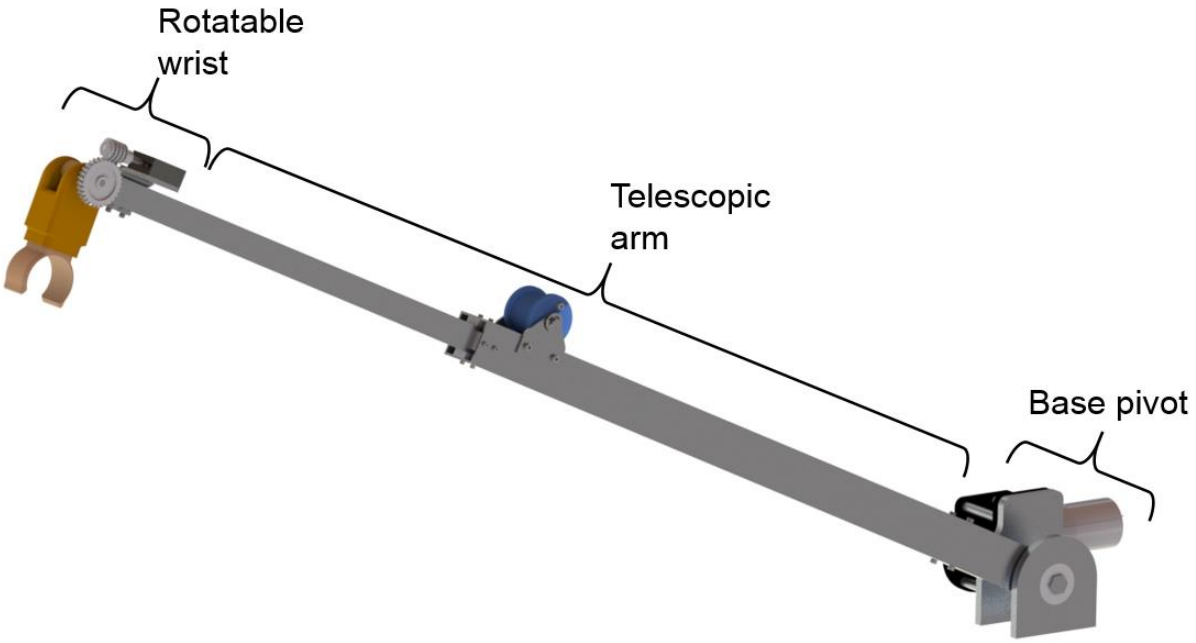

Figure 82. Payload capture device rendering.

Design

The payload capture device will have three degrees of freedom to retrieve and deliver the payload into the launch vehicle. These degrees of freedom will be achieved using a rotatable wrist, telescopic arm, and base pivot which will be further described within this section.

Telescopic Arm

The telescopic arm serves the function of allowing the capture device to extend and retract. This allows the payload capture device to be able to extend to reach the minimum distance outside the AGSE and to shrink small enough when rotated back towards the rocket to avoid interference with the AGSE sub-frame. A rendering of the telescopic arm is shown in Figure 83.

Figure 83. Telescopic extension arm (outer tube transparent for clarity).

The telescopic arm will consist of the following components:

Component	Quantity
Inner Tube	1
Outer Tube	1
Delrin Sliders	8
Motor 1	1
Motor 2	2
Motor 3	3

Table 43: Telescopic arm component list.

The telescopic arm will consist of two 1/16" wall 6061-T6 aluminum structural tubes. The inner tube will be ¾" and the outer tube will be 1 ¼". A motor will rotate a 16 inch ACME screw which will be used to extend and retract the arm. An ACME screw was chosen so that when the arm needs to be held in a desired position, the motor is not stalled.

The telescopic arm will be actuated using a 16-inch long, ¼-16 ACME screw. Analysis was performed on the ACME screw to ensure that the screw would not buckle. A buckling analysis was done for the worst loading case which is when the telescopic arm is fully extended and in a vertical position.

The Euler buckling load was calculated using

$$P_E = \frac{\pi E I}{(L')^2} \qquad (27)$$

where E is the modulus of elasticity, I is the smallest moment of inertia for the cross section, and L' is the effective column length. The moment of inertial was calculated using

$$I = \frac{\pi R^4}{4} \quad (28)$$

where R is the radius of the ACME screw. The effective column length was calculated using

$$L' = \frac{L}{\sqrt{C}} \quad (29)$$

where L is the column length and c is the column end fixity term. A 316 stainless steel 1/4-16 ACME screw was selected and analyzed given the information shown Table 44 ACME screw properties and dimensions and buckling coefficient term for buckling analysis.

Modulus of elasticity (E)	280,000 ksi
Radius of ACME screw (R)	0.0875 in
Column length (L)	16.43 in
Column end fixity (C) for uniform column, axially loaded, fixed ends	4

Table 44. ACME screw properties and dimensions and buckling coefficient term for buckling analysis.

The Euler buckling load was calculated given the desired factor of safety. The results of the buckling analysis are shown in Table 45.

Factor of safety	1.5
Load from weight of system	0.57 lbs
Allowable load	125.82 lbs

Table 45. Buckling analysis results.

The ACME screw can carry a load greater than that of just the weight of the system. The additional margin will account for the additional loading that the ACME screw will experience when pushing the sample into the rocket. While the system ACME screw appears to be over designed, the selected screw was the smallest standard size so it was selected for availability and cost reasons.

The ACME screw will be powered by a 12V DC motor. The motor will be located inside the outer tube at the base of the telescopic arm. To ensure that the motor can provide the torque required to drive the ACME screw was calculated using

$$T=\left(\frac{wd_m}{2}\right)\left(\frac{f\pi d_m+L\cos\alpha_n}{\pi d_m\cos\alpha_n-fL}\right) \quad (30)$$

where w is the lift load, d_m is the mean diameter of thread contact, f is the running friction, L is the lead of the ACME screw, and α_n is the thread angle measured from the normal plane. The system properties that were used to calculate the torque are shown in Table 46.

Lift load (w)	0.57 lbs
Mean diameter of thread contact (d_m)	0.2055 in
Running friction (f)	0.2
ACEM screw lead (L)	0.063 in/rev
Thread angle calculation ($\cos\alpha_n$)	1

Table 46. System properties used to calculate ACME screw torque.

Based on the calculated torque and assuming an operating efficiency, a DC motor was selected to ensure that the torque requirements were met as shown in Table 47.

Operating efficiency	75%
Required torque	0.576 oz-in
Selected motor torque	4 oz-in

Table 47. Assumed motor efficiency and required torque.

In order to ensure that the telescopic arm can perform the required operations in the allotted time frame, analysis was completed to determine the time required for the telescopic arm to fully extend from a fully retracted position as shown Table 48. The minimum required RPM was calculated for the motor. RPM calculations and RPM of the selected motor are shown in Table 48.

Time allotted	15 sec
Required RPM	1042.62
Selected motor RPM	2600

Table 48. Motor RPM requirements and specification.

In order to ensure that the inner and outer tubes slide freely, Delrin sliders will be used. The inner tube will have four Delrin sliders mounted on the exterior of the bottom of the tube, as shown in Figure 84.

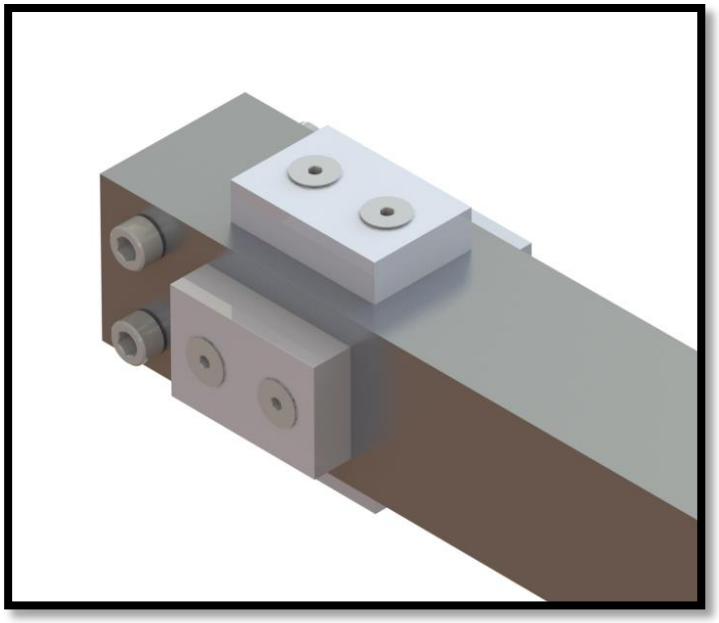

Figure 84: Detailed view of Delrin sliders.

The outer tube will have four additional sliders mounted internally at the top of the tube. These sliders will ensure the inner tube slides freely in and out of the outer tube but will not allow side to side movement.

As a result of the telescopic arm actuating, it is critical to manage the wires that are needed for the wrist and gripper assembly to avoid over tensioning or pinching wires. Organization will be achieved via a wire spool, which is shown in Figure 85.

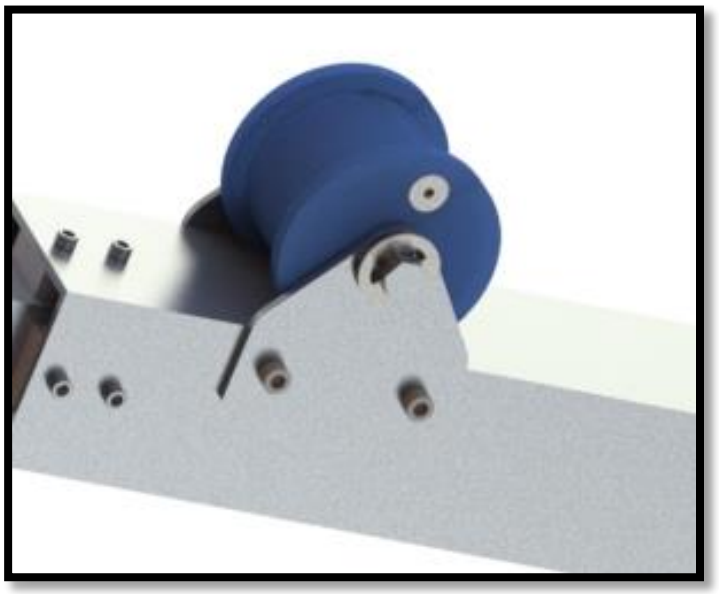

Figure 85. Payload arm wire spool.

The spool will be 3D printed and is broken into two parts as shown in Figure 86.

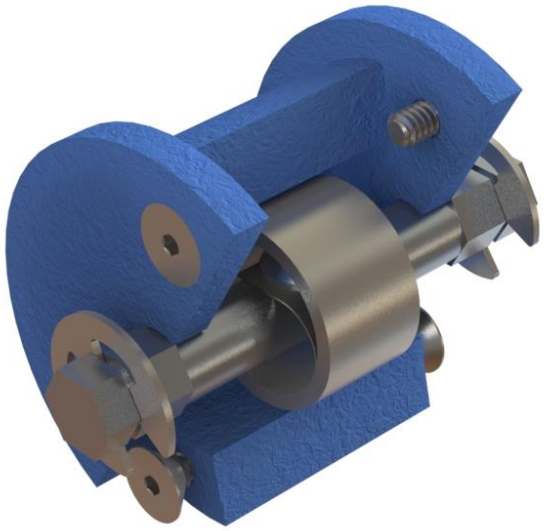

Figure 86: Wire spool with one half removed for clarity.

The spool is broken up into two components in order to allow for mounting on the shaft. Additionally, breaking the spool in half allows for internal mounting of components needed for tensioning the wires. It is important to tension the wires to reduce the risk of tangling or pinching wires during actuation of the payload capture.

The spool will be spring loaded using a 0.006" thick, 25.0" long, 0.5" wide constant force band spring. One end of the spring is mounted to the spool and the other end is mounted to the shaft for the spool as shown in Figure 87.

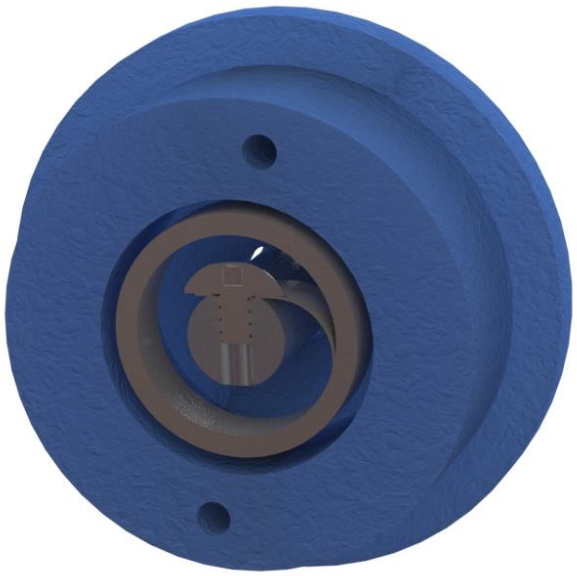

Figure 87: Cross section view of the wire spool.

The spool will also have an Adafruit slip ring with flange - 22mm diameter, 6 wires, max 240V at 2A installed. This will allow the spool to rotate and still maintain electrical connectivity in each wire.

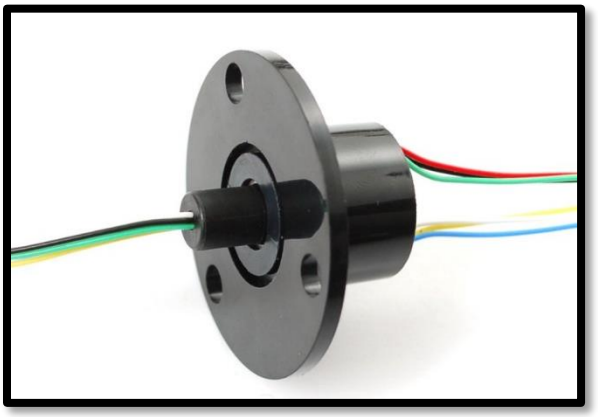

Figure 88. Slip ring with flange - 22mm diameter, 6 wires, max 240V at 2A electrical slip ring.

Base Pivot

The bottom of the telescopic arm will be connected into an actuated pivot point. The telescopic arm will interface with a custom machined hex axle. The pivot point will be actuated using a worm gearbox as shown in Figure 89. This gearbox will be paired with a 12V, 75RPM, 160 oz-in gear motor and a 1/2W linear taper potentiometer with D-Type shaft.

In order to ensure that the selected motor was appropriately sized, calculations were done to determine the required torque using the parameters shown in Table 49.

Weight of telescopic arm	63.84 oz
Center of mass of telescopic arm	29.63 in
Weight of payload	4 oz
Center of mass of payload	42.08 in

Table 49: Weight and center of mass values used in torque calculation for base pivot.

Torque was calculated using

$$T=w_1x_1+w_2x_2 \quad (31)$$

where w1 is the weight of the telescopic arm, x1 is the center of mass of the telescopic arm, w2 is the weight of the payload, and x2 is the center of mass of the payload. Using the parameters for the selected gear box and motor, the required torque was calculated. The parameters and torque value are shown in Table 50.

Gear ratio	30-1
Factor of Safety	1.5
Operating efficiency	75%
Required torque	102.11 oz-in

Table 50: Parameters for gear box and motor selection required to calculate the necessary torque for the base pivot.

Another consideration that was taken when selecting the motor was the RPM. This is important in order to ensure that the motor can rotate the telescopic arm in the required time. This also led to choosing a 75 RPM, 160 oz-in motor.

A potentiometer will be mounted on the shaft of the base pivot in order to provide position feedback to the central processor. The worm gearbox prevents having to stall the motor when holding the telescopic arm at a desired position. Attempting to hold a specific angle with only a motor or standard gearbox could cause damage to the motor while it is stalled. The selected gear box is shown in Figure 89.

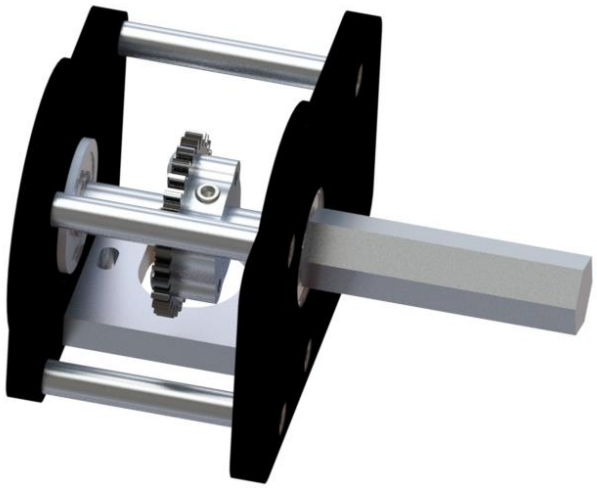

Figure 89. Telescopic arm pivot gearbox.

Removable gripper

The payload will be captured using a gripper which will be 3D printed using ABS plastic. The gripper is designed to allow the arms of the gripper to deflect when the gripper is pressed over the payload, locking the payload into the gripper arm. Analysis will be completed to determine the appropriate geometry for the gripper to ensure there is adequate compression on the payload so the payload isn't dropped during insertion into the launch vehicle. The current gripper design is shown in Figure 91.

Figure 90. Payload capture gripper device.

Once the payload and gripper have entered the rocket, an 11.11 oz-in, 4.8V DC, HS-35HD servo will release the gripper from the payload device. The servo will rotate 90 degrees, rotating a locking bar to release the gripper. Both the gripper and the payload will remain in the launch vehicle for the duration of the flight.

Wrist

A rendering of the wrist is shown in Figure 91.

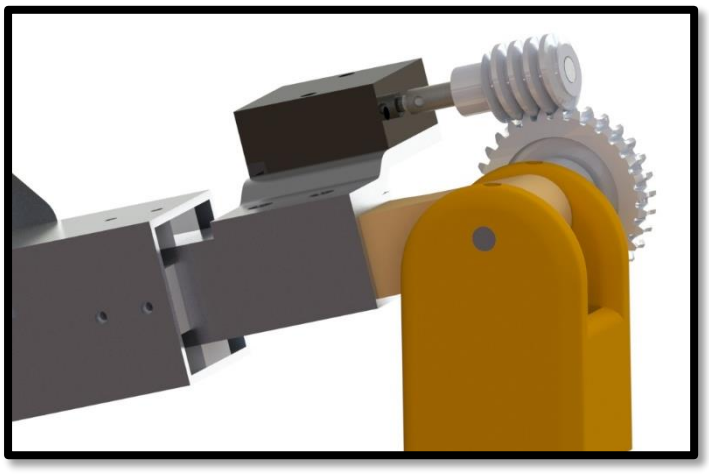

Figure 91. Payload capture device wrist.

The wrist will attach the gripper to the end of the telescopic arm. Similar to the base pivot, the wrist will also utilize a worm gear configuration for actuation. The wrist will be powered by a 12 V DC, 460 RPM 20 oz-in micro gearmotor.

The same analysis was performed on the selected motor as was described in the base pivot section. This gives the team confidence that the motor will provide the required torque at an RPM high enough to complete actuation of the wrist in the allowable time frame.

The worm gearbox prevents having to stall the motor when holding the wrist at a desired position. The wrist connection will be made from 3D printed ABS plastic. An analog encoder will be integrated into the wrist to provide position feedback to the central processor. A support system for this gear configuration may be added later on to prevent gear slippage.

Controls

The payload arm will operate on a series of checks to see if it is ready to go to the next action. The payload arm is a direct subsidiary of the main controller. A general overview of the checks and actions is shown in Figure 92.

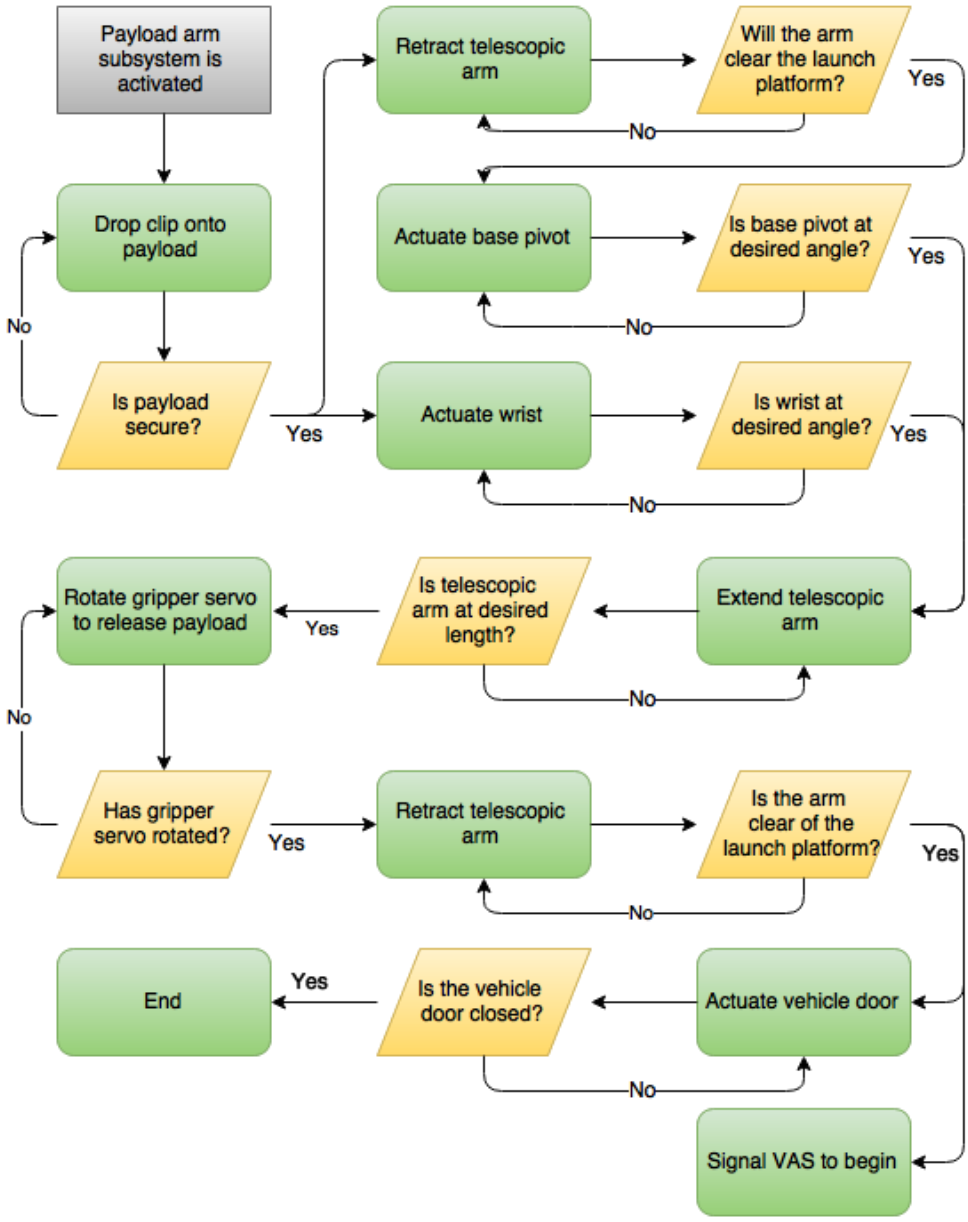

Figure 92: Payload capture system flowchart.

Components

The components that make up the payload arm's electrical systems are outlined below:

Component	Quantity
L298N	2
2600 RPM motor	1
75 RPM motor	1
460 RPM motor	1
10k potentiometer	2
Multi-turn potentiometer	1
Generic servo motor	1

Table 51: Payload arm electrical components.

L298N

The L298N was chosen as the payload arm's motor driver for its simplicity and robust design. This driver fits the needs of each of the payload arm's DC motors. This motor driver satisfies the criteria for this application in the following ways:

- Max DC current above that of the stall currents of the motors (4 amps)
- 5v logic compatible with MC
- Allows for tunable current sensing
- Each L298N can drive up to 2 motors

2600 RPM micro gear motor

This DC motor will be used as the payload arm's telescopic arm actuator. This motor satisfies the criteria set for this application:

- Operating voltage under that of the battery (12v)
- Torque at stall of 4 oz-in at 12v
- Stall current of 1.6 amp at 12v

75 RPM precision gear motor

This DC motor will be used as the payload arm's base pivot actuator. This motor satisfies the criteria set for this application:

- Operating voltage under that of the battery (12v)
- Torque at stall of 166.6 oz-in at 12v
- Stall current of 1 amp at 12v

460 RPM micro gear motor

This DC motor will be used as the payload arm's wrist actuator. This motor satisfies the criteria set for this application:

- Operating voltage under that of the battery (12v)
- Torque at stall of 20 oz-in at 12v
- Stall current of 1.6 amp at 12v

10K potentiometer with D-shaft

This component will be used to measure angle on the payload arm's base pivot, and measure angle on the wrist. The variations in voltage that this component returns will be measured by the MC to determine angle.

Multi-turn potentiometer
This component will be used on the telescopic arm to determine the arm's extended length. This potentiometer was chosen as opposed to the aforementioned 10k linear because of the need for multiple rotations.

Challenges

Table 52: Design challenges and solutions for payload capture system shows the foreseen design challenges for the payload capture system and their chosen solutions.

Challenges	Solution
Measure base pivot angle.	A potentiometer will be attached to the base pivot to provide angle information to the MC.
Measure the telescopic arm's extended length.	A 10-turn potentiometer will be attached to the telescopic arm to provide position information to the MC.
Measure the wrist angle.	A potentiometer will be attached to the wrist to provide angle information to the MC
Determine if payload is secure in gripper.	The base pivot motor will be run from a motor controller with current sensing. When the payload is secure, the extra strain on the motor will translate to a higher current draw.
Determine if gripper and payload have been released.	The MC will check the servo's position to verify that it has made a 90 degree turn.
Implement a programmatic safety feature to prevent the motors from causing damage when stalling.	The MC will monitor the current drawn by each motor and will shut down motors whose current reaches a level of concern.

Table 52: 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 53 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 payload arm will be designed and built to pick up the payload from the ground and place it inside the rocket.	Each subsystem of the payload arm will be tested to ensure it can operate without any problems.
If the pause switch is re-enabled, all actions must stop immediately.	The MC will include an interrupt function to ensure prompt pausing.	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, raise the vehicle, and insert the igniter.	The motors moving the payload arm 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 ensure it falls within its allotted time.
All AGSE system shall be fully autonomous.	The payload arm will be completely controlled by the MC.	The system must operate successfully without any team member intervening while testing.

Table 53: Verification plan for payload arm.

Future Testing

Test	Method	Pass
Verify that the safety feature prevents motors from causing damage by stalling.	Stall a motor with the safety feature enabled and note the promptness of response.	The safety feature responds to the stalling motor by turning it off within 2 seconds.
Determine the accuracy of the base pivot and wrist potentiometers.	Run both the base pivot and wrist to a certain angle and compare the desired angle to the actual measurement as determined by a protractor.	The potentiometer's angle measure is within ± .25 degrees of the actual angle measurement.
Determine the accuracy of the telescopic arm potentiometer.	Run the telescopic arm to a certain length and compare the desired length to the actual measurement as determined by a measuring tape.	The telescopic arm is within ± 1/16" of the actual measurement.
Determine precision of current draw measurement.	The proposed current draw measurement circuit to be used as a method of	T-value is less than 10% of the average measured value.

	verification of payload capture will be tested to determine precision. The values of current drawn as measured by the MC will be used to find a t-value. These measurements will be taken on the base pivot motor as it suspends the payload.	
Determine the accuracy of current draw measurement.	The proposed current draw measurement circuit to be used as a method of verification of payload capture will be tested to determine accuracy. The same procedure as the above precision measurement will be followed but data will be statistically treated and compared to that of a power supply.	The average of n readings according to the current draw circuit deviates by less than 10% from the average of n readings according to the power supply.

Table 54: Payload arm electrical future testing.

5) Igniter Installation

Overview

The igniter installation device must perform the following functions to be considered a success:

1. House and protect the igniter from damage during the actuation of the launch vehicle.
2. Install igniter to maximum interior height of the motor.
3. Hold igniter in position until motor ignition.
4. Be reusable.

The overall approximate dimensions of the igniter installation device are show in Table **55**.

Mass (lb_m)	Width (in)	Height (in)	Depth (in)
3.70	3.25	6.32	3.25

Table 55. Igniter installation device general dimensions.

The ignition installation device is shown in Figure 93.

Figure 93. Igniter installation device.

Design

The igniter installation device will be mounted at the base of the launch platform and will primarily consist of 3D printed components. It has a protective design to withstand the heat of the motor during ignition. 3D printing this device will make it cheap and easy to re-manufacture. The device can be broken down into six basic components: the housing, belt drive system, tensioner, motor, motor mount, and cable spool.

Housing

The igniter installation device housing will be 3D printed out of acrylonitrile-butadiene-styrene (ABS) plastic as shown in Figure 94.

Figure 94. Igniter installation housing.

The housing consists of an exterior shell which will contain all moving components. The housing will have a clear acrylic cover to display all internal components. The housing will be placed at the bottom of the launch tower, aft of the rocket, where a 1/8 inch piece of aluminum will distribute the heat of the motor away from the ignition housing. Two #10-32 threaded holes are located at the top of the housing and will be used to interface with the bottom plate of the launch platform.

Belt geometry

As shown in Figure 95, the belts will have a center groove to help guide the igniter into the motor of the launch vehicle. Since the belts are inexpensive to produce, multiple belts will be printed with several types of materials. Tests will be performed in order to determine the best material that will pull the igniter off of the spool. Comparisons between grip, ease of rotation, and success at installing the igniter will be used as criteria for determining the best belt material.

Both belts will be driven by a spur gear on the lower pulleys to transfer rotational energy between the two belts. The shafts of both bottom pulleys will extend out of the back of the housing. Two meshing 20 tooth gears will ensure that both pulleys rotate in opposite directions.

Figure 95. Igniter installation belt.

Tensioner

The tensioner will be 3D printed out of ABS plastic and will include two ¾" 10-32 UNC-2A socket head aluminum cap screws. The cap screws will provide an adjustment point for the tensioner. The tensioner will wrap over the igniter installer and connect directly to the top two belt pulley axles. The top two axles will be constrained in slots that allow the adjustment of the tensioner. The tensioner assembly is shown in Figure 96.

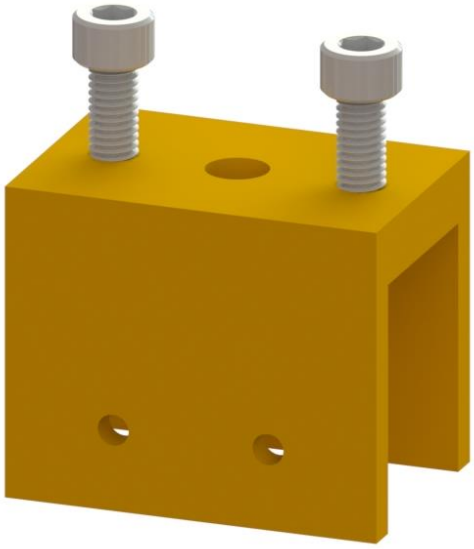

Figure 96. Igniter installation tensioner.

Belt Motor

The motor is a 12V DC 20rpm gear motor. It has a maximum torque of 185 oz/in. It will drive a spur gear that rotates both belts.

Figure 23. Belt motor.

Motor Mount

The motor will be mounted on the back of the housing. It is positioned in order to turn the lower belt gears. The motor mount will be made out of ABS plastic with 4, 3mm bolt holes in the front plate. The mount will be reinforced with a fillet instead of ribs due to constrained space from the tensioner. The motor will drive a 30 tooth spur that will mesh with one of the lower gears to rotate both belts.

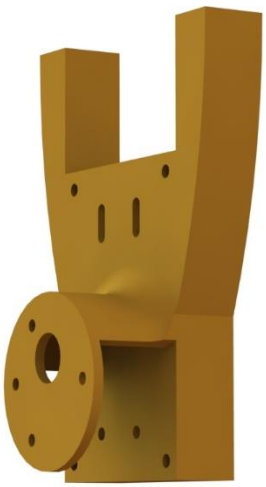

Figure 24. Motor mount.

Cable Spool

The cable spool will also be 3D printed out of ABS plastic and is shown in Figure 97. The wire spool has a diameter of 1 in. The cable spool also includes a damper disc which will interface with a damper pad. The damper will be connected to the spool to control the maximum velocity that the spool can spin. A damper pad configuration was selected because of its simplicity and linear resistance. This will be done with a torsion spring and damper pad. One end of the torsion spring will be fixed to the bottom rim of the housing, while the other end will be attached to a damper pad that covers a damper disc on the spool shaft. This allows the damper to keep tension on the igniter and will assist in straightening.

To determine the optimal spring size tests will be performed to determine the best spring. In several trial runs we will activate the motor and extract the ignitor. If the spring doesn't provide enough resistance, the wire has too much slack, gets tangled on the spool or the ignitor is too fast, a spring with a higher spring constant will be used.

The spool will include a slip ring on one end, similar to the one used on the payload capture device. This will allow the igniter wire to spool properly while maintaining connectivity. An encoder will be attached to opposite side so the system can verify the igniter has been fully inserted. This encoder will determine the number of turns the spool has made, once the spool has reached that number, the motor will be turned off.

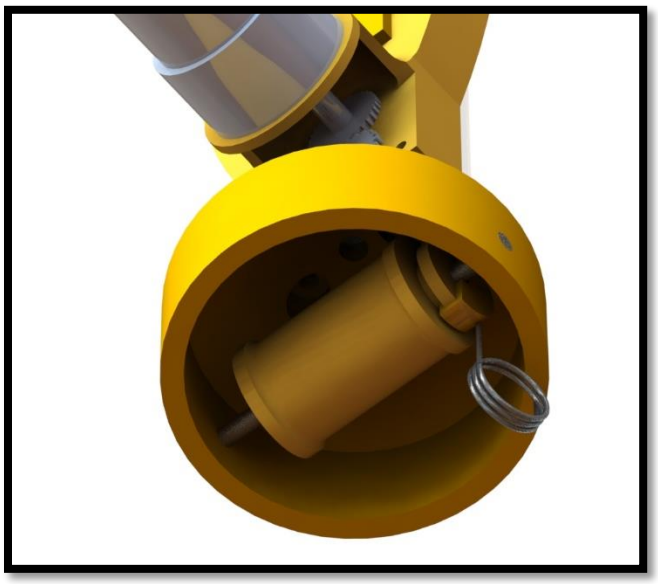

Figure 97: Igniter installation cable spool.

Changes since Proposal

Change	Justification for Change
Added motor mount to the back of housing	Allows for simple and secure position of the motor, and makes the gears easy to manufacture.
Decided on spool damper system	A spring powered friction system will give resistance on the cable spool.
Spool diameter was increased	In order to use a 10 turn potentiometer, the spool size had to increase so it would make less than 10 turns before complete insertion.

Table 8. Changes to the igniter installation device since proposal.

Controls

Once activated, the ignition station subsystem will enter a loop in which it alternates incrementing the igniter and checking if the igniter has reached its destination. A visual representation of this sequencing is shown in Figure 98 below.

Figure 98: Ignition station flowchart.

Components

The components that make up the ignition station's electrical systems are outlined below:

L298N

The L298N was chosen as ignition station's motor driver for its simplicity and robust design. This motor driver satisfies the criteria for this application in the following ways:

- Max DC current above that of the stall currents of the motors (4 amps)
- 5v logic compatible with MC
- Allows for tunable current sensing
- Each L298N can drive up to 2 motors

20 RPM Gear Motor

As mentioned earlier, this gear motor will be used to increment the igniter. This motor satisfies the criteria for this application in the following ways:

- Operates at a range of 3-12v DC
- Stall Current: 0.5 Amps at 12vDC
- Torque at stall of 185 oz-in at 12v DC

10-turn Wirewound Potentiometer

This component will be used on the ignition station to determine the position of the igniter. This potentiometer was chosen because of the necessity of the multi-turn feature.

Challenges

Challenge	Solution
Measuring the igniter position.	Validation testing using multi-turn potentiometer to determine position of igniter.

Figure 99: Design challenges and solutions for igniter installation.

6) Sub-Frame

Overview

The sub-frame must perform the following functions to be considered a success:

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

The approximate overall dimensions of the sub-frame are shown in Table 30.

Mass (lb_m)	Width (in)	Height (in)	Length (in)
30.85	73.02	17.01	91.67

Table 56. Sub-frame general dimensions.

A rendering of the sub-frame is shown in Figure 100.

Figure 100: AGSE sub-frame assembly.

Changes since Proposal

The changes to the sub-frame since the proposal are summarized in

Change	Justification
Changed to larger structural tubing.	Preliminary analysis showed larger tubing was needed
Sub-frame was raised off ground.	Provides better stability with only 3 points of contact. Reduces force required to raise vehicle.

Pivot points adjusted to sheet metal components.	Simplification for easier manufacturing.
Payload arm mount redesigned to fit new sub-frame design.	Sub-frame design changed.

Table 57: Changes to the sub-frame since proposal.

Design

The sub-frame's primary purpose is to provide stability for the AGSE and integration points for all sub systems. The sub-frame consists of the central Y structure, three leg weldments, two pivot points, and the payload capture device mount.

Central Y Structure

The central Y structure is the primary structure for the sub-frame. The central Y structure will be constructed from 2"x4" 1/8" wall 6061-T6 structural aluminum tubing. One main structural tube will be 54 long and will be parallel to the launch platform. This tube will be machined on a manual mill and will be mitered at one end to interface with a leg weldment. Two shorter structural tubes will also be machined on a manual mill and mitered at both ends. One end will be mitered to interface with the leg weldment and the other to intersect the main tube at a 50 degree angle. These tubes will intersect directly at the base pivot brackets and will be welded along all tangent edges.

Leg Weldments

The central Y structure of the sub-frame will be supported by 3 leg weldments. One leg weldment is shown in Figure 101.

Figure 101: Sub-frame leg weldment.

Each leg weldment will consist of a 2"x2" 1/8" wall 6061-T6 structural aluminum tube. This tube will be machined on a manual mill and will be mitered at both ends. The base of the tube will be capped with a sheet metal foot. The sheet metal foot will be cut on a

CNC waterjet and bent on CNC press brake. The foot will be cut from 1/8" thick 6061-T6 aluminum sheet metal. The foot will be welded to the structural tube along all tangent edges. The leg assembly will also include two gussets to fasten the leg to the central Y structure. These gussets will be welded along all tangent edges and will have additional welds along the tangent edges of the slots cut into the gussets.

Pivot points

The base pivot point will be positioned toward the back of the sub-frame. One of the base pivot point brackets is shown in Figure 102.

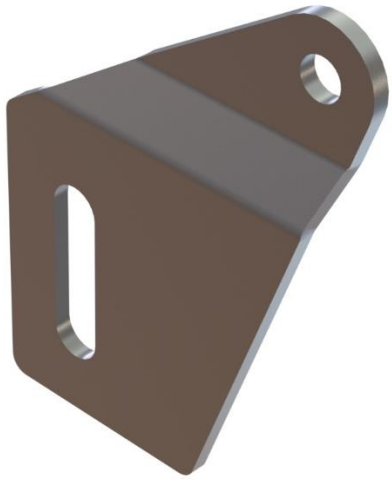

Figure 102: Base pivot bracket.

The base pivot brackets will be cut on a CNC waterjet and will be bent on a CNC press brake. The pivot points will have a bronze bushing installed to reduce friction in the joint. The same bronze bushings used in the articulating arms will be used in the base pivot bracket. Each bracket will be a mirror of the other. The base pivot brackets will be welded to the central Y structural along all tangent edges and will have additional welds along the tangent edges of the slot cut into the bracket.

The actuation pivot plates will be cut on a CNC waterjet from a ¼" thick 6061-T6 aluminum plate. An actuation pivot plate is shown in Figure 103.

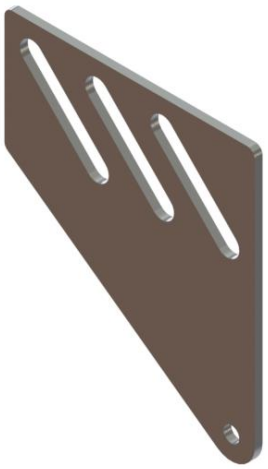

Figure 103: Actuation pivot plate.

The actuation plates will be welded to the central Y frame along all tangent edges included the edges of the slots in the plates. The left actuation plate will have an 8-32 tapped hole that will be used to fasten the potentiometer for the launch platform in place. The potentiometer will be fastened using a 8-32 UNC 3A ¼" long socket head cap screw. The actuation plates will also have a pivot axle welded into the pivot points on the plate. The pivot axle for the actuation plates was sized using similar analysis to the base pivot axle. The value for A, the distance between the support reaction centers, is ¾" for this axle. Also, for this axle F_C is used in place of F_B. A summary of the calculation results are shown in

Table 58.

	Diameter (in)	Shear stress (PSI)	Maximum deflection (in)	Factor of safety
Minimum	0.31	20,000	0.0044	1.5
Design	0.50	4,633	0.0034	6.5

Table 58: Base pivot axle sizing calculations.

The final designed diameter was selected based on common shaft sizes above the minimum diameter and available tooling.

Payload Capture Device Mount

The payload capture device will be mounted using a cantilever beam as shown in Figure 104.

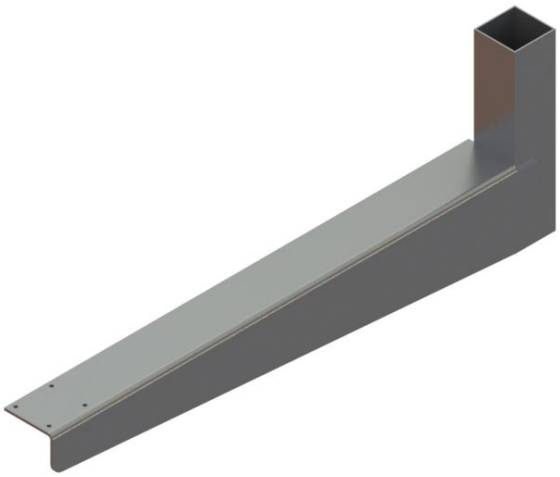

Figure 104: Payload capture device mounting bracket.

The cantilever beam will be supported by a vertical 2”x2” 1/8” wall 6061-T6 structural tube that will be welded to the central Y structure and the articulation pivot plates along all tangent edges. The structural tube will be machined using a manual lathe. A bent piece of 1/8” 6061-T6 aluminum sheet metal will be used to cantilever the payload capture device out to its desired position. The cantilever component will be noticed at the end closes to the sub-frame so it can wrap around the 2”x2” structural tube. The cantilever component will be welded along all tangent edges to the structural tube.

Stability

Stability will be continually analyzed throughout the design cycle of the AGSE. The final footprint of the AGSE and sub-frame will be determined based on the AGSE center of gravity. Lowering the center of gravity will reduce the footprint area required for a stable AGSE. If it is determined that a larger footprint is required, the Y shaped support structure will be extended to increase the size of the footprint. The current approximate center of gravity location is represented in Figure 105 as the yellow sphere.

Figure 105: AGSE center of gravity location.

7) System Controls and Integration

Overview

The relationships between all of the AGSE's electrical components are shown below in Figure 106.

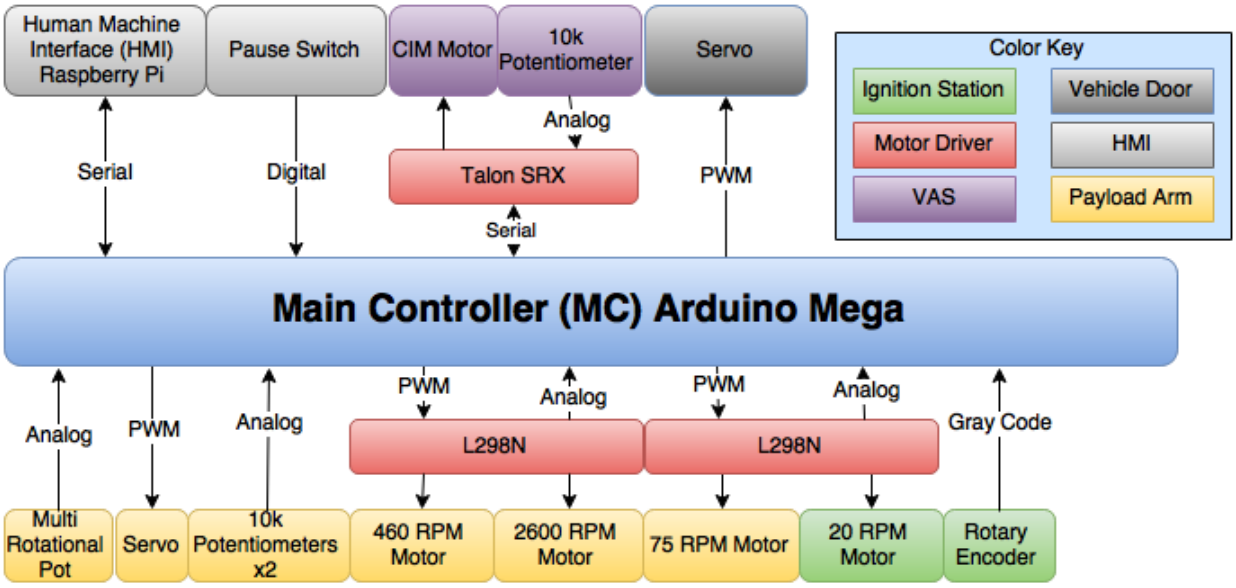

Figure 106: Controls overview.

The system will be governed by a single Arduino Mega acting as the main controller (MC). The MC will be responsible for each of the four subsystems depicted above: ignition station, human machine interface (HMI), vehicle actuation system (VAS), and payload arm. Additionally, the MC will be responsible for the pause procedure and the vehicle door.

General MC programming

Upon booting, the MC will run self-diagnostics to determine if the AGSE is ready to begin. Several of the self-diagnostic functions the MC will run include:

- Confirming the VAS is horizontal
- Confirming that all its subsidiary connections are present
- Confirming that the payload arm is in proper position.

Once the MC has determined that all systems are in the "ready" position, a pause state will be initiated. The AGSE will remain paused until the pause switch is deactivated. Upon deactivation of the pause switch, the MC will signal the beginning of the payload arm sequence. This sequence is explained in further detail in the payload arm controls section.

The payload arm sequence ends with the closing of the vehicle door and a call to the VAS function. This function and its sequencing are explained in further detail in the VAS controls section.

Following a confirmation that the vehicle has been raised to launch position, the MC will enter the ignition sequence which is explained in further detail in the igniter installation controls section.

Location of Electronics Bay

The general location shared by the MC, battery, all motor drivers, voltage conversion circuits, and the HMI will be centrally located opposite the Payload capture arm. This location is ideal when considering the following factors: voltage drop, signal decay, motor exhaust, and battery weight. This location minimizes the length of wire required to reach each subsystem, therefore minimizing voltage drop and signal decay. This location also allows for safe distance from the damaging exhaust of the launch vehicle motor, and at a low enough position that it does not compromise the AGSE's center of gravity and balance.

Electronics Bay Housing

Each component will be housed within custom acrylic and ABS plastic containers. Containers will be designed with the following features:

- Rain proof
- Heat sink ventilation
- Protection from motor exhaust fumes

Human Machine Interfaces (HMI)

The HMI panel will be an interface that provides information on the status of the MC and provides controls to manipulate the AGSE's operations. Among the controls the HMI will provide are the master power switch, the pause switch, and a touchscreen display, allowing for programmable buttons. The status information displayed on the HMI will indicate a power/pause state, an 'all systems go' state, as well as a touchscreen display which will broadcast all processes and sub functions as they occur. System power will be indicated by the blinking of an orange/amber LED at 1Hz. Pause will be indicated by the same orange/amber LED in a solid 'on' state.

The purpose of implementing a touchscreen is to allow for a flexible interface that will ease diagnostics and make the operations of the MC generally more transparent. The touchscreen will display an interactive program with buttons and status indicators and will allow for the manipulation of the AGSE's various functions.

The proposed program will be written in python on the Raspberry Pi microcomputer and will be in communication with the MC via a USB serial connection.

Changes since Proposal

Change	Justification for Change
HMI/MC communication protocol change.	The change from i2c to serial communication between the Raspberry Pi and Arduino Mega was made to avoid the level shifter circuit that would be required to accommodate the difference in operating voltage levels between the two boards.
Replacement of CAT-5E cable with standard wire.	Gauge of wire needed determined to be too large for CAT-5E cables.
No relays and amplifiers	Gauge calculations show voltage drop will be insignificant. (1%)
Physical pause switch.	Pause switch is an important safety feature that should have a direct wired connection to the MC.
Use of the MK-ES17 battery.	The MK-ES17 battery weighs 9.74 lbs less than the U1-36NE.

Table 59: AGSE electrical changes since proposal.

Components

The AGSE's main electrical systems will be comprised of the following components:

Component	Quantity
Arduino Mega	1
MK-ES17 12v battery	1
Raspberry pi 2B	1
L7805 5v regulator	4
855T control tower lights	2
12v DC toggle switch	1
SPST toggle switch	1
PiTFT 7" touch screen	1

Table 60: MC component list.

More detailed descriptions can be found below:

Arduino Mega

The Arduino Mega, which will act as the AGSE's main controller, is suited for this application for the following reasons:

- Generally robust and versatile
- Adequate number of PWM pins (AGSE requires 8, Mega has 15)

- Adequate number of digital I/O pins
- 5v operating voltage compatible with motor driver logic levels

MK-ES17 12v Battery

The MK-ES17 12v battery, which will act as the AGSE's power supply, is suited for this application for the following reasons:

- 17Ah with a reduction to 13.6Ah after 6 months
- 13.8 lbs.; a reduction of 9.74 lbs. from the previous battery

Raspberry Pi 2 B

The Raspberry Pi, which will serve as the AGSE's Human Machine Interface (HMI), is suited for this application for the following reasons:

- USB port allows for simple connection and communication with the MC
- Compatible with touch screen; allows for troubleshooting and advanced controls
- Wifi compatible; allows for connection to a database and data logging

L7805 5v Regulator

The L7805 5v regulator will be used to create a 5v party line from where all the 5v components will be powered. This component is qualified for this application for the following reasons:

- Max output current of 1.5 amps; 4 will be used in parallel to allow for the estimated 3 amps needed
- Heatsinks for dissipating power without thermal overload

855T Control Tower Lights

855T control tower lights will be used as pause, power, and 'all systems go' indicators. An orange/amber unit will be used as pause and power indicator: blinking at 1Hz when powered and solid when paused. A second green unit will serve as an 'all systems go' indicator. The second unit will signal that all systems have passed safety verifications and rocket system is ready to launch.

Figure 107: 855T control tower lights.

12v DC Toggle Switch
This 12v DC toggle switch will be used as the AGSE's power switch. It is rated for 50A at 12v DC which qualifies it for this application.

SPST Toggle Switch
This simple toggle switch will be used as the pause switch. It will be wired to an interrupt pin on the MC.

PiTFT 7" Touchscreen
The touchscreen will serve as an interactive interface on the HMI panel. The device draws .5 amps and connects to the Raspberry Pi via a DSI ribbon cable.

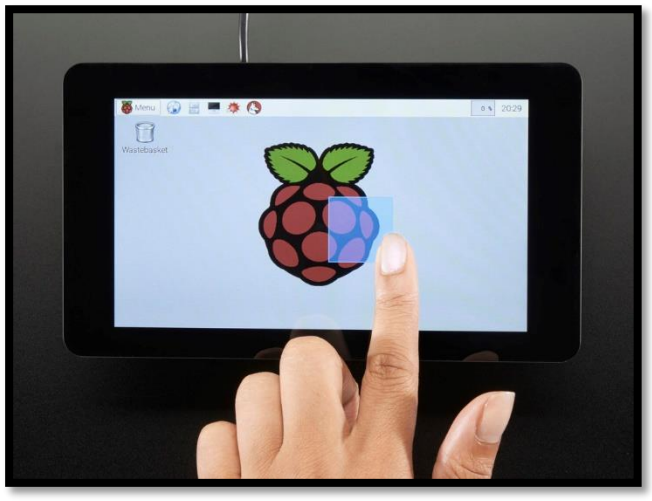

Table 61: HMI touchscreen.

Wire Gauge Analysis

Wire gauges for the AGSE were determined using the following equation.

$$AWG = 4.3122 \ln\left(\frac{(\%Drop \times Voltage)}{(Current \times Length)}\right) + 39.794 \quad (32)$$

This equation derives from Ohm's law and from the relationship between wire gauge and resistivity per length. A data table provided by Cirris Systems was referenced for the relationship between gauge and resistivity per length. This data was plotted and a logarithmic trend-line found. Calculations and units are displayed in **Error! Reference source not found.** below.

		Current at max voltage(amps)	Length (feet)	Max voltage (volts)	AWG
Payload arm	Base pivot power	1.00	2	12	27
	Base pivot pot	0.04	2	5	37
	Servo power	0.25	4	5	26
	Servo data	0.04	4	5	34
	Wrist power	1.60	4	12	22
	Wrist pot	0.04	4	5	34
	Telescopic power	1.60	4	12	22
	Telescopic pot	0.04	4	5	34
VAS	CIM motor power	25.00	10	12	6
	VAS pot	0.04	5	5	33
Ignition station	motor power	0.50	4	12	27
	Rotary encoder	0.04	5	5	33
Main lines	To 12v party line	28.00	1	12	16
	To 5v party line	3.00	1	12	25
	HMI	1.50	1	5	25

Table 62: AGSE wire gauge analysis.

Power

The AGSE electrical components will be powered by the MK-ES17 12v battery. Voltage will be adjusted to suit the 5v systems via 4 5v regulators in parallel as seen below in Figure 108 and distributed to all systems according to Figure 109 below. Additionally, a master power switch will be included on the HMI panel to toggle power on and off.

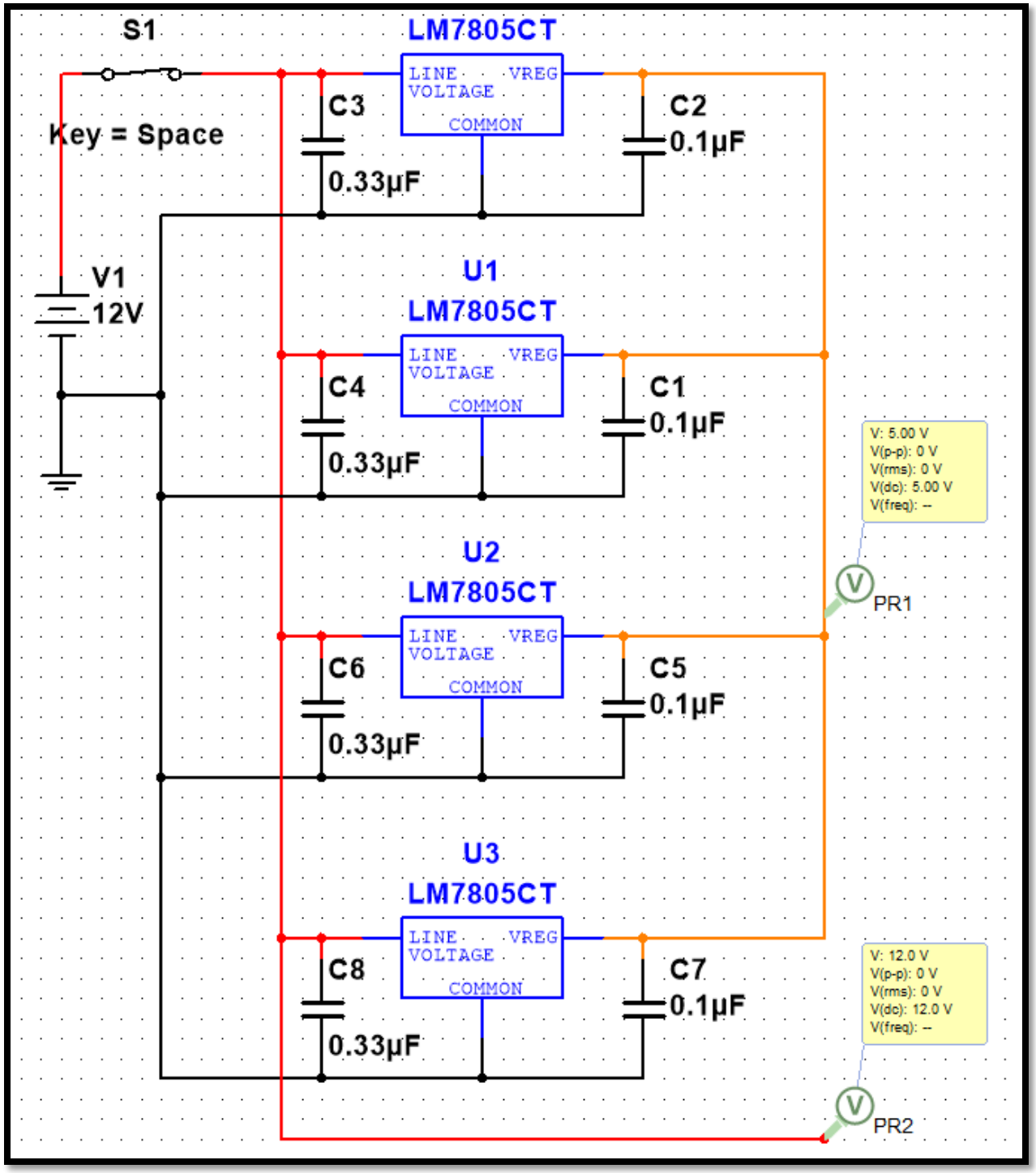

Figure 108: 5v regulation circuit.

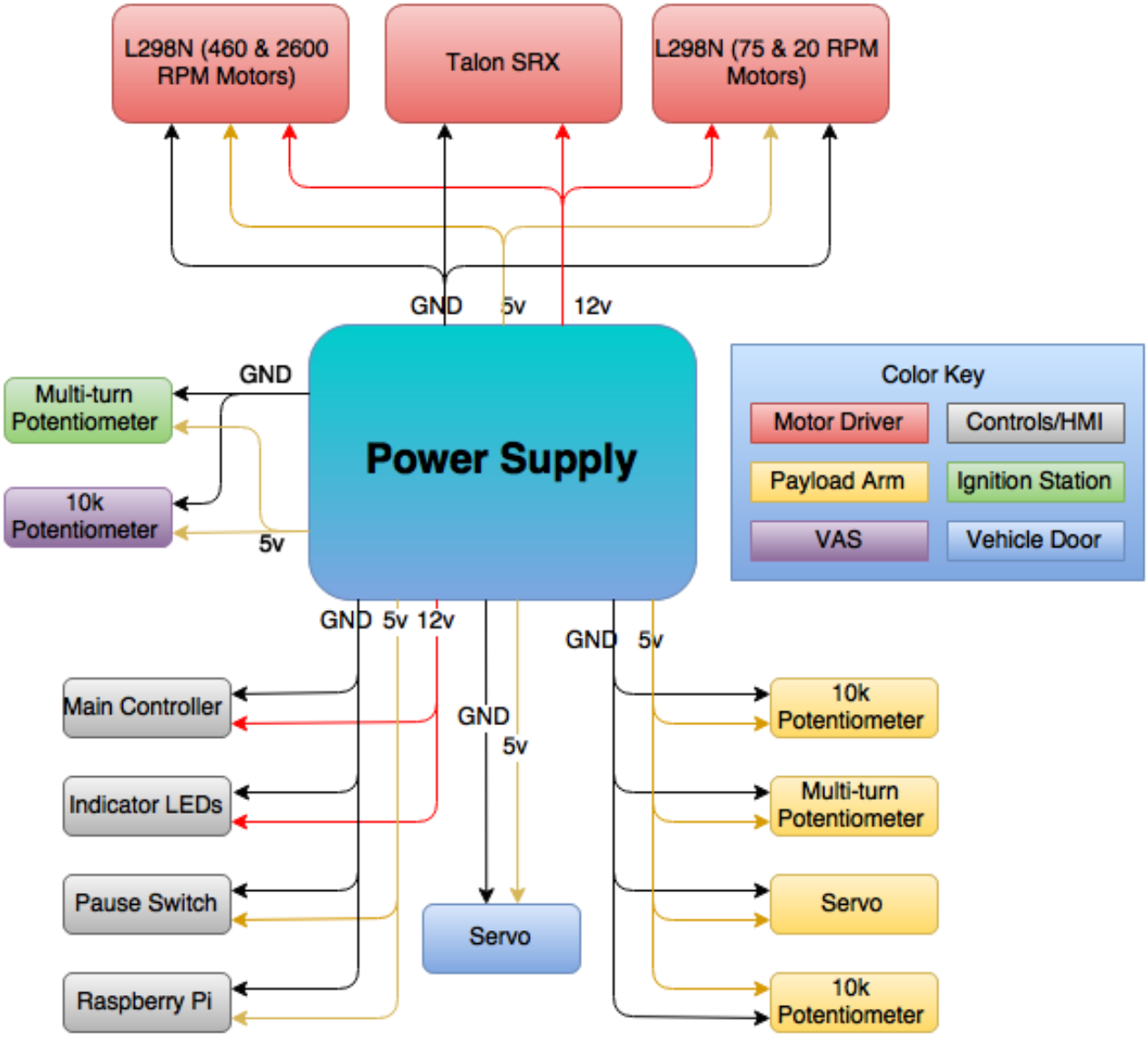

Figure 109: Power distribution diagram.

Pause Function

An important feature of the AGSE is that it must be able to immediately suspend all activity upon the activation of a pause switch. This feature has been taken into consideration from both an electrical and a mechanical standpoint. The mechanical components of the AGSE have been designed such that the AGSE can immediately suspend its activities without the stalling of motors. This function will be implemented into the programming of the MC via an interrupt pin. In this way, the pause switch has highest priority over any other function. The general sequence for this function can be found in Figure 110 below.

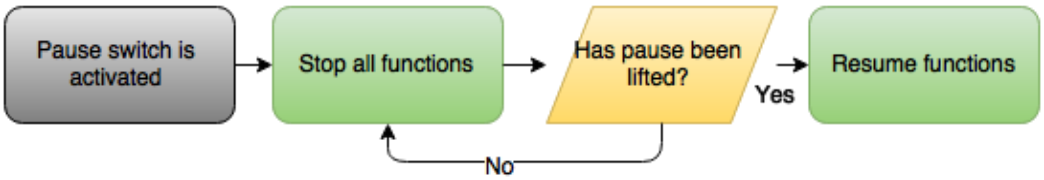

Figure 110: Pause sequence flowchart.

Future Testing

Test	Method	Pass
Qualify wire gauge.	Power a static load on each wire with the intended supply voltage regulator. Measure the voltage drop across the wire with an ammeter and calculate the percentage drop.	The percent voltage drop is below the allowable 1%.
Verify functioning pause switch.	The pause interrupt function will be tested at multiple points in the AGSE's operation to determine that it consistently and immediately halts all operations. The switch must then be deactivated to verify that the AGSE resumes.	The pause switch immediately halts all operations during every test. It resumes from where it left off when deactivated.
Determine charge depletion on battery of a single run.	Charge depletion will be determined by graphing current draw at the battery terminals over time with a Fluke ammeter. The area under this graph will be converted to amp hours.	The amp hours of one run is under that of the battery after 6 months of shelf-life (80% of 17Ah = 13.6Ah).
Determine reliability of serial communications	Serial communication reliability will be tested between both the MC and the HMI and the MC and the talon motor driver. Tests will consist of sending packets between the relevant devices and verifying consistent success.	There are no instances of data loss.

Table 63: System controls and integration future testing.

Section 8. Educational Engagement

Throughout the course of the past four years, the University of Louisville River City Rocketry Team has managed to reach out to over 5,000 students and adults in the local community. The team's outreach gives people from across the state of Kentucky a hands on experience with various fields of engineering and rocketry through working side-by-side with members of the team. The team strives to maintain relationships built with organizations in the community while continuing to reach people in new ways. The focus is never on how many people can be reached, but the quality of education that can be brought to each and every individual.

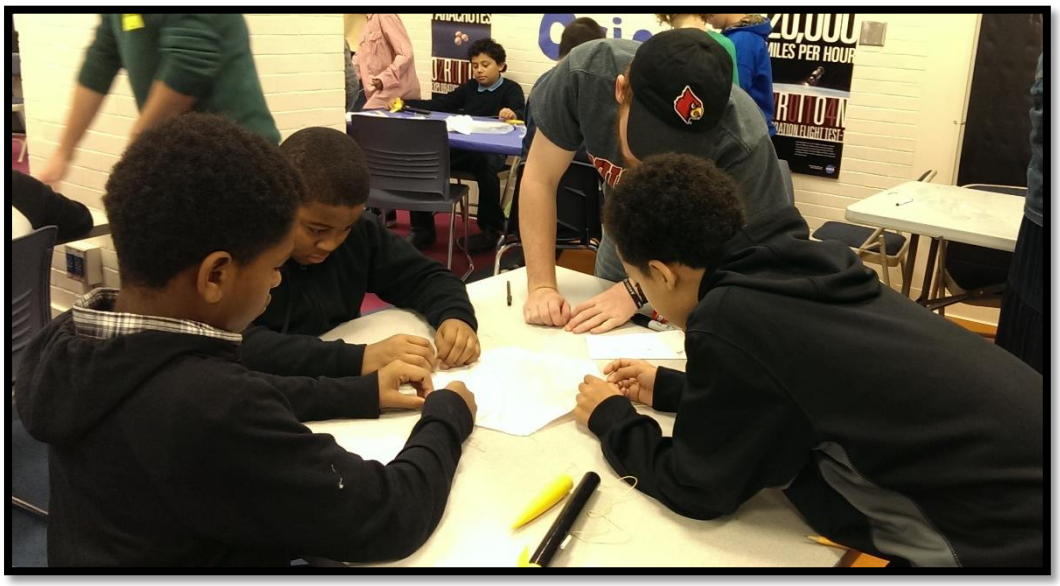

Figure 111: Ross assisting students in assembling their parachute.

1) Classroom Curriculum

The University of Louisville River City Rocketry 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 Programs

The team has developed multiple six week programs that have been a huge success in the local school system. Due to the high demand by the community to have a program offered at their school, the team will continue to offer these programs. There are multiple variations of this program, each focusing more on a different topic.

Figure 112: A young engineer building a paper rocket at E-Expo.

6 Day Aerospace Program Curriculum

Day 1: The Space Race and Mercury and Gemini Program History:

This lesson introduces the cold war, the relationship between the United States and the U.S.S.R. and how it propagated the space race. The beginning of space history is discussed, including the missions and objectives from the Mercury and Gemini programs. America's achievements are highlighted such as Alan Shepard becoming the first American in space and John Glenn becoming the first American to orbit the Earth. Rocketry concepts are taught including rocket stability, principles of aerodynamics, Newton's Laws, and basic rocket building techniques. The day concludes with the building and launching of paper rockets.

Day Two: Apollo Program History:

This lesson examines in detail the most monumental program in the history of manned spaceflight. The students will learn about the 17 Apollo missions, including the fatal fire of Apollo 1, mankind's giant leap of Apollo 11, the "successful failure" of Apollo 13, and the rest of the historic moon landings. Core concepts taught during this lesson are:

- Thrust-to-weight ratio.
- Improved rocket building techniques (Advanced paper rocket activity).

Figure 113: Emily helping students prepare their rocket for launch.

Day Three: Shuttle Program, ISS, and Curiosity Rover History:

This lesson examines in detail the movement of NASA from making deep space missions, to mastering low-earth-orbital techniques. The space shuttle was also analyzed from a standpoint of reusability. The International Space Station is followed with a look into what it takes to sustain life in low earth orbit. Finally, a brief look at the Curiosity Rover mission demonstrates how we land a probe on another planet. Students had the opportunity to do the following:

- Understand the use of composites vs. metals in aerospace applications.

- Design a payload that would fit inside the space shuttle cargo bay.
- Design a space station with the fundamental elements for sustaining life.
- See simulations of extra-terrestrial landing techniques for unmanned missions.
- See videos from inside the International Space Station.

Day Four: OpenRocket Simulation:
The class had the opportunity to model the Estes rocket that they built in the fifth day of the program. A worksheet is prepared with all of the parameters to accurately simulate the rocket. The simulation software allows the students to learn how to use the same program that the University of Louisville River City Rocketry Team uses to simulate their rocket. This stresses the importance of precisely predicting flight trajectories and altitudes. The following concepts are discussed:

- Understanding how math is applied through software simulations.
- Mass balance.
- Stability margin acceptability.
- The relationship between position, velocity, and acceleration curves and flight events.

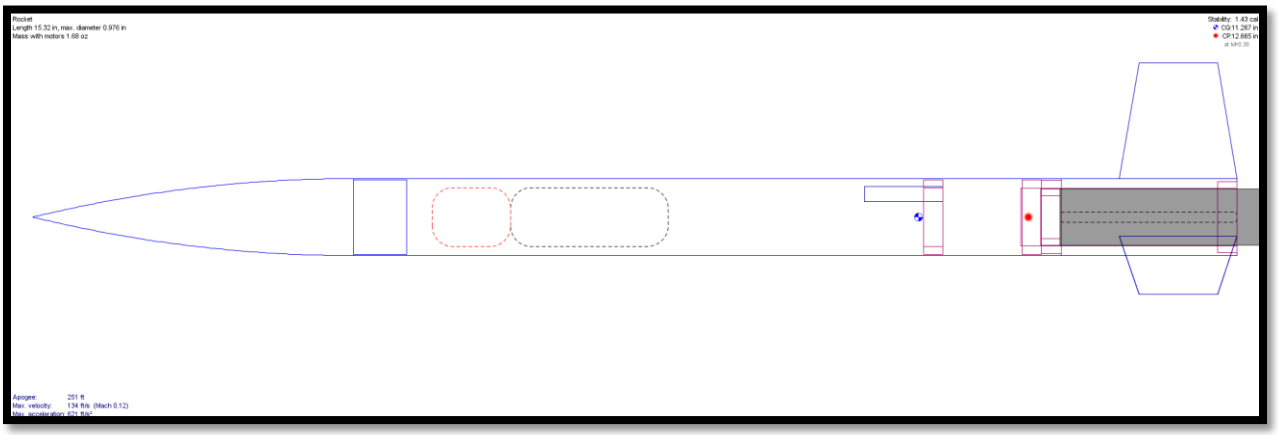

Figure 114: OpenRocket simulation created by students.

Day Five: Rocket Construction:
Each student has the opportunity to construct and launch their own rocket. Rockets are small Estes model rockets using black powder motors. Each student is be carefully supervised. The students are led through a visual walkthrough of rocket assembly. The following concepts are taught:

- Proper measurement and construction techniques.
- Fin installation.
- Launch lug mounting.
- Shock cable and parachute organization.

Day Six: Final Construction/Rocket Launch:

The students are taken through a safety briefing by a member of the University of Louisville River City Rocketry Team. Any remaining construction work on the rockets is completed during this session. The students are taught how to pack parachutes, load motors, install igniters and develop a pre-launch checklist. Finally, the students launched their rockets.

Figure 115: Carlos helping student prepare her rocket for launch.

Six Week Exploring Rocketry and Engineering Program

The goal of this program is to not only talk about rocketry, but to introduce students to the variety of disciplines of engineering that are involved. The goal is to help students to understand that there is more to rocketry than just the mechanical aspects. The first three weeks of the program are focused on exposing students to various aspects of engineering that are involved in the aerospace industry. The last half of the program is spent bringing the concepts together by simulating, building, and launching a rocket. Specific day by day plans are further described below.

Day One: Programming

Team members give an hour presentation to teach students of the importance of programming in today's world. We give an in depth look at the history of programming, discussed the basics of how programming works, and talked about the evolution and innovation of programming and how it can change the world that we live in.

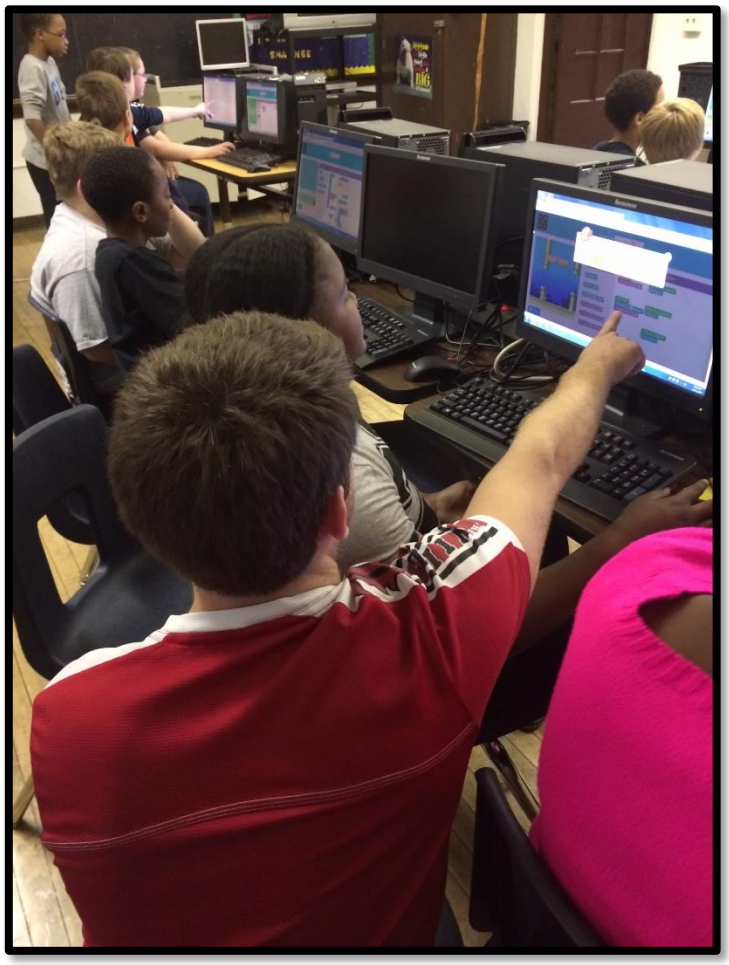

Figure 116: David teaches students how to program a game on code.org.

Students spend a second hour in the programming lab. Here students get the opportunity to utilize online tools from code.org to teach the students how to program on their own. Students are able to build, test, and manipulate their own custom game programs.

Day Two: Satellites

Team members give a presentation to teach students about satellites. We introduce the students into what defines a satellite. The students interact with the team members listing and describing various applications for satellites, and how they function to perform a defined task. We also involve the students in a history of the first satellites all the way up to the most recent Rosetta satellite and Philae lander.

The team stresses the importance of interpreting data from a satellite, and describes how certain satellites transmit data. A team member created a program that took an imported black and white image, recognized the black pixels from the white ones and assigned a coordinate to it. The program breaks down the entire image into various coordinate systems ranging from (A,1) to (J,10). Each coordinate system is a piece of the uploaded image. These coordinate systems are printed on individual pieces of paper for the students to fill out. Coordinates referencing a black pixel are shown in a table. Students

then color in their respective coordinate systems, and at the end of the activity each student's completed coordinate system is taped together to form the original image.

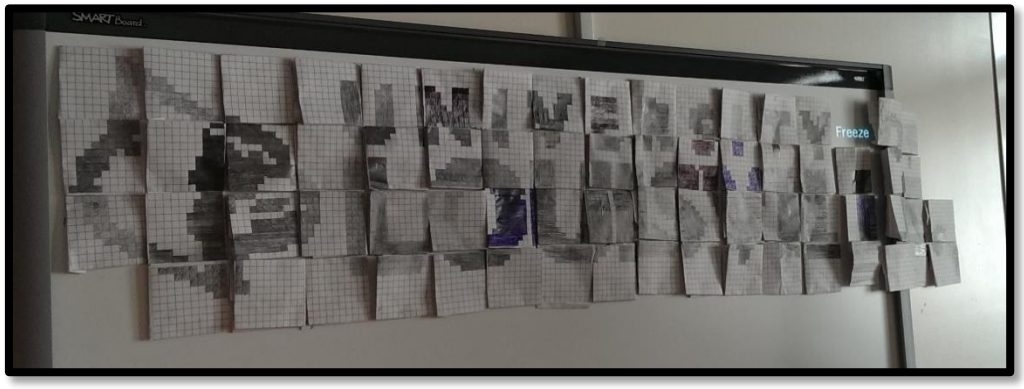

Figure 117: The satellite message that students decoded.

The activity shows how a satellite sends data back in a series of information points. It also stresses the idea that not every data signal is completely correct. The students are able to see various inconsistencies in the final image, whether it be due to the wrong block being filled out, or someone forgetting a particular coordinate. The students are given an understanding as to how and why people are needed to review every set of data from a satellite to interpret, determine if there are unexpected artifacts in the signal, and lay out the completed interpreted signal.

Day 3: Circuits

Team members gave a presentation to teach students about electronics and circuitry. We introduce the students to the basics of electronics with a PowerPoint presentation and an interactive activity. The students interact with the team members listing and describing various components that make up your average circuit board, and how they perform. We also involve the students in a history of circuitry to give the students an appreciation for where we've come to in this technologically advanced world.

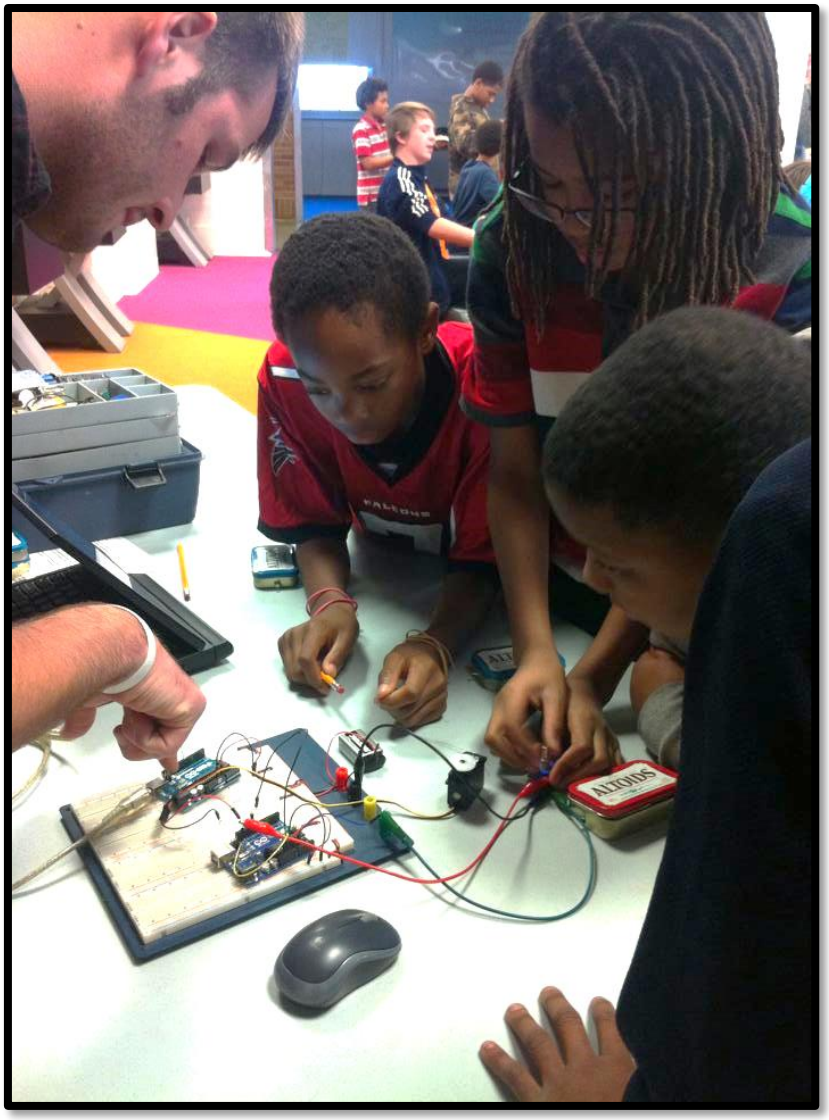

Figure 118: Sherman shows students a circuit that he built and how it works.

The primary focus is to help the students understand how various components work together to complete a certain task. The activity designed for this course is a great tool to do just that. The team helps each student build their very own “Altoid Flashlight.” Together, students are able to build a functioning circuit with a 9V battery, a resistor, an LED, and a toggle switch. They learn the ins and outs of the circuit and are able to ask questions throughout the experiment to gather a better understanding of their custom system.

After the activity, team members set up a bread-board circuit that allows students to manipulate the circuitry to control various small motors. They are able to be hands on with various components to see how varying the voltage and current through a system can have an effect on the output of the system.

Day 4: OpenRocket Simulations

The team gives a presentation to the students on what it takes to build a high powered rocket. We stress the importance of simulation and how it can affect your design. We walk students through the basics of individual components of a rocket. Each primary component is talked about in great detail to give the students a firm understanding of the complete system. The team brings in last year's subscale launch vehicle to act as a "dissectible patient" so the students could look at both the internal and external components of what goes into a high powered launch vehicle.

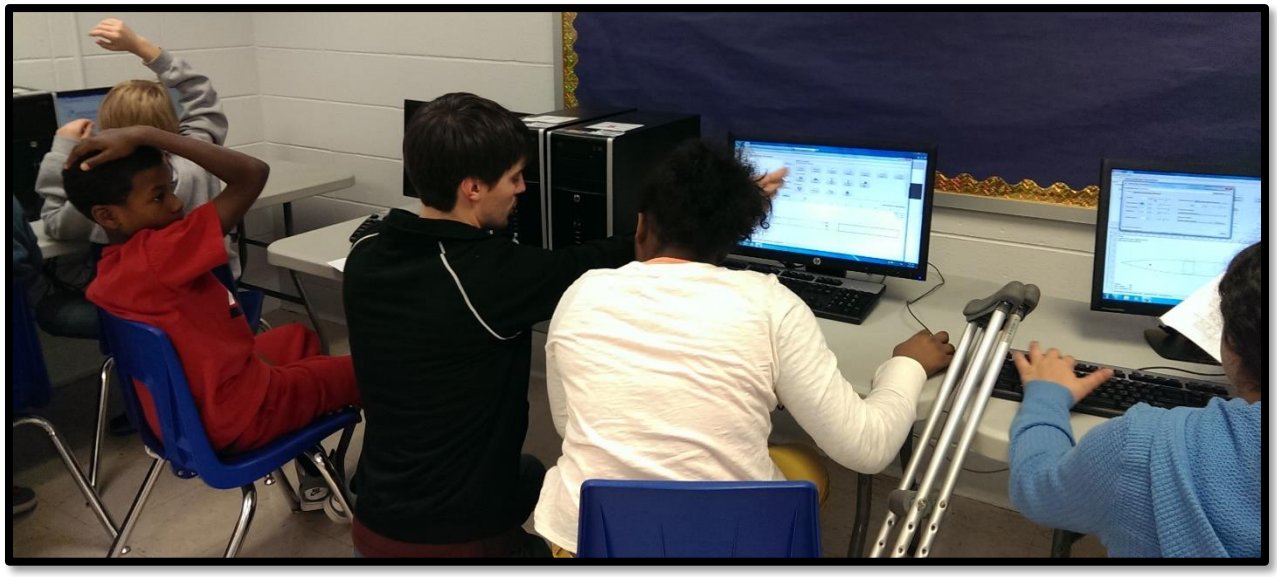

Figure 119: Gregg helps student with her OpenRocket simulation.

When the students have an understanding of all the pieces of a rocket, we introduce them to the OpenRocket simulation software. We walk them through the user interface, how to add components, motors, and how to simulate a flight. The team members teach the students the importance of a stable launch vehicle and how the center of gravity and center of pressure of a launch vehicle plays an important role in determining the rocket's flight. Once the student's know how to run the program, they are given a list of variables to use to simulate the rocket's they build the following week. They are able to estimate their rocket's flight path and altitudes. Afterwards, they were tested to see who could design a rocket to fly the highest!

Day 5: Rocket Construction

Day 6: Rocket Launch

See previous program for details on rocket construction and launch.

Lego Mindstorm Programming

Every year, local students work in teams on building and programming Lego Mindstorm robots to complete specific tasks as defined by the FIRST Lego League competition. The team continually plays a role in educating students on these teams in the fundamentals

of robot design and programming. The team regularly meets with the students to mentor them throughout the process. The students write programs, perform testing, and continue to tweak the programs until the robot performs the desired task.

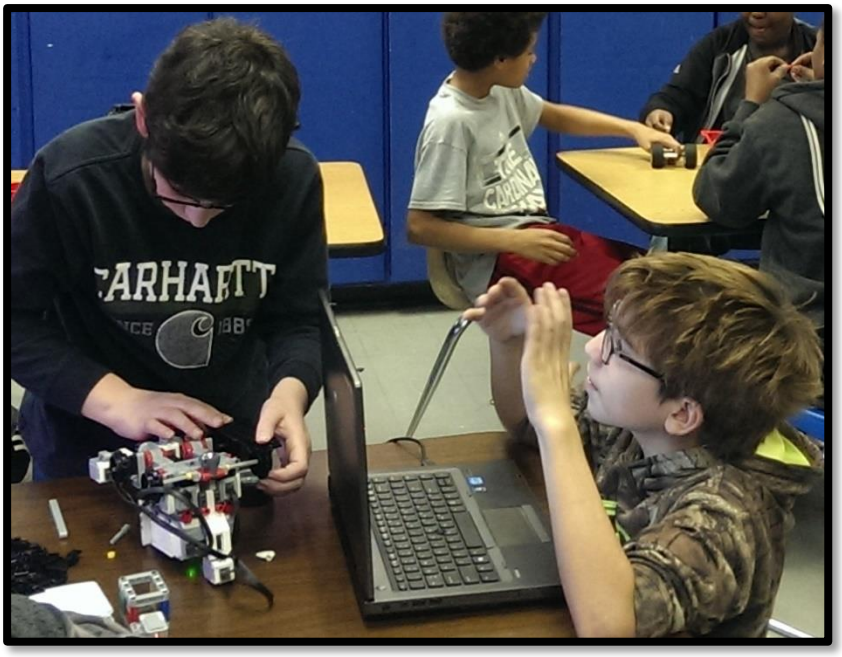

Figure 120: Students discuss designs and modifications to their program.

MathMovesU

Raytheon Missile Systems partnered up with the University of Louisville and River City Rocketry to bring MathMovesU to 100 elementary and middle school age students. This program is meant to make kids excited about STEM while learning key STEM principles. While Raytheon Missile Systems was extremely generous in funding the entire project and the University of Louisville organized transportation and meals for the day, River City Rocketry planned the entire educational aspect and lead all sessions.

The students were each provided transportation from their respective schools to the University of Louisville's J.B. Speed School of Engineering. The students started off the day in a room together for a general introduction. River City Rocketry introduced themselves and gave a short presentation about what we do, why we are passionate about it, and how the students can prepare themselves for a bright future. Raytheon Missile Systems also gave a brief presentation about what they do and stressed the importance of STEM.

The students were broken into two groups: a middle school group and elementary school group. Each of the classes were given a lesson on rocketry fundamentals. Students learned the components of a rocket and the flight path. Students were also taught Newton's laws during this session. We were very impressed with how much the kids retained as they were able to apply the laws to a rocket and identify how each law impacts the flight of a rocket. They were also taught how to determine the stability of a rocket by

using the center of gravity and center of pressure and why this is important. The students then built and launched paper rockets prior to eating lunch.

Figure 121: Students from Wheeler Elementary working on their paper rockets.

After lunch, the students were given a demonstration of the team's rocket and AGSE. Students were walked through the process and how it worked. The AGSE was run through the entire sequence and students were able to ask questions. Having a basic knowledge of the team and rocketry concepts, the students asked very intelligent questions.

Figure 122: Students eagerly ask questions about River City Rocketry's AGSE and rocket from last competition season after a demonstration of the system was given.

The students concluded their day by each building and launching an Estes rocket. Due to time and intensity, the elementary students were broken up into groups to build their rockets. The middle school group was able to successfully launch and recover their

rockets while the elementary students will launch their rockets during a follow up session at their respective schools.

Figure 123: Students anxiously wait their turn to launch their Estes rocket.

This was an extremely successful event and River City Rocketry is excited to continue to partner with Raytheon in the future to make the MathMovesU event at the University of Louisville an annual event.

Future Development

Due to feedback from last year's outreach, the team understands a need for some more advanced courses. The team has continued to work with some of the same organizations year after year and some students have been through all of the offered programs. We want our students to understand that there is always something new and exciting to learn.

One idea that River City Rocketry has proposed is utilizing SparkFun's Mini Inventor's Kit for Redboard, as shown in Figure 124.

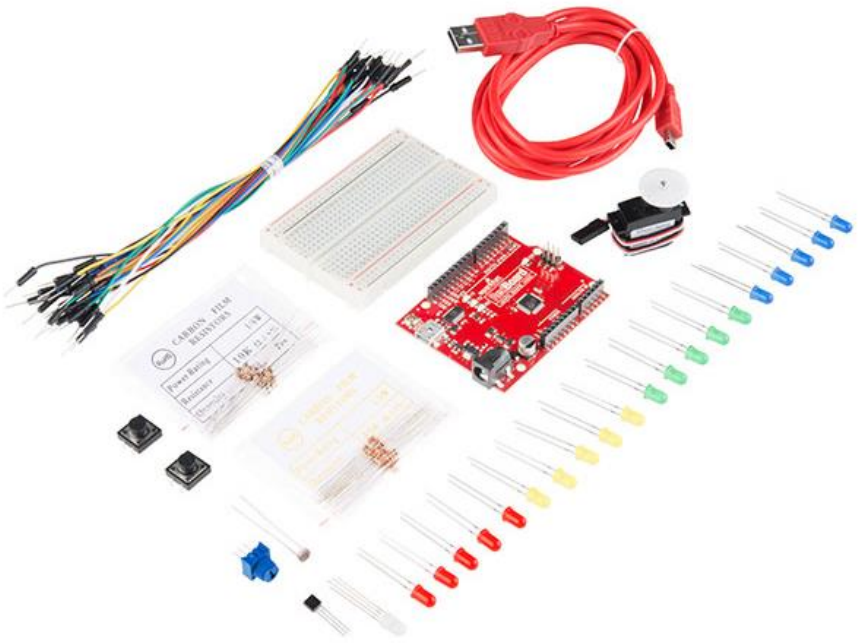

Figure 124: SparkFun Mini Inventor's kit.

The Mini Inventor's kit includes basic electronics that will allow student to get hands on interaction with fundamental programming and wiring up their own circuits. River City Rocketry was recently rewarded a grant which will cover the cost of a classroom set of the electronics kits. This program has not yet been rolled out as it is dependent on when the kits are received and lesson plans are written. However, this is an exciting new addition that the team is looking to roll out in January 2016.

2) 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 activities and scientific demonstrations for the elementary and middle school students to participate in.

The University of Louisville River City Rocketry Team will host its fifth annual water bottle rocket competition for middle school students. Teams from local middle schools can participate in teams of up to three students to design and build their own water bottle rockets out of two liter bottles and other allowable materials. Workshops will be held with schools interested to teach the students about the components of a rocket and aerodynamics in preparation for the competition. The students will get to show off their rockets at the E-Expo event throughout the day and will conclude the day with the

competition. Teams will compete for awards in highest altitude, best constructed rocket, and landing closest to the launch pad. This event has been a huge success in the past and many schools have voice interest in continuing their involvement so we are looking for our best turn out yet this year.

Figure 125: 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.

While cub scouts are not eligible to earn their merit badge, we still enjoy getting to teach them about rocketry. We have had the pleasure of working with scouts troops in educating the kids about the fundamentals of rocketry, while also giving them the opportunity to build and launch their own paper rockets. We plan to continue to build our relationships with these troops this year.

Additionally, a local group of Cub Scout troops is putting on a STEM camp geared toward earning the Dr. Luis W. Alvarez Supernova Award. While the camp lasts four days, River City Rocketry will only be involved on one day and will be in charge of running the "Out of this World" module which focuses on space exploration. This camp will involve approximately 100 students. The plans are currently in work but more detail will be provided as they are solidified.

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 at The Big Carnival for kids that had not yet been paired with a mentor through the program. This is the second year in a row that the team has participated in this event. Both years, this event has been a huge success in brining STEM to under privileged kids.

Figure 126: Zak assisting in the construction of a paper rocket at The Big Carnival.

"Kevin and UL Rocket Team,

On behalf of The Big Leadership Team of Big Brothers Big Sisters of Kentuckiana, we want to express our gratitude for your support of The Big Carnival. Last year the team was definitely the favorite and this year you all did not disappoint! All of the children enjoyed designing and launching their rockets! Your support of The Big Carnival means so much to us but even more to the waitlist children who attended with their families.

Thank you from The Big Leadership Team & Big Brothers Big Sisters!"

Louisville Mini-Maker Faire

Annually, Louisville hosts a Mini-Maker Faire. The team always participates by taking the previous year's project out to show off to anyone attending the event. A mixture of people attend this event ranging from small children to adults with experience in the field. This gives the team an opportunity to talk to the community about our project and what it does. This is an informal setting which is perfect for interacting with visitors and answering their questions about the project, what the team does, and about rocketry in general.

FIRST Lego League Competition

The team initially become involved with the FIRST Lego League Competition during the 2014-2015 season. This was such a successful event that River City Rocketry has been invited back to participate for the second year in a row! The FIRST Lego League

competition is an all-day event and the team performs several activities throughout the day. Throughout the majority of the day, the team has a display set up so that when students are in between events, the team can talk to them about the previous year's project. This is a good way to show the students how programming can be applied into something beyond their Lego Mindstorm robots.

During the competition period, team members assist in the judging process. The team helps to judge a portion of the competition called core values. In this, students are tested in a variety of ways to see how well they work together as a team and how dedicated they are to their project. Students are given a variety of tasks to complete as a team and are then questioned on their methodology and teamwork. This is important to show the students the importance of being able to work together as a team and qualities of a successful team.

Figure 127: Sherman talking with FIRST Lego League participant about how the team has previously developed a hazard detecting rover.

At the end of the day, while all of the teams are waiting for the final results of the competition, River City Rocketry representatives give a presentation to all of the students, parents, and educators present. Here the team is able to talk about what River City Rocketry does as a team and relate that to the students' projects. This is an opportunity to share how the team designs, manufactures, and test just the same as the competitors. It is important that the students realize that the skills learned by participating FIRST Lego League competition can be applied to the real world and that it aligns with STEM career paths.

Louisville Astronomical Society

The team was invited to be the guest speaker at a Louisville Astronomical Society (LAS) meeting. This event was for both those that are members of LAS as well as the public. This was an opportunity for the team so share what was accomplished during the 2014-2015 season as well as what the team is looking to do during the 2015-2016 season. The setting allowed for technical conversations about the project.

Executive Board of Advisors

The team was invited by the Dean of the University of Louisville J.B. Speed School of Engineering to present to his board of advisors. The advisors included CEO's and management from various companies from the region. This presentation consisted of a

technical review of the previous year's design, what the team is about, the tasks that the team are required to complete, and the successes of the season. This provided the team excellent exposure to a variety of companies in the region.

Student Technology Leadership Program (STLP)

STLP is a project based learning competition that is sponsored by the Kentucky Department of Education. K-12 students are challenged through the utilization and creation of technology to solve school and community needs. On November 10th, the University of Louisville will host a regional qualifier for the competition. Approximately 900 students in K-12 will be in attendance. The University of Louisville has invited River City Rocketry to participate by setting up a booth to talk with students throughout the day. The team will bring the rocket from last competition as well as other competition materials to discuss with the students. This is an excellent opportunity for the team to share their work and the possibilities for advancement in STEM with students from the region.

3) Progress

River City Rocketry has already had significant success with outreach this year. The progress bar shown in Figure 128 details the number of students reached through direct education already as well as the events that are on the team schedule.

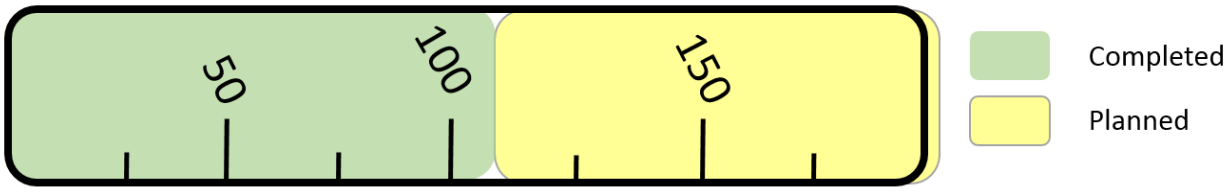

Figure 128: Progress bar detailing number of students reached and planned outreach.

The team already has scheduled direct educational events that will exceed the required number of students reached. However, this is not all that the team intends to do throughout the season. The team has previously set a goal of reaching one thousand students throughout the course of the season. This will be achieved through the implementation of the programs and outreach detailed previously.

Section 9. Project Plan

1) Timeline

Due to the complexity of the NASA Student Launch Project, it is critical that the team generates a timeline for completing each of the required tasks. Given the team's experience, approximations on task completion time can be realistically approximated, leaving the team with reasonable goals for each task listed. In order to make the schedule as easy to understand, the schedule was broken into sub projects by sub-team. Each of these was further broken into subsystem. The project timeline takes the following structure:

- NASA Competition Deadlines
- General Team Business
    - Recruiting/Team Development
    - Team Meetings
    - Sped School Student Council
- Educational Outreach
    - General Events
    - MathMovesU
    - Scouts STEM Camp
    - E-Expo Middle School Competition
- AGSE
    - Launch Platform
    - Vehicle Actuation Devices
    - Payload Capture Device
    - Subframe
- Recovery
- Launch Vehicle

Breaking down the schedule with the given structure allows for each sub-team to clearly understand their responsibilities and goals without being confused by the other group's tasks. Each of the subsystem projects are also broken further down into the following four categories:

1. Design
2. Analysis
3. Fabrication/Assembly
4. Testing

This details the four main phases required for each of the subsystems to complete to ensure a successful system. It is important that each of these sub-projects be brought together and combined into one master project schedule so that the team understands

how each task is dependent on each other. By doing this, the team has the ability to understand the critical path for the entire team and put extra emphasis on ensuring those particular tasks are completed on time. Due to the complexity of the project and the short time frame, there are multiple critical paths to ensure that the project is completed on time. The tasks that are on critical path for the overall project are shown in **Error! Reference source not found.**.

AGSE
Launch Platform
Design
Preliminary design
Finalize design
Analysis
Joint analysis
Fabrication/Assembly
Build welding jig
Weld launch platform assembly
Complete launch platform assembly
Testing
Deflection testing
Rocket integration
Complete launch platform testing
Vehicle Actuation Devices
Design
Preliminary design
Finalize design
Analysis
Track material selection
Track joining method
Weight optimization of track
Fabrication/Assembly
Water jet carriage components
3D print carriage components
Assemble carriage
Final assembly of vehicle actuation device
Testing
Deflection testing
Rocket integration
Complete launch platform testing
Payload Capture Device
Design
Preliminary design
Peer review design
Re-design
Finalize design
Fabrication/Assembly
Manufacture Wire Spool
3D print 2 spool halves
Assemble payload capture device
Testing
Verify payload capture device can pick up and move payload
Full payload test
Sub-frame
Design
Preliminary design
Peer review design
Finalize design
Analysis
Structural analysis of pivot points
Fabrication/Assembly
Waterjet gusset plates
Weld sub-frame
Testing
Structural testing
Final assembly of AGSE
Verify stability
Test ability to raise launch platform to launch orientation
Full system test
Recovery
Design
Preliminary design
Sizing of harnesses
Peer review design
Finalize design
Fabrication/Assembly
Subscale
Cut templates for subscale gores
Cut and number all gores and shroud lines
Hem all gores
Secure lines into gores
Assemble reefing bulk plate
Full Scale
Assemble reefing bulk plate
Testing
Subscale
Ground test reefing bulk plate mechanism
Ground test parachute
Verify proper deployment from bags
Full Scale
Ground test reefing bulk plate mechanism
Ground test parachute
Verify proper deployment from bags
Launch Vehicle
Fabrication/Assembly
Full Scale
Manufacture carbon fiber tubes, measure wall thickness, and update centering ring dimensions
Construct fin slot jig
Epoxy centering rings
Review fitment of fins in airframe and centering rings
Testing
Subscale
Subscale Test 1
Subscale Test 2
Full Scale Test
Verify payload door actuation
Write FRR
FRR Due

Table 64: List of tasks on critical path.

Since each of the sub-teams have their own schedule, it is important that all sub-team members understand the critical path for their portion of the project. A critical path was determined for each sub-team's project timeline. Images of each sub-team timeline are shown below. The pink bars on the Gantt chart indicate that the task is on the critical path.

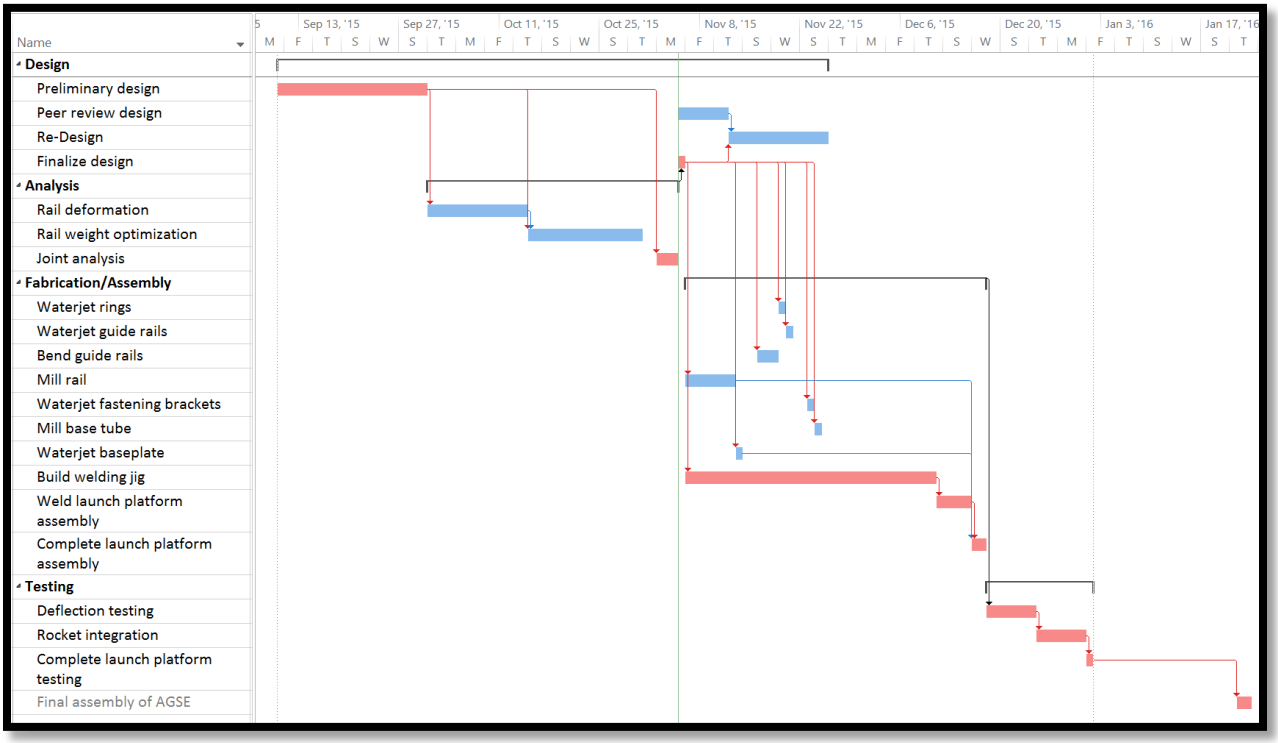

Table 65: Launch platform project timeline.

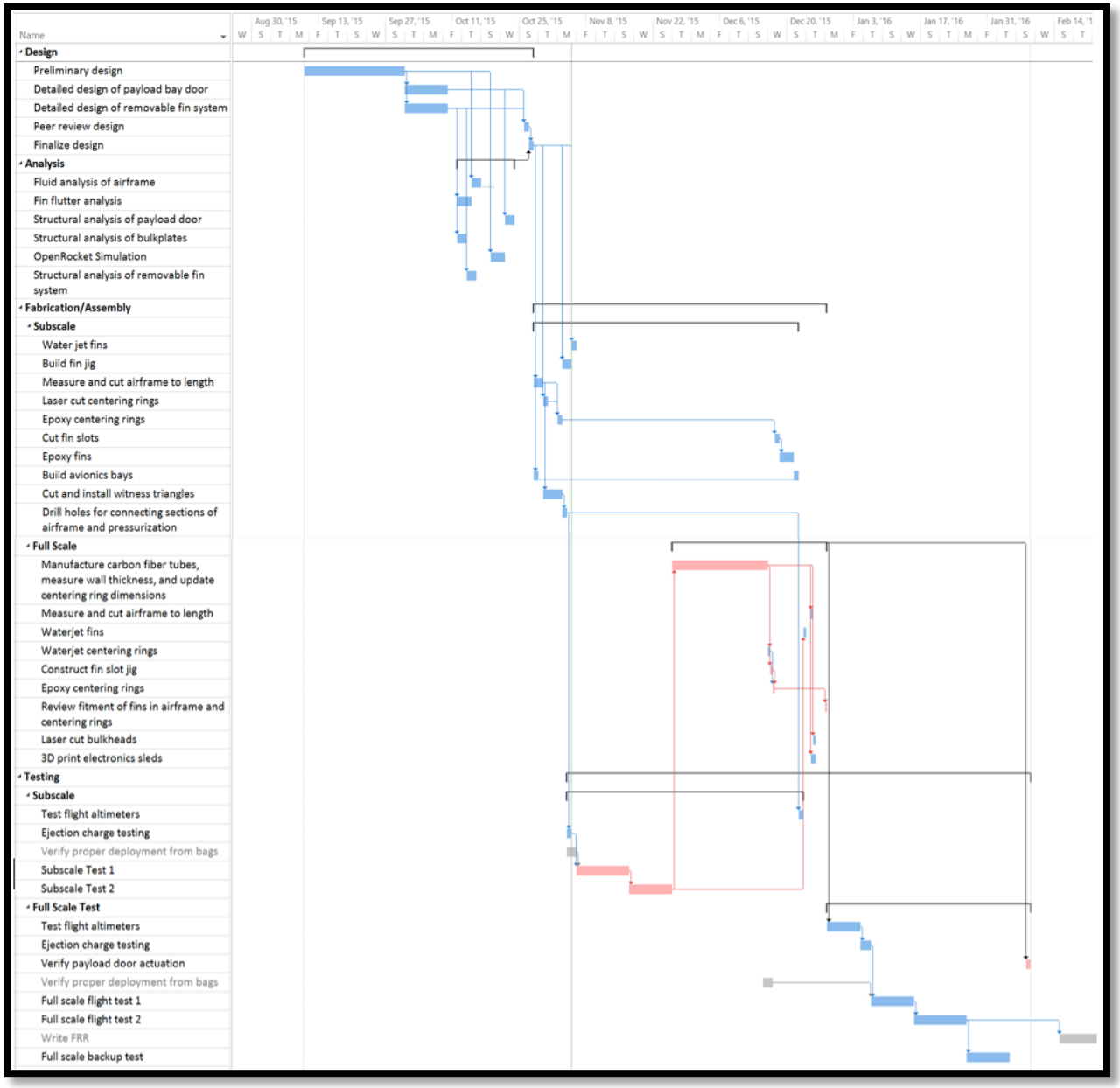

Table 66: Launch vehicle project timeline.

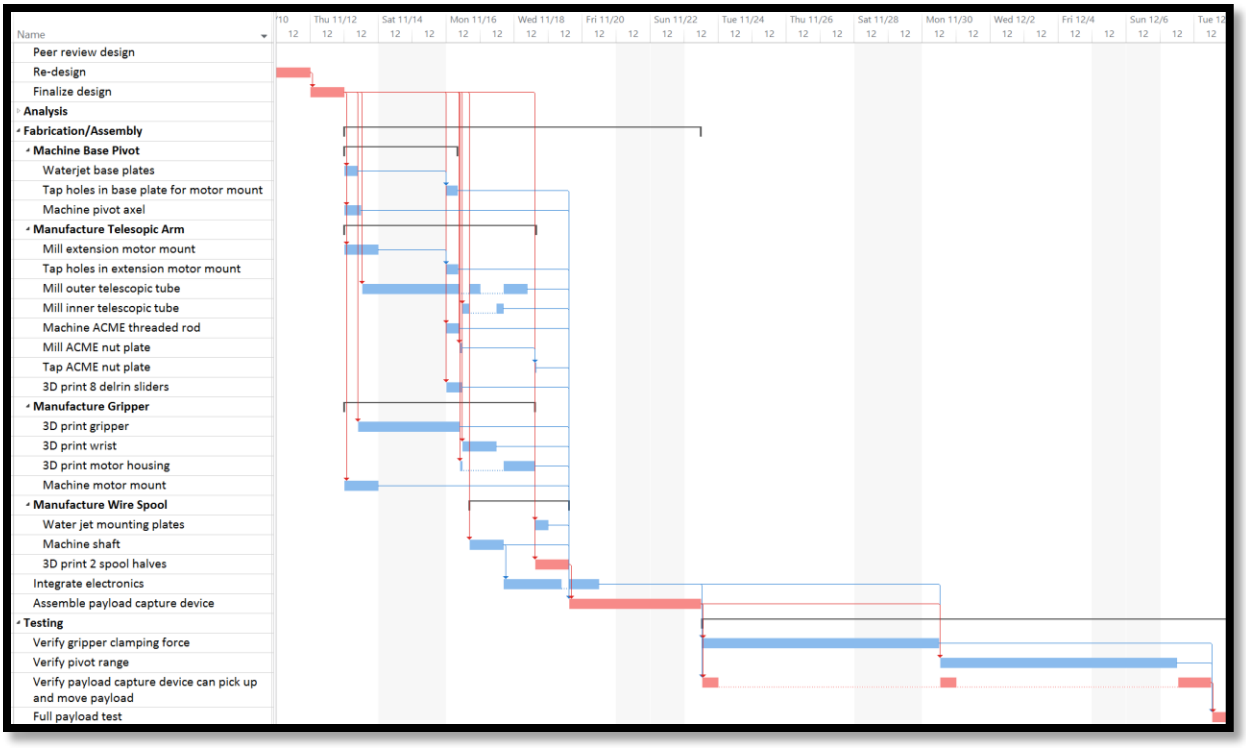

Table 67: Payload capture project timeline.

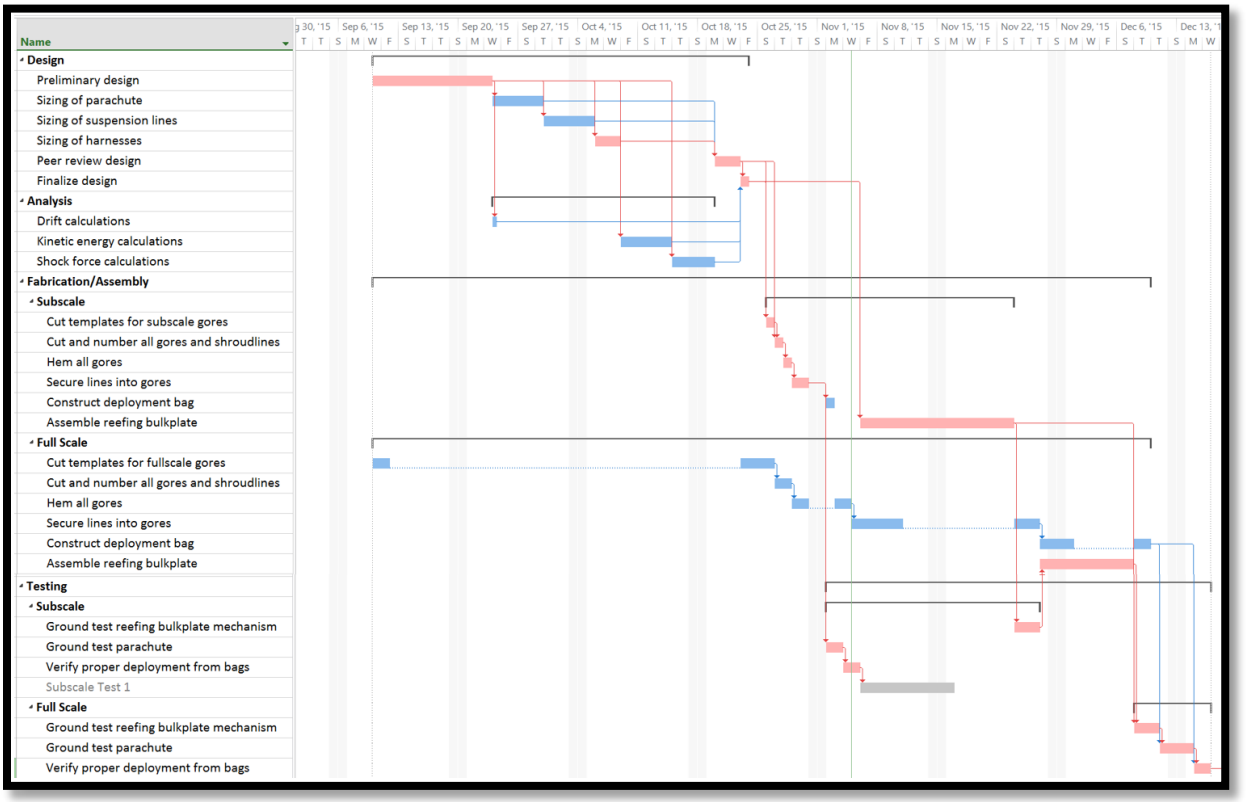

Table 68: Recovery project timeline.

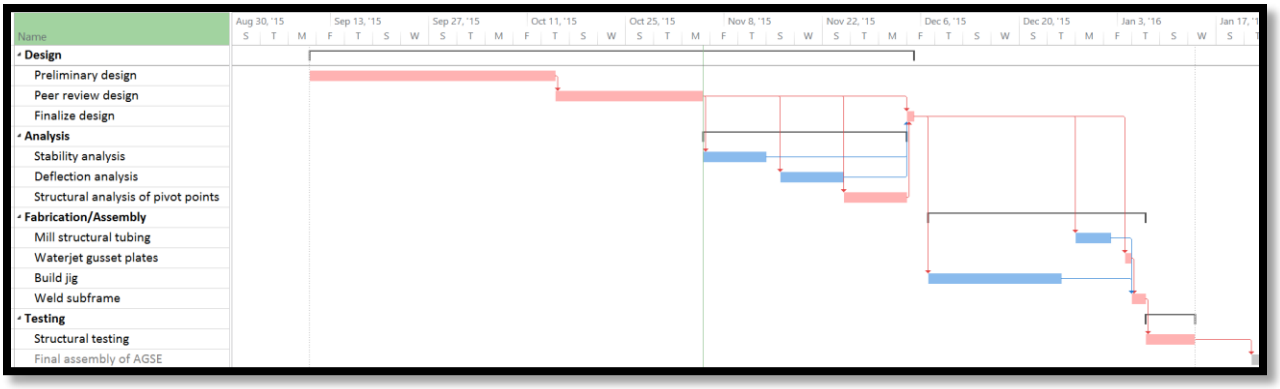

Table 69: Sub-frame project timeline.

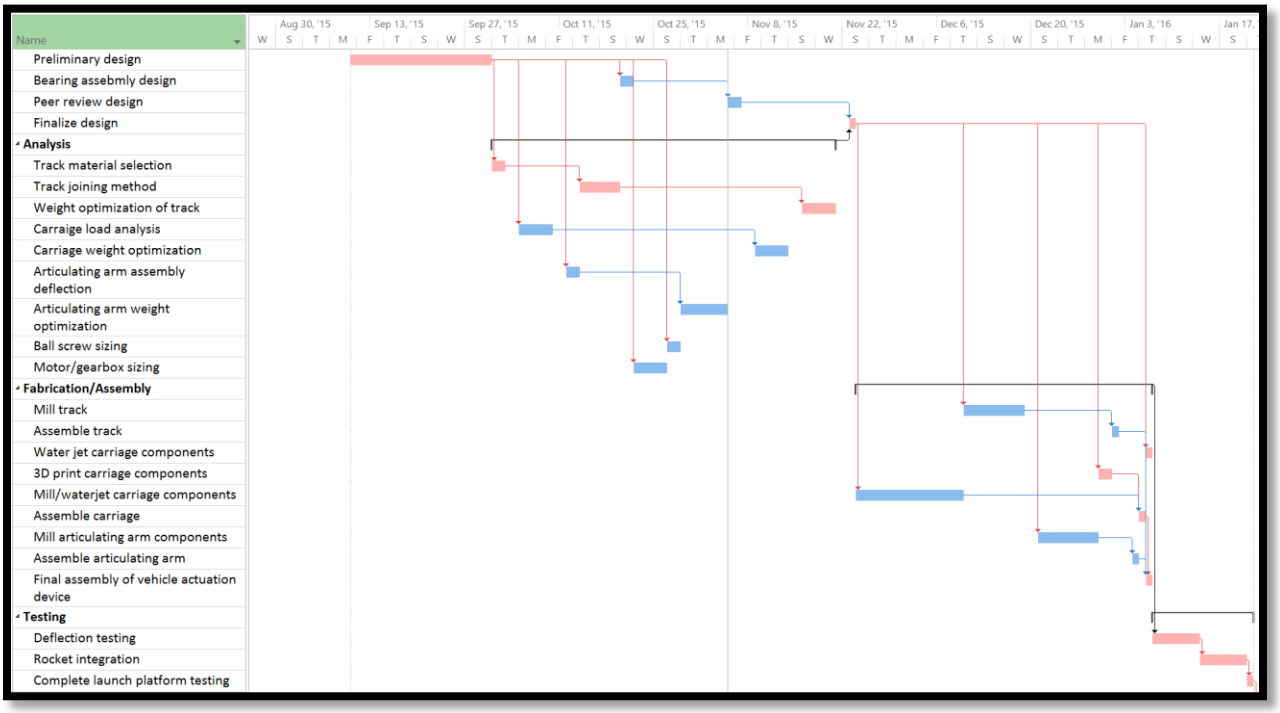

Table 70: Vehicle actuation device project timeline.

2) Comprehensive Budget

A critical aspect of the success of any project is a comprehensive budget. A budget has been formulated by the team which has been broken down into the categories shown in Figure 129, and how resources have been allocated.

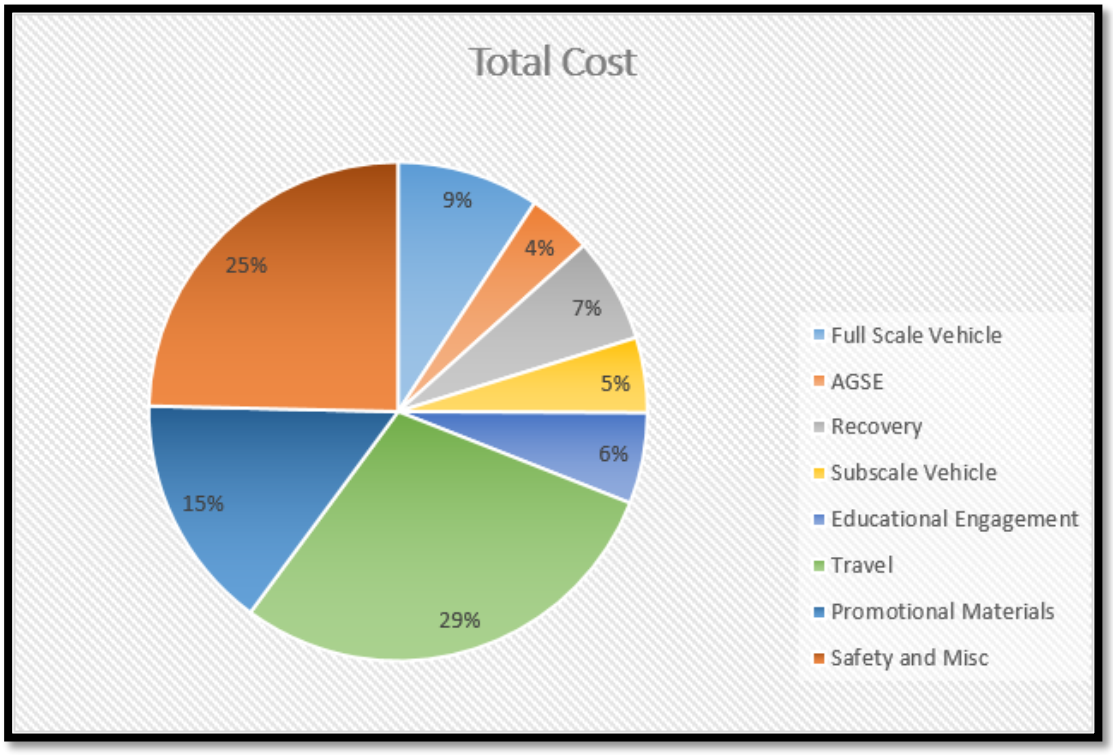

Figure 129: Comprehensive breakdown of entire project budget.

The budget is closely monitored and updated throughout the season as designs and needs change. However, having a close hold on the budget allows leadership to understand where the team stands financially. Understanding the budget also allows for more informed requests for sponsorship and gives leadership goals to set when raising funds.

The detailed breakdown of each subsystem also provides opportunities for corporations to support the team without making a strict financial decision. When the team is able to approach a company with a given set of needs, this provides others with the opportunity to support the team by making material donations, which has significantly helped the team in the past. The detailed budget for each sub system is shown below.

Full Scale Vehicle Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
6" FG Von Karman Nosecone	1	$100.00	$100.00
6" FG Airframe Tubing (5 feet in length)	2	$46.00	$92.00
6" FG Coupler Tubing (1 foot in length)	1	$57.33	$57.33
4" FG Airframe Tubing (2 feet in length)	2	$24.00	$48.00
75mm Motor Mount Tube	1	$14.95	$14.95
6" to 4" FB Transition	1	$89.00	$89.00
1/8" Thick 24" x 36" Fiberglass	4	$35.78	$143.12
6" Plywood Bulkplate - 1/2" Thick (Coupler)	5	$5.90	$29.50
6" Plywood Bulkplate - 1/2" Thick (Airframe)	5	$5.90	$29.50
4" 6061 T-6 Aluminum Centering Rings -1/4" Thick	4	$5.17	$20.66
Cesaroni L990 (Blue Streak) - 6G XL	4	$185.06	$740.24
Cesaroni L990 Hardware	1	$112.30	$112.30
1/4"-20 x 4' Threaded Rod (Aluminum)	2	$4.46	$8.92
1/4"-20 Hex Nuts (Aluminum) (pkg of 100)	1	$6.74	$6.74
4-40 Black Nylon Shear Pins (pkg of 100)	1	$5.42	$5.42
3/8"-16 for 2.5" OD Black-Oxide (18-8 SS) (pkg of 25)	5	$1.55	$7.75
1/4" Flat Washer (Aluminum) (pkg of 100)	1	$6.64	$6.64
3/8" Flat Washer Black-Oxide (18-8 SS) (pkg of 100)	1	$8.49	$8.49
Servo	1	$40.00	$40.00
Neodymium Magnets (1/8" x 1/16")	1	8.99	$8.99
Momentary Contact Switch	3	$0.98	$2.94
Professional Paint Job for Competition	1	$250.00	$250.00
		Overall Cost	**$1,822.49**

Recovery Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
3" x 5" FB Airframe tube	1	$8.54	$8.54
PerfectFlite Stratologgers	4	$54.95	$219.80
1" x 25' TUNSC Nylon Shock Cord	2	$19.95	$39.90
18" X 18" FCP Nomex	1	$10.95	$10.95
1/4"-20 Eyebolts	2	$9.71	$19.42
1/4"-20 U-Bolt	1	$0.75	$0.75
5/16"-18 U-Bolt	1	$1.04	$1.04
Flame Resistant Fabric 54"	3	$10.99	$32.97
64" x 1yd Ripstop Fabric	40	$9.00	$360.00
Type II Nylon Shroud Line (100 Yards)	1	$31.50	$31.50
1/4" Quick Links	3	$3.10	$9.30
9/32" Quick links	2	$3.10	$6.20
Electric Matches	50	$1.25	$62.50
11/16" Vials (pkg of 36)	1	$14.47	$14.47
4FA Black Powder (1lb)	1	$24.20	$24.20
9V Duracell Batteries (x4)	3	$12.73	$38.19
Garmin Astro GPS Unit	2	$189.99	$379.98
1/4"-20 Hex Nuts (pkg of 50)	1	$11.46	$11.46
1/4"-20 Washers (pkg of 100)	1	$8.25	$8.25
3" Plywood Bulkplate - 1/4" thick (Airframe)	2	$1.99	$3.98
1/8" Thick 24" x 36" Fiberglass	1	$42.49	$42.49
Nylon Thread	1	$20.99	$20.99
		Overall Cost	**$1,346.88**

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
2" FG Airframe Tubing (18" in length)	2	$18.00	$36.00
54mm Motor Mount Tube	1	$15.50	$15.50
3" to 2" FG Transition	1	$59.99	$59.99
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
2" Plywood Centering Rings - 3/16" Thick	4	$1.62	$6.48
1/4"-20 x 4' Threaded Rod (Aluminum)	2	$4.46	$8.92
1/4"-20 Hex Nuts Black-Oxide (pkg of 50)	2	$4.53	$9.06
1/4"-20 for 1.5" ID Black -Oxide U-Bolt (Steel)	5	$1.14	$5.70
4-40 Black Nylon Shear Pins (pkg of 100)	1	$5.42	$5.42
1/4"-20 Flat Washer (Aluminum) (pkg of 100)	1	$6.64	$6.64
Standard Parachute Large	1	$25.00	$25.00
Standard Parachute Small	1	$7.50	$7.50
PerfectFlight Stratologger	4	$54.95	$219.80
Electric Matches	15	$1.25	$18.75
4FA Powder (1lb)	1	$29.94	$29.94
9V Duracell Batteries (x4)	3	$12.73	$38.19
		Overall Cost	**$962.30**

Educational Engagement Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Key Switch	1	$2.93	$2.93
Toggle Switch	2	$2.95	$5.90
Battery Holder	1	$2.00	$2.00
Momentary Button w/ LED	2	$4.95	$9.90
Alligator Clips	4	$0.50	$2.00
Acrylic Sheet (2'x2') - black	1	$26.39	$26.39
Bristol Bot (40 pk)	2	$225.00	$450.00
SparkFunMini Inventor's Lot for Redboard	14	$47.45	$664.30
		Overall Cost	**$1,163.42**

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

Promotional Materials Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
Shirts	40	$20.00	$800.00
Polos	40	$40.00	$1,600.00
Stickers	750	$0.15	$112.50
Miscellaneous Marketing	N/A	N/A	$500.00
		Overall Cost	**$3,012.50**

Safety and Misc. Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
4-Axis Model 4X-23	1	$2,995.00	$2,995.00
41 foot "L" belt	1	$189.00	$189.00
6" OD Aluminum 6061 Tubing 6ft	1	$239.89	$239.89
4" OD Aluminum 6061 Tubing 6ft	1	$190.76	$190.76
4" OD Aluminum 6061 Tubing 2ft	1	$85.86	$85.86
3" OD Aluminum 6061 Tubing 6ft	1	$154.39	$154.39
3" OD Aluminum 6061 Tubing 1ft	1	$38.60	$38.60
3" OD Aluminum 6061 Tubing 3ft	1	$91.09	$91.09
2.25" OD Aluminum Tubing 3 ft	1	$74.17	$74.17
Level 1 Rocket Kit (with recovery)	4	$98.95	$395.80
Level 1 Rocket Motors	4	$19.79	$79.16
Industrial Shelving	1	$102.60	$102.60
Arduino Megas	5	$45.95	$229.75
		Overall Cost	**$4,866.07**

Autonomous Ground Support Equipment Budget			
Description	**Quantity**	**Per Unit Cost**	**Total Cost**
1/8" Wall 6061 T-6 (1" x 2" Structural Tubing) (6 feet)	6	$44.17	$265.02
1/8" Wall 6061 T-6 Plate	3	$36.13	$108.39
1/4" x 10" x 3ft (1020 Cold Rolled Steel)	1	$98.46	$98.46
3/4" x 1 3/4" x 3ft 6061 Bar	1	$46.64	$46.64
1 1/4" (1/16" Wall) 6061 T-6 Aluminum	3	$6.60	$19.80
3/4" (1/16" Wall) 6061 T-6 Aluminum	3	$3.78	$11.34
3/16" x 12" x 1ft Delrin Plate	1	$33.75	$33.75
2 1/2" Sim Motor	1	$28.00	$28.00
Gem 500 Gearbox	1	$135.00	$135.00
Payload Capture Device Motors	4	$15.00	$60.00
Igniter Installation Device Motor	1	$15.00	$15.00
		Overall Cost	**$821.40**

Overall Tentative Budget	
Budget	**Total Cost**
Full Scale Vehicle	$1,822.49
AGSE	$821.40
Recovery	$1,346.88
Subscale Vehicle	$962.30
Educational Engagement	$1,163.42
Travel	$5,750.00
Promotional Materials	$3,012.50
Safety and Misc	$4,866.07
Overall Cost	**$19,745.06**

3) Funding

Due to the strong success and history of the team, River City Rocketry has been extremely successful with regards to funding. Many organizations have been incredibly generous in supporting the team. A summary of the funding received so far this year is shown in Table 71.

Funding 2015-2016	
Descrption	**Amount**
UPS Foundation Grant and Volunteerism	$8,750.00
University of Louisville (Deans Office)	$5,000.00
Raytheon	$1,000.00
Remaining 2014-2015 Budget	$2,848.85
Kentucky Space Grant	$5,000.00
Samtec	Donation of 1030 aluminum extrusion
Total	**$22,598.85**

Table 71: Summary of funding received during 2015-2016 season.

In addition to grants and corporate sponsors, the team has received funding from alternative sources that target support from individuals.

Kickstarter: For the past four 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 for sponsors to 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.

Community Outreach: River City Rocketry will enable a PayPal link on www.rivercityrocketry.org to allow anyone contribute to funding this year's team. This is a way for people to make small personal donations in any amount that they feel is necessary.

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.

Speed School Student Council: Since the birth of River City Rocketry, Speed School Student Council (SSSC) has supported the team. By maintaining a good relationship with SSSC, River City Rocketry is able to receive funding from Speed School of Engineering.

4) Community Support

Throughout the past four years of the team's involvement in NASA Student Launch Projects, the team has developed a strong network within the University of Louisville, local industry, and the local community. Year after year, the team acknowledges that the success the team has seen would not have been possible without the support of the community.

Due to the mandatory co-op program that the University of Louisville's J.B. Speed School of Engineering has, the team has made many connections with different companies. As a result of team members spending a year of their undergraduate career working in the industry, lasting relationships have been formed between companies and the team. This is a huge contribution to the team's growing network. A compiled list of our community supporters and method of support is shown in Table 72.

Supporter	Method of Support
Art's Rental Services	Discounted trailer rental.
Big Brothers Big Sisters Louisville	Invite to participate in outreach opportunities.
Bro Ties	Apparel donation.
Darryl Hankes	Team mentor, high power rocketry knowledge and experience, discounted rocketry materials.
Dr. Yongsheng Lian	Team advisor for four years, oversees budget, campaigns for funds, and builds relations within university and industry.
Engineering Garage Manager (Mike Miller)	Machine shop equipment and storage and workshop space.
FirstBuild	Material donation, manufacturing support, equipment time and training.
Gregg Blincoe	Support with manufacturing processes and advice from previous team leadership experience.
Jefferson County Public Schools	Invites team to teach students STEM in their classrooms.
Kyle Hord	Provides knowledge and expertise on recovery design and manufacturing.
Lowes	Discounted tooling and materials.
Metal Supermarkets	Discounted metal.
NASA (SL Team)	Critical review of technical package.
NASA Space Grant Consortium	Financial.
Nick Greco	Provides knowledge and expertise on vehicle design and team management.
Raytheon	Financial
Samtec	Material donations
Speed School Administrative Assistant (Diane Jenne)	Runs team university bank account, orders materials and components, purchases are tax free.
Speed School Communications and Marketing (Kari Donahue)	Helps the team receive exposure, promotes events, organizes press releases.
Speed School Director of Outreach (Gary Rivoli)	Establishes connections with local schools for educational events, financially sponsors outreach.
UPS	Acquiring UPS Foundation Grant and Volunteerism

Table 72: List of community supporters and their method of support.

5) Project Sustainability

In order to ensure the continuation and success of River City Rocketry, it is important that while working towards success this season, the team also looks to prepare for the following seasons. This is important from a financial and community support standpoint as well as student involvement and knowledge.

Local Exposure

River City Rocketry will continue increasing awareness of the team in the local area. Has been and will be done through a variety of ways including but not limited to:

- Educational outreach events
- Community outreach events
- Local news media
- University press releases

River City Rocketry in the past year has received a significant amount of exposure by appearing on WDRB local news, Discover Channel (Canada), NASA TV, the University of Louisville's webpage and in the University of Louisville magazine.

Table 73: River City Rocketry on the front page of the University of Louisville website.

To further gain additional media exposure locally, the team will initiate follow-up stories from currently interested media as well as attempt intrigue the interest of unexplored media outlets. The team finds that one of the most rewarding methods of increasing exposure is through working with youth. Because of the success of last year, the team plans to host outreach events at the Louisville Science Center in the future to give both student and adult visitors an opportunity to gain hands-on experience in rocketry. Media coverage and publicity regarding previous years' achievements will likely gain the attention of newly interested participants. In turn, the team hopes to see an increase in participation in the future.

Recruitment and Retention

A secondary form of exposure is to highlight the importance of the rocket project. While local exposure increases future team membership and initial awareness, university exposure explains the importance of the rocket team as well as the excitement that ensues. To date, this was executed with a series of interest meetings which allowed previously uninvolved university students the opportunity to partake in a serious rocket project. Although many of these meetings are limited to initial design stages of the project, the meetings have been very successful, if not crucial, to the present and recent history of the rocket team. Interest meetings strongly encourage skeptical students to join and peak interest because the meetings are held during the exciting stage of design process.

Table 74: Team members earned their level 1 certifications after completing a series of training sessions taught by experienced team members.

However, no matter how many young, enthusiastic members the team gains, it won't bode well for the future of the team unless each individual is learning and engaged. The team is looking to do the following in order to help students grow in all aspects of the competition:

- New students work under and are mentored by experienced member.
- Students all own a small portion of the project.
- Training on manufacturing techniques.
- Regular targeted training sessions on various aspects of rocketry (ex. Recovery, simulation, electronics, etc.).
- Involved in technical writing – revise with mentor to learn technical writing skills.
- Involved in presentations – improve technical and informal presentation skills.

By getting new members involved in all aspects of the project and working closely with a mentor, they will develop into the next generation of leaders for the team, which is crucial to success in the future. This has proven to be successful as all of the current leadership has be brought in and mentored closely by former and current team members.

Securing Continuing Funding

Securing funds is fundamental to the core functions of the rocket project and team. Just as fuel launches the rocket, funding moves the project. The team plans to secure funds through two primary methods: community and individual contribution. Through public outreach, the team will continue gaining local community support for the project in terms of morale and monetary support. Individual companies will be used as means of funding. Local businesses and industries have already expressed excitement in supporting the team this year. Outside of approaching companies for support, the team will seek support through private donations.

Section 10. Conclusion

After last year's success, River City Rocketry plans to attack the 2015-2016 NASA Student Launch competition by utilizing the key skills and knowledge the team gained throughout the previous year's competition. The team understands the importance of continuous improvement in the quality of design as well as manufacturing the rocket and AGSE. Therefore, the team will continue to strive for excellence in design efficiency, documentation, educational engagement programs, and safety awareness. River City Rocketry's goal this year is to create the most efficiently integrated launch vehicle and ground station by showcasing the team's engineering knowledge and creativity. The team's educational outreach has been designed to help spread passion for rocketry throughout the community while teaching students the importance of math and science in the aerospace industry.

Appendix I – Launch Procedures

Safety Checklist: AGSE Payload Capture Device

AGSE Payload Capture Device Setup: To be checked and initialed by AGSE Safety representative.

AGSE Safety Representative Signature: _____

Required Equipment:

- *AGSE Payload Capture Device*

Prior to leaving for launch site:

1. ___Check all 3D printed components for any cracks. If any are present, replace with one of the backup parts.

At launch site:

1. ___ Make sure the arm is lined up with the rocket's payload bay.
2. ___ Make sure the payload arm is securely attached to the AGSE side rail.
3. ___ Lower the gripper assembly right above the payload with the arms in the open position.
4. ___ Make sure Arduino is connected to main computer and is sending/receiving data.

Post-flight Inspection:

1. ___ Verify all components are still attached and undamaged. If any parts are damaged make sure to write it down below so that it can be replaced before the next launch.

Safety Checklist: Launch Platform

To be checked and initialed by AGSE Safety representative.

Launch Platform Assembly:

AGSE Representative Signatures:

1. _____ *2.* _____

Required Equipment:

- *Upper launch platform section*
- *Lower launch platform section*
- *3/16" T-handled Allen Wrenches*
- *Fasteners*
- *Pivot point bearings (2x)*

Prior to leaving for launch site:

1. ___ Ensure launch platform is clean and free of debris.

At launch site:

1. ___ Attach upper launch platform section to lower launch pad section.
2. ___ Slide section of airframe into launch pad. If section of airframe does not freely slide up and down the entirety of the launch pad, troubleshooting may be necessary.

   ⚠WARNING Launch pad is not to be cleared for launch until the section of airframe moves freely. If the airframe gets hung up on the launch pad, too much friction will be seen by the rocket, risking a successful flight.
3. ___ Slide bearings over pivot points.
4. ___ Place launch platform on ground station.
5. ___ Verify mounting location for launch platform.
6. ___ Fasten bearings to ground station.
7. ___ Attach articulating arms to launch platform using a washer and a socket head cap screw.
8. ___ Connect launch platform power and data lines.

Safety Checklist: Ground Station

To be checked and initialed by AGSE Safety representative.

Ground Station Assembly:

AGSE Representative Signatures:

1. _____ *2.* _____

Required Equipment:

- *Front ground station section*
- *Middle ground station section*
- *Rear ground station section*
- *Articulating arms*
- *T-handled Allen Wrenches*
- *Additional fasteners*

Prior to leaving for launch site:

1. ___ Ensure outrigger ball screws are clean and free of debris.
2. ___ Ensure outrigger ball screw nuts are clean and free of debris.
3. ___ Verify outriggers are able to actuate over their full travel distance using motor bench-top testing unit.
4. ___ Verify that all fasteners on the ground station assembly are tight.

At launch site:

1. ___ Attach front ground station section to middle ground station section.
2. ___ Attach rear ground station section to middle ground station section.
3. ___ Connect ground station power and data lines.
4. ___ Actuate carriage over full travel to check for jamming issues.
5. ___ Attach articulating arms to carriage.
6. ___ Actuate outriggers to ground position.

Safety Checklist: Igniter Installation

To be checked and initialed by AGSE Safety representative.

Igniter Installation Assembly:

AGSE Representative Signatures:

2. _____ *2.* _____

Required Equipment:

- *Igniter station*
- *T-handled Allen Wrenches*
- *Fasteners*
- *Igniter*
- *Aluminum tape*
- *Dowel rods*

Prior to leaving for launch site:

1. ___ Assemble wheel extrusion sub-assemblies.
2. ___ Attach drive motors to mounting plate.
3. ___ Attach spring tensioner sub-assemblies to side plates.
4. ___ Mount wheel extrusion assembles to motor shaft.
5. ___ Insert secondary shaft and wheel extrusion assembles.
6. ___ Mount side plates.
7. ___ Mount assembly to base of launch platform.

Note: For the next three steps, reference document on constructing augmented wire.

8. ___ Augment igniter with dowel.

   ⚠WARNING Leading edge of chained dowels must NOT have sharp or hard edges. Sharp or hard leading edges could damage motor grains during insertion, resulting in a false signal, potentially causing the motor to ignite unintentionally.
9. ___ Augment igniter with aluminum tape.
10. ___ Shrink sleeve dowel assembly.

At launch site:

1. ___ Connect igniter station power and data lines.
2. ___ Verify that igniter station motors are both fully operational.

3. ___ Thread igniter into system.

Safety Checklist: Electrical and Computer Systems

To be checked and initialed by Electrical and Computer Systems team member.

Electrical and Computer Systems team member signatures:

1. _____ *2.* _____

At launch site:

1. ___ Master power in off position.
2. ___ Recovery has fresh batteries.
3. ___ Turn master power on.
4. ___ Ensure 12v power is active.
5. ___ Check that payload arm is in position.
6. ___ Check that payload arm is powered.
7. ___ Check that ignition station is in position.
8. ___ Check that ignition station is powered.
9. ___ Check that VAS is horizontal.
10. ___ Check that VAS is powered.
11. ___ Check HMI for self-diagnostics errors.

Safety Checklist: Stability and Propulsion

To be checked and initialed by S&P Safety representative.

Stability and Propulsion Representative Signatures:

2. _____ *2.* _____

Prior to leaving for launch site:

Propulsion Bay Assembly Checklist:

Required Equipment:

- *Gorilla Glue*
- *Grease*
- *Lower Sustainer Stand*
- *CTI3147-L935-IM-P motor*
- *Motor retainer*
- *Dead blow*
- *#10-32 Shoulder Screws (x3*
- *#10-24 Socket Head Cap Screws (x3))*

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. ___ Inspect forward fin tabs for signs of cracking or fatigue.
3. ___ Install three fins by tapping into place with a dead blow. Ensure that the fins are fully seated.
4. ___ Install fin retainer using three #10-24 Socket Head Cap Screws.
5. ___ Slide motor casing fully into the motor mount tube.
6. ___ Attach motor retention ring using three #10-32 Shoulder Screws. Do not over-torque.
   Note: This step must be completed after fin installation and the fin retainer is secure.
4. ___ Set completely assembled bay on stand; do not rest on fins.
5. ___ Inspect each fin for any signs of cracking or fatigue.

Note: If any damage is identified, **immediately** inform the following:

- Team captains

- Launch Vehicle Lead
- 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 (x2)*
- *E-matches (x2)*
- *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 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.

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*
- *Main parachute*
- *Deployment bag*

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 per the folding procedures document in the team owncloud folder. 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.

Upper Airframe Avionics Bay:

- *Precision flathead screwdriver*
- *Standard Phillips head screwdriver*
- *Nosecone altimeter sled*
- *StratoLogger altimeter (x2)*
- *4x40 shear pins (x4)*
- *Battery holster cover*
- *Duracell 9V battery (x2)*
- *Battery clips (x2)*
- *Multimeter*
- *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, 4-40 shear pin.
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.

Launch day procedures

Parachute Assembly:

Required Equipment:

- *Nomex cloth*
- *Shock chord (x2)*
- *Swivel*
- *Pilot parachute*
- *QuickLink*

1. ___ Attach upper airframe shock chord to U-bolt on nosecone via quick link.
2. ___ Attach shock chord to swivel.
3. ___ Attach second length of shock chord to U-bolts on lower recovery bay bulkplate.
4. ___ Attach parachute to swivel
5. ___ Attach pilot parachute to deployment bag.
6. ___ Wrap deployment bag in Nomex.
7. ___ Insert parachutes into airframe.

Lower Airframe Avionics Bay:

Required Equipment:

- *Multimeter*
- *Precision flathead screwdriver*

1. ___ Verify both batteries have a charge greater than 5V.
2. ___ Verify proper shielding.

   ⚠WARNING Ensure that the entire inside of the avionics bay is properly shielded in order to protect from interference. In the incident that interference occurs, pyrotechnic devices may be actuated prematurely, causing potential harm to personnel and mission failure.
3. ___ Plug a battery into each altimeter.
4. ___ Verify wiring of altimeters is correct.
5. ___ Install avionics bay into lower airframe.

Nosecone Avionics Bay:

Nosecone Assembly

Required Equipment:

- *Precision flathead screwdriver*
- *¼"-20 nut (x2)*
- *¼"-20 washer (x2)*
- *GPS tracking device*
- *Black powder charges (x2)*

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*

1. ___ Attach propulsion bay to payload bay using six 8-32 metal bolts.
2. ___ Attach upper payload bay to recovery bay lower coupler tube using four 8-32 metal bolts
3. ___ Attach recovery bay nosecone using 4-40 shear pins. Ensure that all shear pins are tight fitting and will not fall out during ascent.
4. ___ Check that the coupling does not allow for any flexing of the rocket between payload bay and recovery bay. Should this occur, add layers of painters tape to the coupler tubing on the payload bay until sufficient coupling is achieved.
5. ___ Tape motor igniter to the outside of the lower sustainer in a place easily seen by the field RSO.
6. ___ A final visual inspection will need to be done to ensure all systems are go.

Safety Checklist: Clear to Leave for Launch Pad:

All sections of the safety checklist preceding the “at the launch pad checklist” must be complete prior to leaving for the launch pad. A signature of completion is required for launch.

*General Pre-Launch Day Preparations:*_____

*Stability and Propulsion:*_____

Recovery: _____

Overall Final Assembly: _____

Signatures indicating the rocket is a “Go” for launch:

Team Captain: _____

Team Co-Captain: _____

Safety Officer Signature: _____

Safety Checklist: At Launch Pad Checklist

Required Equipment:

- *Pen or pencil*
- *Level 2 Certification card.*
- *Propulsion Bay Stand*
- *Magnetic Switch Magnet*
- *Switch Rods*
- *GoPro camera*
- *Level*

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 reefed parachute.

Observer Signature: _____ Time: _____

Second Event: Deployment of reefing system – deployment of fully disreefed parachute.

Observer Signature: _____ Time: _____

Landing Events:

Launch Vehicle Assembly

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. _____

Appendix II – Safety Risk Assessments

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

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

	producing toxic fumes.					
Potential burns to team members while soldering.	Team members do not pay attention while soldering	The team member could suffer minor to severe burns.	4	3	Low	Team members will be trained how to solder and will follow all safety protocols related to soldering.
Overcurrent from power source while testing.	Failure to correctly regulate power to circuits during testing	Team members could suffer electrical shocks which could cause burns to heart arrhythmia	2	4	Low	The circuits will be analyzed before they are powered to ensure they don't pull too much power. Power supplies will also be set to the correct levels.
Use of cutting fluid.	Use cutting fluid when machining metals.	Contains carcinogens.	1	5	Low	Face shield shall be worn at all times when machining metals.
Use of white lithium grease.	Use in installing motor and on ball screws.	1. Irritation to skin and eyes. 2. Respiratory irritation.	3	4	Low	1. Nitrile gloves and safety glasses are to be worn when applying grease. 2. When applying grease, it should be done in a well ventilated area to avoid inhaling fumes.
High voltage shock.	Improper use of welding equipment.	Death or severe injury.	1	5	Low	All team members are required to be trained on the equipment prior to use. Any time personnel is welding, there must be at least two people present.
Break bit on mill.	Spindle speed too high.	Injury to personnel and damage to equipment and/or part.	2	5	Low	All team members are required to be trained on the mill prior to use. If personnel is uncertain about the proper settings, they are to consult an experienced member prior to operation.

Metal shards.	Using equipment to machine metal parts.	Metal splinters in skin or eyes.	2	5	Low	Team members must wear long sleeves and safety glasses whenever working with metal parts.

Table 75: 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 or loose bolts.	If the launch pad is unstable while the rocket is leaving the pad, the rocket's path will be unpredictable.	1	3	High	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.
Unleveled launch platform.	Un-level ground or improperly leveled launch tower.	The launch tower could tip over during launch, making the rocket's trajectory unpredictable.	1	4	High	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.
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. Friction between guide rails and rocket.	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, talcum powder will be applied to each beam in order to reduce any frictional forces on the rocket.

						Analysis has been performed to determine a rail length of 6 ft is necessary. Therefore, the 8 ft length of the rail will be sufficient.
Sharp edges on the launch pad.	Manufacturing processes.	Minor cuts or scrapes to personnel working with, around, and transporting the launch tower.	4	3	Low	Sharp edges of the launch pad should be filed down and de-burred.
Brush fire caused by rocket during launch.	Dry launching conditions.	Small brush fire.	4	3	Low	Wait until the range safety officer has cleared personnel to approach the launch pad and extinguish any fires that have been started.
Vehicle not properly aligned.	Incorrect loading of vehicle.	Payload will not be able to be inserted, vehicle maybe unstable, igniter may not be able to be installed, fins may be damaged.	2	3	Moderate	An alignment device has been added to the base of the launch platform which will ensure the vehicle is in the correct orientation for payload insertion. Also, the motor retainer will seat into a plate at the bottom of the rocket to ensure proper vehicle alignment to igniter installation system and launch platform.
Shearing of critical connections.	1.Rail extension connections 2. Bearing connections 3. Articulating connections	Launch platform collapses, damaging vehicle and/or injuring personnel.	1	5	Moderate	All components will be analyzed for the loads that each component will be experiencing. All personal will be required to maintain a minimum safe distance away from the AGSE during operation.

Movement of pivot or articulating points.	Improper pre-load on fasteners.	Launch platform falls, damaging vehicle, and injuring personnel.	1	5	Moderate	All fasteners will be properly tightened during assembly and will be checked prior to launch. Locating features were added to launch rails to ensure proper placement of critical connections. All personal will be required to maintain a minimum safe distance away from the AGSE during operation.
Pivot point bearings seize.	1. Load is larger than specifications. 2. Debris enters bearings.	Launch platform will experience higher resistance to motion causing a potential hindrance the vehicle raising.	1	4	Moderate	Bearings will be sized based on expected loads with a minimum factor of safety of 2. The launch platform will be cleaned following each launch and will be cleaned prior to each launch. Proper lubrication will be applied to any point expected to receive friction.
Personal injury.	Personnel pinned between launch platform and ground station.	Minor to serious injuries to personnel working with, around, and transporting the vehicle actuator.	1	4	Moderate	All personnel will be required to maintain a minimum safe distance away from the AGSE when in operation.
Failure of ground station connection joints.	Load is larger than anticipated	Minor injuries to personnel working with, around, and transporting ground station. Ground station will collapse under weight and not function	1	4	Moderate	All personnel will be required to maintain a minimum safe distance away from the AGSE when in operation. During assembly this failure mode will be tested to ensure it does not happen.

Table 76: Launch pad functionality risk assessment.

AGSE – Vehicle Actuation Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Sharp edges on the vehicle actuation.	Manufacturing processes.	Minor cuts or scrapes to personnel working with, around, and transporting the vehicle actuation.	4	3	Low	Sharp edges of the vehicle actuator should be filed down and de-burred.
Carriage jams.	1. Carriage tracks not square. 2. Too much track deflection under load. 3. Uneven loading or overloading. 4. ABS guides dislodge. 5. Buildup of foreign objects and debris (FOD) on tracks and/or carriage.	Vehicle actuator is unable to complete the task of raising the rocket.	1	2	High	1. Tolerance on tracks will be checked during manufacturing and assembly of vehicle actuator. 2. Deflections in the track have been analyzed and are within the tolerances of our system. 3. The carriage geometry was selected to provide a wide base to better distribute the load. This wide geometry reduces the impact of uneven loading. 4. Appropriate fasteners and pre-load on installed fasteners will be used during the assembly of the carriage. 5. The vehicle actuation system will be cleaned following each launch and will be inspected for FOD prior to each launch. WD-40 will be applied to the track to help reduce friction between the track and the ABS guides.

Shoulder bolts shear.	Material failure.	Launch platform falls back to horizontal position.	1	4	Moderate	Analysis has been performed to determine the minimum bolt specifications based on the maximum loads the bolts will encounter and a factor of safety has been incorporated into the design.
Shoulder bolt unscrews.	Vibration/cycling.	Launch platform falls back to horizontal position.	1	4	Moderate	Appropriate pre-load will be applied to the bolts. Thread locker will be used as a secondary locking mechanism.
Bearing fixtures fail on power screw.	Fatigue.	Launch platform falls and power screw jams.	1	4	Moderate	An appropriate bearing has been selected to handle the expected loads on the power screw. If the bearing fails, a bushing is also used as a secondary bearing which will hold the screw in place.
Articulating arms buckle under load.	Material failure.	Launch platform falls.	1	4	Moderate	Testing will be performed prior to launch day to ensure the rings can handle the expected loads.
Articulating arm interference.	Articulating arms protrude into vehicle or payload arm path.	Launch platform may not be able to reach desired position. Possible damage to rocket and/or payload arm.	1	4	Moderate	All components will be checked for interference with solid models during the design phase and will be physically checked during assembly. Systems that can be manually actuated on launch day will be manually actuated to check for interferences.
Carriage to power screw nut connection fails.	Material failure.	Power screw spins without advancement of nut, causing	1	4	Moderate	Proper bolt and mounting plate specifications have been determined.

		vehicle actuator to be motionless.				
Power screw jams.	1. Cross thread. 2. Buildup of debris on screw. 3. Galling of nut.	Vehicle actuator will not reach final position.	1	4	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. Proper lubrication will be used to reduce binding.
Power screw shears.	Material failure.	Vehicle actuator will not reach final position. Launch platform may fall or be at risk of falling back to horizontal.	1	4	Moderate	Analysis has been performed to adequately size the power screw with a minimum factor of safety of 2. Personnel will remain clear of AGSE until the situation has been assessed and deemed safe by the safety officer.
Launch platform travel obstructed.	Miscellaneous objects obstruct travel.	Launch platform may not be able to reach desired position. Possible damage to interfering objects.	1	4	Moderate	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.
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	High	Analysis has been performed to ensure the proper motor was selected.
Pinch points.	1. Power screw. 2. Carriage ends of travel.	Minor to serious injuries to personnel working with, around, and	2	4	Moderate	Guards will be installed to protect objects and personnel from entering pinch point areas. Personnel will be required to

	3. Carriage and track interfaces. 4. Articulating arm.	transporting the vehicle actuator. Possible damage to surrounding equipment.				remain clear of AGSE during operation, and will maintain a minimum safe distance away until the system has been deemed safe by the safety officer. Wires, tubing, and other systems will be routed away from pinch point areas to avoid possible damage.
Vehicle is not lifted at a high enough rate.	The motor was not sized correctly.	Vehicle won't be lifted with-in time requirement.	2	3	Moderate	Analysis has been performed to ensure the proper motor was selected.
Personal injury from AGSE.	Personnel in close proximity while AGSE is in operation.	Personal injury.	2	3	Moderate	Power will be disconnected from AGSE prior to working on the system or surrounding systems. When the AGSE is powered on all personnel will be at a minimum safe distance away.
Non-Functioning and unresponsive system.	Break in wires.	1. Rocket will not raise or lower. 2. Rocket will stall at position.	1	3	Moderate	Wires will be shielded from pinch points and other mechanical hazards.
Motor failure.	Motor short.	1. Rocket will not raise or lower. 2. Rocket will stall at position.	1	4	Moderate	Electrical redundancy measures will be implemented.
Electrical failure.	Power loss. Dead or low battery.	1. Rocket will not raise or lower. 2. Rocket will stall at position. 3. Possible short to exterior parts.	1	4	Moderate	Electrical redundancy measures will be implemented. Battery will be charged.

Table 77: Vehicle actuator 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 wire becomes cut, exposing wire causing false signal to be sent, prematurely igniting the motor.	2	3	Moderate	Sharp edges of the igniter installer should be filed down and de-burred.
Igniter is not fully installed in motor.	1.Igniter slips during installation 2. Igniter gets tangled prior to insertion 3. Igniter is not straight upon insertion	Possible catastrophic failure of rocket motor during ignition; loss of vehicle, damage to AGSE, and personnel Injury.	1	2	High	1. Additional feedback mechanisms will be used to confirm the igniter has been fully installed. 2/3.To avoid tangling and to keep the igniter straight as it enters a dowel rod will be attached to the igniter and will equal the length required for igniter to be inserted.
Igniter gets bent upon insertion into the motor.	Igniter causes blockage within motor.	Motor will choke itself causing pressurizing which could cause an explosion.	1	5	Moderate	The igniter will be straightened prior to installation and below the calculated blockage percentage.
Damage to igniter.	Extruder assembly applies	Unresponsive igniter.	1	3	High	The igniter will be heavily shielded and protected from sharp edges.

	an amount of pressure to igniter assembly to shear igniter wire.					The igniter installation system will be inspected for any possible sharp edges.
Igniter prematurely lights.	1. EMF feedback from motors causes ignition. 2. Ignitor circuit is prematurely energized.	Injury to personnel 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.
Non-functioning and unresponsive.	1. Break in line. 2. Error in code.	Igniter installation fails.	1	4	Moderate	The igniter installer will be run through various tests, verifying each of the functionalities of the system. Code will be checked the night before the launch to ensure that the proper code is still installed.
Motor failure.	Short in stepper motor.	Igniter installation fails.	1	4	Moderate	Additional motors will be on hand for replacement upon failure. All electronics will be checked for functionality during pre-launch procedures.
Driver failure.	1. Short in the driver. 2. Incorrect wire placement.	Igniter installation fails.	1	4	Moderate	A secondary driver will on hand for quick replacement upon failure.

Gear mechanical failure.	Material failure.	Igniter installation fails.	1	4	Moderate	All mechanical components will be inspected for damage or signs of fatigue prior to launch.

Table 78: 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	High	Analysis has been performed to ensure the proper motor was selected.
Power screw jams.	1. Cross thread. 2. Buildup of debris on screw. 3. Galling of nut.	Vehicle actuator will not reach final position.	1	4	Moderate	The power screw will be cleaned after each launch and will be inspected prior to each launch. The power screw nut will not be removed between launches reducing the potential for cross threading. The power screw and nut materials will be lubricated with proper lubrication to prevent galling.
Sub-frame feet sink into ground.	1. Insufficient surface contact between foot and ground.	Ground station can't raise itself high enough for vehicle actuation.	1	2	High	Outriggers will be sized to provide adequate surface contact. Weather conditions will be monitored prior to and on launch

	2. Ground is too soft.	Launch platform unstable.				day to anticipate ground conditions.
Unstable ground station.	1. High winds. 2. Unstable ground. 4. Ground station footprint.	Ground station falls possibly injury to personnel surround ground station.	1	4	Moderate	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.
Ground station is not lifted and leveled at a high enough rate.	The motor was not sized correctly.	Ground station won't be lifted with-in time requirement.	2	3	Moderate	Analysis has been performed to ensure the proper motor was selected to raise and level the ground station within the time requirement.
Inconsistencies in leveling process time.	Inconsistent terrains between launches.	Ground station won't be lifted with-in time requirement.	2	4	Moderate	Launch fields will be inspected to check for level terrain or terrain that is within the constraints for the leveling system.
Ground station bows/sags.	Material failure.	Carriage may jam, launch platform will be unstable.	1	3	High	Testing will be performed prior to launch day to ensure ground station performs as expected.
Ground station collapses.	Material failure.	Vehicle may be damaged, personal injury to personnel, damage to sub systems.	1	4	Moderate	Testing will be performed prior to launch day to ensure ground station performs as expected.
Ground station interference.	Sub systems collide with ground station structure.	Sub-systems won't be able to complete their tasks.	2	5	Low	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 79: ASGE – Ground station risk assessment.

Payload Capture Device 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	4	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. Grips break off with applied force. 3. Gripping motor does not have enough torque. 4. Grips break off upon applied force.	Arm fails to retrieve and load payload.	1	4	Moderate	Testing will be completed to verify grips close consistently on payload and can support pressure applied.

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	3	High	Testing will be completed to verify payload is gripped adequately and properly oriented when entering rocket.

Table 80: 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	High	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	High	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	High	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	High	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	High	Testing will be completed to verify all systems are sequenced properly.

Table 81: Main controller 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	High	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	High	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	High	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	High	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.	Vehicle fails to launch.	1	3	High	Redundancies will be implemented to ensure the igniter

	2. Communication failure between switch and controller. 3. Code error.					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	High	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	High	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	High	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	High	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	High	AGSE systems fail to actuate, AGSE mission failure.

Table 82: Master controls risk assessment.

Stability and Propulsion Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Motor fails to ignite.	1. Faulty motor. 2. Delayed ignition. 3. Faulty e-match. 4. Disconnected e-match.	1. Rocket will not launch. 2. Rocket fires at an unexpected time.	3	4	Low	Follow NAR safety code and wait a minimum of 60 before approaching the rocket to ensure that the motor is not simply delayed in launching. If there is no activity after 60 seconds, have the safety officer check the ignition system for a lost connection or a bad igniter. If this does not fix the failure mode, be prepared to remove the ignition system from the rocket motor, retrieve the motor from the launch pad and replace the motor with a spare. Igniters have been securely installed throughout the season, having a 100% success rate.
Motor explodes on the launch pad.	Faulty motor.	Rocket and interior components significantly damaged.	1	5	Low	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR in order to ensure that no one is hurt by flying debris. Extinguish any fires that may have been started when it is safe to approach. Collect all debris to eliminate any hazards created due to explosion. The motors the team have selected are from a

						reliable supplier. The team has had a 100% success rate.
Rocket doesn't reach high enough velocity before leaving the launch pad.	1. Rocket is too heavy. 2. Motor impulse is too low. 3. High friction coefficient between rocket and launch tower.	Unstable launch.	1	5	Low	Too low of a velocity will result in an unstable launch. Simulations are run to verify the motor selection provides the necessary exit velocity. The launch pad will be coated in talcum powder prior to each launch in order to minimize friction. Full scale test launches have verified that the launch rocket will exit the launch pad at a safe velocity. Should the failure mode still occur, the issue should be further examined to determine if the cause was due to a faulty motor or in the booster needs to be redesigned.
Fins shear during flight.	Insufficient fin retention during installation resulting in a failure in the epoxy.	Unstable rocket, causing the flight path to become unpredictable.	1	5	Low	Confirm all personnel are alert and at a distance allowed by the Minimum Distance Table as established by NAR. The removable fin system was designed for a press fit tolerance and has been flight tested, resulting in fins remaining rigidly in place.
Airframe buckles during flight.	Airframe encounters stresses higher than the material can support.	Rocket will become unstable and unsafe during flight.	1	5	Low	Through prediction models, appropriate material selection, and a secure factor of safety, this failure mode can be nearly eliminated.

Internal bulkheads fail during flight.	Forces encountered are greater than the bulkheads can support.	1. Internal components supported by the bulkheads will no longer be secure. 2. Parachutes attached to bulkheads will be left ineffective.	1	5	Low	The bulkheads have been designed to withstand the force from takeoff with an acceptable factor of safety. 1. Electrical components are mounted using fasteners that will not shear under the forces seen during the course of the flight. 2. A catastrophic failure is likely. A portion of the rocket or the cache capsule would become ballistic. Calculations have been made to ensure that the bulkheads can withstand all forces that will be seen during flight. Flight tests have verified such calculations.
Fins are not properly aligned.	Fins are not mounted straight or do not have equal radial spacing.	Rocket becomes unstable or spins excessively during flight.	1	5	Low	The removable fin design has been incorporated, ensuring that the fins are properly aligned. Due to the capability of machining the centering rings, all slots have been aligned within a tolerance that will not negatively affect the flight of the rocket. Through flight tests with this system, the removable fin design has proven to maintain proper fin alignment.
Retaining bulk plate fails.	Retaining bulk plate tabs are too small.	Fins fall out during flight.	1	5	Low	This system has been integrated before and no signs of stresses were seen in the tabs after multiple flights.

Motor retainer falls off.	Joint was did not have proper preload or thread engagements.	Motor casing and spent motor fall out of rocket during when the main parachute opens.	1	5	Low	This system has been tested during full scale flights without any signs of failure. Analysis has been completed to validate that the current design is strong enough to withstand forces seen during flight.

Table 83: Stability and propulsion risk assessment.

Recovery Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Rocket does not split to allow for recovery system deployment.	1. Not enough pressurization to break shear pins. 2. Coupling has too tight of fit.	Rocket follows ballistic path, becoming unsafe.	1	5	Low	1. The separation section of the rocket was designed to ensure that the black powder charge provides sufficient pressurization, allowing the rocket to separate and deploy its recovery system. Each separation section was both ground tested prior to a full scale flight test to ensure that the black powder charges appropriately sized. 2. The coupling between the sections will be sanded down to have a loose fit, preventing the two sections from getting stuck together during flight. Ground tests will be performed prior to flight to ensure that the black powder charges are properly sized and that the coupling has a low enough

						coefficient of friction. If separation does not occur, the rocket will follow a ballistic path, becoming unsafe. All personnel at the launch field will be notified immediately.
Altimeter or e-match failure.	Parachutes will not deploy.	Rocket follows ballistic path, 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	5	Low	Deployment bags have been specially made for the parachutes. This will allow for an organized packing that can reduce the chance of the parachute becoming stuck or the lines becoming tangled. Parachute deployment has been both ground tested and flight tested verifying that the setup results in repeatable successful results. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.
Rocket descends too quickly.	Parachute is improperly sized.	The rocket falls with a greater	2	5	Low	The parachutes have each been carefully selected and designed to

		kinetic energy than designed for, causing components of the rocket to be damaged.				safely recover its particular section of the rocket. Simulations have been performed to validate the design. All custom made parachutes were extensively ground tested to validate the design. Subscale versions were built and tested to verify the coefficient of drag.
Rocket descends too slowly.	Parachute is improperly sized.	The rocket will drift farther than intended, potentially facing damaging environmental obstacles.	3	3	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Extensive ground testing was performed to verify the coefficient of drag is approximately that which was used during analysis.
Parachute has a tear or ripped seam.	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	Through careful inspection prior to packing each parachute, this failure mode will be eliminated. Rip stop nylon was selected for the parachute material. This material prevents tears from propagating easily. In the incident that a small tear occurs during flight, the parachute will not completely fail.
Parachute or chords become burnt.	Parachute is less effective or completely ineffective depending on the	The rocket falls with a greater kinetic energy than designed for, causing components of	2	5	Low	Parachutes will all be packed in their own, custom deployment bag that is made out of Nomex, a fire retardant material. With proper packing of the parachute and use

	severity of the damage.	the rocket to be damaged.				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	5	Low	A custom deployment bag will be designed and tested for the 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.
Parachute does not inflate.	Improperly sized lines.	Parachute does not generate enough drag.	1	5	Low	A subscale parachute was constructed and tested to verify the design of the vortex ring. All full scale parachutes have been ground tested to ensure that the parachute will properly inflate during flight.
Ejection pin does not release.	1. Battery on Arduino mini fails. 2. Cam does not rotate. 3. Pin becomes jammed.	Parachute does not open.	1	3	High	1. Battery will be checked before launch to ensure proper voltage. 2/3. Cam and pin system will undergo strict ground testing prior to launch. Additionally, a secondary mechanism of a tender descender will be in place.

Ejection pin prematurely releases.	Parachute prematurely opens.	Rocket drifts farther than allowable.	1	3	High	The cam and pin system will undergo strict ground testing prior to launch to ensure that it activates at the required altitude.

Table 84: Recovery 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 damage to the rocket.	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.

Black powder charges go off prematurely.	1. Altimeters send a false reading. 2. Open flame sets off charge.	1,2. Charges prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket.	1	5	Low	All electronics will be kept in their OFF state for as long as possible during preparation. Altimeters are not to be armed until the rocket is in the launch pad and all autonomous systems have been completed. Open flames and other heat sources will be prohibited in the area.
Seized nut or bolt due to galling or cross threading.	Repetitive uninstalling and reinstalling of parts made of materials prone to galling.	Component becomes unusable, potentially ruining expensive, custom machined parts. Amount of rework depends on the location and component that seized.	2	4	Low	Through proper choice in materials, appropriate pre-load, and proper installation, the risk of galling can be eliminated.

Table 85: Vehicle assembly risk assessment.

Environmental Hazards to Rocket Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Low cloud cover.	N/A	Unable to test entire system.	1	4	Moderate	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit

						launching or testing the entire system.
Rain.	N/A	1. Unable to launch. 2. Damage electrical components and systems in the rocket.	1	4	Moderate	1. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. 2. Have a plan to place electrical components in water tight bags. Have a location prepared to store the entire rocket to prevent water damage. Electronics on the ground station are all stored in water tight control boxes to seal out any moisture.
Thunderstorms.	N/A	Damage due to electrical shock on system.	1	5	Moderate	When planning test launches, the forecast should be monitored in order to launch on a day where the weather does not prohibit launching or testing the entire system. Should a storm roll in, the entire system should be promptly packed and removed from the premise to avoid having a large metal object exposed during a thunderstorm. In the event that the system cannot be removed, personnel are not to approach the launch pad during a thunderstorm.
High winds.	N/A	1. Have to launch at high	1	4	Moderate	1,2,3. When planning test launches, the forecast should be

		angle, reducing altitude achieved. 2. Increased drifting. 3. Unable to launch.				monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. If high winds are present but allowable for launch, the time of launch should be planned for the time of day with the lowest winds.
Trees.	N/A	1. Damage to rocket or parachutes. 2. Irretrievable rocket components.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. Drift calculations have been computed, so we can estimate how far each component of the rocket will drift with a particular wind velocity. The rocket should not be launched if trees are within the estimated drift radius.
Swampy ground.	N/A	Irretrievable rocket components.	1	4	Moderate	With the potential of the ground being extremely soft at local launch sites and in Huntsville, the rocket should not be launched if there is swampy ground within the predicted drift radius that would prevent the team from retrieving a component of the rocket.
Ponds, creeks, and other bodies of water.	N/A	1. Loss of rocket components. 2. Damaged electronics.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. The rocket should not be launched if a body of water is within the estimated drift radius. Should the rocket be submerged in water, it should be

						retrieved immediately and any electrical components salvaged. Electrical components are to be tested for complete functionality prior to reuse.
Extremely cold temperatures.	1. Batteries discharge quicker than normal. 2. Shrinking of fiberglass.	1. Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events. 2. Rocket will not separate as easily.	1	5	Low	1. Batteries will be checked for charge prior to launch to ensure there is enough charge to power the flight. Should the flight be delayed, batteries will should be rechecked and replaced as necessary. 2. If the temperatures are below normal launch temperature, black powder charges should be tested to ensure that the pressurization is enough to separate the rocket. If this test is successful, the rocket should be safe to launch.
Humidity.	N/A	Motors or black powder charges become saturated and don't ignite.	1	5	Low	Motors and black powder should be stored in a location free from moisture.
UV exposure.	Rocket left exposed to sun 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 86: Environmental hazards to rocket risk assessment.

Hazards to Environment Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Harmful substances permeating into the ground or water.	Improper disposal of batteries or chemicals.	Impure soil and water can have negative effects on the environment that in turn, work their way into humans, causing illness.	4	3	Low	Batteries and other chemicals should be disposed of properly in accordance with the MSDS sheets. Should a spill occur, proper measure are to be followed in accordance with the MSDS sheets and any EHS standards.
Release of hydrogen chloride into the atmosphere.	Burning of composite motors.	Hydrogen chloride dissociates in water forming hydrochloric acid.	4	1	Moderate	While the probability of hydrochloric acid forming is high, the amount that would be produced over the course of a season is negligible. Fewer than six motors are predicted to be fired during the year, all of which are relatively small in size.
Release of reactive chemicals.	Burning of composite motors.	Reactive chemicals work to deplete ozone layer.	4	1	Moderate	While the probability of releasing reactive chemicals into the environment is high, the quantity released will result in negligible effects. Fewer than six motors are predicted to be fired during the year, all of which are relatively small in size.
Release of toxic fumes in the air.	Burning of ammonium perchlorate motors.	Biodegradation.	4	1	Moderate	Ammonium perchlorate will be burned in small quantities and infrequently. The amount of toxins released will cause minimal degradation.

Production of styrene gas.	Through the use of fiberglass in the overall design, fiberglass is manufactured by a second party.	Toxic air emissions.	4	1	Moderate	Productions methods for fiberglass produces toxic air pollutants, particularly styrene, which evaporate during the curing process. Due to the quantity of fiberglass utilized on the rocket, the amount of pollutants produced throughout manufacturing process will have a negligible effect on the environment.
Spray painting.	The rocket will be spray painted.	1. Water contamination. 2. Emissions to environment.	2	5	Low	All spray painting operations will be performed in a paint booth. This prevents any overspray from entering into the water system or air.
Soldering wires.	All wires will be soldered together to retain strength and proper connection.	1. Air contamination 2. Ground contamination	4	2	Low	The amount of vapor from the soldering process is at such a low quantities that no action will be needed.
Use of lead acid battery leakage.	Old or damaged housing to battery	1. Acid will leak onto the ground and get into the water system. 2. Chemical reaction with organic material that could potentially cause a fire.	3	4	Low	1. We are using new batteries that have been factory inspected and tested. 2. Proper lifting and storing procedures according to manufacturer's specifications will be adhered to.

Plastic waste material.	Plastic using in the production of electrical components and wiring.	1. Sharp plastic material produced when shaving down plastic components could harm animals if ingested by an animal. 2. Plastic could find its way down a drain and into the water system.	3	5	Low	1. All plastic material will be disposed of in proper waste receptacles.
Wire waste material.	Wire material used in the production of electrical components.	1. Sharp bits of wire being ingested by an animal if improperly disposed of.	3	5	Low	1. All wire material will be disposed of in proper waste receptacles.
CO2 emissions.	Travel to launch sites and competition.	Destroying the ozone layer.	4	1	Moderate	While the effects of CO2 emissions cannot be reversed, the amount produced is negligible.

Table 87: Hazards to environment risk assessment.

Appendix II – Drawing Package

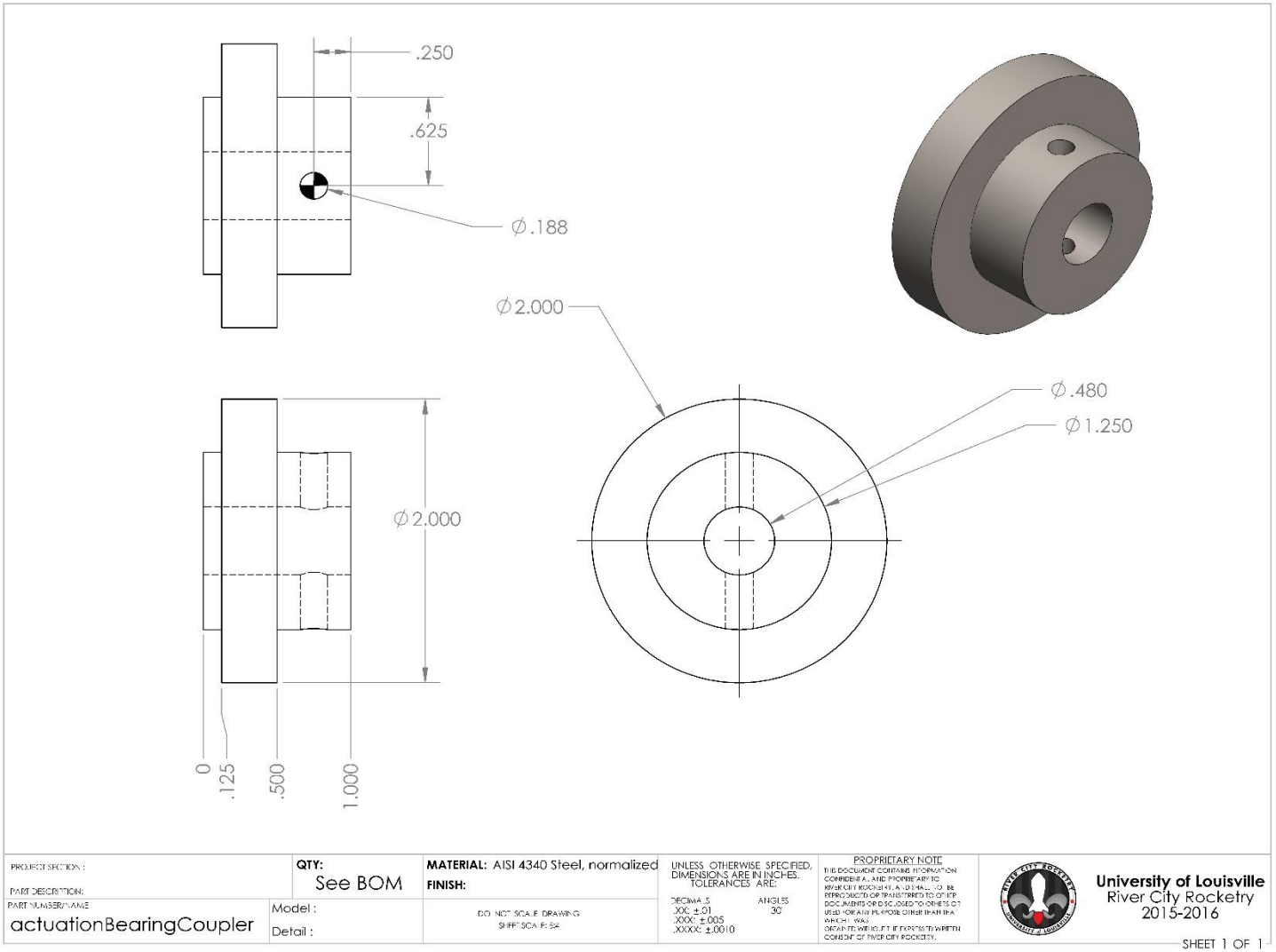

Figure 130: Actuating bearing coupler drawing.

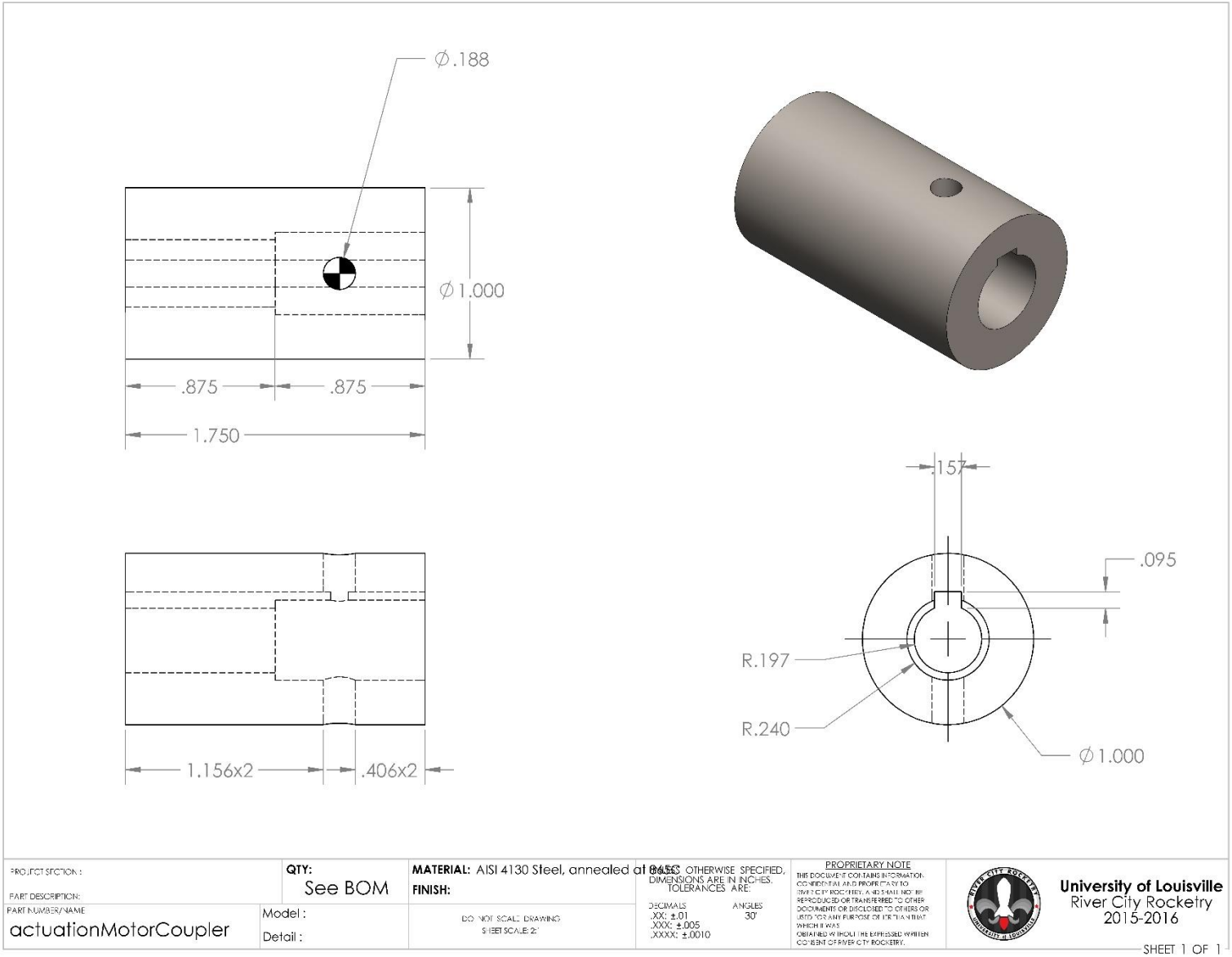

Figure 131: Actuation motor coupler drawing.

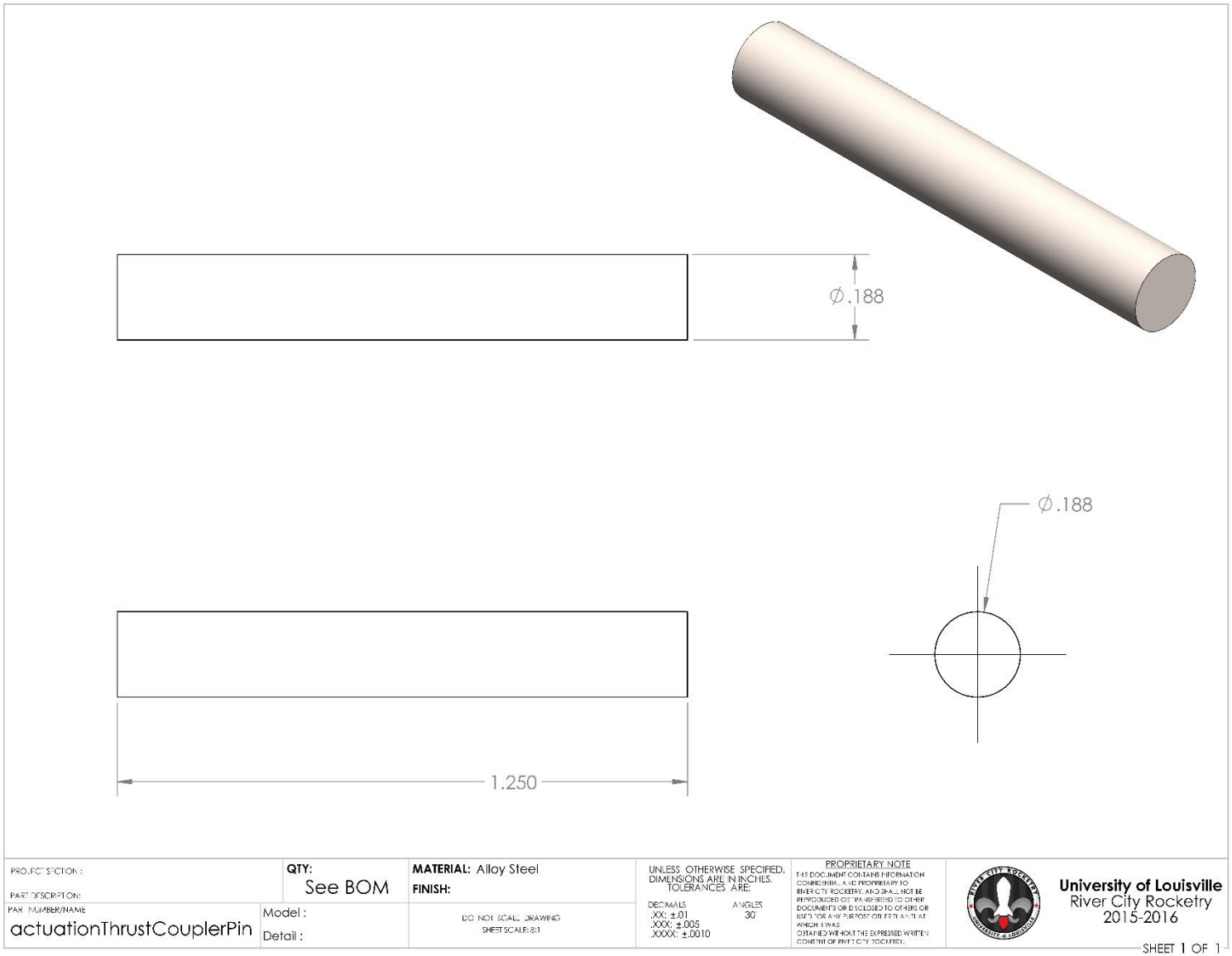

Figure 132: Actuation thrust coupler pin drawing.

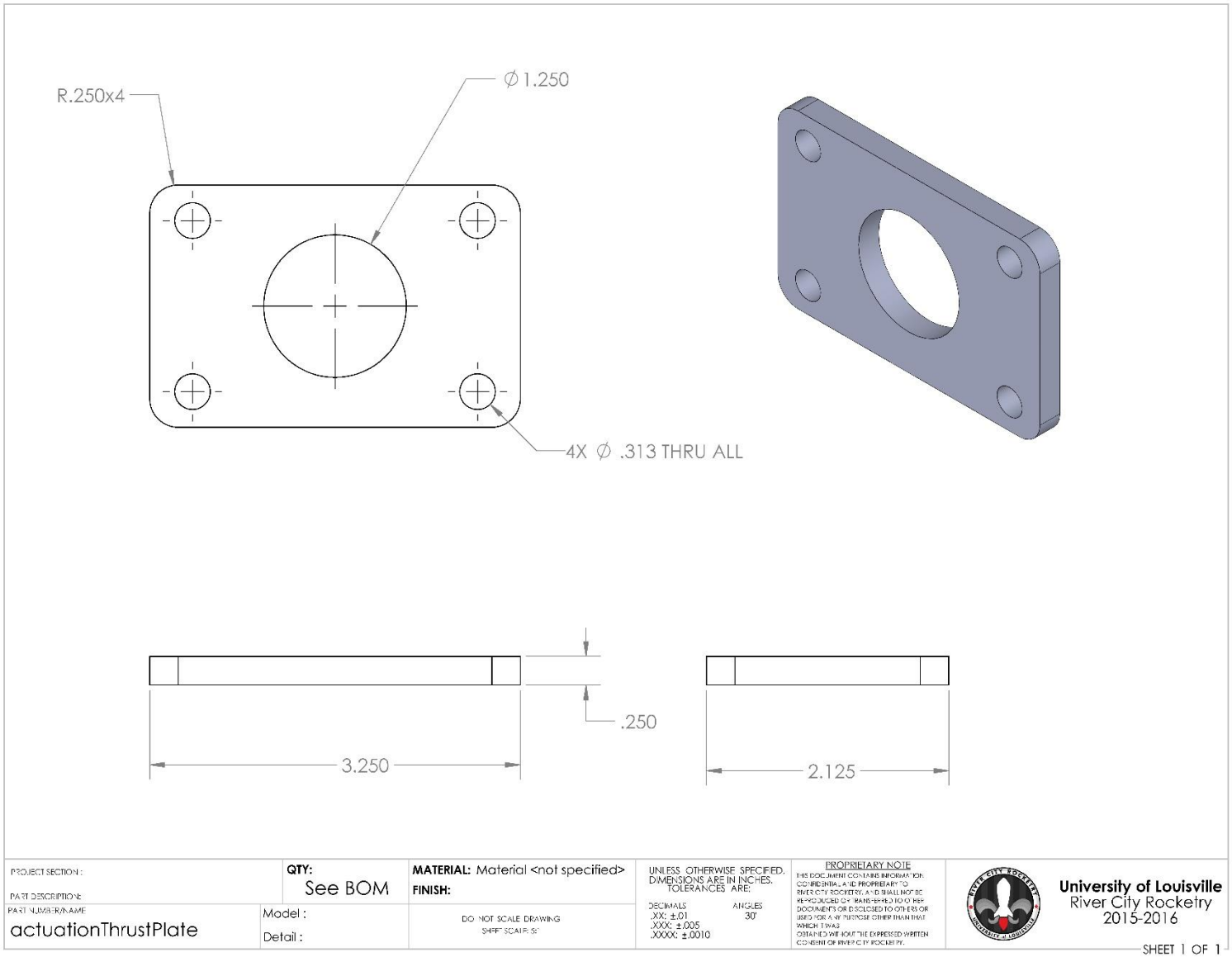

Figure 133: Actuation thrust plate drawing.

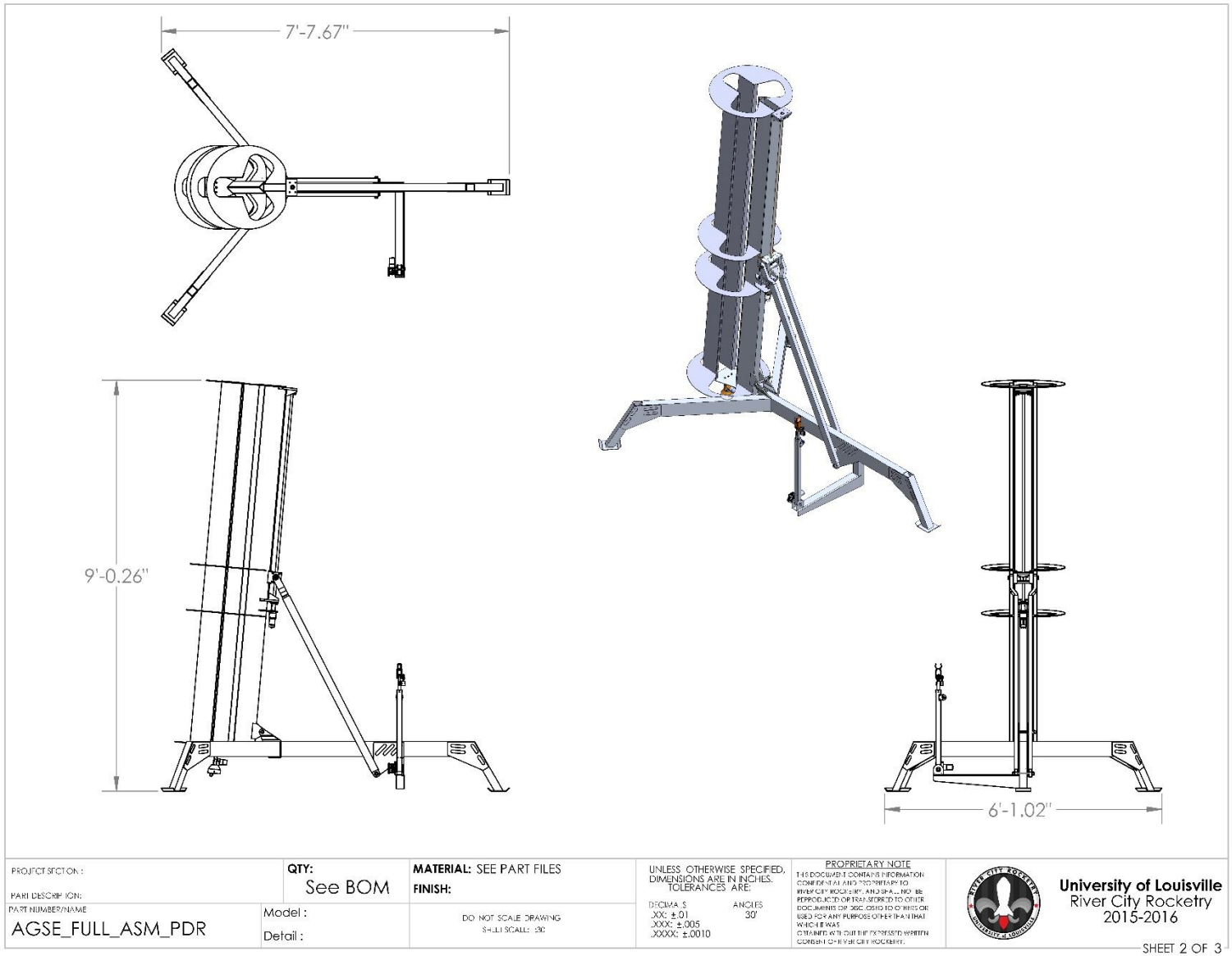

Figure 134: AGSE full assembly launch position drawing.

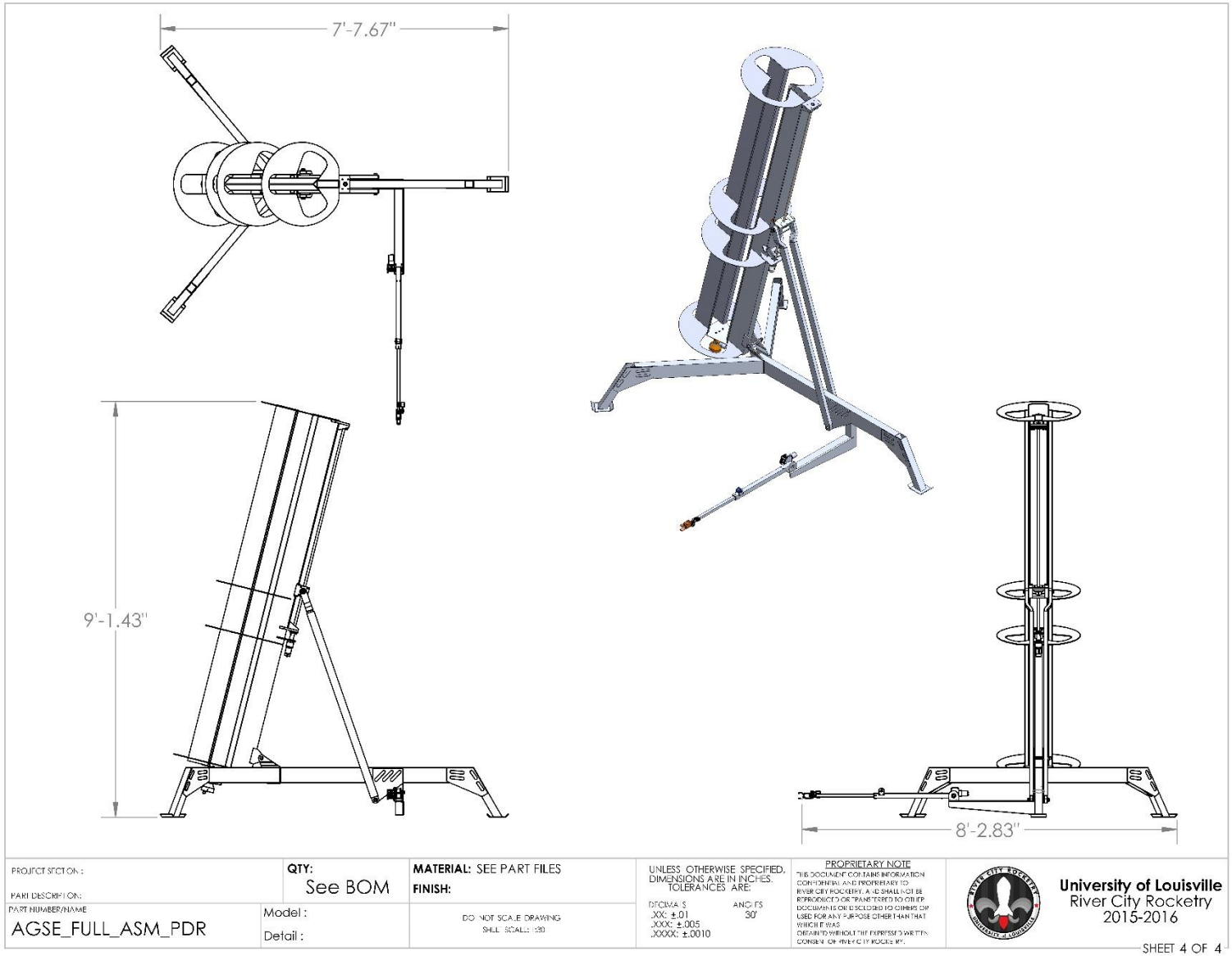

Figure 135: AGSE full assembly maximum volume drawing.

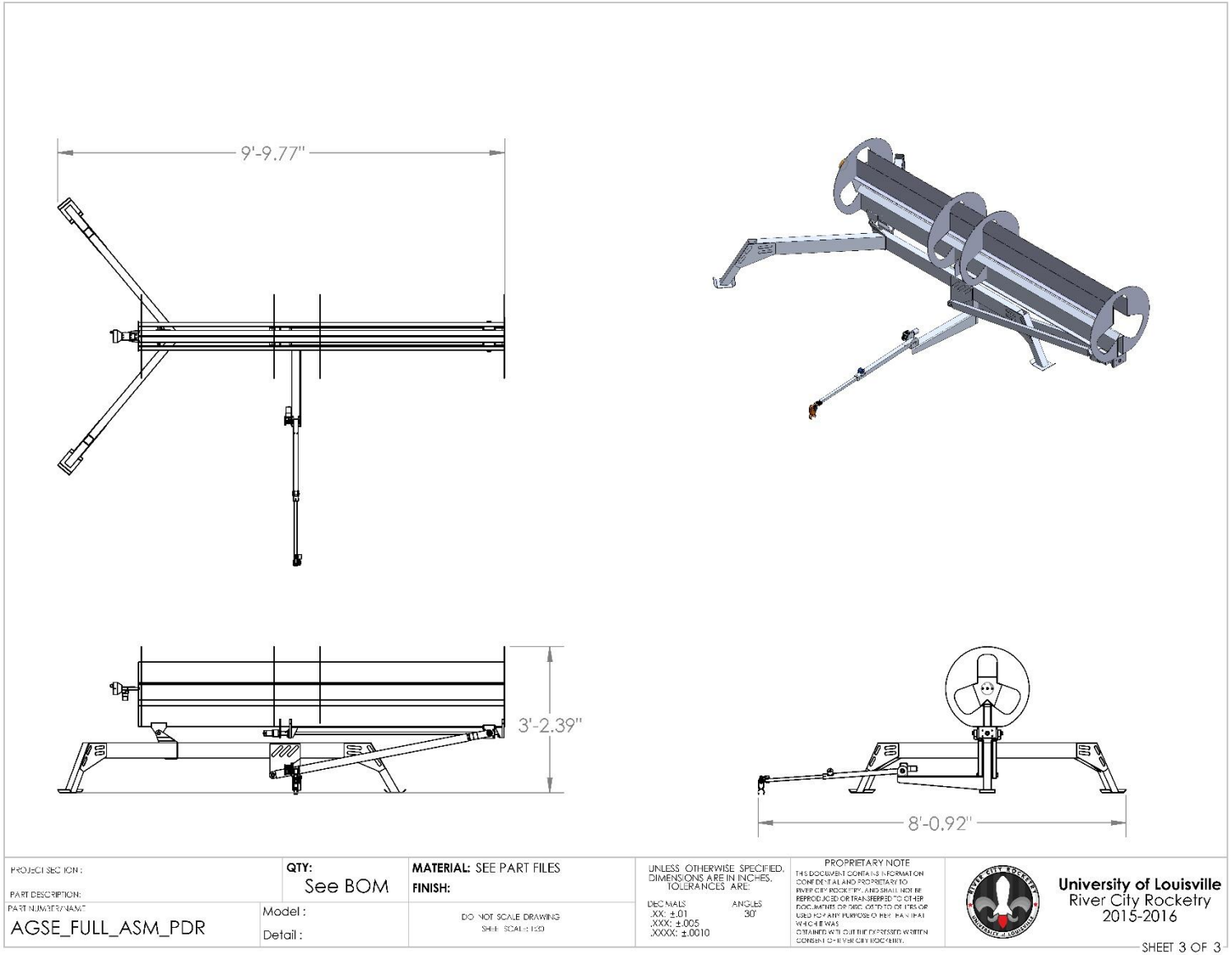

Figure 136: AGSE full assembly payload capture position drawing.

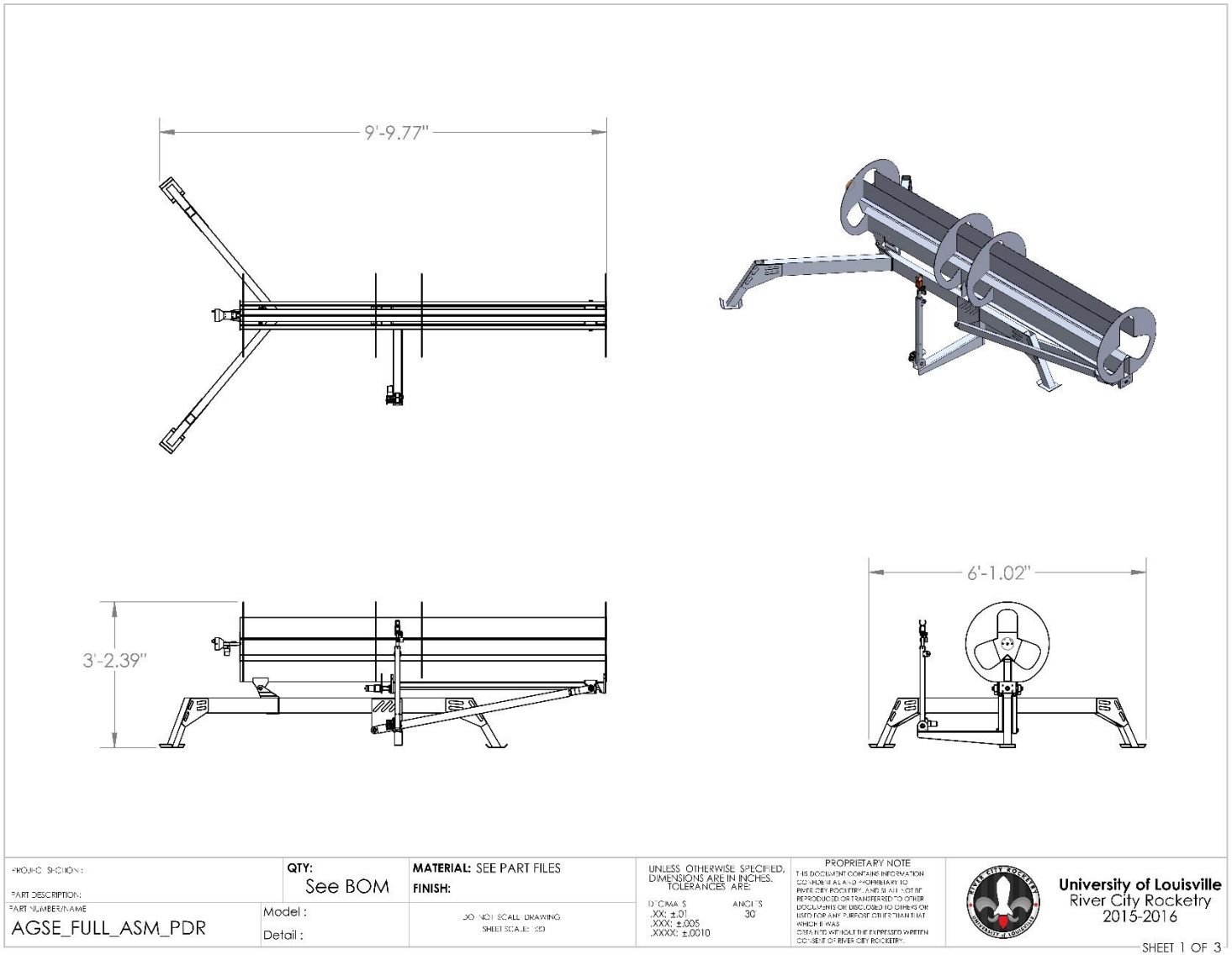

Figure 137: AGSE full assembly stowed position drawing.

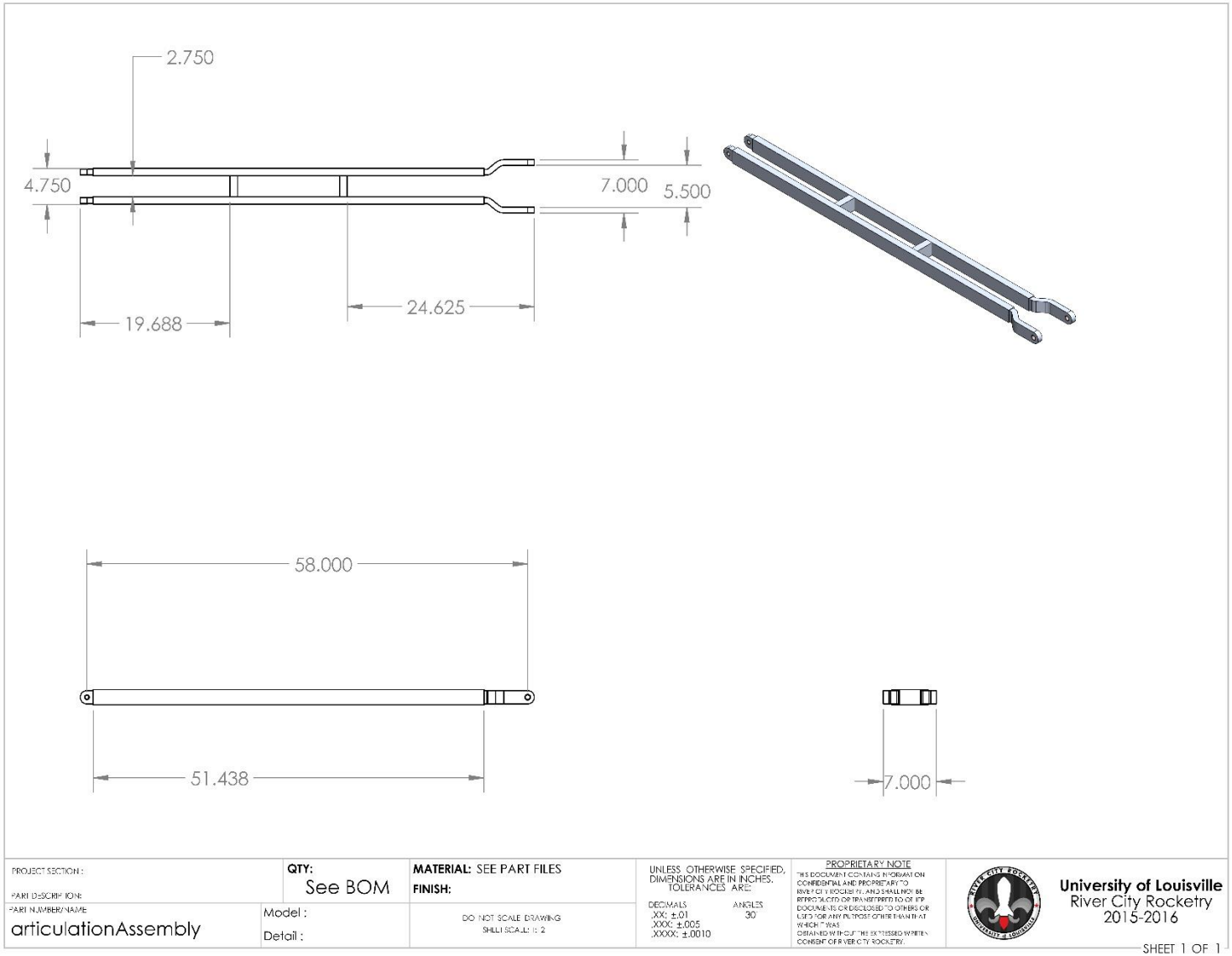

Figure 138: Articulation assembly drawing.

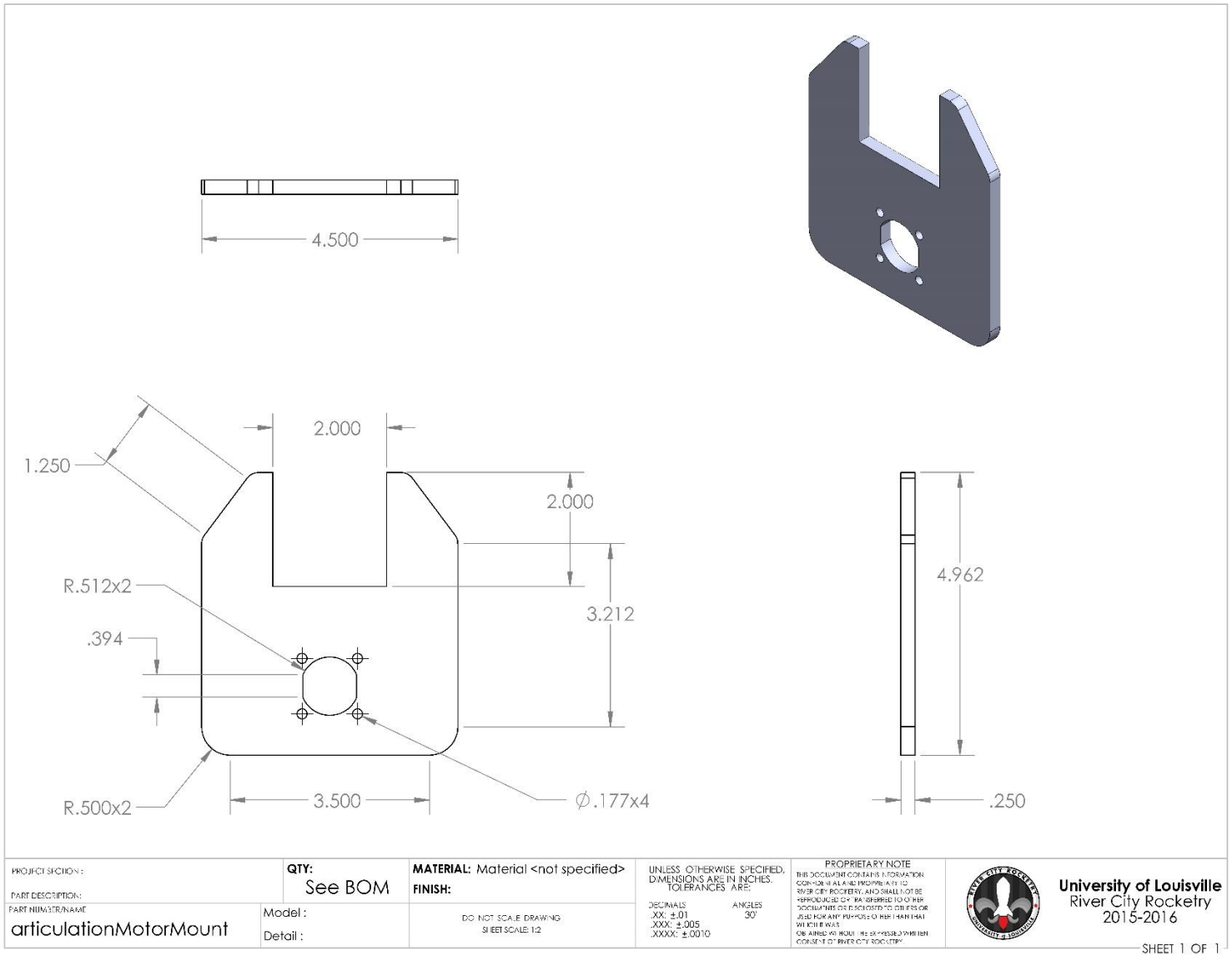

Figure 139: Articulation motor mount drawing.

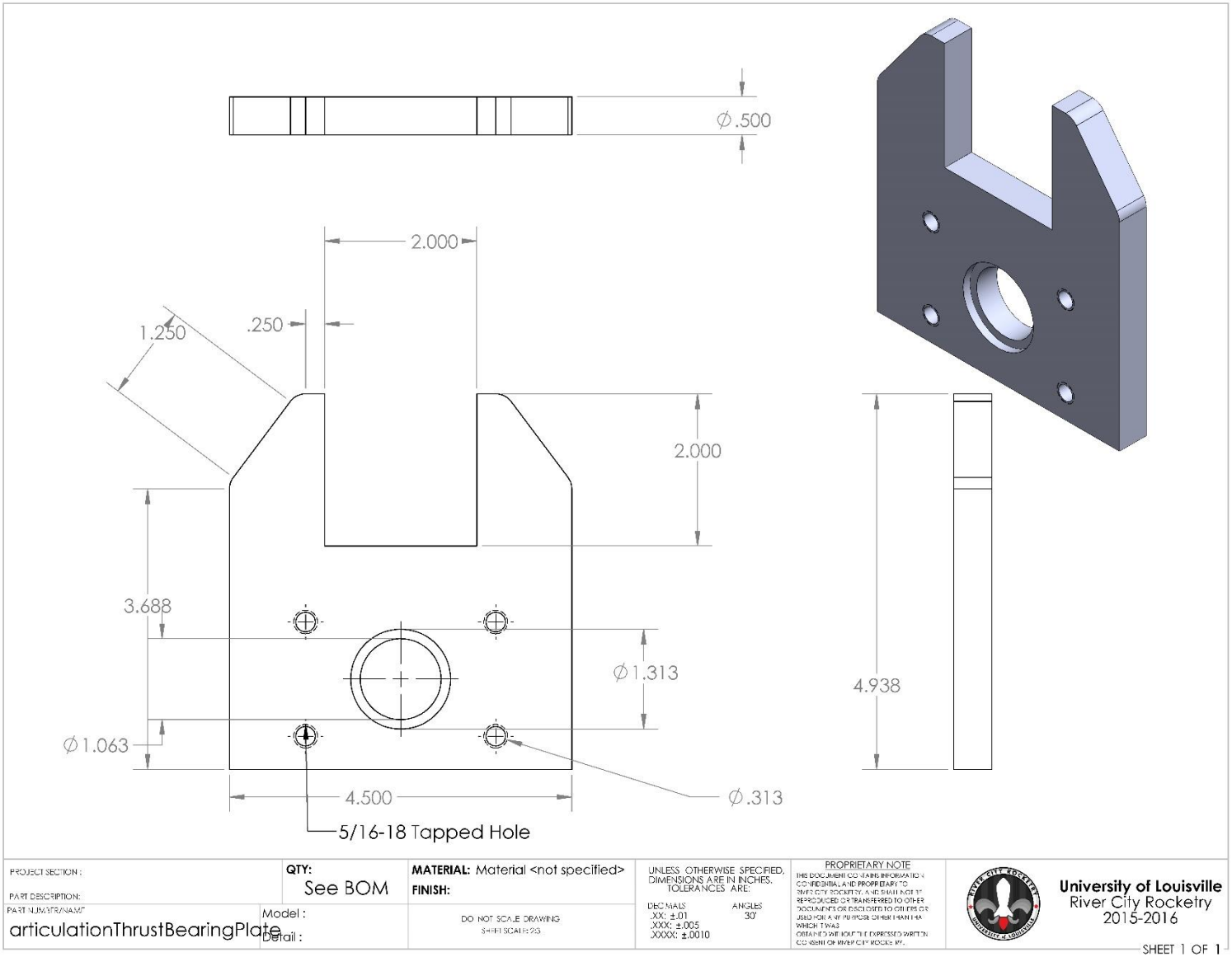

Figure 140: Articulation thrust bearing plate drawing.

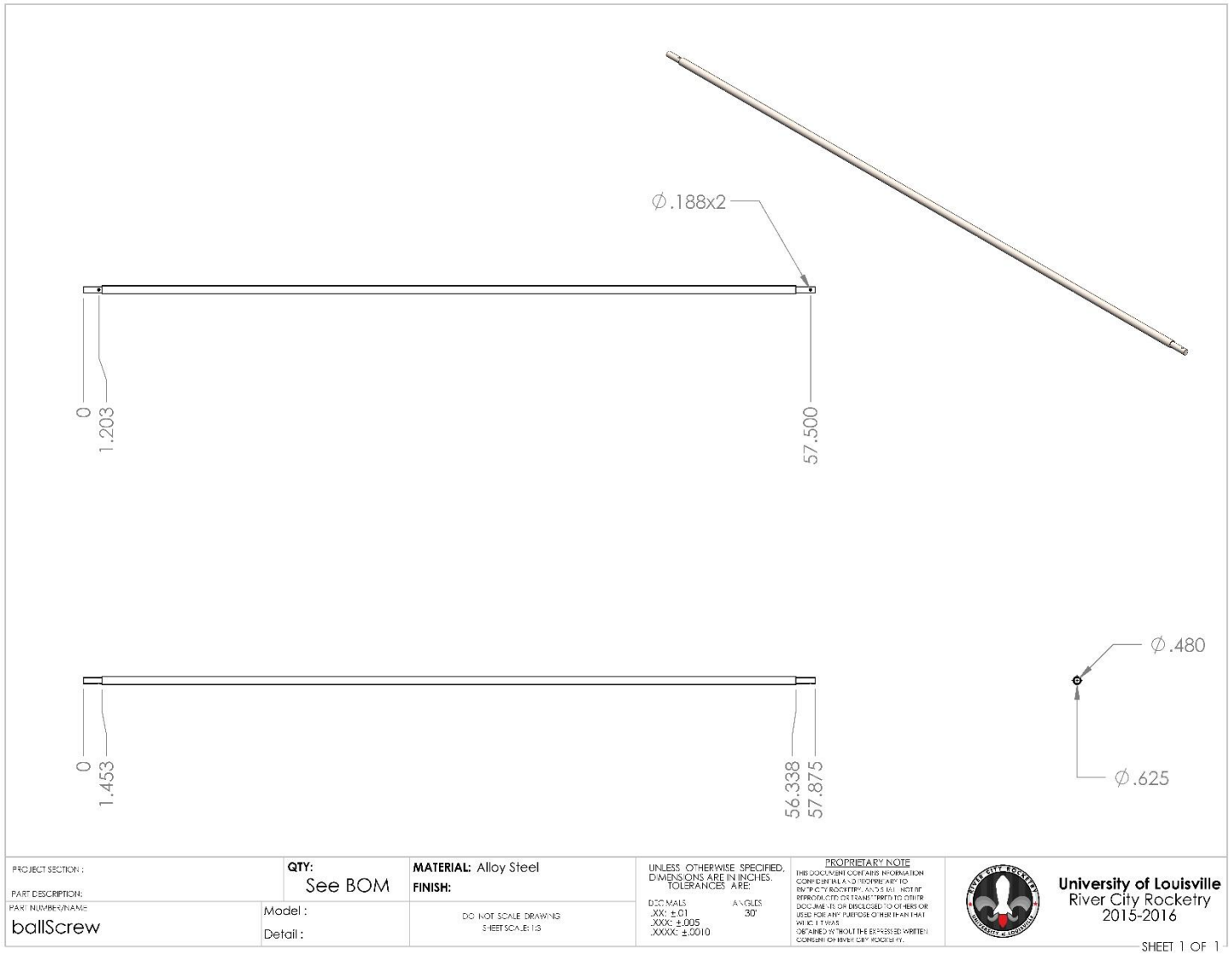

Figure 141: Ball screw drawing.

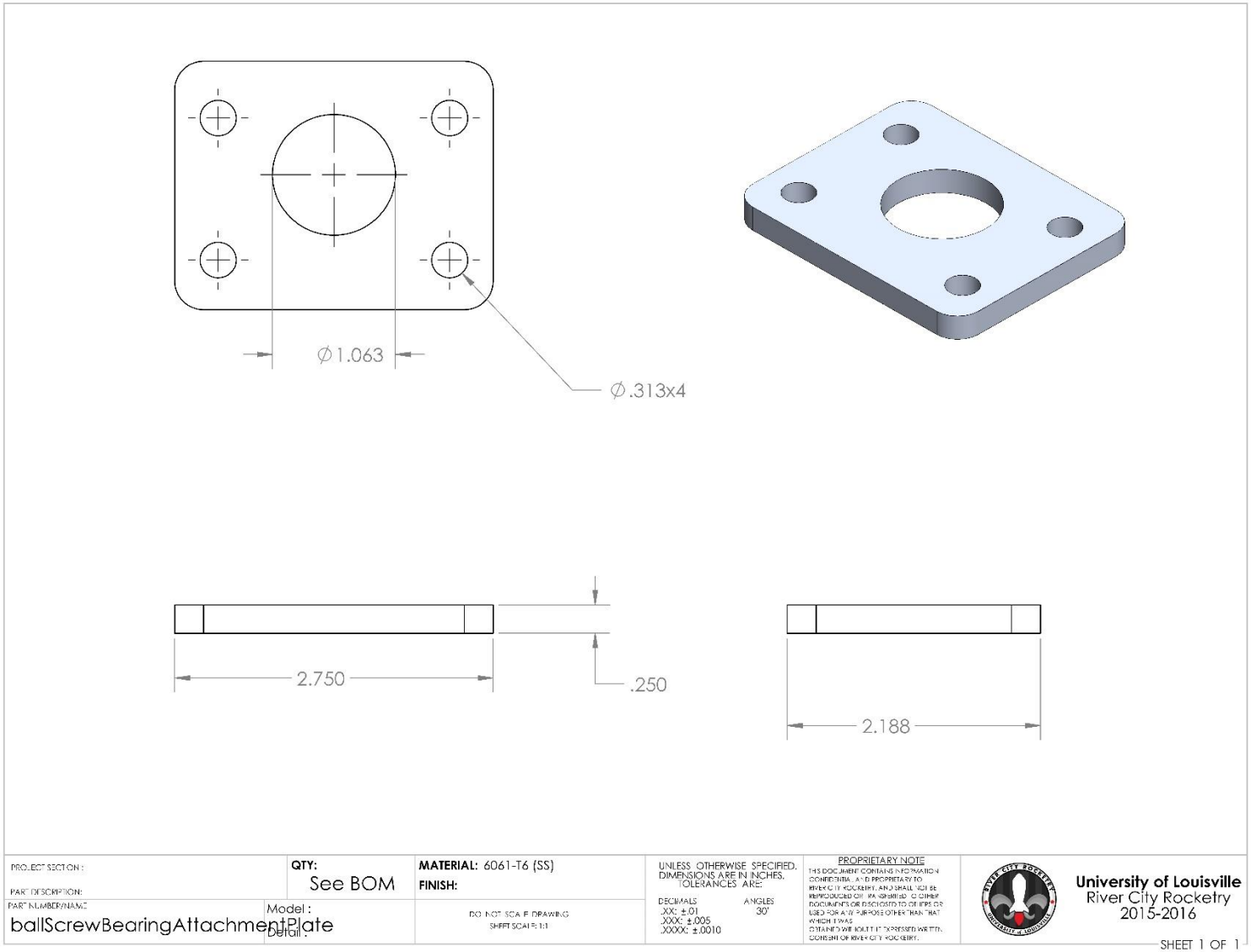

Figure 142: Ball screw bearing attachment plate drawing.

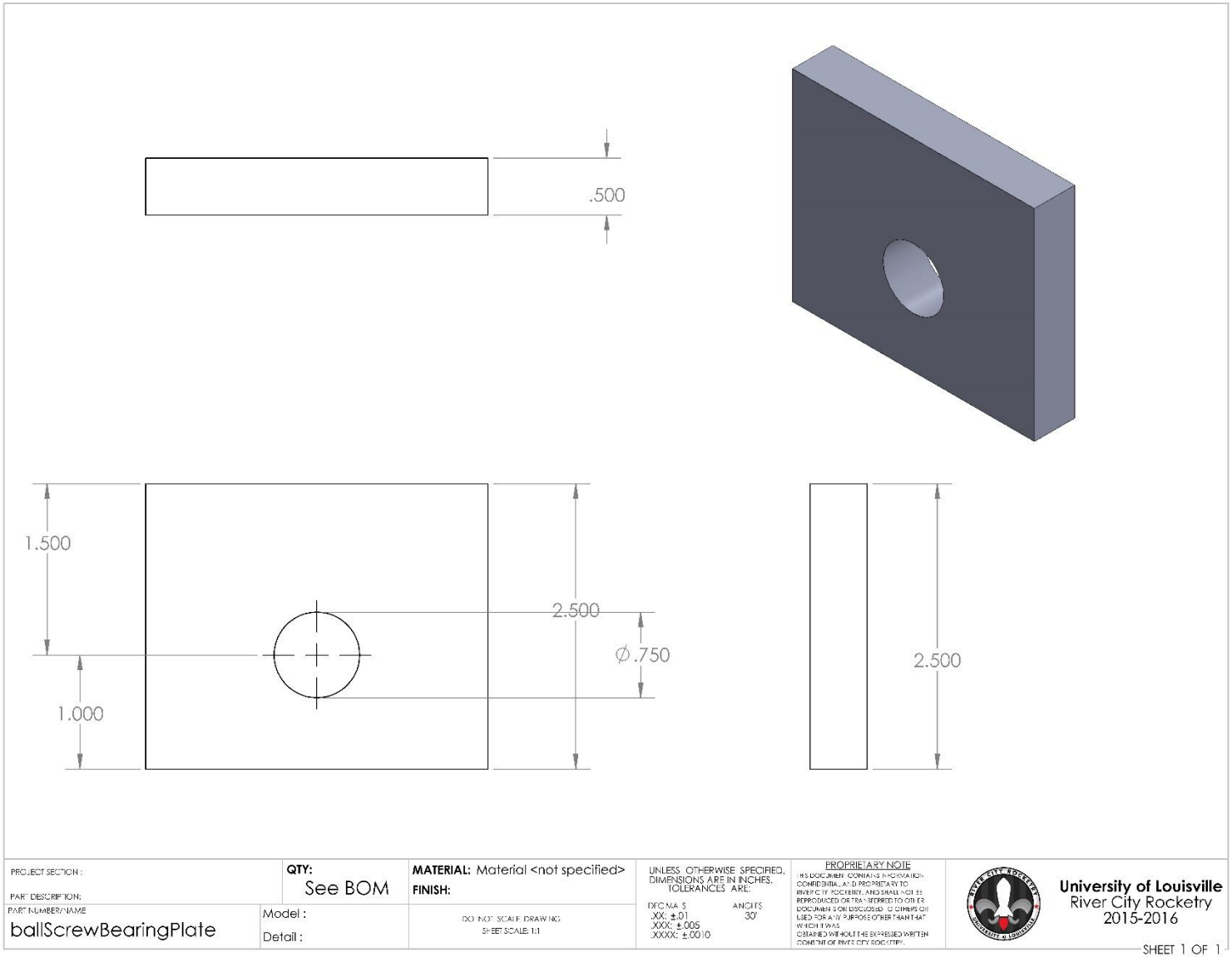

Figure 143: Ball screw bearing plate drawing.

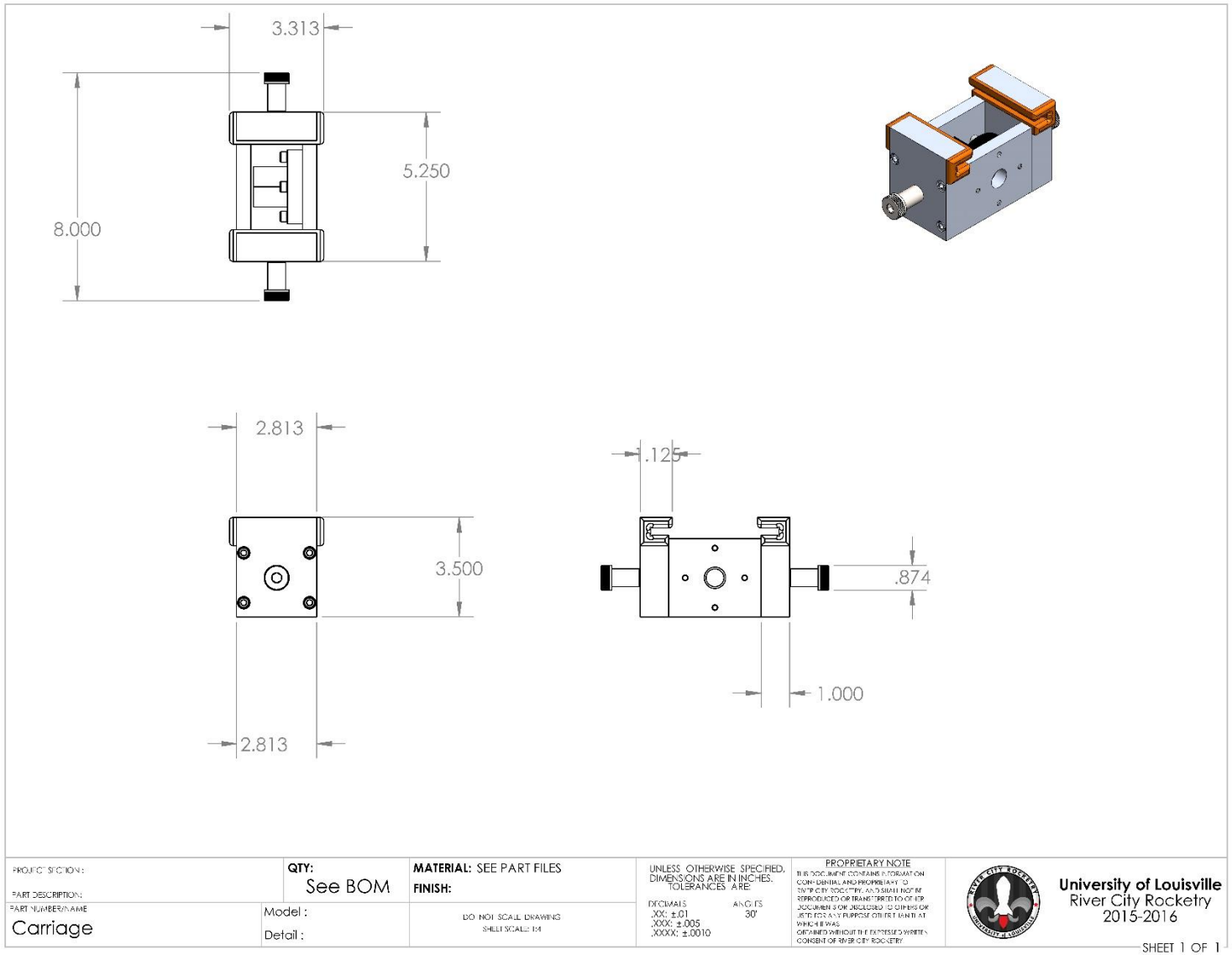

Figure 144: Carriage drawing.

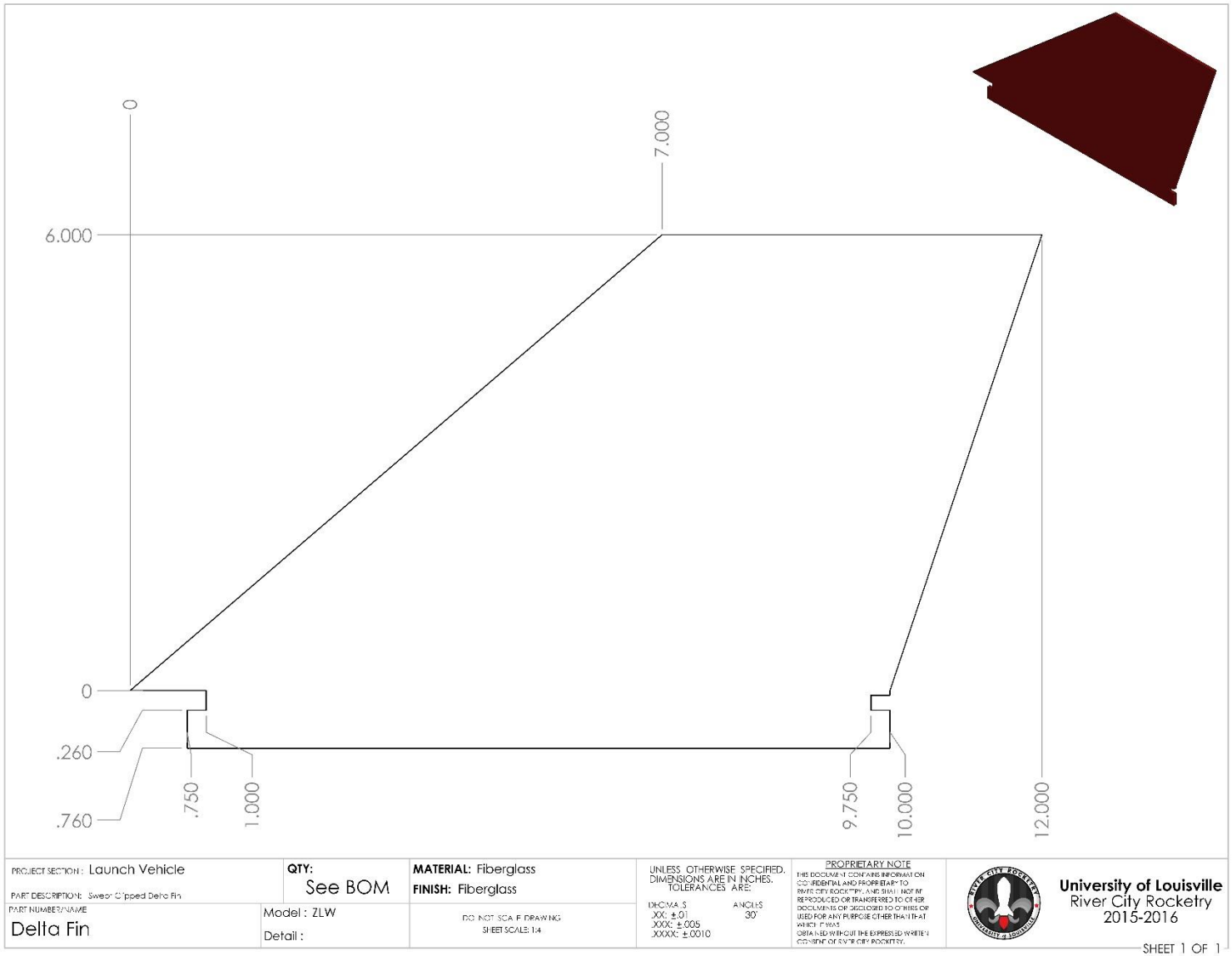

Figure 145: Delta fin drawing.

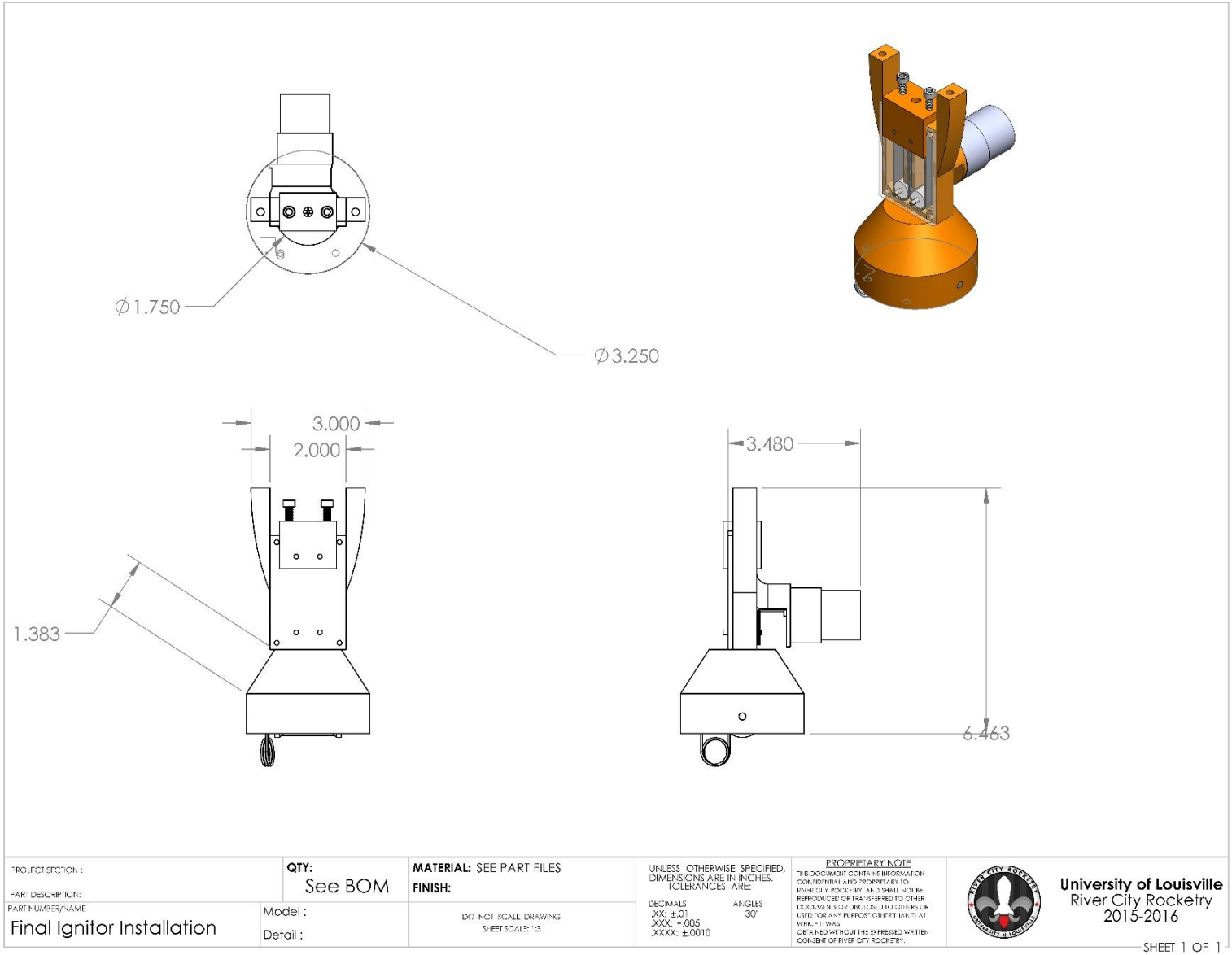

Figure 146: Ignitor installation assembly drawing.

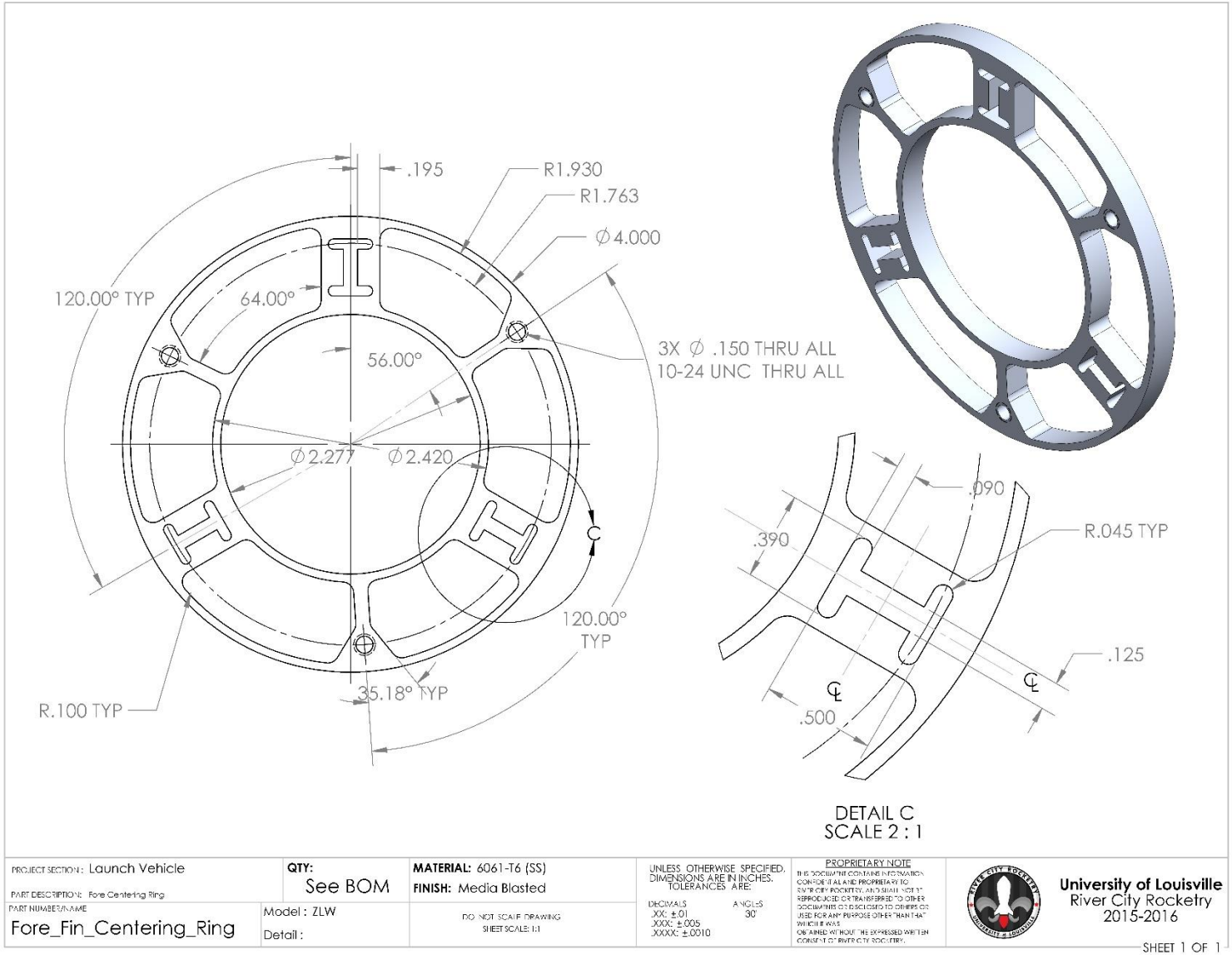

Figure 147: Fore fin centering ring drawing.

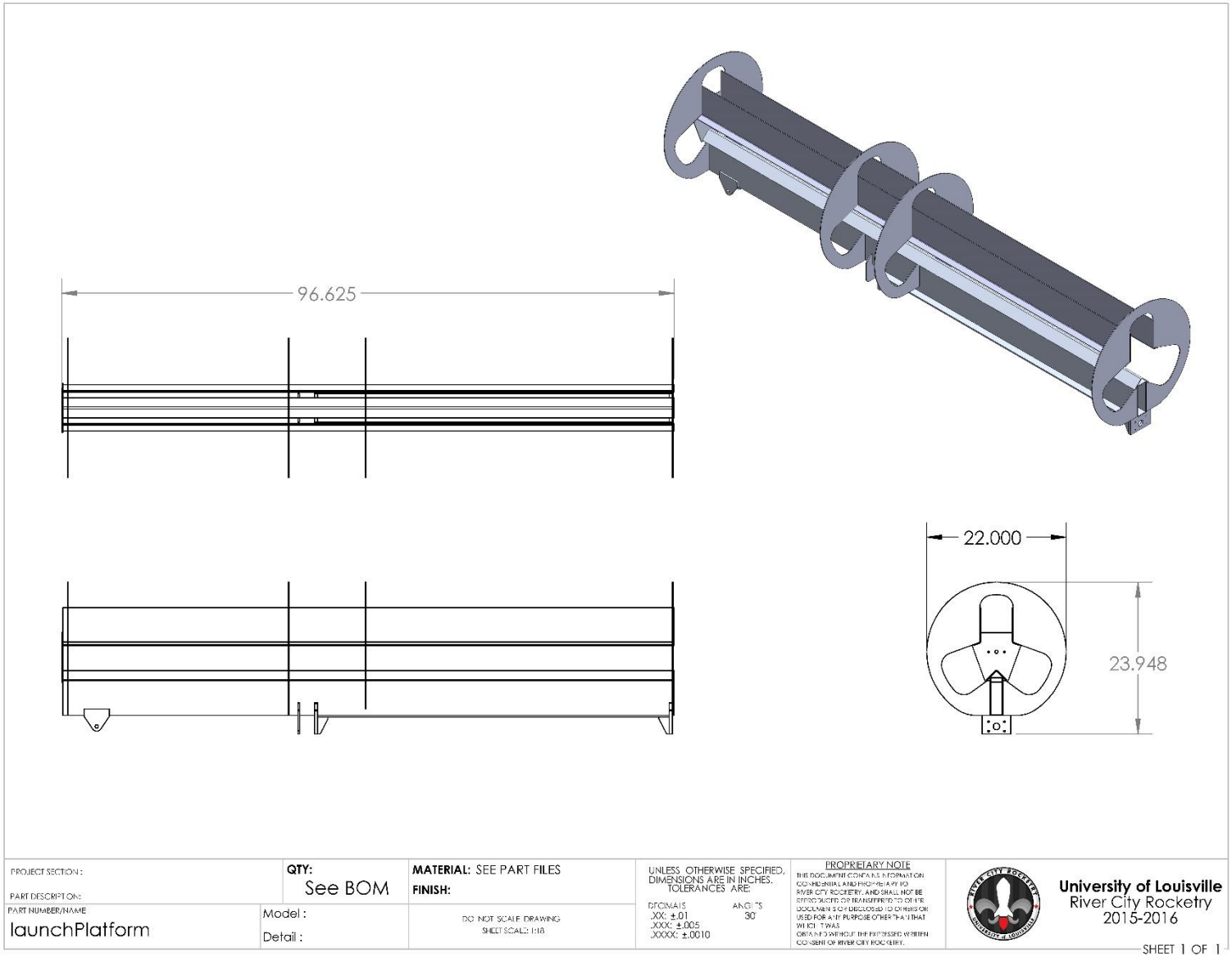

Figure 148: Launch platform drawing.

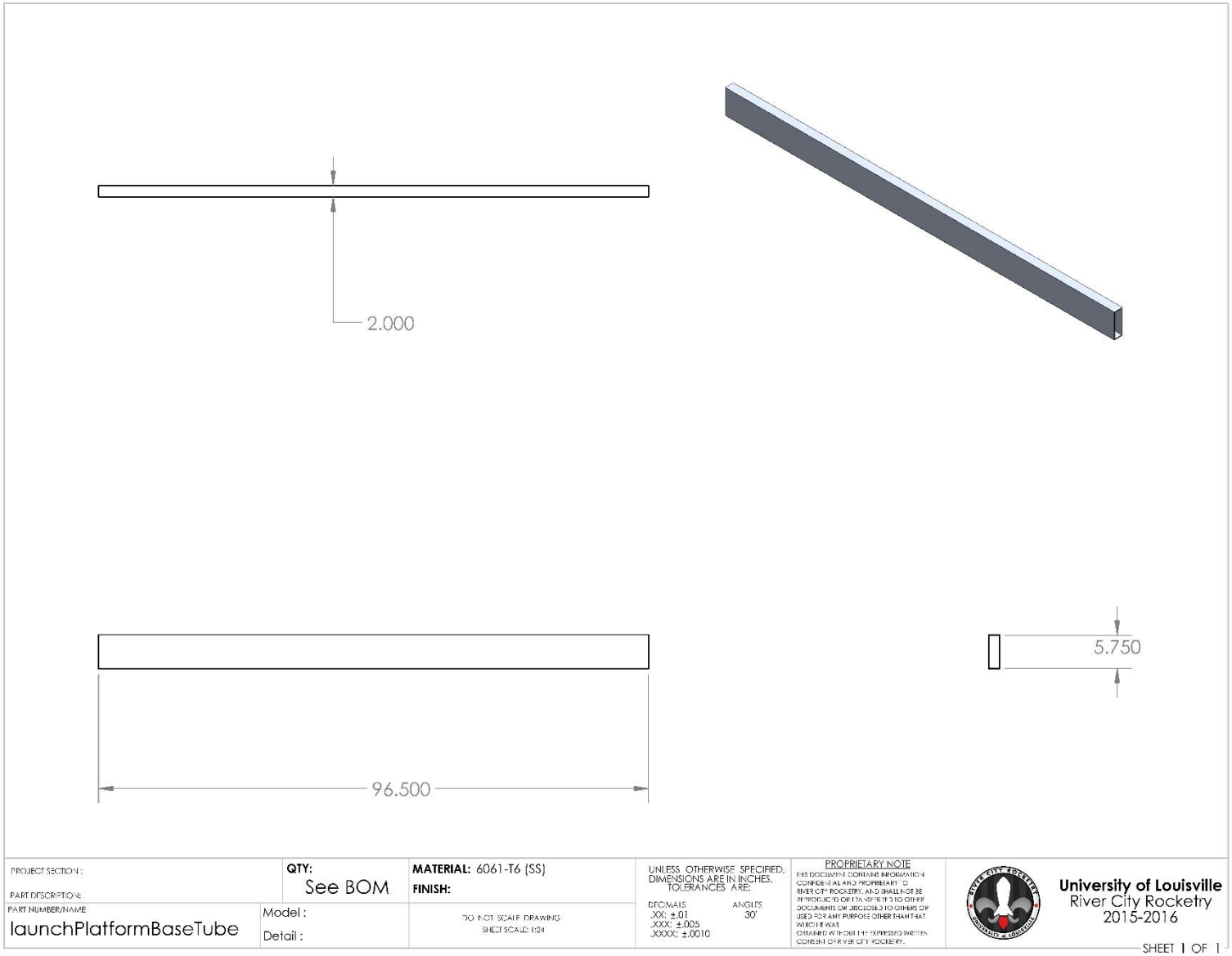

Figure 149: Launch platform base tube drawing.

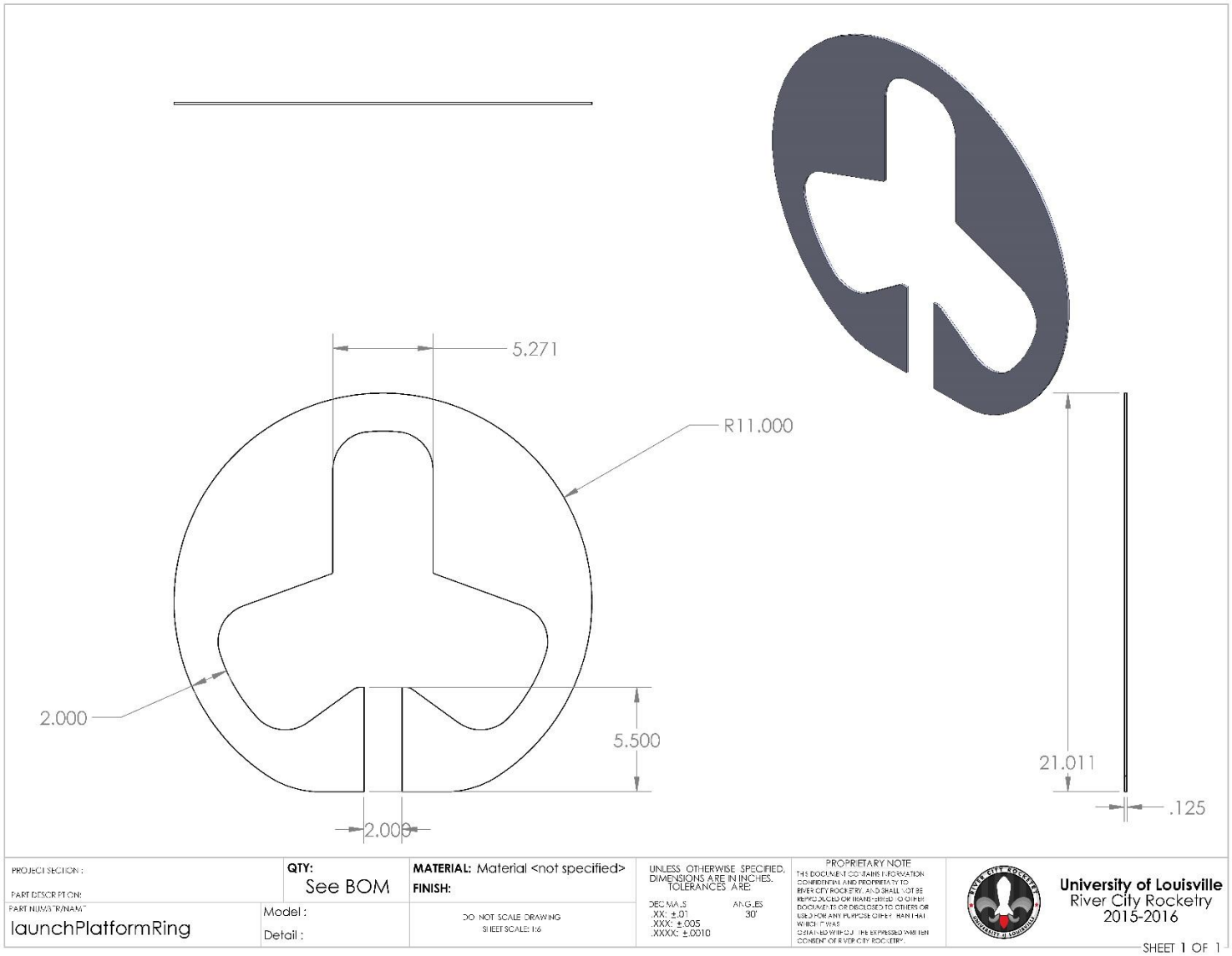

Figure 150: Launch platform ring drawing.

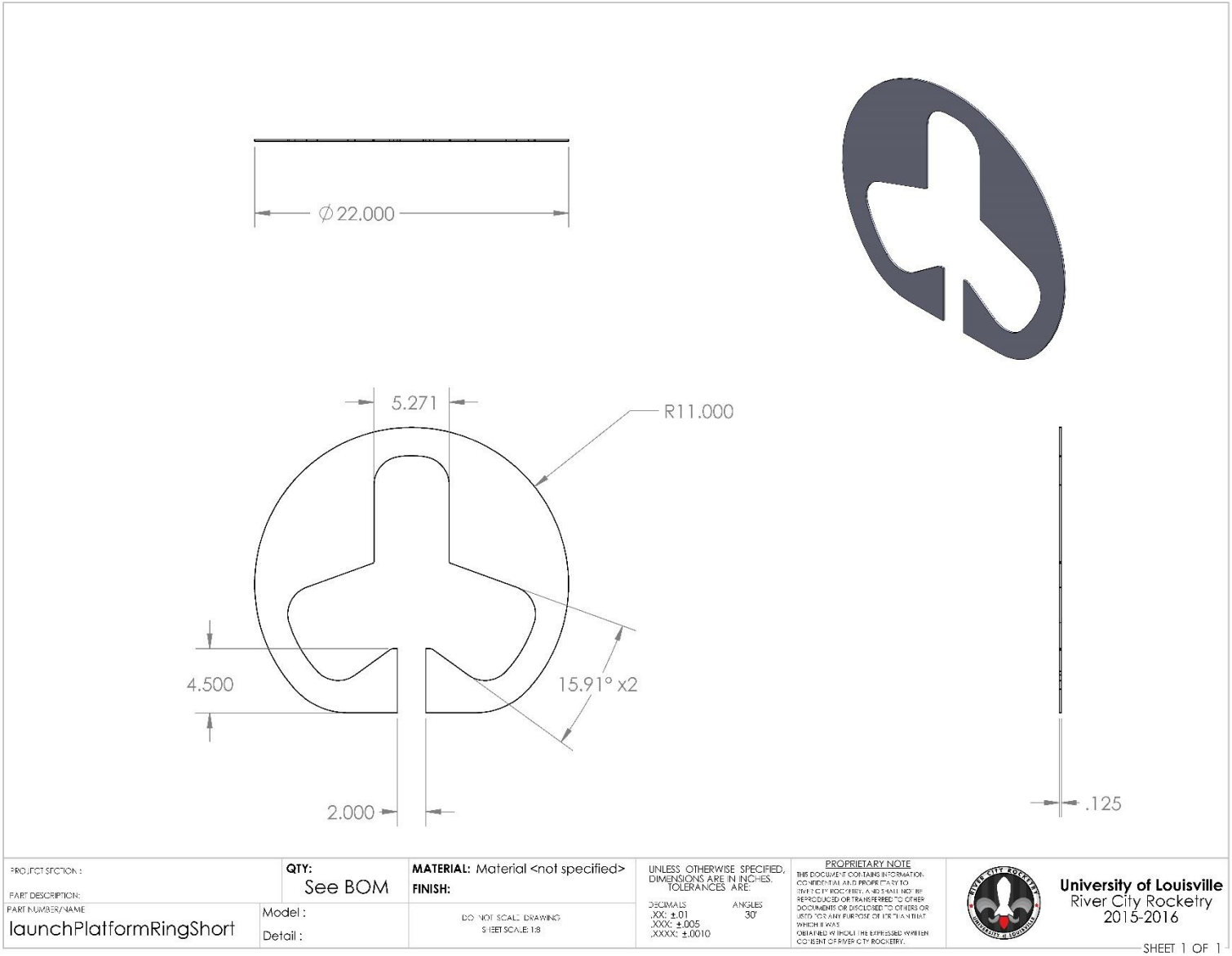

Figure 151: Launch platform ring short drawing.

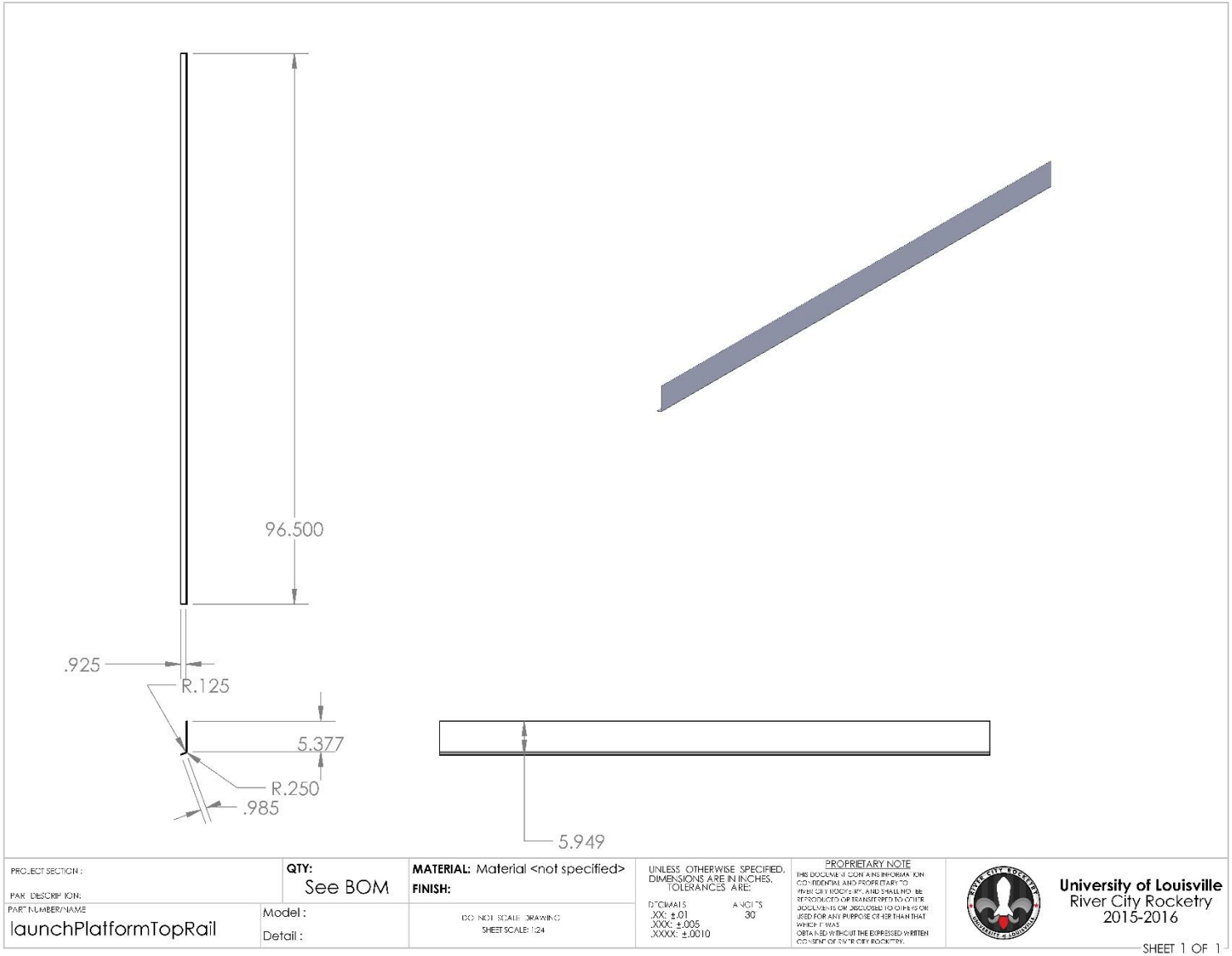

Figure 152: Launch platform top rail drawing.

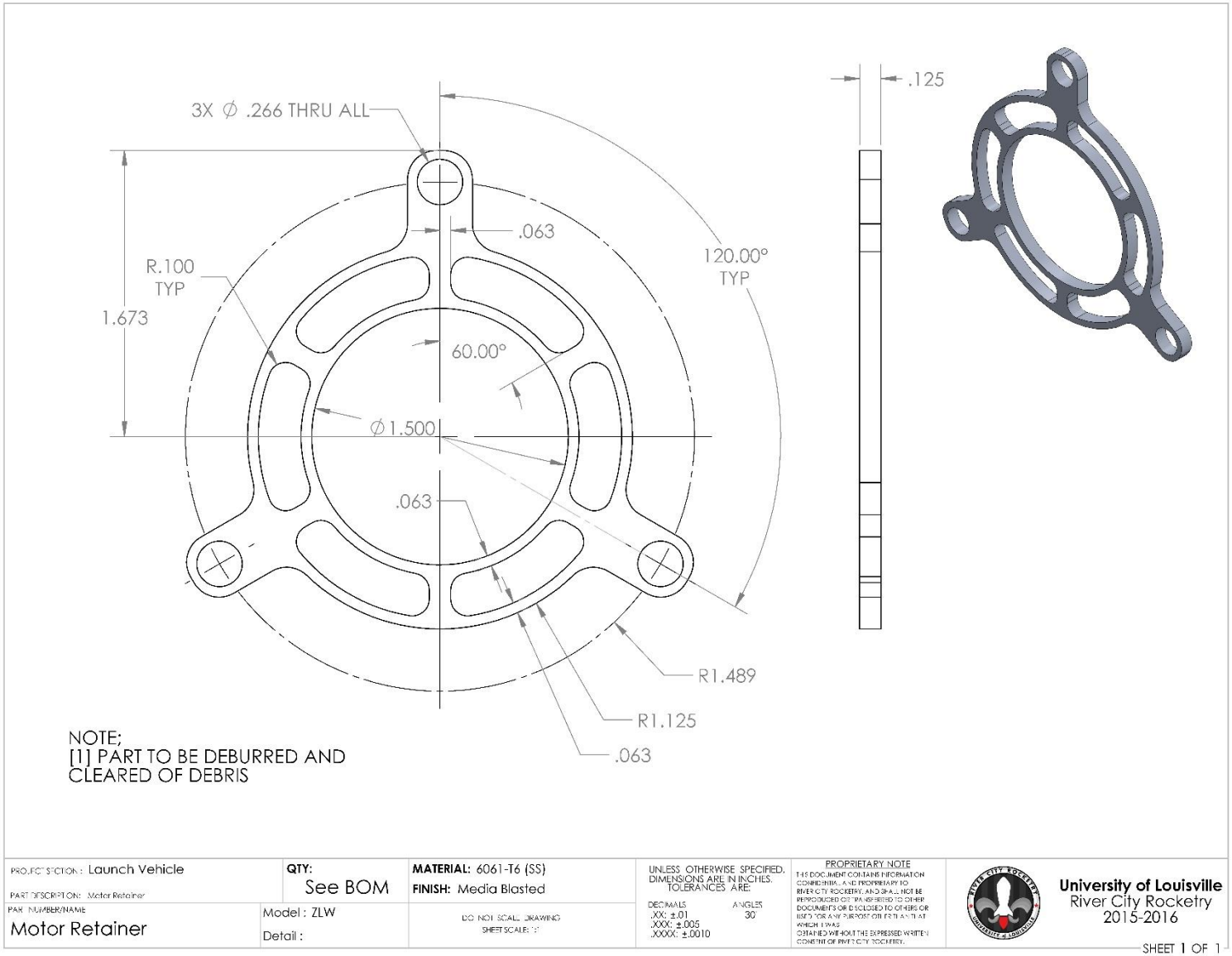

Figure 153: Motor retainer drawing.

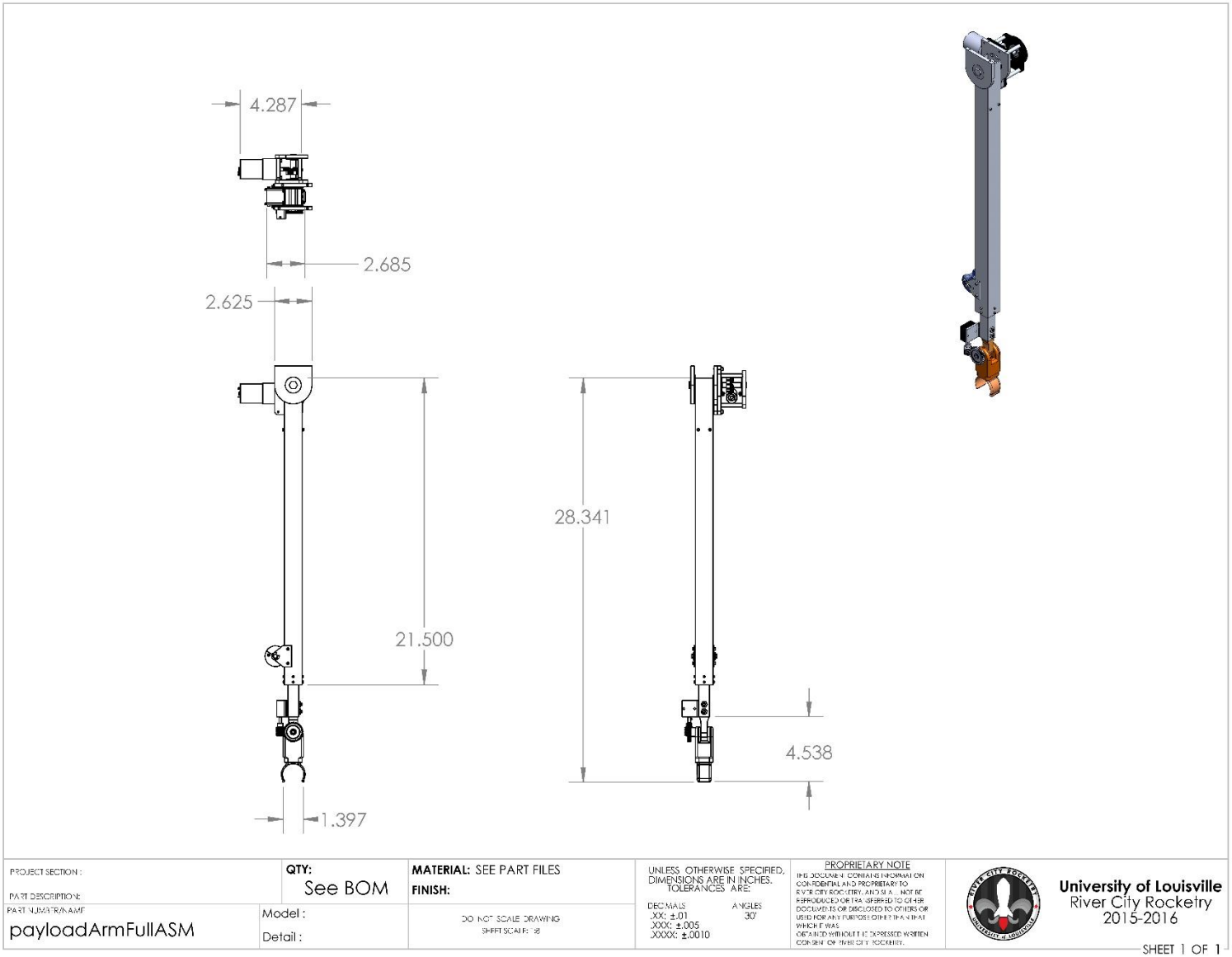

Figure 154: Payload arm full assembly drawing.